International Energy Agency

ENERGY TECHNOLOGY PERSPECTIVES 2010

Scenarios & Strategies to 2050

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To meet the challenges of energy security and climate change as well as the growing energy needs of the developing world, a global energy technology revolution is essential. This was the key message of the 2008 edition of *Energy Technology Perspectives* (ETP). But is this fundamental transformation happening? What are the key technologies that can play a role? What are the costs and benefits? And what policies do we need?

The new *ETP 2010* explores such questions and many others, drawing on the extensive expertise of the International Energy Agency (IEA) and its energy technology network.

ETP 2010 presents updated scenarios from the present to 2050 that show which new technologies will be most important in key sectors and in different regions of the world. It highlights the importance of finance to achieve change, examines the implications of the scenarios for energy security and looks at how to accelerate the deployment of low-carbon technologies in major developing countries. It presents roadmaps and transition pathways for spurring deployment of the most important clean technologies and for overcoming existing barriers.

With extensive data, projections and analysis, *Energy Technology Perspectives 2010* provides decision makers with the detailed information and insights needed to accelerate the switch to a more secure, low-carbon energy future.

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy.

The IEA carries out a comprehensive programme of energy co-operation among 28 advanced economies, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

IEA member countries:

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The European Commission also participates in the work of the IEA.

International Energy Agency

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FOREWORD

The previous edition of *Energy Technology Perspectives* (ETP), published in summer 2008, called for an energy technology revolution to tackle the undesirable consequences of our current patterns of energy supply and use. It also highlighted that, if we did not alter course, concerns about energy security and the threat of dangerous climate change would only become much worse. So what – if any – progress have we made over the last two years in meeting these challenges?

At first sight, it may seem as though not much has changed. Countries are still discussing what a long-term climate change framework should look like, while greenhouse-gas emissions go on rising. Concerns about energy security are still with us and oil prices remain high and prone to further volatility.

However, I believe that in fact we may be witnessing the early signs of the historic transition that we so badly need: high oil prices and the global financial crisis may have changed the demand structure for energy. We may indeed see an "oil-less recovery" in OECD countries, in which our economies return to positive growth without a notable pick-up in oil demand. We are also seeing some promising signs of accelerated deployment for a number of important low-carbon technologies, particularly in renewable energy, energy efficiency and advanced vehicle technologies. Funding for clean energy research, development and demonstration is increasing again after more than two decades of decline and stagnation, and many countries have committed to spend even more in the future.

But we still have formidable challenges before us. Tackling climate change and enhancing energy security require a massive decarbonisation of the energy system leading to a new age of electrification. We need to break the historic link between CO_2 emissions and economic output; and do this not just for a few years, but from now on. *ETP 2010* shows how this can be achieved. It identifies the technologies that we require and the policies that we will need to stimulate the necessary investment. Importantly, it also clearly demonstrates the benefits in terms not only of reduced CO_2 emissions, but also of fossil fuel savings.

We also need to think about what a low-carbon energy mix will mean for comprehensive energy security. On the one hand, reduced dependence on imported fossil fuels and broader development of alternative energy sources can help alleviate some of the current concerns around security of supply for these fuels. Yet as the demand for decarbonised electricity and also for biofuels increases, so new challenges will no doubt emerge requiring innovative policies to ensure that we have the affordable and reliable energy supplies that we need.

ETP 2010 also shows how efforts to tackle climate change will need to include all major economies and so require truly global co-operation. We at the IEA acutely recognise this challenge, with our member states now representing a decreasing share of the world's energy demand, production and CO_2 emissions. In the face of this, the IEA and its members must create ever stronger ties with key non-member countries such as China, India, Russia and many other countries. The newly proposed international low-carbon energy technology platform is one way in which we are doing this. The platform, which was endorsed by the IEA Ministerial meeting in October 2009, will bring together policy makers, business representatives and technology experts to discuss how best to encourage the spread of clean energy technologies and, we hope, will usher in a new era of broader, heightened and proactive collaboration.

By working together we can and must meet the global energy challenges we now face. There simply is no alternative. *ETP 2010* shows us what we have to do. Let us make that revolutionary future a reality together.

This publication has been produced under my authority as Executive Director of the IEA. The views expressed do not necessarily reflect the views or policies of individual IEA member countries.

Nobuo Tanaka

Executive Director

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- Enhancing International Technology Collaboration, 12-13 November 2008, Washington, DC;
- Electric and Plug-in Hybrid Vehicle Roadmap Meeting, 26-27 January 2009, Paris;
- CCS Roadmap Meeting – Financing, Legal & Regulatory and Public Awareness Issues, 23 February 2009, Paris;
- Expert Review of Industry Scenarios, 9-10 February 2009, Paris;
- The Global R&D Portfolio – Strategies to Accelerate Technology Development, 28-29 April 2009, Paris;
- Energy Technology Transition Project Launch Workshop, 13-14 June 2009, Beijing;

- First IEA-Indian ETP Expert Group Workshop, 20 October 2009, Delhi;
- From Roadmaps to Implementation, 2-3 November 2009, Paris;
- Workshop on Regional Analysis for the Energy Technology Perspectives 2010, 19 January 2010, Beijing;
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- Joint IEA-India Workshop on Regional Analysis of India in the Energy Technology Perspective 2010, 29 January 2010, New Delhi;
- Chief Technology Officer Roundtable, 2 February, 2010;
- Energy Efficient and Low-Carbon Buildings: Heating and Cooling. Workshops were held on heat pumps (9 November, 2009); thermal energy storage (9 December, 2009); solar thermal (2 February, 2010); CHP (3 February, 2010) and policy and finance issues (6-7 May, 2010).

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EXECUTIVE SUMMARY

Throughout energy circles, the threat of climate change has held the spotlight in recent years. Meanwhile, two other concerns have re-emerged from the shadows. The financial crisis of 2008/09, which some analysts link with volatile oil prices, reinforced the concern that high energy prices can cripple economic growth. Headlines announcing gas supply cuts to the Ukraine, oil tanker hijackings along the coast of Somalia, pipeline bombings in Nigeria, and hurricanes destroying oil rigs in the Gulf of Mexico showed that threats to energy security arise in many forms and unexpected places. For several years, the IEA has been presenting the case that an energy revolution, based on widespread deployment of low-carbon technologies, is needed to tackle the climate change challenge. *Energy Technology Perspectives 2010 (ETP 2010)* demonstrates that a low-carbon future is also a powerful tool for enhancing energy security and economic development.

Equally important, *ETP 2010* highlights early signs that such an energy technology revolution is under way. Investment in renewable energy, led by wind and solar, is increasing substantially. A number of countries are considering building new nuclear power stations. The rate of energy efficiency improvement in OECD countries is starting to accelerate again, after many years of modest gains. Public investment is increasing for low-carbon technology research, development and demonstration (RD&D). In transport, major car companies are adding hybrid and full-electric vehicles to their product lines and many governments have launched plans to encourage consumers to buy these vehicles. Yet these encouraging developments represent but the first small, fragmented steps on a long journey towards transforming the way we supply and use energy. The trends that drive growth in energy demand and carbon dioxide (CO_2) emissions associated with climate change continue to surge forward at an unrelenting pace.

Current energy and CO_2 trends run directly counter to the repeated warnings sent by the United Nations Intergovernmental Panel on Climate Change (IPCC), which concludes that reductions of at least 50% in global CO_2 emissions compared to 2000 levels will need to be achieved by 2050 to limit the long-term global average temperature rise to between 2.0°C and 2.4°C. Recent studies suggest that climate change is occurring even faster than previously expected and that even the "50% by 2050" goal may be inadequate to prevent dangerous climate change.

Efforts to forge a long-term policy framework for tackling climate change are continuing, but the 15th Conference of the Parties (COP 15) to the UN Framework Convention on Climate Change demonstrated the difficulty of reaching agreement on "top-down" legally binding targets. Nonetheless, COP 15 did make progress on some crucial issues. The Copenhagen Accord, while not formally adopted at COP 15, reflected a large degree of consensus on a number of vital elements, including: limiting the increase in global temperature to less than 2.0°C; achieving deep cuts in global greenhouse-gas emissions by 2050; the role of technology in meeting these goals; and the need for additional funding for developing countries. Many governments are already backing up their support for the Accord's principles through increased funding for low-carbon energy research and development, new and more effective policies, and national emissions reduction targets.

ETP 2010 feeds into this momentum by providing an IEA perspective on how low-carbon energy technologies can contribute to deep CO_2 emissions reduction targets. Using a techno-economic approach that assesses costs and benefits, the book examines least-cost pathways for meeting energy policy goals while also proposing measures to overcome technical and policy barriers. Specifically, *ETP 2010* examines the future fuel and technology options available for electricity generation and for the key end-use sectors of industry, buildings and transport. For the first time, this edition includes an analysis of OECD Europe, the United States, China and India, which together account for about 56% of today's global primary energy demand. It then sets out the technology transitions needed to move to a sustainable energy future, and provides a series of technology roadmaps to chart the path. Other new elements of *ETP 2010* include chapters on financing, behavioural change, the diffusion of technologies amongst developed and emerging economies, and a discussion of the environmental impacts of key energy technologies.

It is clear that, at present, the energy technology revolution is coming from the "bottom up". In many ways, this is a healthy sign: many energy challenges have the greatest impact on local populations – and those populations need to find solutions that work for their local contexts. Ultimately, the scale of the challenge demands a global strategy, not least because globalisation makes major economies increasingly interdependent in terms of trade, investment and the spread of technology. Another striking development is that many of these efforts already reflect stronger engagement between government, industry and civil society. *ETP 2010* highlights innovative policies and actions that warrant thoughtful consideration and broader application.

The next decade is critical. If emissions do not peak by around 2020 and decline steadily thereafter, achieving the needed 50% reduction by 2050 will become much more costly. In fact, the opportunity may be lost completely. Attempting to regain a 50% reduction path at a later point in time would require much greater CO_2 reductions, entailing much more drastic action on a shorter time scale and significantly higher costs than may be politically acceptable.

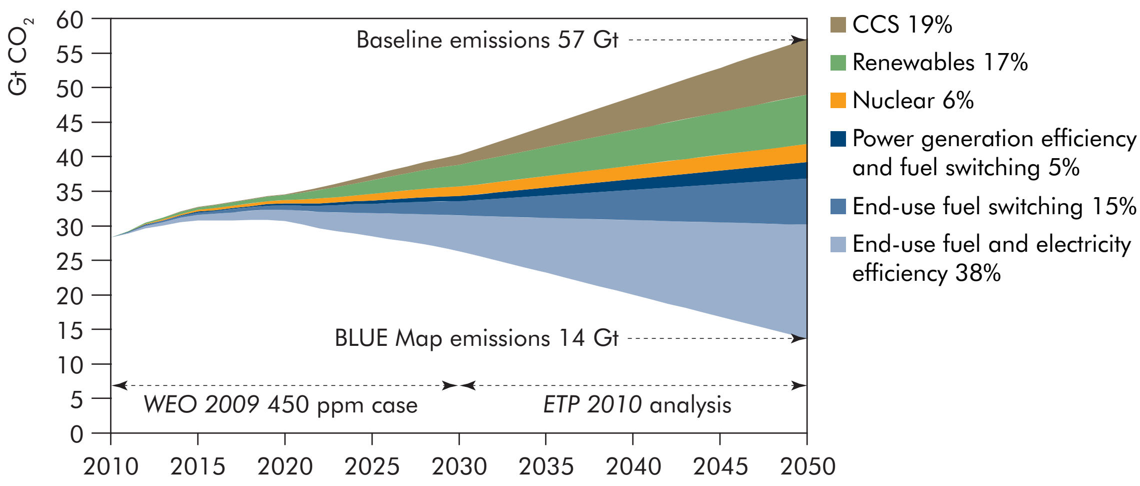
Concern about energy security, the threat of climate change and the need to meet growing energy demand (particularly in the developing world) all pose major challenges to energy decision makers. Advancing the low-carbon technology revolution will involve millions of choices by a myriad of stakeholders – all individuals acting in personal or professional spheres. Yet choice, in itself, can be a barrier: wading through the reams of information to arrive at the best choice can be quite paralysing. This book demonstrates that a portfolio of existing and new technologies will be needed to address these challenges, and lays out both the priority areas for action and the mechanisms that can help deliver change. This approach is designed to help decision makers from all spheres identify which combinations of technologies and policies will be most effective in their specific situations. By incorporating detailed roadmaps to facilitate technology deployment, *ETP 2010* hopes to prompt two aspects of the energy revolution: the necessary step change in the rate of progress and broader engagement of the full range of countries, sectors and stakeholders.

ETP scenarios present options rather than forecasts

ETP 2010 analyses and compares various scenarios. This approach does not aim to forecast what will happen, but rather to demonstrate the many opportunities to create a more secure and sustainable energy future.

The *ETP 2010* Baseline scenario follows the Reference scenario to 2030 outlined in the *World Energy Outlook 2009*, and then extends it to 2050. It assumes governments introduce no new energy and climate policies. In contrast, the BLUE Map scenario (with several variants) is target-oriented: it sets the goal of halving global energy-related CO_2 emissions by 2050 (compared to 2005 levels) and examines the least-cost means of achieving that goal through the deployment of existing and new low-carbon technologies (Figure ES.1). The BLUE scenarios also enhance energy security (*e.g.* by reducing dependence on fossil fuels) and bring other benefits that contribute to economic development (*e.g.* improved health due to lower air pollution). A quick comparison of *ETP 2010* scenario results demonstrates that low-carbon technologies can deliver a dramatically different future (Table ES.1).

Figure ES.1 ▶ Key technologies for reducing CO_2 emissions under the BLUE Map scenario



Key point

A wide range of technologies will be necessary to reduce energy-related CO_2 emissions substantially.

Table ES.1 ▶ ***Energy and emission trends under the Baseline and BLUE Map scenarios: 2050 compared to 2007***

Baseline scenario	BLUE Map scenario
• Energy-related CO_2 emissions roughly double	• Energy-related CO_2 emissions reduced by 50%
• Primary energy use rises by 84%; carbon intensity of energy use increases by 7%	• Primary energy use rises by 32%; carbon intensity of energy use falls by 64%
• Liquid fuel demand rises by 57% requiring significant use of unconventional oil and synthetic fuels; primary coal demand increases by 138%; gas demand is 85% higher	• Liquid fuel demand falls by 4% and biofuels meet 20% of total; coal demand drops by 36%; natural gas falls by 12%; renewables provide almost 40% of primary energy supply
• CO_2 emissions from power generation more than double; CO_2 intensity of power generation declines slightly to 459 g/kWh	• CO_2 emissions from power generation are cut by 76%; its CO_2 intensity falls to 67 g/kWh
• Fossil fuels supply more than two-thirds of power generation; the share of renewable energy increases slightly to 22%	• Renewables account for 48% of power generation; nuclear provides 24% and plants equipped with CCS 17%
• Carbon capture and storage (CCS) is not commercially deployed	• CCS is used to capture 9.4 Gt of CO_2 from plants in power generation (55%), industry (21%) and fuel transformation (24%)
• CO_2 emissions in the buildings sector, including those associated with electricity use, nearly double	• CO_2 emissions in buildings are reduced by two-thirds through low-carbon electricity, energy efficiency and the switch to low- and zero-carbon technologies (solar heating and cooling, heat pumps and CHP)
• Almost 80% of light-duty vehicles (LDVs) sales rely on conventional gasoline or diesel technology; petroleum products meet more than 90% of transport energy demand	• Almost 80% of LDVs sales are plug-in hybrid, electric or fuel-cell vehicles; the share of petroleum products in final transport demand falls to 50%
• CO_2 emissions in industry grow by almost half, as industrial production increases	• CO_2 emissions in industry fall by around a quarter mainly thanks to energy efficiency, fuel switching, recycling, energy recovery and CCS
• Total investment in energy supply and use totals USD 270 trillion	• Investment is USD 46 trillion (17%) more than in Baseline; cumulative fuel savings are USD 112 trillion higher than in Baseline
• Non-OECD countries are responsible for almost 90% of growth in energy demand and account for nearly three-quarters of global CO_2 emissions	• Non-OECD countries achieve CO_2 emissions reduction of around 30% compared to 2007; OECD countries account for less than one-quarter of global CO_2 emissions, having reduced emissions by 70% to 80% below 2007 levels

Box ES.1 ▶ Messages from the models

The findings of ETP 2010 reinforce conclusions from previous editions while also serving as a reminder that, since the first edition was released in 2006, the world has continued to move – and even at an accelerated pace – in the wrong direction. From 1990 to 2000, global CO_2 emissions increased by an average of 1.1% per year. Over the following seven years, the annual growth rate in emissions jumped to 3.0%. Two main factors are evident: rising energy demand in coal-based economies; and an increase in coal-fired power generation in response to higher oil and gas prices. The rate of increase in emissions from coal use rose from 0.6% per year (between 1990 and 2000) to 4.8% per year (between 2000 and 2007).

The most important message remains unchanged: current trends – as illustrated by the Baseline scenario – are patently unsustainable in relation to the environment, energy security and economic development. Ongoing dependence on fossil fuels (especially coal) continues to drive up both CO_2 emissions and the price of fossil fuels. Oil prices, for example, are assumed to reach USD 120 per barrel (in 2008 prices) by 2050.

But this carbon-intensive future is not a given. Using a combination of existing and new technologies, as envisaged in the BLUE scenarios, it is possible to halve worldwide energy-related CO_2 emissions by 2050. Achieving this will be challenging, and will require significant investment. But the benefits in terms of environmental outcomes, improved energy security and reduced energy bills will also be large. Oil prices in these scenarios are assumed to be only USD 70 per barrel (in 2008 prices) by 2050.

- *A portfolio of low-carbon technologies, with costs of up to USD 175/tCO_2 when fully commercialised, will be necessary to halve CO_2 emissions by 2050. No one technology or small group of technologies can deliver the magnitude of change required.*
- *Widespread deployment of low-carbon technologies can reduce global oil, coal and gas demand below current levels by 2050. Even so, fossil fuels will remain an important element of the world's energy supply for the foreseeable future.*
- *Increasing energy efficiency, much of which can be achieved through low-cost options, offers the greatest potential for reducing CO_2 emissions over the period to 2050. It should be the highest priority in the short term.*
- *Decarbonising the power sector, the second-largest source of emissions reductions, is crucial and must involve dramatically increasing the shares of renewables and nuclear power, and adding carbon capture and storage (CCS) to generation from fossil fuels.*
- *A decarbonised electricity supply offers substantial opportunities to reduce emissions in end-use sectors through electrification (for example, switching from internal combustion engine vehicles to electric vehicles (EVs) and plug-in hybrids (PHEVs), or from fossil fuel heating to efficient heat pumps).*
- *New low-carbon technologies will be needed to sustain emissions reductions beyond 2030, particularly in end-use sectors such as transport, industry and buildings.*

The future is inherently uncertain and always will be. Trends in economic growth (and therefore energy use and emissions) and technology development are difficult to predict. A portfolio approach to low-carbon technology development and deployment can help deal with this uncertainty.

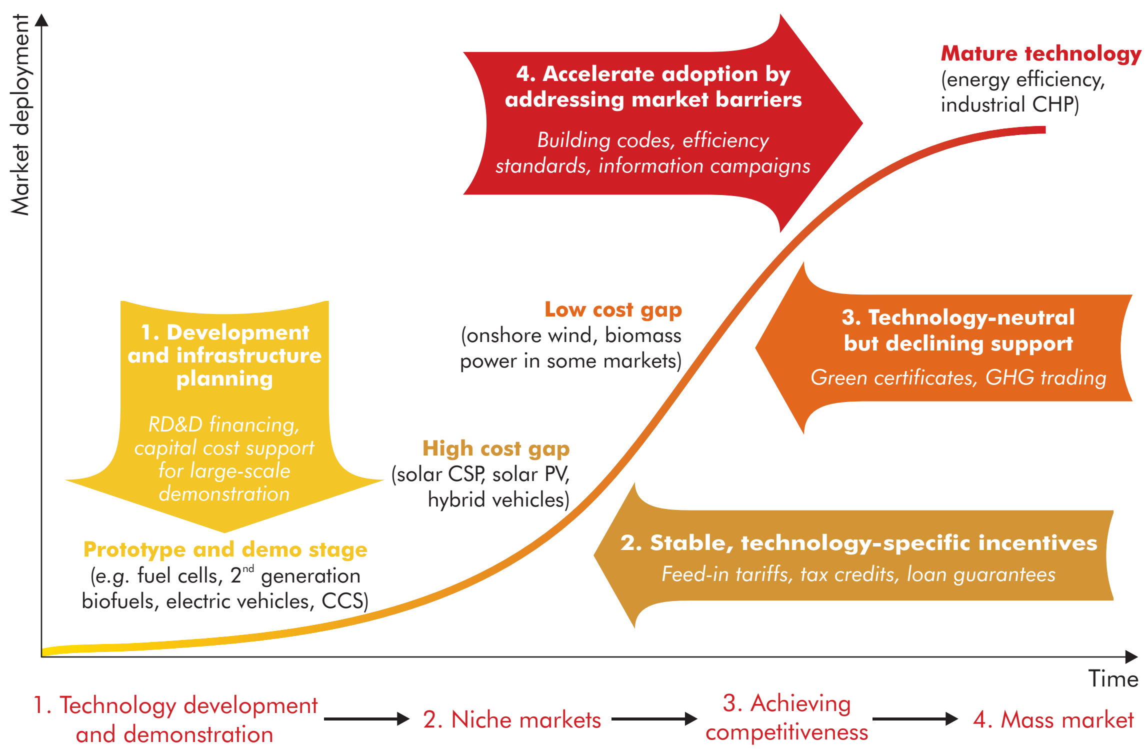
Technology policy

Many of the most promising low-carbon technologies currently have higher costs than the fossil-fuel incumbents. It is only through technology learning from research, development, demonstration and deployment (RDD&D) that these costs can be reduced and the technologies become economic. Thus, governments and industry need to pursue energy technology innovation through a number of parallel and interrelated pathways. Most new technologies will require, at some stage, both the "push" of RD&D and the "pull" of market deployment.

The role of governments in developing effective technology policy is crucial: policy establishes a solid foundation and framework on which other stakeholders, including industry, can build. Where appropriate, policies will need to span the entire spectrum of RDD&D. In this way, governments can reduce the risk for other actors in the early phases of technology development and then gradually expose the technology to greater competition, while allowing participants to realise reasonable returns on their investments as a low-carbon economy takes hold.

Governments will need to intervene on an unprecedented level in the next decade to avoid the lock-in of high-emitting, inefficient technologies. They must take

Figure ES.2 ▶ **Policies for supporting low-carbon technologies**



Note: The figure includes generalised technology classifications; in most cases, technologies will fall in more than one category at any given time.

Key point

Government support policies need to be appropriately tailored to the stage(s) of development of a technology.

swift action to implement a range of technology policies that target the cost-competitiveness gap while also fairly reflecting the maturity and competitiveness of individual technologies and markets (Figure ES.2). The overriding objectives should be to reduce risk, stimulate deployment and bring down costs. Evidence suggests that a large proportion of breakthrough innovations come from new firms that challenge existing business models. Thus, government steps to remove barriers to the entry and growth of new firms may have an important part to play in low-carbon energy technology development.

In recent years, much attention has been given to the importance of policies that put a price on carbon emissions as a way of stimulating the clean technology development and deployment needed to deliver an energy revolution. The Copenhagen Accord acknowledges market approaches as a means to enhance cost-effectiveness. While such policies (*e.g.* carbon trading) are likely to be an important driver of change, they are not necessarily the most effective way to deliver short-term investment in the more costly technologies that have longer-term emissions reduction benefits. Moreover, a truly global carbon market is likely to be many years away. Governments can draw upon a wide variety of other tools to help create markets for the technologies that meet national policy objectives, including regulations, tax breaks, voluntary programmes, subsidies and information campaigns. But they also need to have exit routes: the level of government support should decrease over time and be removed altogether as technologies become competitive – or indeed, if it becomes clear that they are unlikely to do so.

ETP 2010 estimates that to achieve the 50% CO_2 emissions reduction, government funding for RD&D in low-carbon technologies will need to be two to five times higher than current levels. This message is being taken seriously by many countries. Governments of both the Major Economies Forum and the IEA have agreed to dramatically increase and co-ordinate public-sector investments in low-carbon RD&D, with a view to doubling such investments by 2015. Simply increasing funding will not, however, be sufficient to deliver the necessary low-carbon technologies. Current government RD&D programmes and policies need to be improved by adopting best practices in design and implementation. This includes the design of strategic programmes to fit national policy priorities and resource availability; the rigorous evaluation of results and adjusting support if needed; and the increase of linkages between government and industry, and between the basic science and applied energy research communities to accelerate innovation.

Reducing CO_2 emissions ultimately depends on the uptake of low-carbon technologies by industry, businesses and individual consumers. To date, efforts to encourage the adoption of energy-efficient and low-carbon technologies have focused primarily on overcoming technological and economic barriers. In fact, research suggests that consumer choices are more heavily influenced by social and behavioural factors. Improved understanding of the human dimensions of energy consumption, particularly in the residential and commercial sectors and in personal transport, will help policy makers to catalyse and amplify technology-based savings. A sampling of successful programmes highlighted in *ETP 2010* indicates that policy strategies to influence consumer choices should target, inform, motivate and empower consumers.

Governments also have an important role in encouraging others to take the lead in relevant areas. Industry can demonstrate leadership through active involvement in public-private partnerships. Universities can expand training and education to develop and deploy the human capacity needed to exploit the innovative energy technologies. Non-governmental organisations can help engage the public and communicate the urgency of the need to deploy new energy technologies on a large scale, including the costs and benefits of doing so. Finally, all stakeholders must work together to strengthen international technology collaboration to accelerate RDD&D, diffusion and investment. Technology roadmaps can be an effective tool to help this process.

Box ES.2 ▶ IEA technology roadmaps

At the request of G8 Ministers, the IEA is developing roadmaps to support accelerated development and deployment of the most important low-carbon technologies. Each roadmap sets out a shared vision to 2050 and charts the actions required, at international and national levels, by relevant stakeholders. This collective approach is vital to maximising the net benefit of investment in the RDD&D of new technologies. The roadmaps also address several cross-cutting issues, on the international and regional levels, that will underpin the successful exploitation of these technologies.

Many of the IEA technology roadmaps recommend private-sector partnerships to accelerate innovation and the transition from demonstration to commercial deployment. Such partnerships may be particularly appropriate for technologies such as CCS and electric vehicles, both of which will depend on establishing new business models for industries and technologies

Increasing international technology diffusion

All of the scenarios used in *ETP 2010* confirm a somewhat startling fact: nearly all of the future growth in energy demand and in emissions comes from non-OECD countries. Accelerating the spread of low-carbon technologies to non-OECD countries is therefore a critical challenge, particularly for the largest, fast-growing economies such as Brazil, China, India, the Russian Federation and South Africa.

Non-OECD countries have traditionally been assumed to access new technologies as a result of technology transfer from industrialised countries, presupposing a general trend that technological knowledge flows from countries with higher technological capacities to those with lower capacities. The situation is, however, becoming more complex, with an increasing multi-directional flow of technologies among and between OECD and non-OECD countries, and emerging economies establishing strong manufacturing bases and becoming exporters in their own right.

To be successful, a low-carbon economy should be based on market principles in which energy technologies spread primarily through commercial transactions. The challenge is to reorient these transactions to support the transfer of low-carbon technologies while also helping emerging countries to become technology developers and market players. Careful consideration must be given to the capacity of countries to absorb new technologies. Some emerging economies, led by China, are rapidly improving their capability to develop and deploy key low-carbon technologies. Given their economic growth rates, they must advance at an even more rapid pace to decouple CO_2 emissions from economic activity.

Financing and returns on investment

ETP 2010 shows that a very considerable investment will be needed to meet the world's growing energy needs. The Baseline scenario estimates a total investment, between 2010 and 2050, of USD 270 trillion.[1] Most of this (USD 240 trillion or almost 90%) reflects demand-side investments that will be made by energy consumers for capital equipment that uses energy, including vehicles, electric appliances and plants in heavy industry.

Meeting energy demand growth in a way that supports the "50% by 2050" goal will be considerably more expensive: the BLUE Map scenario projects investment requirements of USD 316 trillion, a further increase of 17% (USD 46 trillion).

Over the past three years, annual investments in low-carbon energy technologies averaged approximately USD 165 billion. Implementing the BLUE Map scenario will require investments to reach approximately USD 750 billion per year by 2030 and rise to over USD 1.6 trillion per year from 2030 to 2050. The level of investment doubles in the latter period as a result of increased demand for cars and other consumer products, which rises alongside incomes in emerging and developing countries.

The flip side is that the energy technology revolution holds significant potential for very positive returns on investment. For example, the low-carbon economy will lead to substantial fuel savings due to efficiency improvements and as lower fuel demand drives down prices. *ETP 2010* calculates that the additional USD 46 trillion investment needs in the BLUE Map scenario will yield, over the period from 2010 to 2050, cumulative fuel savings equal to USD 112 trillion. Even if both the investments and fuel savings over the period to 2050 are discounted back to their present values using a 10% discount rate, the net savings amount to USD 8 trillion.

Moreover, the energy revolution offers substantial opportunities to business. Forward-looking companies recognise the enormous potential for developing and deploying – on a global scale – a wide range of new breakthrough and emerging technologies, as well as the possibility to make use of mechanisms that facilitate investment in non-OECD countries (*e.g.* in return for carbon credits). The role of governments in setting stable policy frameworks and providing some direct funding for RDD&D has already been stated. A second point is the need for increased dialogue between government and the investment community to improve understanding and establish appropriate boundaries to their unique but complementary spheres of activity.

ETP 2010 also examines the wider economic, social and environmental impacts (referred to as "co-impacts" because of the degree to which they are interrelated) of

1. Excluding upstream investments in the production and transportation of coal, oil and gas.

low-carbon technologies. The analysis focuses primarily on issues that, particularly in developing countries, may be more immediate political and social priorities than reducing CO_2 emissions, namely: air quality and related impacts on human health; water quality and availability; and land use. Reducing air pollution through low-carbon technologies, for example, delivers other energy-related environmental benefits and reduces negative health impacts on local populations.

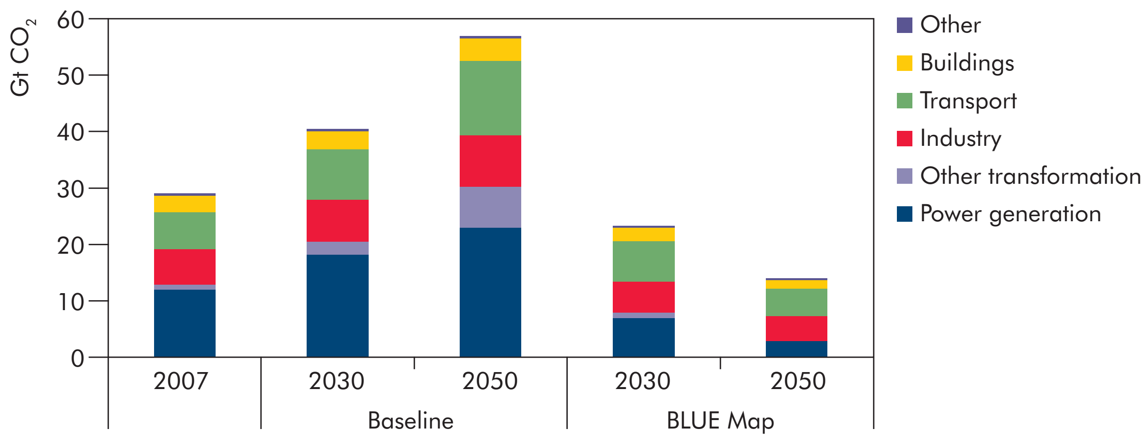
Further work is needed to refine the estimates in this assessment, including ways to leverage potential co-benefits and to ensure that any negative co-impacts are understood, quantified and, where possible, mitigated. It is equally important to assess co-benefits and potential conflicts at regional, national and local levels, as many will be setting-specific.

Sectoral findings

About 84% of current CO_2 emissions are energy-related and about 65% of all greenhouse-gas emissions can be attributed to energy supply and energy use. All sectors will need to reduce dramatically their CO_2 intensity if global CO_2 emissions are to be halved. However, this does not mean that every sector needs to cut its own emissions by 50% (Figure ES.3). Each sector has different growth prospects under the Baseline scenario and a different range of low-carbon options that can be deployed to reduce emissions. *ETP 2010* examines in detail each sector's potential to contribute to a cost-optimal low-carbon future, including the technologies and policies that will be needed.

For advancing deployment of both existing and new technologies across all sectors, a key message is the need for rapid action that takes account of long-term goals. Without a long-range perspective, there is a risk that inappropriate and costly capital investments made in the near term could undermine future emissions reduction targets or will need to be scrapped well in advance of their normal life cycles.

Figure ES.3 ▶ **Global CO_2 emissions in the Baseline and BLUE Map scenarios**



Key point

The BLUE Map scenario implies deep emission cuts across all sectors.

Power sector

It bears repeating that decarbonising the power sector will be at the heart of efforts to make deep cuts in global CO_2 emissions. The power sector currently accounts for 41% of energy-related CO_2 emissions. The Baseline scenario projects a doubling of these emissions over the period to 2050, because of continued reliance on fossil fuels. By contrast, the BLUE Map scenario achieves almost a 90% reduction (compared to 2007 levels) in the carbon intensity of electricity generation, with renewables accounting for almost half of global production and nuclear for slightly less than one-quarter. The other key change is that most remaining electricity production from fossil fuels has much lower CO_2 emissions thanks to widespread adoption of CCS.

Significant policy change is needed to break the current dependence on fossil fuels in the power sector, as is significant investment. The BLUE Map scenario requires investment of USD 32.8 trillion (40% more than the USD 23.5 trillion needed in the Baseline scenario), more than half directed towards new power generation plants. A key challenge is that, at present, many low-carbon alternatives are considerably more expensive than traditional fossil-based technologies. In addition to expanding RD&D support and creating market mechanisms to foster technological innovation, governments should adopt policies that encourage the earliest possible closure of the dirtiest and least efficient plants. All low-carbon generation options need to be pursued: excluding any one option could significantly increase the costs of achieving CO_2 emissions reductions from the sector.

Some low-carbon generation technologies raise unique challenges. For example, system integration will be needed to support large quantities of variable renewables (such as wind, solar PV, run-of-river hydropower, and wave and tidal power). There is also an urgent need to accelerate the demonstration of CCS in the power sector and to develop comprehensive regulatory approaches to enable its large-scale commercial deployment. Nuclear power requires further progress on building and operating disposal facilities for radioactive waste.

Achieving a near zero-carbon electricity supply creates opportunities to reduce CO_2 emissions in all end-use sectors by shifting energy consumption from fossil fuels to electricity. For example, from internal combustion engine (ICE) cars running on diesel or gasoline to EVs and PHEVs, or from fossil-fuel heating to efficient heat pumps.

There are some signs that the necessary changes in power generation are starting to happen. Investment in renewable energy, led by wind and solar, reached an all-time high in 2008 and stayed at similar levels in 2009 despite the economic downturn. In 2009, more wind power was installed in Europe than any other electricity-generating technology. Similar developments have been seen in other parts of the world; in terms of global installed renewable capacity, China now ranks second and India fifth. There is also evidence that nuclear power is undergoing a renaissance. Major expansions of nuclear capacity are planned in China, India and Russia. Several other countries with existing nuclear plants but where no new construction has been launched in recent years are also actively considering new nuclear capacity.

Electricity networks

Changing profiles for demand and generation will require modifications in the design, operation and deployment of electricity networks, with regional characteristics becoming more important in determining network configurations.

Although system-scale demonstration is still needed, the flexibility of smart grids (which integrate both electricity and thermal storage technologies) appears to support balancing of variable generation and demand, better management of peak loads and delivery of energy efficiency programmes. Smart grids can contribute to reducing CO_2 emissions from both electricity generation and use. In developing countries, smart grids will facilitate expansion of electricity services, and show significant potential to reduce transmission and distribution losses.

Industry

Over recent decades, industrial energy efficiency has improved and CO_2 intensity has declined in many sectors. However, this progress has been more than offset by growing industrial production worldwide. Direct emissions from industry account for around 20% of current CO_2 emissions. Achieving deep cuts in CO_2 emissions will require the widespread adoption of current best available technology, as well as the development and deployment of a range of new technologies (such as CCS, smelting reduction, separation membranes and black liquor gasification).

Successful application of CCS in a number of energy-intensive industrial sectors (*e.g.* iron and steel, cement, chemical and petrochemical, and pulp and paper) represents potentially the most important new technology option for reducing direct emissions in industry. To fulfil its promise, the large-scale demonstration of CO_2 capture technologies in industry should be undertaken in parallel with demonstration projects planned for the power sector. Fuel and feedstock substitution with biomass and waste represents another important option but as the resource will be fairly limited, competition could drive up prices and make industrial applications less attractive. A decarbonised power sector will offer new opportunities to reduce the CO_2 intensity through electrification of industrial processes.

Clear, stable, long-term policies that support carbon pricing will be needed to stimulate the technology transition in industry. The current situation, in which only developed countries are subject to emission constraints, gives rise to legitimate concerns about competitiveness and carbon leakage. A global system of emissions trading may eventually be most effective; in the meantime, international agreements covering specific energy-intensive sectors may be a practical first step. Government intervention will be needed to establish standards, incentives and regulatory reforms. Removing energy price subsidies should be a priority in countries where they persist.

Buildings

Direct emissions from buildings account for around 10% of global CO_2 emissions; including indirect emissions from the use of electricity in the sector increases this share to almost 30%. From an energy perspective, buildings are complex systems consisting of the building envelope and its insulation, space heating and cooling systems, water heating systems, lighting, appliances and consumer products, and business equipment.

Most buildings have long life spans, meaning that more than half of the current global building stock will still be standing in 2050. The low retirement rate of buildings in the OECD and in economies in transition, combined with relatively modest growth, means that most of the energy and CO_2 savings potential lies in retrofitting and purchasing new technologies for the existing building stock. In developing countries, where new building growth will be very rapid, opportunities exist to secure significant energy savings (rather quickly and strongly) through improved efficiency standards for new buildings.

The implementation of currently available, low-cost energy-efficient and low-carbon options is essential to achieve cost-effective CO_2 emissions reductions in the short run. This will buy time to develop and deploy less mature and currently more expensive technologies that can play an important role in the longer term. For space and water heating, these include highly efficient heat pumps, solar thermal systems, and combined heat and power (CHP) systems with hydrogen fuel cells.

In the residential sector, the main barriers to change are higher initial costs, lack of consumer awareness of technologies, split incentives and the low priority placed on energy efficiency. Overcoming these barriers will require a comprehensive policy package that may include information campaigns, fiscal and financial incentives, and other deployment policies, as well as minimum energy performance standards. Such policies must address financial constraints, develop industry capacity and boost R&D investment.

In the service sector, policies to achieve improvements in the building shell of new buildings, together with highly efficient heating, cooling and ventilation systems will be needed. Given their larger share of total use (compared to the residential sector), significant policy measures will be required to improve the efficiency of energy use in lighting and other electrical end-uses such as office equipment, information technology (IT) equipment and refrigeration.

Recent years show some encouraging signs of a shift in consumer preferences towards new technologies that can reduce CO_2 emissions. In 2007/08, sales of heat pumps showed double-digit growth in a number of major European markets. Demand has also been growing rapidly for solar thermal systems that can provide low-temperature heat for cooling and/or space and water heating.

Transport

The transport sector is currently responsible for 23% of energy-related CO_2 emissions. Given the increases in all modes of travel, especially passenger light-duty vehicles (LDVs) and aviation, the Baseline scenario shows a doubling of current transport energy use by 2050 and slightly more than a doubling of associated CO_2 emissions. Achieving deep cuts in CO_2 emissions by 2050 will depend on slowing the rise in transport fuel use through greater energy efficiency and increasing the share of low-carbon fuels. Encouraging travellers and transporters to shift from LDVs, trucks and air travel to more frequent use of bus and rail is another route for substantial savings.

While absolute reductions in transport emissions from 2007 levels are possible in OECD countries, strong population and income growth in non-OECD countries will make it extremely difficult to achieve absolute emissions reductions in the transport sector. In the BLUE Map scenario, by 2050 emissions in OECD countries are about 60% less than in 2007, but those in non-OECD countries are 60% higher on a well-to-wheel basis.

Prospects are good for cutting fuel use and CO_2 emissions from LDVs by improving the efficiency of ICEs, and through vehicle hybridisation and adoption of PHEVs, EVs and fuel-cell vehicles. Virtually all incremental efficiency improvements to gasoline and diesel vehicles seen in the BLUE Map scenario are paid for by fuel savings over the vehicle lifetime. Most OECD governments now have strong fuel economy standards and many governments worldwide have announced plans to support wider use of EVs and PHEVs. Taken together, these commitments could place more than 5 million EVs and PHEVs on the road by 2020.

In the BLUE Map scenario, biofuels, electricity and hydrogen together represent 50% of total transport fuel use in 2050, replacing gasoline and diesel. Biofuel demand for light-duty ICE vehicles begins to decline after 2030 owing to a strong shift towards electricity and hydrogen fuels. In contrast, biofuels use rises rapidly for trucks, ships and aircraft through 2050, replacing middle distillate petroleum fuels.

Despite promising signs that governments are introducing policies to reduce CO_2 emissions from transport, much more effort is needed to increase RDD&D funding and co-ordination especially to more rapidly cut the costs of advanced technologies. In addition, greater attention must be directed toward encouraging consumers to adopt the technologies and lifestyle choices that underpin the transition away from energy-intensive, fossil-fuel based transport systems.

Box ES.3 ▶ Regional differences

ETP 2010 *undertook a more detailed analysis of CO_2 trends and abatement options for four countries or regions that will have a major role in reducing global emissions: OECD Europe, the United States, China and India. Each faces unique challenges, reflecting current and future levels of economic development and diverse endowments of natural resources (represented in their energy mixes). Thus, each will have very different starting points and future trajectories in terms of their CO_2 emissions and develop in different ways in both the Baseline and the BLUE Map scenarios. Although many of the same technology options are needed to reduce emissions, the policy options associated with their application may be dramatically different.*

In the Baseline scenario, CO_2 emissions in India show the largest relative increase, rising almost fivefold by 2050. China also shows a substantial rise, with emissions almost tripling between 2007 and 2050. The United States show a much more modest rise, of 1% and emissions in OECD Europe decline by 8%. In the BLUE Map scenario, all countries show considerable reductions from the Baseline scenario: emissions in 2050 (compared to 2007) are 81% lower for the United States, 74% lower for OECD Europe and 30% lower in China, while India's emissions rise by 10%.

The BLUE Map scenario also brings significant security of supply benefits to all four countries or regions, particularly through reduced oil use. In the United States and OECD Europe, oil demand in 2050 is between 62% and 51% lower than 2007 levels (gas demand shows similar declines). In China and India, oil demand still grows in the BLUE Map scenario, but is between 51% and 56% lower by 2050 than in the Baseline scenario.

*In **OECD Europe**, the electricity sector will need to be almost completely decarbonised by 2050. More than 50% of electricity generation is from renewable energy, with most of the remainder from nuclear and fossil fuels using CCS (the precise energy mix varies widely among individual countries, reflecting local conditions and opportunities). In industry, energy efficiency and CCS offer the main measures for reducing emissions.*

In buildings, efficiency improvements in space heating can provide the most significant energy savings and more than half of the sector's emissions reductions in the BLUE Map scenario. Other mitigation measures include solar thermal heating, heat pumps, CHP/district heating and efficiency improvements for appliances. Transport volumes in OECD Europe are expected to remain relatively constant. Deep CO_2 emissions reductions in transport can be achieved through more efficient vehicles, a shift towards electricity and biofuels, and progressive adoption of natural gas followed by a transition to biogas and bio-syngas.

*For the **United States**, energy efficiency and fuel switching will be important measures in reducing CO_2 emissions across all end-use sectors. Infrastructure investments will be vital to supporting the transition to a low-carbon economy, particularly in the national electricity grid and transportation networks. Most of the existing generation assets will be replaced by 2050 and low-carbon technologies such as wind, solar, biomass and nuclear offer substantial abatement opportunities. Many energy-intensive industries have substantial scope to increase energy efficiency through technological improvements. Similarly, the average energy intensity of LDVs is relatively high; doubling the fuel efficiency of new LDVs by 2030 can help reduce emissions. Advanced vehicle technologies can also play an important role in the LDV and commercial light- and medium-duty truck sectors. In buildings, improving the efficiency of space cooling, together with more efficient appliances, offers the largest opportunity to reduce CO_2 emissions.*

*Given the dominance of coal, **China** must invest heavily in cleaner coal technologies (such as CCS) and improve efficiency of coal use in power generation and industry (which accounts for the largest share of China's energy use and CO_2 emissions). Priority should also be given to measures to improve energy efficiency and reduce CO_2 emissions in energy-intensive sectors such as iron and steel, cement and chemicals. The Chinese transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure construction and the introduction of new technologies. The BLUE Map scenario shows that significant emissions reductions will depend on the electrification of transport modes and substantial decarbonisation of the electricity sector.*

*For **India**, the challenge will be to achieve rapid economic development — which implies a significant increase in energy demand for a growing population — with only a very small increase in CO_2 emissions. Electricity demand will grow strongly and the need for huge additional capacity creates a unique opportunity to build a low-carbon electricity system. While India has some of the most efficient industrial plants in the world, it also has a large share of small-scale and inefficient plants. Thus, improving overall industrial efficiency will be a significant challenge. Rising incomes and increased industrial production will spur greater demand for transport in India, making it imperative to promote public transport and new, low-carbon vehicle technologies. The buildings sector will also see strong growth in energy demand: efficiency improvements in space cooling and appliances will be critical to restraining growth in energy consumption and emissions.*

Conclusion

A truly global and integrated energy technology revolution is essential to address the intertwined challenges of energy security and climate change while also meeting the growing energy needs of the developing world. *ETP 2010* shows that key players, from both public and private sectors, are starting to take the steps needed to develop and deploy a very broad range of new low-carbon technologies. Action can be seen in all of the most important sectors, and across most regions of the world.

Clearly, financing remains a substantial challenge as does identifying appropriate mechanisms to accelerate the deployment of low-carbon technologies in major developing countries. A related issue is that several sources predict a severe skills shortage, which could quickly become a major barrier to deployment across all sectors and in all regions. There is an urgent need to properly assess the skills required, considering regional situations and human resource availability, and to develop recommendations on how to fulfil these needs.

As citizens of a changing world, we all live with a degree of uncertainty at all times; as energy producers and consumers entering a period of rapid change, the sense of uncertainty is likely to be amplified. The roadmaps and transition pathways presented in *ETP 2010* aim to overcome existing barriers and spur much-needed RDD&D in the very near term and throughout the period to 2050. The extensive data, projections and analysis contained in this volume will provide decision makers with the detailed information and insights they need to throw their weight behind rapid acceleration — in their own backyards or at the international level — of the switch to a more secure, low-carbon energy future.

In short, the most vital message of *ETP 2010* is that an energy technology revolution is within reach. Achieving it will stretch the capacities of all energy-sector stakeholders and entail substantial upfront costs, but over the long term these will be more than offset by the benefits. Governments, investors and consumers around the world need to take bold, decisive action to initiate and advance change in their respective spheres of influence – and increase their commitment to working together.

Chapter 1 INTRODUCTION

Secure, reliable and affordable energy supplies are fundamental to economic stability and development. The erosion of energy security, the threat of disruptive climate change and the growing energy needs of the developing world all pose major challenges to energy decision makers. This book deals with the role of energy technologies in meeting these challenges. This will involve both making better use of existing technologies and developing new ones.

In recent years fossil fuel prices have been very volatile. They look set to remain at high levels compared to the past. A number of factors contribute to this trend, including rising energy demand, particularly in the developing world, and concerns over the security and availability of oil and gas supplies. Reducing fossil fuel dependency is an important energy policy target in many countries.

These energy security concerns are compounded by the increasingly urgent need to mitigate greenhouse-gas emissions, including those relating to energy production and consumption. About 84% of all CO_2 emissions are energy-related, and about 65% of all greenhouse-gas emissions can be attributed to energy supply and energy use. The International Energy Agency's (IEA) *World Energy Outlook 2009* (*WEO 2009*) (IEA, 2009a) projects that by 2030, in the absence of new policies, fossil fuel demand will have increased by 37% from 2007 levels and global energy-related CO_2 emissions will have grown by 40%.

The current trend of rising energy demand and rising emissions runs directly counter to the major emissions reductions that are required to prevent dangerous climate change. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that reductions of 50% to 85% in global CO_2 emissions compared to 2000 levels will need to be achieved by 2050 to limit the long-term global mean temperature rise to 2.0°C to 2.4°C (IPCC, 2007). Higher emission levels will result in more significant climate change (Table 1.1). Recent studies have suggested that climate change is occurring faster than previously expected and that even a 50% reduction in global CO_2 emissions by 2050 may not be enough to avoid dangerous temperature increases (UNSW, 2009).

Table 1.1 ▶ ***The relationship between CO_2 emissions and climate change***

Temperature increase (°C)	**All GHGs** (ppm CO_2-eq.)	**CO_2** (ppm CO_2)	**CO_2 emissions 2050** (% of 2000 emissions)
2.0-2.4	445-490	350-400	–85 to –50
2.4-2.8	490-535	400-440	–60 to –30
2.8-3.2	535-590	440-485	–30 to +5
3.2-4.0	590-710	485-570	+10 to +60
4.0-4.9	710-885	570-660	+25 to +85
4.9-6.1	885-1 130	660-790	+90 to +140

ppm: parts per million.

Source: IPCC (2007).

The longer the current trend of increasing emissions continues, the deeper will be the future emissions cuts that are needed to protect the climate and the greater the consequential costs. *WEO 2009* calculates that each year of delay before moving onto an emissions path consistent with a 2.0°C temperature increase would add approximately USD 500 billion to the global incremental investment cost. A delay of just a few years would probably put that goal completely out of reach. All countries and regions must contribute to emissions reductions if this goal is to be met. Even in the very unlikely event that the member countries of the Organisation for Economic Co-operation and Development (OECD) were to emit no CO_2 by 2050, non-OECD countries would still need to reduce their own CO_2 emissions below current levels if significant climate change was to be avoided.

The political context

At the IEA Ministerial Meeting in October 2009, Ministers agreed:
…that we need to act now to combat climate change if we are to avoid the devastating effects both for our citizens and for the world, particularly poor and developing countries. Such efforts can also contribute to economic growth, technological advancement and innovation, energy security and access to energy for the poor (IEA, 2009b).

Ministers welcomed:
…the Major Economies Forum (MEF) recognition of the scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed two degrees Celsius and stated their willingness *to share with all countries the goal of achieving at least a 50% reduction of global emissions by 2050 and recognise that this implies that global emissions need to peak as soon as possible and decline thereafter.*

As part of this, they also acknowledged:
…the goal, as stated in the Leaders' Declaration of the G8 L'Aquila Summit, to reduce developed countries' collective emissions of greenhouse gases in aggregate by 80% or more by 2050 compared to 1990 or more recent years.

The Ministers also noted that:
…most of the actions to mitigate climate change need to take place in the energy sector which accounts for over 60% of global greenhouse-gas emissions and recognised that *international efforts to improve energy efficiency and accelerate research, development and deployment of a wide spectrum of low-carbon technologies are essential*. In turn, they agreed that *more effort should be made to increase substantially public-sector investments in research, development and demonstration of these technologies, with a view to doubling such investments by 2015.*

Finally, Ministers called upon the private sector to increase its investment in these areas as well.

Many of these statements were echoed in the Copenhagen Accord developed by some of the world's largest economies at the 15th Conference of the Parties (COP15) to the United Nations Framework Convention on Climate Change (UNFCCC) in

December 2009 (UNFCCC, 2009). This Accord recognised the importance of limiting the increase in global temperature to below 2.0°C and agreed that deep cuts in global emissions were required to meet this goal. Although the Copenhagen Accord was not formally adopted by the Conference of the Parties to the UNFCCC, a vast majority of governments worldwide expressed their support. This represents a significant step forward in developing a shared global understanding of the challenges of climate change and a commitment to action to address it.

The purpose and scope of this study

The goal of the analysis in this book is to provide an IEA perspective on the potential for energy technologies to contribute to deep CO_2 emissions reduction targets and the associated costs and benefits. As in earlier editions of *Energy Technology Perspectives*, a suite of updated scenarios are used to explore possible future technology options and the combinations of those options across both the supply and demand sectors that can meet energy policy goals at least cost. It uses a techno-economic approach to identify the role of current and potential new technologies in reducing CO_2 emissions and improving energy security. The analysis does not deal with the political feasibility of such goals. Investment needs and financing mechanisms are reviewed but the analysis makes no attempt to allocate responsibility among countries for funding the significant investment that will be needed.

This book aims to review and assess the energy technologies that will be important in addressing climate change and energy security challenges over the next 40 years. It identifies the main technical and policy barriers to the implementation of change, and the measures that may be needed to overcome these barriers. It sets out detailed roadmaps for selected technologies. It is intended to be a reference point for policy makers and others interested in identifying how existing and emerging clean energy technologies and policies can bring about the energy revolution that is needed.

The analysis builds on *Energy Technology Perspectives 2008* (IEA, 2008) and *WEO 2009*, by providing decision makers with more detailed practical information and tools that can help kick-start the transition to a more secure, sustainable and affordable energy future. New features in this edition include:

- **Updated scenarios** with greater regional detail that provide insights into the new technologies that are likely to be most important in different regions of the world.
- **Detailed sectoral analyses** that highlight the most significant technological challenges and opportunities in each of the main energy-using sectors and the new policies that will be needed to realise change.
- **Roadmaps and transition pathways** that identify ways of accelerating the deployment of some of the most important clean energy technologies.

The study draws heavily on the extensive IEA store of data and analysis, and is a result of close co-operation between all IEA offices. It has profited greatly from the unique international IEA network for collaboration on energy technology described in Annex A. More than 5 000 experts from 25 IEA member countries, 17 IEA non-member countries, 48 companies, the European Commission, the Organization of the Petroleum Exporting Countries and the United Nations Industrial Development Organisation participate in the IEA Implementing Agreements, part of the larger energy technology network under the auspices of the IEA Committee on Energy Research and Technology (CERT), its Working Parties and Expert Groups. Although the analysis in this book has benefited from numerous contributions from network members and other experts, the conclusions are those of the IEA Secretariat.

Energy Technology Perspective 2010 comprises two parts:

Part 1 (Chapters 2 to 11) examines the fuels and technologies that are likely to be important in a Baseline scenario and in a range of scenarios in which global CO_2 emissions are reduced by 50% from 2005 levels by 2050 (the BLUE Map scenario and a series of variants of it). It provides insights into the future of energy technologies for electricity generation and in the key end-use sectors of industry, buildings and transport. It then analyses the current status and future energy options for OECD Europe, the United States, China and India, which together make up about 56% of today's global primary energy demand.

Part 2 (Chapters 12 to 17) sets out the technology transitions that will be required to help the world move towards a more sustainable energy future and a series of technology roadmaps that can help to achieve this objective. It addresses how these transitions can be financed, the role of behavioural change in facilitating technological deployment and the diffusion of technologies from developed to emerging economies. It also discusses the other environmental impacts of new energy technologies.

PART 1 TECHNOLOGY AND THE GLOBAL ENERGY ECONOMY TO 2050

Chapter 2 OVERVIEW OF SCENARIOS

Key findings

In the absence of new policies, global energy demand and CO_2 emissions will double by 2050. This is unsustainable.

- *In the Baseline scenario, global CO_2 emissions grow rapidly, oil and gas prices are high, and energy security concerns increase as imports rise. In this scenario, energy-related CO_2 emissions in 2050 would be twice the level they were in 2007. These developments are not sustainable. Nearly all of the growth in energy demand and in emissions comes from non-OECD countries.*

- *Liquid fuel demand in 2050 in the Baseline scenario is 58% higher than in 2007, requiring the significant use of unconventional oil and synthetic fuels. Coal demand increases by 138% and gas demand is 85% higher. The carbon intensity of primary energy use increases, largely driven by increasing coal use in power generation and, after 2030, by the increased use of coal to produce liquid transport fuels.*

The widespread deployment of a range of existing and new energy technologies can lead to a more secure and sustainable energy future.

- *Using a combination of existing and new technologies, as envisaged in the BLUE scenarios, it is possible to halve worldwide energy-related CO_2 emissions by 2050. Achieving this will be challenging, and will require significant investment. But the benefits in terms of environmental outcomes, improved energy security and reduced energy bills will also be large.*

- *In the BLUE Map scenario, oil demand in 2050 is 27% lower than in 2007 and coal and gas demand are 36% and 12% lower respectively. These reductions in demand lead to substantial fuel savings. Even so, fossil fuels remain an important element of the world's energy supply in 2050 in all scenarios.*

- *The BLUE Map scenario delivers net financial benefits compared to the Baseline. Investments over the period 2010 to 2050 in the BLUE Map scenario are USD 46 trillion higher than those in the Baseline scenario. This represents an increase of 17%. But cumulative fuel savings over the same period are even larger at USD 112 trillion. Discounting both investments and fuel savings between 2010 and 2050 at a discount rate of 10% yields a net saving of USD 8 trillion.*

- *The outcomes envisaged in the BLUE scenarios are not possible with only the technologies that are commercially available today. The electricity sector will need to be substantially decarbonised through the use of renewable energy, nuclear power and fossil-fuel-based generation combined with carbon capture and storage (CCS). The rate of energy efficiency improvement will need to increase substantially across all end-use sectors. New low-carbon technologies will be required in transport, buildings and in industry.*

- *Fuel switching to low- or zero-carbon fuels will be a significant source of carbon reductions. In the BLUE Map scenario, biomass use doubles and low-carbon electricity is increasingly used in buildings, transport and industry. Hydrogen also plays a role after 2030.*
- *To reduce CO_2 emissions by 50% by 2050, emissions must peak around 2020 and thereafter show a steady decline. If this does not happen, the 50% reduction by 2050 will become much more costly to achieve, and possibly unachievable at any realistic price. Urgent action is needed.*
- *Policies that raise CO_2 targets incrementally risk locking the world into options and strategies that are unsuited for the deep emission cuts that are needed by 2050. Many of the investments made in the next 10 years in buildings, industrial installations and power plants will still be in operation in 2050. If costly early scrapping is to be minimised, then from now on investments in energy infrastructure will need to take account of long-term CO_2 emission goals.*
- *OECD countries account for less than one-third of global CO_2 emissions in 2050 in the Baseline scenario. In the BLUE Map scenario, these countries reduce their emissions by 70% to 80% of their 2007 levels. But global emissions can only be halved if non-OECD countries collectively also reduce their emissions below current levels. This will require the widespread deployment of low-carbon technologies in non-OECD countries.*
- *Even if CO_2 emissions are reduced by 50% below current levels by 2050, this may not be enough to keep expected temperature rises to below 2 degrees centigrade (°C). While it is technically possible to reduce emissions further than this, the cost of achieving additional incremental reductions rises rapidly. Achieving much deeper emission cuts than 50% by 2050 will not be possible in the absence of more radical, and politically potentially very challenging, policy measures designed to achieve substantial lifestyle changes.*

Scenario characteristics

The scenarios in *Energy Technology Perspectives 2010* (*ETP 2010*) further develop earlier IEA scenario analyses, particularly the BLUE scenarios presented in *Energy Technology Perspectives 2008* (*ETP 2008*) (IEA, 2008a) and the Reference and 450 parts per million (ppm) scenarios published in *World Energy Outlook 2009* (IEA, 2009a).

The *ETP 2010* Baseline scenario assumes that no new energy and climate policies are introduced during the scenario period. It follows the *World Energy Outlook 2009* (*WEO 2009*) Reference scenario for the period 2007 to 2030. For the period 2030 to 2050, it updates the *ETP 2008* analysis. In the Baseline scenario, the world economy grows by 3.1% a year on average between 2007 and 2050, although the pattern of economic growth changes after 2030 as population growth slows and the economies of developing countries begin to mature.

A BLUE Map scenario has also been developed, together with a number of variants which are described in detail in the relevant sector chapters (Box 2.1). The BLUE scenarios assume that global energy-related CO_2 emissions are reduced to half their current levels by 2050. The scenarios examine ways in which the introduction of existing and new low-carbon technologies might achieve this at least cost. The BLUE scenarios are consistent with a long-term global rise in temperatures of 2°C to 3°C, but only if the reduction in energy-related CO_2 emissions is combined with deep cuts in other greenhouse-gas emissions. They also bring energy security benefits in terms of reduced dependence on oil and gas, and health benefits as air pollutant emissions are also reduced. The BLUE scenarios are based on the same macro-economic assumptions as the Baseline scenario. The modelling approach and framework assumptions are described in more detail in Annex A.

Box 2.1 ▶ Scenarios in *ETP 2010*

The following scenarios have been analysed for ETP 2010*.*

Economy-wide

Two main scenarios are used in the publication:

- *a* Baseline *scenario, which assumes that no new policies are introduced and follows the* WEO 2009 *Reference scenario to 2030;*
- *a* BLUE *Map scenario, which assumes that global energy-related CO_2 emissions are reduced to half their 2005 levels by 2050 and is broadly optimistic for all technologies.*

In addition a number of variants are used for different sectors:

Electricity sector

Four variants of the BLUE scenario are used, with the following differences as compared to the BLUE Map scenario:

- BLUE hi NUC *which assumes nuclear capacity of 2 000 gigawatts (GW) instead of the 1 200 GW maximum in the BLUE Map scenario;*
- BLUE no CCS *which assumes that CCS is not commercially deployed;*
- BLUE hi REN *which assumes that renewables provide 75% of global electricity production in 2050;*
- BLUE 3% *which uses a uniform 3% discount rate for all electricity generating technologies, rather than market rates of between 8% and 14% that are used in the BLUE Map scenario.*

Buildings

Three variants of the BLUE Map scenario are used, with the following differences as compared to the BLUE Map scenario:

- BLUE CHP *assumes more rapid declines in the costs of fuel-cell combined heat and power (CHP) units using hydrogen;*
- BLUE Solar Thermal *assumes that low-cost compact thermal storage is available by 2020 and that system costs come down more rapidly in the short term;*
- BLUE Heat Pumps *assumes the development of ultra-high efficiency air-conditioners and faster cost reductions for space and water heating applications.*

../..

Industry

Two variants are used, with the following differences as compared to the Baseline and BLUE Map scenarios:

- High Baseline*, which assumes a higher growth in industrial production for key energy-intensive materials;*
- High BLUE*, which is consistent with the industrial production in the High Baseline.*

Transport

A variant of the Baseline scenario and two variants of the BLUE Map scenario are used, with the following differences as compared to the original scenarios:

- High Baseline *assumes a higher growth in passenger light-duty vehicle ownership in the developing world and faster growth in vehicle travel and freight transport, especially trucking;*
- BLUE Shifts *assumes that travel is shifted towards more efficient modes and a modest reduction in total travel growth;*
- BLUE Map/Shifts *combines the technology changes in BLUE Map with the travel pattern changes in BLUE Shifts.*

These scenarios are not forecasts. The Baseline scenario illustrates what is likely to happen if no new action is taken through the energy system to address climate change and energy security concerns. This is used as a reference scenario, against which the potential impact of actions to further reduce CO_2 emissions can be assessed. The BLUE scenarios explore what needs to be done to meet ambitious emissions reduction goals and other policy objectives. The scenarios are internally consistent analyses, based on a set of optimistic but plausible technology assumptions, which enable an assessment of the least-cost pathways that may be available to meet these goals. The BLUE scenarios can help policy makers identify technology portfolios and policy strategies that may deliver the outcomes they are seeking. The scenarios are also the basis for technology roadmaps that can help to establish more detailed action plans, including areas in which further international technology co-operation is needed (see Chapter 13).

Technology development is inherently uncertain. The BLUE scenarios assume that technologies that are not available today are developed to the point at which they become commercial. It also requires the rapid and widespread uptake of such technologies into the market. Without the rapid commercialisation of new energy technologies, the objectives of the BLUE scenarios will be considerably more expensive and possibly completely unachievable.

The analysis does not reflect on the likelihood of these changes occurring, or on the precise mix of climate policy instruments that might best help achieve these objectives. But it is clear that achieving the outcomes implicit in the BLUE scenarios will depend on the implementation of a wide range of policies and measures to overcome barriers to the adoption of the necessary technologies. Both the public and the private sectors have major roles to play in creating and disseminating new energy technologies.

Box 2.2 ▶ Substantial CO_2 reductions will require a global effort

OECD countries currently account for around 45% of global energy-related CO_2 emissions. The Baseline scenario projects that, by 2050, this share will have fallen to less than one-third. So even in the implausible event that OECD countries emitted no CO_2 by 2050, the 50% reduction target could not be met unless the rest of the world also reduced its emissions below current levels. Halving global emissions by 2050 will require a global effort.

Achieving such significant CO_2 reductions will only be possible if a way can be found rapidly to accelerate the deployment of existing low-carbon technologies, and the development of a wide range of new low-carbon technologies and their widespread deployment in all major economies. The scenarios demonstrate that the achievement of ambitious CO_2 reductions requires an energy technology revolution in all energy-consuming sectors across all regions and countries. Against this background, ETP 2010 *examines issues such as the massive upscaling in research and development (R&D), financing, and technology deployment and transfer that will be needed if such a revolution is to be achieved.*

2

The increased uptake of cleaner and more efficient energy technologies envisaged in the BLUE scenarios will need to be driven by:

- *Increased support for the R&D* of energy technologies that face technical challenges and need to reduce costs before they become commercially viable;
- *Demonstration programmes* for energy technologies that need to prove they can work on a commercial scale under relevant operating conditions;
- *Deployment programmes* for energy technologies that are not yet cost-competitive but whose costs could be reduced through learning-by-doing. These programmes would be phased out when the technology becomes cost-competitive;
- *CO_2 reduction incentives* to encourage the adoption of low-carbon technologies. Such incentives could take a number of forms – such as regulation, pricing, tax breaks, voluntary programmes, subsidies or trading schemes. The *ETP 2010* BLUE scenarios assume that policies and measures are put in place that lead to the adoption of low-carbon technologies with a cost of up to USD 175 per tonne of CO_2 saved in 2050;[1]
- *Policy instruments to overcome other commercialisation barriers* that are not primarily economic. These include enabling standards and other regulations, third-party financing schemes, labelling schemes, information campaigns and energy auditing. These measures can play an important role in increasing the uptake of energy-efficient technologies in the buildings and transport sectors, as well as in non-energy-intensive industry sectors where energy costs are low compared to other production costs.

1. All costs are shown in 2008 US dollars.

Energy prices in all the scenarios respond to changes in demand and supply. In the Baseline scenario, oil prices are assumed to increase to USD 120 per barrel (bbl) in 2050. In nominal terms this means that oil prices would reach USD 312/bbl in 2050.[2] This price trajectory is consistent with the *WEO 2009* Reference scenario.[3] At these prices, substitutes for conventional oil such as oil sands, as well as transport fuels produced from biomass, gas and coal, will begin to play a larger role. Unconventional gas is also starting to have a substantial impact in North America and may do so in other regions in the future. If the necessary investments in oil and gas production do not materialise, prices will be considerably higher (IEA, 2008b, 2009a). Reduced demand for oil and gas in the BLUE Map scenario is assumed to result in oil prices of around USD 70/bbl in 2050. But as the BLUE Map scenario has a CO_2 price of USD 175/tCO_2 in 2050, the effective oil price seen by consumers in this year is much higher, at around USD 140/bbl in real terms.

Energy and CO_2 emission trends

From 1990 to 2000, CO_2 emissions increased by an average of 1.1% a year. From 2000 to 2007, emissions growth accelerated to 3% a year, despite the increased focus on climate change. This was mainly as a result of high economic growth, particularly in coal-based economies, and higher oil and gas prices which led to an increase in coal-fired power generation. Emissions from coal use increased by 0.6% a year between 1990 and 2000, but by 4.8% a year between 2000 and 2007.

In the *WEO 2009* Reference scenario, CO_2 emissions increase from 29 Gt CO_2 in 2007 to 40 Gt by 2030. CO_2 emissions continue to grow in the *ETP 2010* Baseline scenario projections beyond 2030, reaching 57 Gt in 2050, *i.e.* almost double that in 2007 (Figure 2.1). For the period 2007 to 2050, this is an average increase of 1.6% a year. CO_2 emissions in 2030 and 2050 in the Baseline scenario are lower than those in *ETP 2008*. They are 8% lower in 2050 owing to a combination of higher fossil-fuel prices leading to lower energy demand and the greater penetration of low-carbon fuels and technologies.

Nearly all the growth in global CO_2 emissions in the Baseline scenario comes from outside the OECD. Emissions from non-OECD countries grow from 15 Gt CO_2 in 2007 to 42 Gt CO_2 in 2050. OECD emissions grow from 14 Gt CO_2 to 15 Gt CO_2 over the same period. Most of the increase in OECD countries comes after 2030.

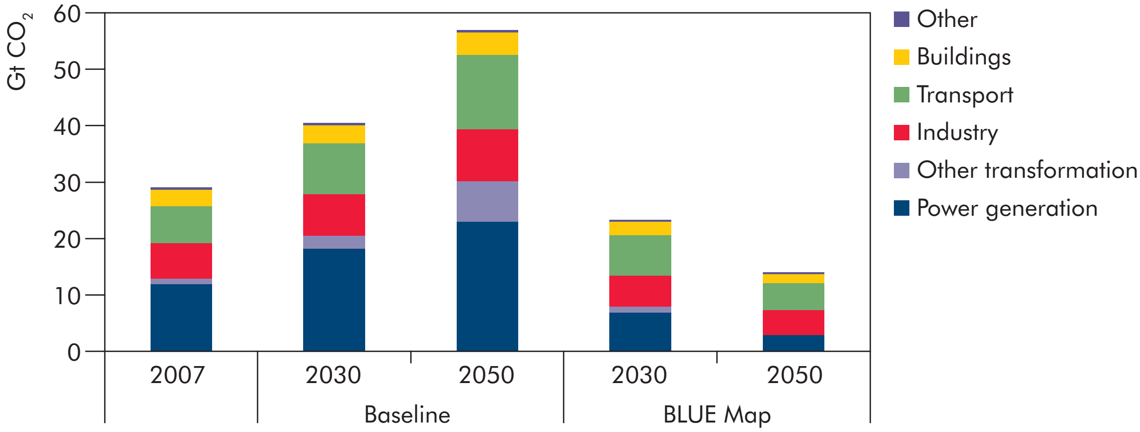
Long-term emission projections are highly uncertain. In the *WEO 2009* higher GDP case, CO_2 emissions reach 43 Gt by 2030, compared to 40 Gt in the Reference scenario and 38 Gt in the low GDP case. Similarly, the high energy demand projections for 2050 described in the sector chapters of this publication show that emissions could be up to 20% higher than the 57 Gt projected in the Baseline scenario for that date.[4] Higher Baseline emissions in 2050 would make reaching the objectives of the BLUE scenarios much harder.

2. Nominal price assumes inflation of 2.3% per year from 2008.

3. These prices are substantially higher than in *ETP 2008*, reflecting market developments over the last two years. *ETP 2008* used an oil price of USD 65/bbl in 2050 and was consistent with the price assumptions in the 2007 edition of the *World Energy Outlook*.

4. The high-demand scenarios in *ETP 2010* only explore changes in a limited number of factors that impact future emissions. A review by the Intergovernmental Panel on Climate Change (IPCC, 2007) of a large number of scenarios by different organisations shows a much wider range of outcomes for 2050.

Figure 2.1 ▶ **Global CO_2 emissions in the Baseline and BLUE Map scenarios**



Notes: In this chapter, unless otherwise noted, industry includes blast furnaces and coke ovens, as well as the non-energy use of petrochemical feedstocks. Industrial-process emissions are excluded. Other includes agriculture, fishing and forestry. Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

The BLUE Map scenario implies deep emission cuts across all sectors.

In the Baseline scenario, primary energy use rises by 84% between 2007 and 2050 and the carbon intensity of primary energy increases by 7%. As a result of technical energy efficiency gains and structural change, energy use grows less rapidly than economic activity, but these benefits are more than offset by the pace of economic growth and the increasing carbon intensity of energy use. Emissions from the power sector show the largest absolute increase, although the largest percentage increase is in the fuel transformation sector.

An increasing dependence on coal in the power sector energy mix, displacing oil, nuclear and hydro, contributes a significant proportion of the emissions growth in the Baseline scenario. Coal accounts for 44% of power generation in 2050, up from 42% in 2007. Given their long lifespan, investment in coal-fired plants in the next twenty years risks locking the world into a highly carbon-intensive energy future.

Oil and gas demand will also continue to rise. IEA analysis suggests that total reserves of oil are large enough to meet the projected rise in demand to 2050, although it is less clear that the necessary investment will occur in time to exploit those reserves. If the Organization of the Petroleum Exporting Countries (OPEC) and Russia do not invest enough in the coming decades, oil and gas prices will rise further, thus increasing the demand for alternatives whether high- or low-carbon. But if the oil and gas demand implicit in the Baseline scenario is met, it will result in significant climate change. It will also make oil and gas importers increasingly reliant on energy imports from a relatively small number of supplier countries. This will create further supply security risks for importing countries and may undermine sustained economic growth.

The outcomes projected in the Baseline scenario are not inevitable. The BLUE scenarios show that it is possible to completely transform the energy system over the next half century using a combination of existing and new technologies, if the right decisions are taken early enough. This would enable a more secure and sustainable energy future, but would require significant investments to achieve substantial changes in both energy supply and energy demand infrastructure. Such investments would also generate significant fuel savings in buildings, transport and industry over the longer term.

Technologies for reducing CO_2 emissions

In the BLUE Map scenario, CO_2 emissions in 2050 are reduced to 14 Gt, around half the level emitted in 2005. This means emissions are 43 Gt lower in 2050 than the 57 Gt CO_2 projected in the Baseline scenario. Achieving these CO_2 emissions reductions will require the development and deployment of a wide range of energy-efficient and low-carbon technologies across every sector of the economy (Figure 2.2). End-use efficiency improvements in the use of fuels and electricity, and power sector measures dominate the short- and medium-term emissions reductions. But to achieve the deeper emission cuts needed by 2050, these measures will need to be supplemented by the widespread introduction of new technologies such as electric vehicles (EVs) and CCS between 2030 and 2050.

The results of the BLUE Map scenario show that 2005 emission levels can be halved by 2050 by exploiting technology options with costs of up to USD 175/tCO_2 saved. This is USD 25/tCO_2 lower than in *ETP 2008*. This cost reduction results from two factors: first, the need to achieve smaller emissions reductions in 2050 since the *ETP 2010* Baseline scenario has a lower level of emissions in 2050 than the equivalent *ETP 2008* scenario; and second, higher fossil-fuel prices, which lead to larger fuel cost savings from implementing a given low-carbon option. If technologies were not to emerge at the rate or at the cost assumed, the levels of emissions reduction needed could only be achieved at a higher cost per tonne of CO_2 saved. For example, in the BLUE variant in which CCS is not available, the marginal cost of CO_2 abatement rises to around USD 300/tCO_2. However, under all BLUE variants, most abatement options have costs that are much less than the marginal cost.

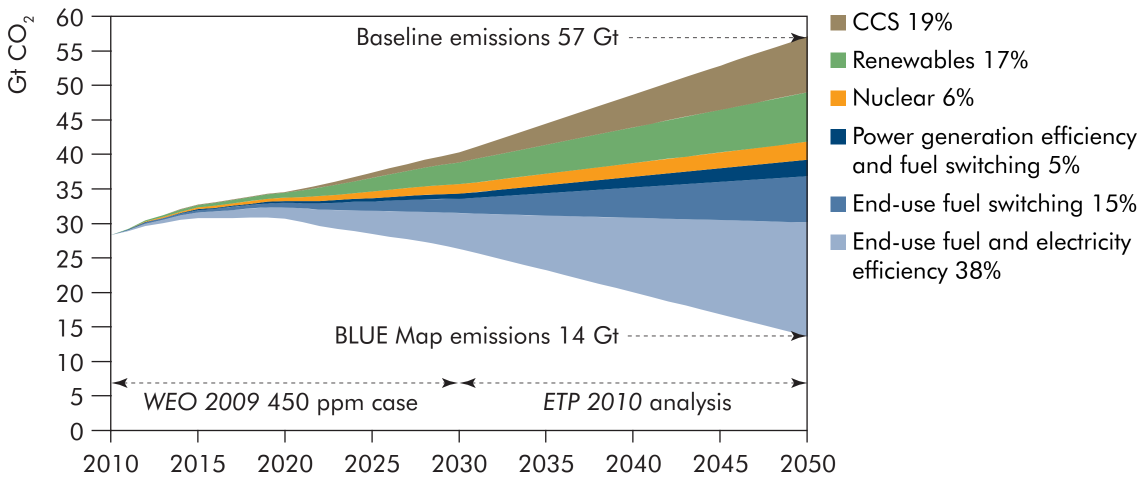
The BLUE Map scenario emissions profile (Figure 2.2) suggests a peak in CO_2 emissions at just below 31 Gt CO_2 between 2015 and 2020. Emissions then start to reduce from that point onwards. The later the peak, and the higher it is, the more difficult and costly it will be to achieve deep emission cuts by 2050.

The pledges made by countries under the Copenhagen Accord, although they represent a substantial deviation from the Baseline scenario, seem unlikely to be sufficient to deliver the BLUE Map scenario. Based on these pledges, CO_2 emissions are likely still to be on a slight upward path by 2020 and at that point around 1 Gt CO_2 a year higher than in the BLUE Map scenario.[5] This pathway is broadly consistent with a long-term rise in global temperatures of around 3°C. Although it may not be impossible subsequently to recover from this position to a pathway that leads to a 50% emissions reduction by 2050, this could only

5. The business-as-usual baseline chosen by countries and other details about their pledges are not always clear and so a number of assumptions have been made in this calculation.

be achieved by measures that are likely to be much more disruptive and more expensive than any options envisaged in this publication. Given the long lead times before new policies can be put in place and have effect, there is therefore a need for strong global action to be taken urgently to implement policies that will realise the pledges currently made and to go beyond these as part of a new global deal on climate change.

Figure 2.2 ▶ Key technologies for reducing CO_2 emissions under the BLUE Map scenario



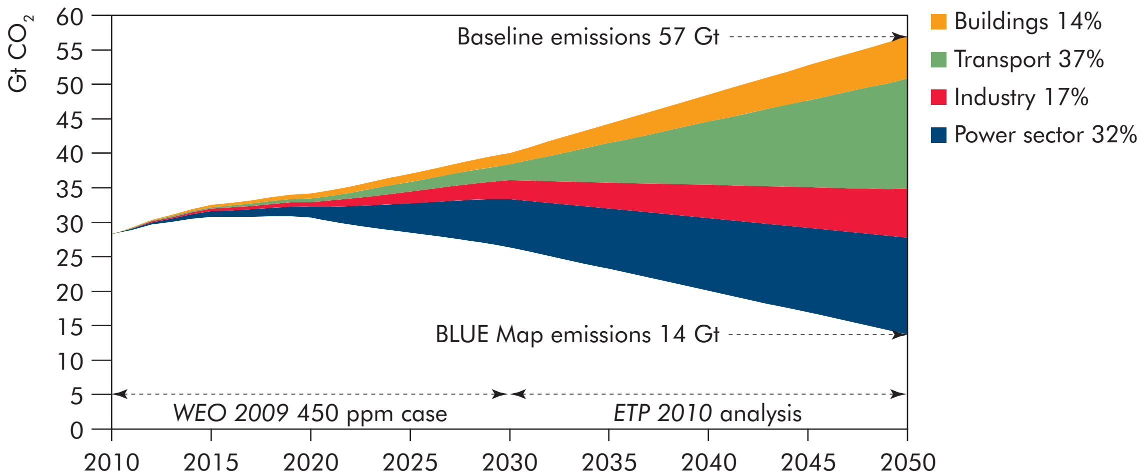
Key point

A wide range of technologies will be necessary to reduce energy-related CO_2 emissions substantially.

All sectors will need to achieve emissions reductions between 2007 and 2050 to deliver the outcomes implicit in the BLUE Map scenario (Figure 2.3). In the next 20 years, the power sector and all end-use sectors together need to play an equal part in the emissions reduction effort. Within the end-use sectors, energy efficiency measures need to play the biggest role in the next twenty years. Beyond 2030, the transport sector has an increasingly important role to play in reducing emissions.

OECD countries account for just over 30% of the total global emissions reduction in 2050 in the BLUE Map scenario as compared to the Baseline scenario. The least-cost approach of the BLUE Map scenario leads to OECD countries reducing their emissions by 77% compared to 2005 levels. Non-OECD countries reduce their emissions by 24% over the period, although their emissions continue to grow up to 2020, reducing significantly only after 2030. These developments reflect different trends in CO_2 emissions under the Baseline scenario, with much higher CO_2 emissions growth in developing countries than in the OECD countries in coming decades. They also imply a significant and sustained effort to reduce emissions in all major economies. The sharing of any financial burden for such change is beyond the scope of this analysis.

Figure 2.3 ▶ **CO_2 emissions reductions in the BLUE Map scenario by sector**



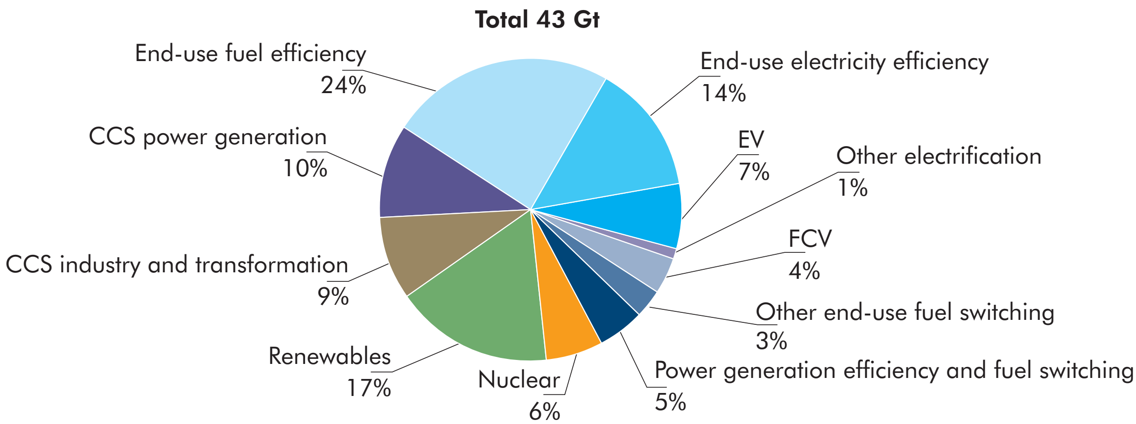
Note: CO_2 emission savings from fuel transformation have been allocated to the transport sector and the CO_2 reductions from electricity savings are allocated to end-use sectors.

Key point

The share of end-use sectors in emissions reductions increases between 2030 and 2050.

In the BLUE Map scenario, end-use efficiency accounts for 38% of the CO_2 emissions reduction in 2050 (Figure 2.4). CCS in power generation, fuel transformation and industry accounts for 19% of the total emissions reduction. The increased use of renewable energy accounts for 17% of the total emissions reduction, while nuclear energy accounts for 6%. About a quarter of the renewables contribution in the BLUE Map scenario comes from biofuels, with most of the remainder from the use of renewables in the power sector. These figures downplay the full importance of nuclear and renewables, since both options already play an important role in the Baseline scenario.

Figure 2.4 ▶ **CO_2 emissions reductions by technology area in 2050 in the BLUE Map scenario**



Note: CO_2 savings from CCS take into account the resulting loss in energy efficiency.

Key point

End-use efficiency and power generation options account for the bulk of emissions reductions in 2050.

2

Box 2.3 ▶ Economic impacts of the BLUE Map scenario

The scenarios presented in this publication are based on a partial equilibrium model. This takes into account technology investment and operating costs, as well as fuel costs. The costs associated with research, development, demonstration and deployment (RDD&D) have also been considered. The analysis does not specifically consider transaction costs. This may underestimate the total costs involved in reducing CO_2 emissions where millions of small-scale investment decisions are involved.

While this approach provides important insights into the cost of CO_2 reductions for consumers and for the global economy, the analysis does not assess the full impacts on gross domestic product (GDP). The redistribution of production factors will affect the growth potential of the economy. Other studies have looked into the impact of climate policies on global economic structures and on economic growth. The Stern Review (Stern, 2007) looked at 21 studies that had estimated the GDP loss for scenarios that stabilised CO_2 concentrations at 450 ppm (consistent with the BLUE Map scenario). These showed a range in 2030 between a loss of global GDP of 3.4% compared to the Baseline scenario and an increase in GDP of 3.9%. WEO 2009 calculated a narrower range for its 450 ppm CO_2 scenario, with a global GDP loss in 2030 of between 0.9% and 1.6%.

The impact on GDP is likely to grow over time and could become substantial by 2050. The OECD has calculated that in 2050 the GDP loss for a scenario which stabilises CO_2 emissions at 550 ppm is 4%. For a 450 ppm CO_2 scenario, this increases to a loss of almost 7% (OECD, 2009). However, the model used by the OECD does not include some important low-carbon technologies such as carbon capture and storage, which the ETP analysis shows can help reduce emissions at lower costs. Many studies have shown that over the longer term the cost of inaction would far outweigh the cost of reducing CO_2 emissions.

The technologies and policies needed to reduce CO_2 emissions in the BLUE Map scenario will have a considerable impact on energy demand, particularly for fossil fuels. Lower demand for oil in the BLUE Map scenario means there is less need to produce oil from costly fields higher up the supply curve in non-OPEC countries. As a result, the oil price is assumed to reach USD 90/bbl in 2020 and then decline to USD 70/bbl in 2050. This is in line with the assumptions of WEO 2009. As long-term gas supply contracts are also often indexed to oil prices, these are also assumed to be lower in the BLUE Map scenario. Coal prices are also substantially lower owing to the large shift away from coal in the BLUE Map scenario.

Energy efficiency

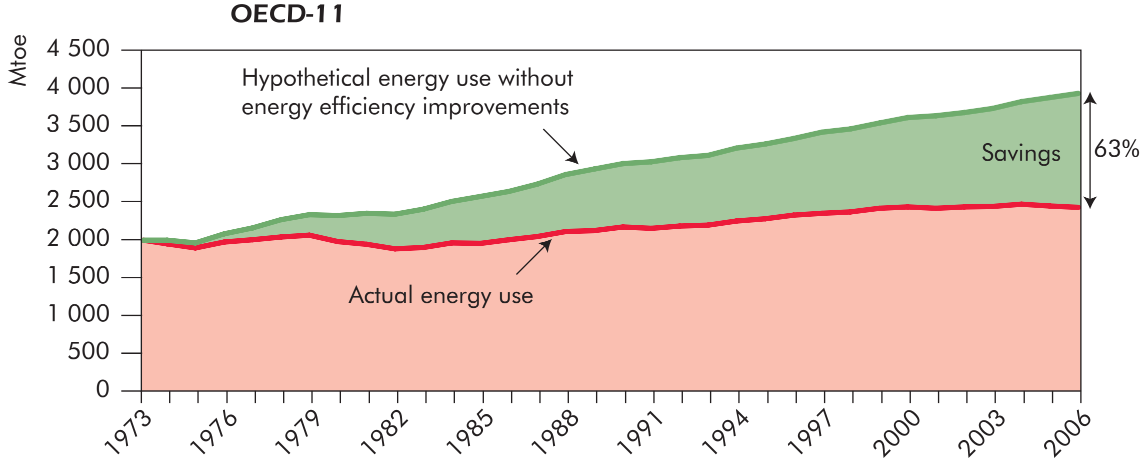
Energy efficiency improvements in the supply and demand sectors make the single largest contribution to CO_2 emissions reductions in the BLUE Map scenario. This is in addition to significant efficiency gains already implicit in the Baseline scenario.

Final energy demand in 2050 is 4 477 million tonnes of oil equivalent (Mtoe) (31%) lower in the BLUE Map scenario than in the Baseline scenario. Around 29% of this reduction occurs in industry, 36% in the transport sector and 35% in the buildings sector. These figures include the full benefits of electrification on final energy use, recognising that electric technologies often have much higher end-use efficiencies than those using gas or oil products.[6]

Since 1973, global energy intensity (final energy use per unit of GDP) has improved at an average rate of 1.7% a year. This decoupling of energy consumption and economic growth has been the main factor restraining the growth of CO_2 emissions in recent years. The carbon intensity of energy use (CO_2 emissions per unit of energy) changed very little between 1973 and 2007. The improvements in final energy intensity have come from a combination of increased energy efficiency and structural changes in economies. Structural changes, such as a shift from the production of raw materials to less energy-intensive manufactured products, have played a significant role in some countries.

The impact of energy efficiency improvements in OECD countries has been to restrain growth in final energy consumption. Without the energy efficiency improvements achieved since 1973, final energy use in the OECD-11[7] would have been 63% higher in 2006 than it actually was (Figure 2.5).

Figure 2.5 ► ***Long-term energy savings from improvements in energy efficiency, OECD-11***



Source: IEA (2009b).

Key point

Without 30 years of energy savings from improved energy efficiency, energy consumption in OECD countries would be much higher than it is today.

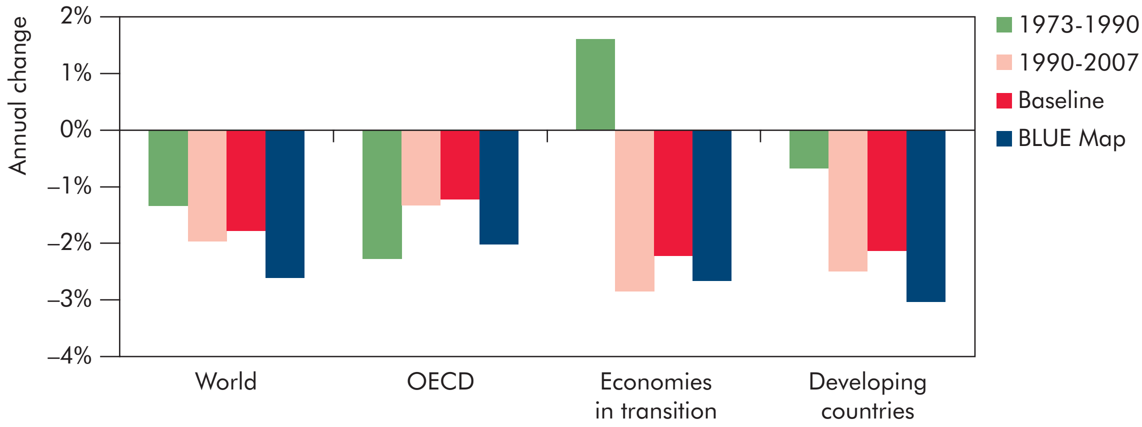
The further decoupling of energy use and economic growth continues in all scenarios (Figure 2.6). In the Baseline scenario, global final energy intensity falls by 1.8% per year, a rate similar to that seen over the past 30 years. This means that, by 2050, the amount of energy used on average to produce one unit of GDP

6. Final energy savings from increased electrification may not be reflected in primary energy terms because of the efficiency losses in power generation.

7. The OECD-11 comprises Australia, Denmark, Finland, France, Germany, Italy, Japan, Norway, Sweden, the United Kingdom and the United States. Together, these countries account for more than 75% of current total final energy use in OECD countries.

will be less than half that needed today. In the BLUE Map scenario, the global improvement in energy intensity increases to an average of 2.6% a year between 2007 and 2050, resulting in the energy used per unit of GDP in 2050 being only about one-third of that in 2007.

Figure 2.6 ▶ ***Historical and projected changes in final energy consumption per unit of GDP***



Key point

In the BLUE Map scenario, significant additional reductions in final energy intensity above those already implicit in the Baseline scenario occur across all regions.

The energy intensity of the economies in transition improves by more than that of the OECD countries in both the Baseline and BLUE Map scenarios, reflecting the significant potential in these countries to improve energy efficiency. Many developing countries have achieved rapid improvements in their energy consumption relative to GDP as their economies have modernised. In the Baseline scenario, developing countries continue strongly to improve their energy intensity, but at a slower rate than between 1990 and 2007. In the BLUE Map scenario, the introduction of more energy-efficient end-use technologies increases the improvement in energy intensity in developing countries to 3% a year.

Globally, energy efficiency improvements average 0.7% per year in the Baseline scenario. Over the period 2007 to 2050, these improvements in energy efficiency play a significant role in limiting the increase in final energy demand under the Baseline scenario. Without these savings, final energy demand would be 35% higher in 2050. In the BLUE Map scenario, substantial additional energy savings are achieved in the final demand sectors compared to the Baseline scenario thanks to further improvements in energy efficiency. The rate of energy efficiency improvement roughly doubles to 1.5% per year.

Power sector

Emissions from the power sector are reduced considerably in the BLUE Map scenario, owing partly to reduced demand for electricity as a result of end-use efficiency gains, but mostly to fuel switching and the introduction of a range of low-carbon technologies. Electricity demand in the BLUE Map scenario is 13% lower in 2050 than in the Baseline scenario. This is as a result of much larger efficiency gains being partly offset by additional demand for CO_2-free electricity in buildings and in the transport sector, particularly for heat pumps and plug-in hybrid electric vehicles (PHEVs) and EVs.

Coal's share of power generation in 2050 declines from 44% in the Baseline scenario to 12% in the BLUE Map scenario. At the same time, the contribution from gas declines from 23% to 15%. By 2050 in the BLUE Map scenario, more than 90% of the electricity produced from coal-fired power stations comes from plant fitted with CCS. Reflecting the fact that CCS is significantly more expensive per tonne of CO_2 saved for gas than for coal, a much smaller percentage of gas-fired generation, around 30%, comes from gas plant fitted with CCS. The share of gas generation capacity fitted with CCS is even lower, as gas peaking plants, with a low number of operating hours as backup for variable renewables, play an important role in the BLUE Map scenario.

Nuclear power generation already plays an important role in the Baseline scenario, with capacity increasing from 374 GW to 610 GW in 2050, representing 10% of total generation by the end of the period. As most of the existing capacity must be replaced in the next 40 years, the Baseline scenario implies on average around 15 new reactors a year. Without this capacity replacement, more CO_2-emitting capacity would need to be built and emissions would be even higher.

The nuclear share of global electricity generation in the BLUE Map scenario more than doubles to 24% in 2050. The build rate of nuclear power is constrained in the model to reflect growth limitations based on past experience of maximum annual reactor construction rates (about 30 GW per year).

Electricity generation from renewable energy grows almost threefold in the Baseline scenario. As a result it increases its share of global electricity generation from 18% in 2007 to 22% in 2050. The growth in non-hydro renewables is even more dramatic, with almost a ninefold increase. By 2050, these "new" renewables have a share of 10%, up from 2.5% in 2007.

The total share of renewables in power generation more than doubles in 2050 between the Baseline and BLUE Map scenarios to 48%. As total electricity production also more than doubles in the BLUE Map scenario between 2007 and 2050, this implies a more than fivefold increase in power production from renewables. Most of the growth comes from emerging renewable energy technologies: wind, solar, biomass, and to a lesser extent geothermal. The use of hydropower also almost doubles from today's level.

Fuel switching in end-use sectors

Fuel switching in end-use sectors plays an important role in reducing CO_2 emissions. Fuel switching to less carbon-intensive fuels in buildings, industry and transportation contributes 21% of the CO_2 emissions reduction in the BLUE Map scenario, with an increased share of electricity and biomass making the biggest contribution.

In the Baseline scenario, electricity use increases by almost 237% between 2007 and 2050, despite significant energy efficiency gains. This means that electricity's share of total final consumption increases from 17% in 2007 to 23% in 2050. This is due to the rapid growth in electric end-uses such as appliances. There is also an impact from the increased use of electricity as a substitute for fossil fuels, particularly for heat pumps and PHEVs, especially in countries where the CO_2 intensity of power generation is low.

In the BLUE Map scenario the electricity sector is virtually decarbonised. This enables the buildings and transport sectors to reduce CO_2 emissions by additional electrification. As a result, the share of electricity in final consumption rises to 27% in 2050 as low-carbon electricity increasingly substitutes for fossil fuels. In the buildings sector, heat pumps play an increasing role. In the transport sector, the BLUE Map scenario assumes an important role for PHEVs and EVs.

In 2050, the share of biomass in final energy consumption increases from 10% in the Baseline scenario to 18% in the BLUE Map scenario. At the same time, the efficiency of biomass use rises considerably as traditional biomass is reduced and modern biomass technologies gain significant market shares.

Most of the increase in biomass in end-use sectors comes from the use of biofuels in the transport sector to reduce CO_2 emissions. Biofuel use increases from 34 Mtoe in 2007 to 764 Mtoe in the BLUE Map scenario. Biofuels are particularly important to decarbonise modes of transport that lack other options (especially trucks, ships and aircraft). However, the use of biofuels for all modes will depend on the development of viable, sustainable, second-generation technologies that are not commercial today. A major change in the effectiveness of the world's management of agricultural and natural lands will also be needed.

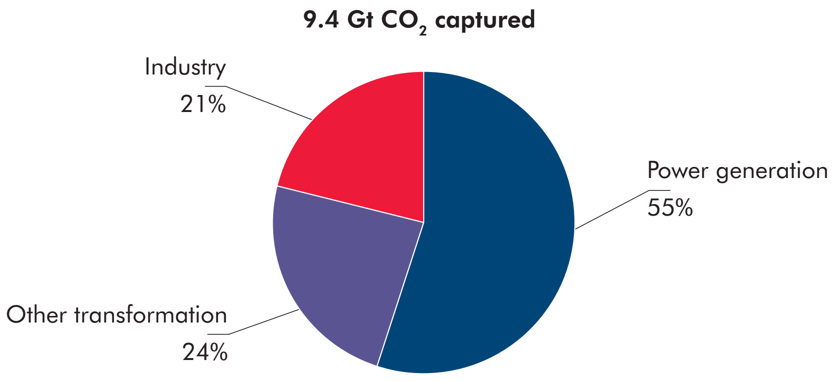
Hydrogen is also introduced after 2030, with almost 200 Mtoe used in transport. In addition, 97 Mtoe is consumed in the buildings sector in small-scale fuel-cell CHP systems.

Carbon capture and storage

The use of CCS in the industrial, fuel transformation and power generation sectors accounts for 19% of the CO_2 emissions reduction in the BLUE Map scenario over the Baseline scenario. The total amount of CO_2 captured is 9.4 Gt. This is 10% to 20% more than the net CO_2 reduction achieved by the use of CCS as, even with future advanced technologies, CCS itself entails significant additional energy use. In the BLUE Map scenario, 55% of the CO_2 captured comes from the power sector (Figure 2.7). The remainder takes place in refineries, synthetic fuel (synfuel) production and blast furnaces in the fuel transformation sector and in large-scale processes such as cement kilns and ammonia plants and industrial CHP in manufacturing industry. CCS is especially important for industry because it is the only way to achieve deep emission cuts in the production of major commodities such as steel and cement.

In the power sector, the retrofit of power plants with CCS is expected to play a significant role in reducing emissions before 2030 in the BLUE Map scenario. This highlights the importance that new fossil-fuel plant built over the next 10 to 20 years utilise technologies and practices that enable such retrofitting to take place. Over the period to 2050, 114 GW of coal-fired capacity is retrofitted with CCS, and 550 GW of new coal-fired and 298 GW of new gas-fired capacity with CCS is installed. This includes industrial large-scale generation units (CHP).

Figure 2.7 ▶ Use of carbon capture and storage in the BLUE Map scenario, 2050



Note: The total amount of CO_2 captured by CCS is greater than its net contribution to CO_2 reduction because of efficiency losses.

Key point

Carbon capture and storage can play a significant role outside the power sector.

Investment costs and fuel savings

The total investment[8] implied by the developments in the Baseline scenario is estimated to be USD 270 trillion between 2007 and 2050. Most of this (USD 240 trillion) is accounted for by investments on the demand side that energy consumers will make in capital equipment that consumes energy, including vehicles, electric appliances, and plants in heavy industry. The investment required is not uniform over time; the level needed between 2030 and 2050 is almost double that for the period up to 2030. These higher investment levels are driven by the demand for cars and other consumer durables, which rises alongside incomes in emerging and developing countries.

The BLUE Map scenario results in a need for investment USD 46 trillion higher than the Baseline scenario. Consumers invest in more energy-efficient equipment, buildings, vehicles and industrial plants with CCS, while electricity generators invest in more capital-intensive renewables, nuclear and CCS-equipped plants. Additional investment needs are dominated by the transport sector, accounting for 50% of total additional investments, as consumers invest in more expensive alternative vehicle technologies. The buildings sector accounts for 26% of the total additional investment, power generation for 20%, and industry for 4%.

The additional investment needs in the BLUE Map scenario will yield significant savings in fossil fuel consumption, partially offset by increased bioenergy fuel costs.

8. Excluding upstream investments in the production and transportation of coal, oil and gas.

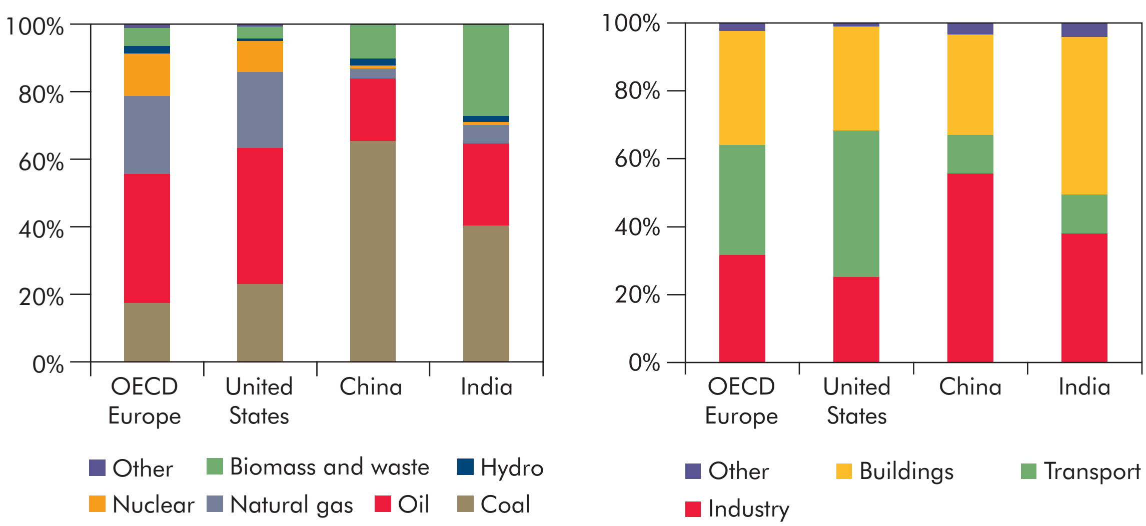
Overall, the undiscounted fuel savings from 2010 to 2050 total USD 112 trillion in the BLUE Map scenario. Subtracting these undiscounted fuel savings from the undiscounted additional investments that will be required, yields a net saving of USD 66 trillion over the period to 2050. Discounting the additional investment needs and the fuel savings at a 3% discount rate yields net discounted savings of USD 32 trillion. At a 10% discount rate, net savings are USD 8 trillion. These aspects are explored in more detail in Chapter 14.

Regional and country-level trends

More detailed analysis of CO_2 trends and abatement options has been undertaken for China, India, OECD Europe and the United States. Each of these four countries or regions will have a crucial role to play in helping to achieve a 50% reduction in global CO_2 emissions by 2050. But as each has different levels of current and future economic development and different endowments of natural resources, each will develop in different ways in both the Baseline and the BLUE Map scenarios.

The primary energy mix and the shares of end-use sectors of final energy demand vary widely between countries and regions (Figure 2.8). Coal dominates in China and, because of its use in power generation and in industry, delivers two-thirds of total primary energy supply. In India, biomass plays a significant role, mostly in the form of traditional fuels used for cooking and water heating in the buildings sector. Natural gas plays only a very small role in both India and China. In contrast, in OECD Europe and the United States, oil and gas are the dominant fuels, with coal having a much smaller share, reflecting a highly developed transport sector and the use of natural gas in power generation as well as in buildings and industry.

Figure 2.8 ▶ ***Shares of primary energy use by fuel and final energy use by sector, 2007***



Key point

The primary fuel mix and share of sectors in final energy demand vary significantly between countries and regions.

Table 2.1 ▶ **High-level energy indicators for the world and four countries or regions, 2007**

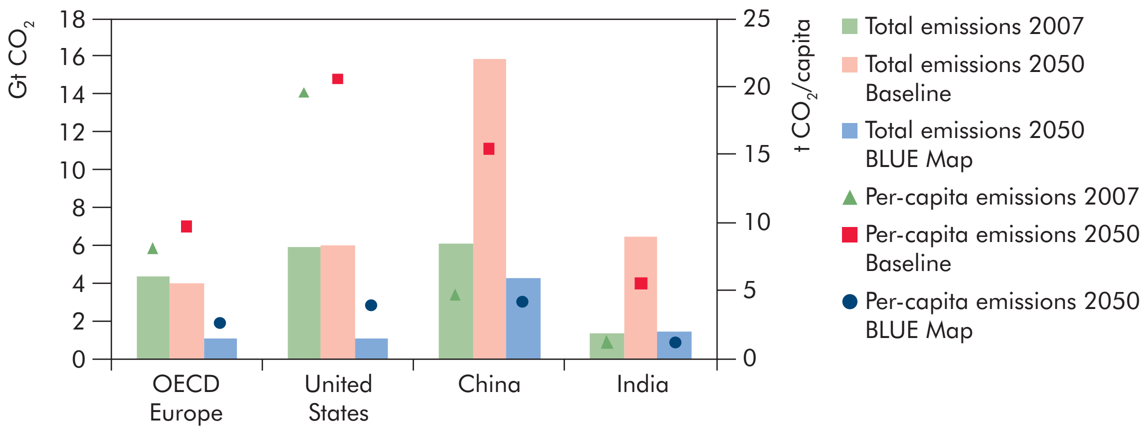
	World	India	China	OECD Europe	United States
Energy production (Mtoe)	11 940	451	1 814	1 067	1 665
Net imports (Mtoe)	n.a.	150	194	846	714
Total primary energy supply (Mtoe)	12 029	600	1 994	1 926	2 387
Net oil imports (Mtoe)	n.a.	107	200	495	634
Oil supply (Mtoe)	4 090	146	382	735	957
Electricity consumption (TWh)	18 187	610	3 114	3 387	4 113
CO2 emissions (Gt)	28.86	1.34	6.15	4.37	5.92
GDP (billion USD 2000 using MER)	39 493	771	2 623	10 532	11 468
GDP (billion USD 2000 using PPP)	61 428	4 025	10 156	13 223	11 468
Population (millions)	6 609	1 123	1 327	543	302
Land area (million km2)	148.94	2.97	9.57	4.95	9.16
Total self-sufficiency	1.00	0.75	0.91	0.55	0.70
Coal and peat self-sufficiency	1.00	0.87	1.02	0.56	1.02
Oil self-sufficiency	1.00	0.27	0.49	0.32	0.33
Gas self-sufficiency	1.00	0.71	0.94	0.53	0.83
TPES/GDP (toe per thousand USD 2000)	0.30	0.78	0.76	0.18	0.21
TPES/GDP (toe per thousand USD 2000 PPP)	0.20	0.15	0.20	0.14	0.21
TPES/population (toe per capita)	1.82	0.53	1.50	3.55	7.90
Net oil imports /GDP (toe per thousand USD 2000)	n.a.	0.14	0.08	0.05	0.06
Oil supply /GDP (toe per thousand USD 2000)	0.10	0.19	0.15	0.07	0.08
Oil supply /population (toe/capita)	0.62	0.13	0.29	1.35	3.17
Electricity consumption /GDP (kWh per USD 2000)	0.46	0.79	1.19	0.32	0.36
Electricity consumption /population (kWh per capita)	2 752	543	2 347	6 239	13 616

Notes: MER is market exchange rates and PPP is purchasing power parity. International marine bunkers and aviation are included in TPES and CO_2 emissions.

As a result of their current economic development and fuel mixes, the four countries/regions have very different starting points and future trajectories in terms of their CO_2 emissions (Figure 2.9). China has recently overtaken the United States to become the biggest emitter of CO_2, but its per-capita emissions are still much lower at 4.6 tCO_2/capita compared to 19.6 tCO_2/capita. Total CO_2 emissions from OECD Europe are around three-quarters of those of the United States. Average emissions per capita are less than half the level in the United States, although this average masks substantial differences among European countries. India currently has by far the lowest absolute emissions and average emissions per capita, the latter being only 6% of those in the United States.

In the Baseline scenario, CO_2 emissions in India show the largest relative increase, rising nearly fivefold by 2050. China also shows a substantial rise, with emissions almost tripling between 2007 and 2050. In the United States emissions increase only slightly by 1%, and in OECD Europe, emissions decline by 8%. In the BLUE Map scenario, all countries/regions show considerable reductions from the Baseline scenario. For the United States and OECD Europe, CO_2 emissions are 81% and 74% respectively lower in 2050 than in 2007. China shows a 30% reduction over the same period, while emissions in India rise by 10%. As a result of these changes, per-capita emissions converge, and the gap between the United States and India narrows to a factor of just over three. China overtakes OECD Europe in terms of per-capita emissions.

Figure 2.9 ▶ ***CO_2 emissions by region/country in the Baseline and BLUE Map scenarios***



Note: CO_2 emissions include international aviation and marine bunkers.

Key point

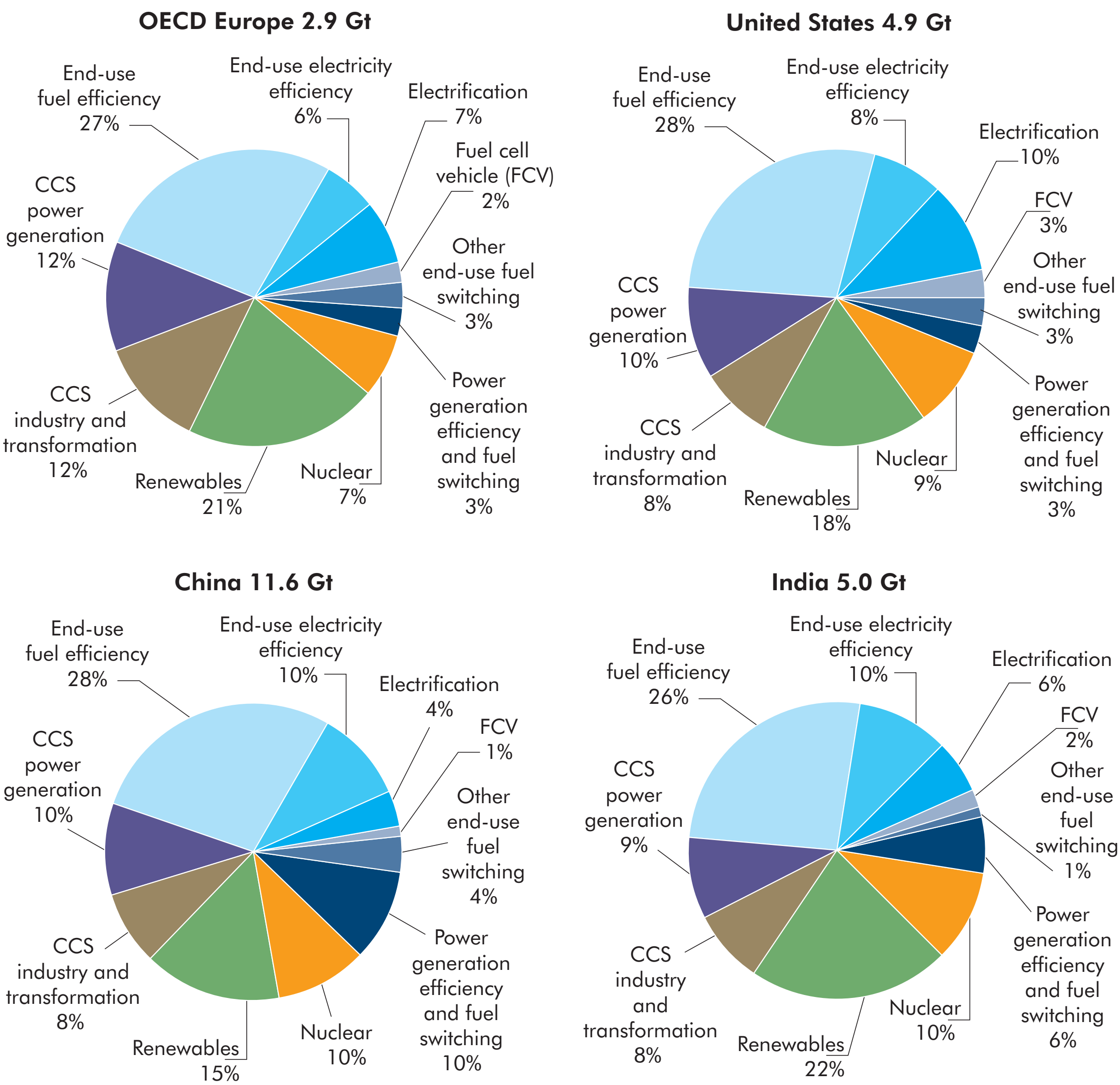
The CO_2 emissions path for different countries and regions varies considerably in both the Baseline and BLUE Map scenarios.

Achieving the emissions reductions implicit in the BLUE Map scenario will be a substantial challenge for all countries and regions (Figure 2.10). Each faces particular challenges and opportunities.

For China, given the dominance of coal, special attention needs to be given to the development of cleaner coal technologies, including the more efficient use of coal in power generation and industry as well as CCS. Of the three end-use sectors, industry accounts for the largest share of China's energy use and CO_2 emissions. The BLUE Map scenarios show that measures to improve energy efficiency and reduce CO_2 emissions in energy-intensive sectors such as iron and steel, cement, and chemicals should be a priority as they will have significant impact on the country's overall energy use and emissions. The Chinese transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure construction and the introduction of new technologies. The BLUE Map scenario shows that significant emissions reductions in China, as in many other countries, will depend on the electrification of different transport modes combined with substantial decarbonisation of the electricity sector.

India will exhibit very strong electricity demand growth over the next forty years to sustain economic development and as households increasingly become electrified. This will require huge additional capacity, which opens up the possibility of building a low-carbon electricity system almost from scratch. The BLUE Map scenario identifies solar as the most promising renewable energy technology for India and it could play an important role along with nuclear and some fossil fuel with CCS. India has some of the most efficient industrial plants in the world, but also has a large share of inefficient plants. Although there is significant potential to improve overall energy efficiency, the large number of small-scale plants, the low quality of indigenous coal and the quality of some primary sources (such as iron ore) may make this potential harder to achieve in India than in other regions.

Figure 2.10 ▶ Contribution of technologies to CO_2 emissions abatement in the BLUE Map scenario for different countries and regions, 2050



Key point

The mix of CO_2 abatement options needed to realise the BLUE Map scenario varies between countries and regions.

The increase in Indian household incomes and in industrial production will generate large increases in demand for transport. Although India's passenger vehicle stock is already relatively efficient, improvements in new vehicle technology and the penetration of hybrid, plug-in hybrid, battery and natural gas vehicles all help to limit increases in CO_2 emissions under the BLUE Map scenario. In the buildings sector, strong growth in energy demand will be driven by increases in living conditions and higher demand for services. Migration from rural to urban areas will also play a role in increasing energy consumption. Efficiency improvements in space cooling and appliances will be critical in restraining growth in energy consumption and emissions.

In OECD Europe, the electricity sector in 2050 is nearly decarbonised under the BLUE Map scenario. More than 50% of electricity generation is projected to come from renewable energy, with most of the remainder from nuclear and fossil fuels using CCS, although the precise energy mix varies widely among individual European countries, reflecting different local conditions and opportunities. In industry, energy efficiency and CCS offer the main measures for reducing emissions in the BLUE Map scenario.

High recycling rates as well as relatively high shares of biomass in the paper industry and of alternative fuels in the cement sector contribute to limiting the growth of CO_2 emissions in the Baseline scenario in OECD Europe. In buildings, the most significant energy savings in the BLUE Map scenario come from efficiency improvements in space and water heating, which provide more than two-thirds of the emissions reduction in the buildings sector. Further important mitigation measures are solar thermal heating, heat pumps, CHP/district heating and efficiency improvements for appliances.

Transport volumes in OECD Europe are expected to remain relatively constant in the future. The BLUE Map scenario shows that deep emissions reductions can be realised by more efficient vehicles as well as the shift towards electricity and biofuels. The progressive adoption of natural gas followed by a transition to biogas and bio-syngas is a further option for decreasing emissions in the transport sector.

For the United States, the BLUE Map scenario shows that energy efficiency and fuel switching measures are very important in reducing CO_2 emissions across all end-use sectors. Infrastructure investments will also be important for supporting the transition to a low-carbon economy, particularly in the national electricity grid and transport networks. Virtually all the existing generation assets will be replaced by 2050 and low-carbon technologies such as wind, solar, biomass and nuclear offer substantial abatement opportunities.

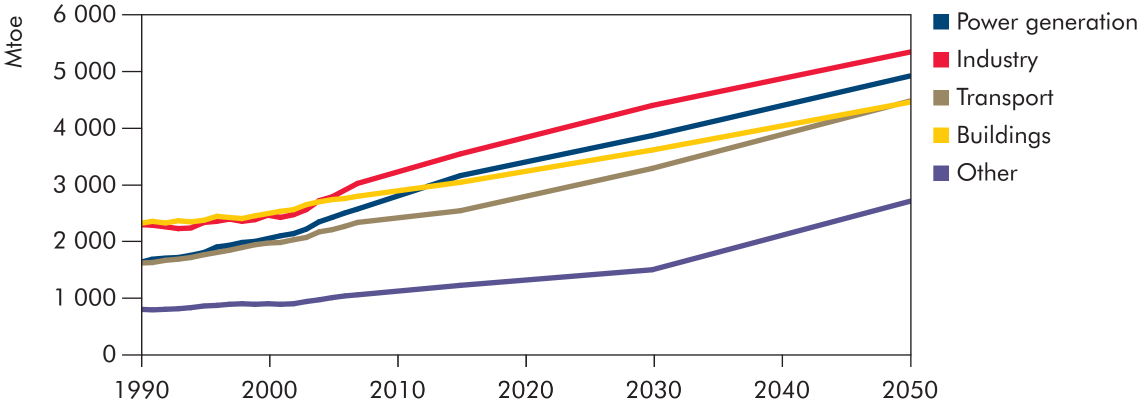
For a variety of reasons, many of the energy-intensive industries in the United States are relatively inefficient when compared to their counterparts in other parts of the OECD. Many opportunities exist to improve efficiency through technological improvements, as well as changes in the structure of the overall industrial sector. In terms of vehicle technologies, the average energy intensity of light-duty vehicles (LDVs) in the United States is currently relatively high. The BLUE Map scenario shows how doubling the fuel efficiency of new LDVs by 2030 can help reduce emissions. Advanced vehicle technologies can also play an important role in the LDV and commercial light- and medium-duty truck sectors. In buildings, improving the efficiency of space cooling, together with more efficient appliances offers the largest opportunity to reduce CO_2 emissions.

Sectoral trends

Energy use increases in all sectors in the Baseline scenario. Energy use roughly doubles in power generation, industry, transport and buildings (Figure 2.11). The energy used for fuel transformation accelerates from an average annual growth rate of 0.8% between 2007 and 2030 to 3.0% between 2030 and 2050. This is due to the increased production of synfuels from coal and gas.

Energy consumption in the transport, buildings and industry sectors together increases on average by 1.3% a year between 2007 and 2050 in the Baseline scenario, *i.e.* less than the 1.7% a year that it grew between 1971 and 2007. Driven by continued strong population and income growth in developing countries, transportation demand increases on average by 1.6% a year between 2007 and 2050. Energy consumption in the industrial sector grows at an average of 1.3% a year. Nearly all the growth in industrial energy consumption occurs outside the OECD. Energy use in the buildings sector also grows by 1.1% a year, with around 64% of this growth coming from developing countries.

Figure 2.11 ▶ Energy use by sector in the Baseline scenario



Notes: The power generation sector includes heat plants. Other includes the net consumption of power and fuel for the transformation sectors, plus energy use in agriculture, forestry and fishing.

Key point

Energy demand continues to grow rapidly in all sectors in the Baseline scenario.

The growth of CO_2 emissions under the Baseline scenario and the cost of achieving emissions reductions vary according to the sector. As a consequence, the BLUE Map scenario results in different sectors achieving different levels of emissions reduction in 2050 (Table 2.2).

In the BLUE Map scenario, the energy consumption of the power generation sector in 2050 is 20% lower than in the Baseline scenario thanks to an overall reduction in the demand for electricity. The energy consumed in the fuel transformation sector, including refineries, coal-to-liquid (CTL) and gas-to-liquid (GTL) plants, is about 10% less than in the Baseline scenario. The lower demand can be explained by end-use fuel demand reductions.

Table 2.2 ▶ **CO_2 emissions reductions by sector in the BLUE Map scenario, 2050**

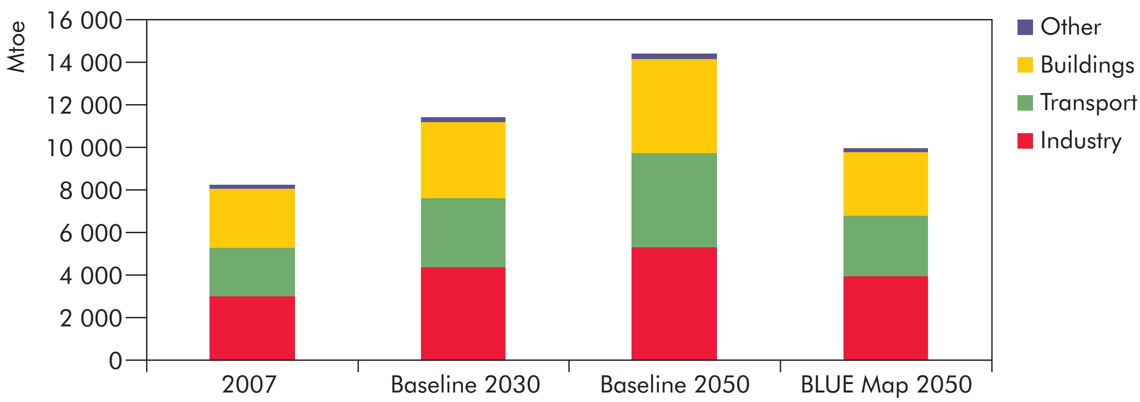
	Reduction from 2007 levels	Reduction from 2050 Baseline levels
Power sector	–76%	–88%
Transport	–28%	–64%
Industry	–27%	–51%
Buildings	–40%	–57%
Total	–52%	–75%

Note: Industry includes blast furnaces and coke ovens, as well as emissions from non-energy use of petrochemical feedstocks. Industrial-process emissions are excluded. The totals include reductions in fuel transformation.

Energy savings are achieved in all end-use sectors in the BLUE Map scenario compared to the Baseline scenario. As a consequence, total final energy demand is 31% lower in the BLUE Map scenario in 2050 than in the Baseline scenario (Figure 2.12). The largest absolute reductions in energy use occur in the buildings and transport sectors. In buildings, savings of 1 509 Mtoe in 2050 reflect the significant technical potential to reduce space heating and cooling needs in both existing and new buildings, as well as to improve the energy efficiency of lighting, electric appliances and equipment. OECD countries account for a little under half the total energy savings in buildings. In transport, savings of 1 631 Mtoe in 2050 come from significant fuel efficiency improvements in conventional engines, together with a move to hybrid and then fully electric vehicles. Slightly larger savings come from developing countries than from OECD countries. Industry contributes relatively smaller savings (1 350 Mtoe), reflecting the high efficiencies already achieved in a number of energy-intensive sectors and the intrinsic need for energy in many industrial processes. Around one-third of this is in OECD countries and two-thirds is in non-OECD countries.

Despite the savings achieved in the BLUE Map scenario, energy demand continues to grow in all end-use sectors between 2007 and 2050. The highest growth rate is in industry, followed by transport and buildings. Final energy consumption in the industry, buildings and transport sectors grows on average by 0.4% a year in the BLUE Map scenario.

Figure 2.12 ▶ **Final energy use by sector**



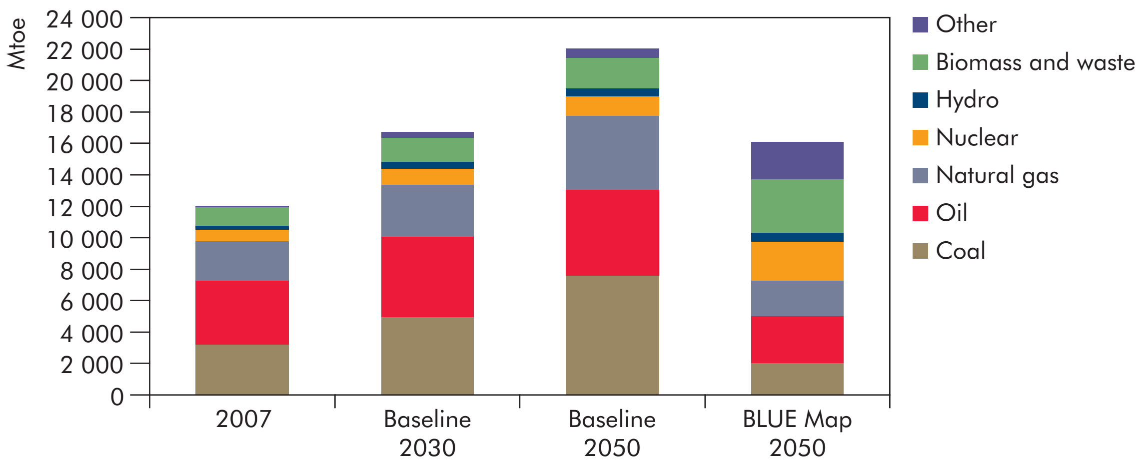
Key point

Final energy demand in the BLUE Map scenario is significantly less than in the Baseline scenario in 2050.

Energy trends

In the Baseline scenario, total primary energy supply (TPES) grows by 1.4% on average per year, from 12 020 Mtoe in 2007 to 22 078 Mtoe in 2050 (Figure 2.13). This rate of growth is less than the 2.2% a year that occurred between 1971 and 2007, but it still represents an increase of 84% in primary energy demand between 2007 and 2050.

Figure 2.13 ▶ World total primary energy supply



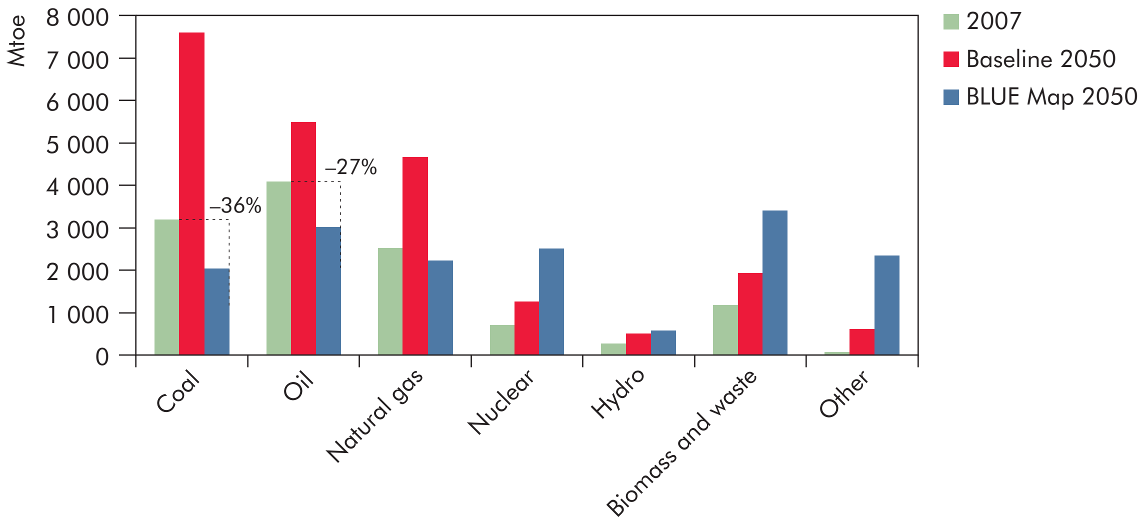
Key point

Primary energy use more than doubles in the Baseline scenario between 2007 and 2050, with a very high reliance on coal.

In the Baseline scenario, the share of fossil fuels in total demand remains fairly constant between 2007 and 2050, despite strong growth in nuclear and renewable energy in absolute terms. By 2050, coal becomes the predominant fuel and accounts for 34% of primary energy use. Oil's share of TPES declines from 34% in 2007 to 25% in 2050. The share of natural gas stays constant at 21%. Of the non-fossil fuels, nuclear's share remains at 6% in 2050, while the share of renewables increases to 14%. It should be noted that accounting for nuclear and renewables in primary energy terms does not properly reflect their importance for the energy system, as the conversion efficiencies from electricity to primary energy follow somewhat arbitrary statistical conventions.

The use of fossil fuels in 2050 is 59% lower in the BLUE Map scenario than in the Baseline scenario (Figure 2.14). In absolute terms, total demand for fossil fuels in the BLUE Map scenario in 2050 is 26% below the level of 2007. But even in the BLUE Map scenario, fossil fuels are an important contributor to the energy system. The reduction in fossil-fuel use can be attributed to energy efficiency gains and fuel switching. The use of carbon-free fuels increases much faster than TPES. The growth in biofuels, to a point where their use in 2050 in the BLUE Map scenario is similar to the level of coal use today, demonstrates just how significant a change is needed to deliver the outcomes implicit in the BLUE Map scenario.

Figure 2.14 ▶ Primary energy demand by fuel and by scenario



Key point

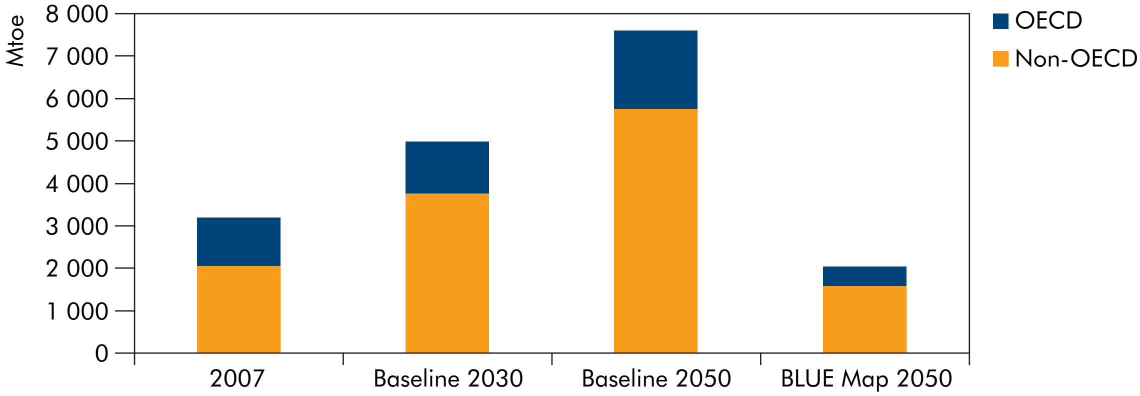
Oil and gas demand falls substantially under the BLUE Map scenario.

Coal

In the Baseline scenario, coal demand in 2050 is 138% higher than in 2007 (Figure 2.15). Coal's share of total demand grows from 27% in 2007 to 34% in 2050. Between 2030 and 2050, coal eclipses oil as the single most important fuel. Coal's strong growth in the Baseline scenario is driven by three factors. First, high oil prices make CTL technologies more economical, and the production of synfuels from coal increases significantly after 2030. In 2050, around 2 000 Mtoe of coal is being consumed by CTL plants. Second, high gas prices result in more new coal-fired electricity generating plants being built. Third, energy-intensive industrial production grows rapidly in developing countries, especially China and India, which have large coal reserves, but limited reserves of other energy resources.

In the BLUE Map scenario, coal demand in 2050 is 36% below the 2007 level, a reduction of over 70% compared to the Baseline scenario. This very significant reduction comes as a result of many sectors switching out of coal in favour of lower-carbon energy sources, even with the prospect of CCS. In percentage terms, coal use declines most in OECD countries. In non-OECD countries, coal use in the BLUE Map scenario in 2050 is 22% less than today's consumption.

Figure 2.15 ▶ World coal demand by scenario



Key point

There is a strong reduction in coal demand in the BLUE Map scenario relative to the Baseline scenario.

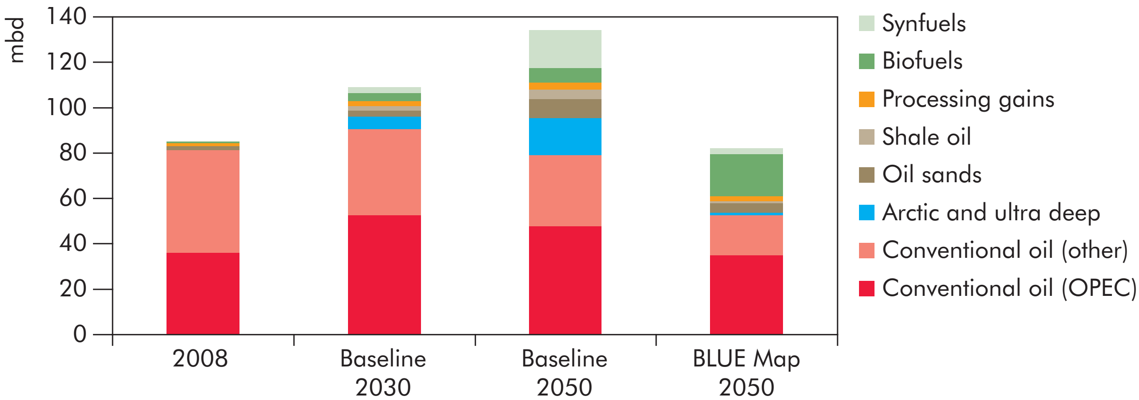
Liquid fuel

Liquid fuel demand in the Baseline scenario increases by 58% between 2007 and 2050, from 4 208 Mtoe in 2008 to 6 633 Mtoe in 2050 (Figure 2.16). This is an increase from 85 million barrels a day (mbd) to 134 mbd. Such growth is unlikely to be met by conventional oil. In the Baseline scenario there is significant growth in the production of non-conventional oil from heavy oil, oil sands, shale oil and arctic oil, to about 29 mbd. These sources account for about 20% of total supply in 2050. A rising share of demand is also met by synfuels produced from coal and gas, which increase from very low levels today to 17 mbd in 2050, comprising 12% of total supply. Biofuels play a limited role in the Baseline scenario, with a 5% share. Liquid fuel demand grows most rapidly in the transport sector, at 1.6% on average a year. In the buildings sector it grows by 0.4% a year and in the industrial sector by 1.0% a year.

In the BLUE Map scenario, the increased use of biofuels and improvements in the average fuel efficiency of transportation vehicles mean that total liquid fuel demand is only 4 045 Mtoe in 2050, 39% lower than in the Baseline scenario. Oil demand in 2050 is about 23% below the 2007 level. This will make a potentially significant contribution to security of supply, although a substantial oil import dependence will remain for many countries. The significant demand reductions in the BLUE Map scenario imply that there would be much less need for non-conventional oil and synfuels. Biofuels would account for 23% of supply. This has important CO_2 benefits.

Even in the BLUE Map scenario, OPEC oil production in 2050 will need to stay at least at the level of 2007, while conventional oil from other sources declines. Given the depletion of current sources of supply, substantial new OPEC production will be needed in both the Baseline and BLUE Map scenarios. Very large investments, especially in the Middle East, will be required to meet demand growth and to maintain secure supplies of transport fuels. The development of new oil supplies is an important challenge in all of the scenarios.

Figure 2.16 ▶ World liquid fuel supply by scenario



Key point

Liquid fuel demand in 2050 returns to today's level in the BLUE Map scenario, but with a very different mix.

Box 2.4 ▶ Oil supply prospects

The world's total resources of oil are large enough to support the projected rise in demand in the ETP 2010 *Baseline scenario through to 2050. Estimates of remaining proven reserves of oil and natural gas liquids range from about 1.2 trillion to 1.3 trillion barrels including about 0.2 trillion bbl of non-conventional oil. They have almost doubled since 1980. This is enough to supply the world with oil for over 40 years at current rates of consumption. The volume of oil discovered each year on average has been higher since 2000 than in the 1990s, thanks to increased exploration activity and improvements in technology, although production continues to outstrip new discoveries.*

Ultimately recoverable conventional oil resources, which include initial proven and probable reserves from discovered fields, reserves growth and oil that has yet to be found, are estimated at 3.5 trillion bbls. Only a third of this total, or 1.1 trillion bbl, has been produced up to now. Undiscovered resources account for about a third of the remaining recoverable oil, the largest volumes of which are thought to lie in the Middle East, Russia and the Caspian region. Non-conventional oil resources, which have been barely developed to date, are also very large. Between one and two trillion bbl of oil sands and extra-heavy oil may be ultimately recoverable economically. These resources are largely concentrated in Canada (mainly in Alberta province) and Venezuela (in the Orinoco Belt). The total long-term potentially recoverable oil-resource base, including extra-heavy oil, oil sands and oil shales (another largely undeveloped but costly resource), is estimated at around 6.5 trillion bbl. Adding production from CTL and GTL increases this potential to about 9 trillion bbl.

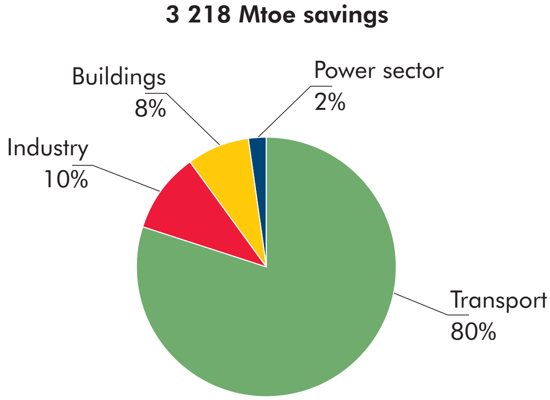
Globally, oil resources may be plentiful, but there can be no guarantee that they will be exploited quickly enough to meet the level of demand projected in the Baseline scenario. Annual average investments of USD 330 billion in the upstream oil and gas sector will be required over the period to 2030. That is more than is currently being spent. And there needs to be a major shift in the location of that investment. The opportunities for international companies to invest in non-OPEC regions will diminish as the resource base contracts. Much more capital needs to go to resource-rich regions, notably the Middle East, where unit costs are lowest, either directly through national companies or indirectly in partnership with foreign investors. It cannot be taken for granted that these countries will be willing to make this investment themselves or to attract sufficient foreign capital to keep up the necessary pace of investment.

Source: IEA (2008b), IEA (2009a).

The reduction in oil demand in the BLUE Map scenario can be largely attributed to the transport sector (Figure 2.17). This reflects the fact that oil demand for transport rises rapidly in the Baseline scenario. The reduction in primary oil demand is less than the reduction in the demand for oil products as synfuel production is phased out in the BLUE Map scenario.

In the Baseline scenario, non-OECD countries' share of primary oil demand rises from 47% in 2007 to 71% in 2050. This share only drops slightly in the BLUE Map scenario.

Figure 2.17 ▸ Reduction in oil demand by sector in the BLUE Map scenario, 2050



Note: Includes conventional oil, non-conventional oil, and synfuels from coal and gas.

Key point

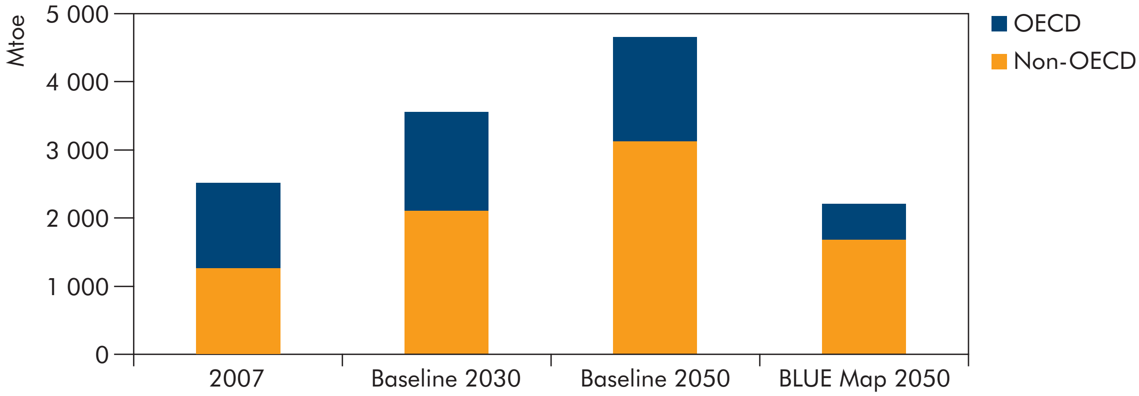
The transport sector accounts for most of the savings in oil demand.

Natural gas

Primary demand for natural gas in the Baseline scenario grows by 85% between 2007 and 2050, rising from 2 520 Mtoe to 4 653 Mtoe (Figure 2.18). Global gas use by the electricity generation sector increases from 992 Mtoe in 2007 to 2 174 Mtoe in 2050. Natural gas used in other transformation activities grows from 254 Mtoe in 2007 to 432 Mtoe in 2050. Most of this increase is for GTL plants and refinery hydrogen production. Demand for natural gas in the final consumption sectors grows at 1.2% a year, with little difference between the growth in industry and that in buildings at the global level.

Primary demand for natural gas in non-OECD countries increases in the Baseline scenario from 1 261 Mtoe in 2007 to 3 071 Mtoe in 2050. Non-OECD countries' share of world gas demand rises from 50% in 2007 to 66% in 2050. It rises further to 76% in the BLUE Map scenario. Almost half the growth in demand in non-OECD countries in the BLUE scenario comes from electricity generation and the remainder from end-use sectors and fuel transformation. Demand for gas in OECD countries falls from 1 259 Mtoe in 2007 to 526 Mtoe in 2050 in the BLUE Map scenario.

Figure 2.18 ▶ World natural gas demand by scenario



Key point

Gas demand in the BLUE Map scenario in 2050 is 12% lower than in 2007 and 52% lower than in the Baseline scenario in 2050.

Box 2.5 ▶ Gas supply prospects

The world's remaining resources of natural gas are easily large enough to cover any conceivable rate of increase in demand through to 2050, although the cost of developing new resources is set to rise over the long term. Proven gas reserves at the end of 2008 totalled more than 180 trillion cubic metres (tcm) globally — equal to about 60 years of production at current rates. Over half of these reserves are located in just three countries: Russia, Iran and Qatar. Estimated remaining recoverable gas resources are much larger. The long-term global recoverable gas resource base, including only those categories of resource with currently demonstrated commercial production, is estimated at more than 850 tcm). Unconventional gas resources such as coal-bed methane, tight gas from low-permeability reservoirs and shale gas, make up about 45% of this total. To date, only 66 tcm of gas has been produced or flared.

The recent rapid development of unconventional gas resources in the United States and Canada, particularly in the last three years, has transformed the gas market outlook, both in North America and in other parts of the world. New technology, especially horizontal-well drilling combined with hydraulic fracturing, has increased productivity per well from unconventional sources, notably shale gas, and cut production costs.

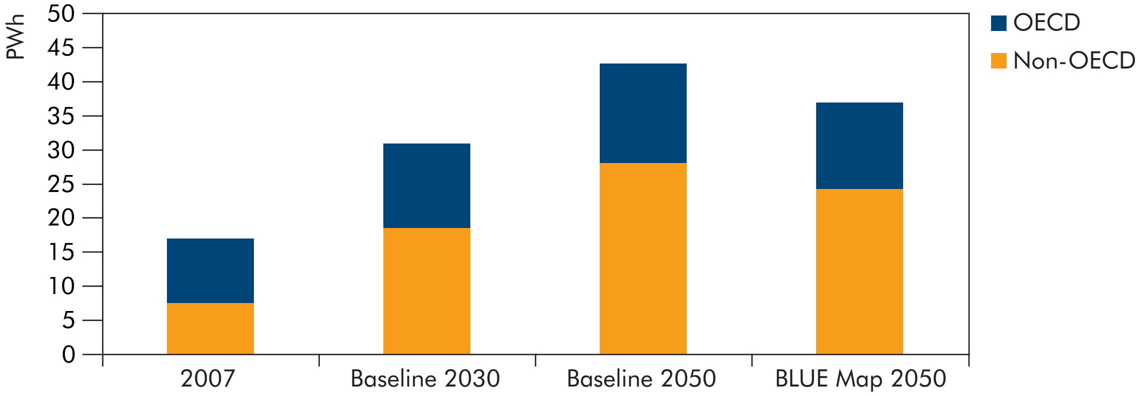
The extent to which the boom in unconventional gas production in North America can be replicated in other parts of the world endowed with such resources remains highly uncertain. Outside North America, unconventional resources have not yet been appraised in detail and gas production is still small. Some regions, including China, India, Australia and Europe, are thought to hold large resources, but there are major potential obstacles to their development in some cases. These include limitations on physical access to resources, the requirement for large volumes of water for completing wells, the environmental impact and the distance of resources from the existing pipeline infrastructure. In addition, the geological characteristics of resources that have not yet been appraised may present serious technical and economic challenges to their development.

Source: IEA (2009a).

Electricity

Electricity demand in the Baseline scenario increases on average by 2.0% a year between 2007 and 2050, making electricity the fastest-growing component of total final demand (Figure 2.19). Electricity demand increases from 16 999 terawatt-hours (TWh) in 2007 to 42 655 TWh in 2050. Electricity's share of final demand increases from 17% in 2007 to 23% in 2050. These trends are driven by rapid growth in population and incomes in developing countries, by the continuing increase in the number of electricity-consuming devices used in homes and commercial buildings, and by the growth in electrically driven industrial processes.

Figure 2.19 ▶ World electricity demand by scenario



Key point

Significant efficiency improvements reduce electricity demand in the BLUE Map scenario as compared with the Baseline scenario.

Baseline electricity demand in non-OECD countries grows on average by 3.1% a year, almost three times as fast as in OECD countries. This is primarily due to higher population growth and rapid increases in GDP and per-capita incomes in developing countries. Between now and 2050, tens of millions of people in developing countries will gain access to electricity.

In the BLUE Map scenario, global electricity demand growth is reduced to an average of 1.8% a year, with demand reaching 36 948 TWh in 2050. Electricity demand in 2050 is 13% below the Baseline scenario level. Electricity savings occur mostly in the buildings sector and in industry in the BLUE Map scenario, but these are partially offset by increased electricity demand in the transport sector as a result of the uptake of PHEVs and EVs.

Biomass

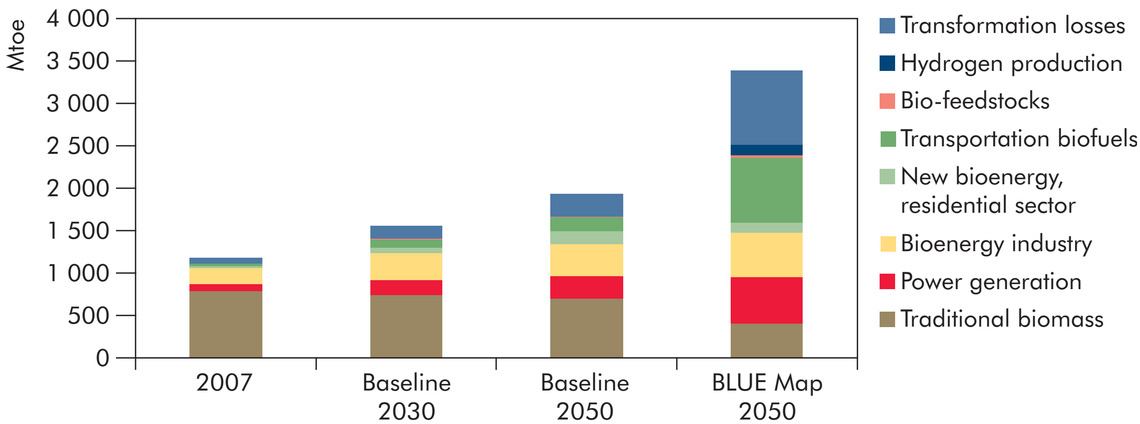
Biomass is by far the most important source of renewable energy today, accounting for about 10% of total primary energy use and 78% of total renewable energy. Most biomass is currently used for traditional small-scale domestic heating and cooking.

Only about 10% of biomass is used on an industrial scale for the production of electricity or fuels.

The role of biomass almost triples in the BLUE Map scenario (Figure 2.20). In this scenario, bioenergy use in 2050 is slightly higher than the level of coal consumption today. This would require fundamental improvements in agriculture and forestry. The challenge is that the world population will grow by 50% during the same period, with food demand rising correspondingly. To meet this demand, the total productivity of land currently in production must triple. Such growth has happened in recent decades, but its continuation in the future will require major effort. The development and use of high-yield crops, water management, soil management and land-use policies and considerations of ecological sustainability all need to be closely co-ordinated. Recent problems with rain forest and bushland clearing for first-generation biofuel crops show that a focus on energy alone can yield undesirable outcomes.

About half of the primary bioenergy in the BLUE Map scenario would be used for the production of liquid biofuels. The other half would be used for power generation, heating and industrial feedstocks.

Figure 2.20 ▶ World biomass use by scenario



Note: The chart includes transformation losses in the production of liquid biofuels from solid biomass.

Key point

Biomass use more than triples in the BLUE Map scenario.

In the buildings sector, the use of biomass increases by 4% in the Baseline scenario. Biomass use declines in the BLUE Map scenario but, as it is used much more efficiently, the share of biomass in delivered energy services increases. Solar water-heating and space-heating systems increase fourfold between the Baseline and BLUE Map scenarios.

In the BLUE Map scenario, the share of biomass and waste in industry increases from 6% in 2007 to 14% in 2050. Part of this is biomass for steam and process heat. Biomass feedstocks also play an increasing role.

Going beyond the BLUE scenarios

The BLUE Map scenario examines the technology options that could reduce global energy-related CO_2 emissions by 50% in 2050 compared to 2005 levels. According to the Intergovernmental Panel on Climate Change (IPCC), this is the minimum reduction necessary to keep the long-term rise in global temperatures to within 2°C to 3°C. However, the IPCC also concludes that reductions of up to 85% may be needed to keep within these temperature rises. This would imply that CO_2 emissions in 2050 should be constrained to less than 6 Gt CO_2. At the 15th Conference of the Parties (COP-15) to the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen, some countries also argued that the appropriate temperature goal should be a rise of no more than 1.5°C.

Taking all these factors together, and given the uncertainty of technology development, a prudent approach might be to identify a portfolio of low-carbon technologies that could exceed the 50% reduction target in case deeper cuts are needed or some of the technological options identified do not become commercially available as originally thought. With these issues in mind, the *ETP* model has been used to examine whether it is likely to be technologically possible to reduce emissions by more than 50% in 2050 and, if so, what technological options would need to be exploited.

In 2050, power generation in the BLUE Map scenario will produce 2.9 Gt CO_2. To reduce emissions below this level, it would be possible to bring on stream more generation from nuclear, renewables or fossil fuels with CCS. Assuming that around 2 000 GW of gas capacity is needed globally for balancing services, these technologies could reduce emissions by a further 1.4 Gt CO_2 to 1.7 Gt CO_2 at an additional investment cost of up to USD 1.8 trillion.

In industry, additional reductions could be achieved by greater implementation of CCS in the iron and steel, cement, chemicals and pulp and paper sectors, by the accelerated adoption of best available technologies in new plants (including early scrapping) and all refurbishments, by greater use of CO_2-free energy and feedstock sources such as biomass, and by the earlier demonstration and deployment of breakthrough technologies. Such measures could deliver a further 0.6 Gt CO_2 reductions by 2050 at a cost of up to USD 1.3 trillion.

In buildings, additional CO_2 reductions would require the application of technologies in more expensive end-use applications. This would require wider deployment of technologies that facilitate the use of CO_2-free energy carriers such as electricity or hydrogen, or which use renewable energy (*e.g.* solar thermal). For example, ground-source heat pumps for space and water heating could be used more widely, even in milder climates, or solar thermal systems for space and water heating could be deployed even in areas with relatively low levels of sunshine. Up to 0.8 Gt CO_2 of additional reductions would be possible from these measures, at a total additional investment of between USD 1.2 trillion and USD 1.4 trillion.

Greater reductions in CO_2 emissions from transport could be achieved by accelerating efficiency gains, the more rapid introduction of advanced technologies such as EVs and fuel-cell vehicles into the market, and moving to higher-levels of biofuels use. The first two options would certainly incur higher marginal costs. The greater use of biofuels could require higher-cost feedstocks, but more importantly may threaten sustainability. Thus higher levels of production would need to take account of the total availability of land and feedstocks that could sustainably be produced in the long term. On the basis of these options, further reductions of up to 1.5 Gt CO_2 might be achieved in 2050, at an investment cost of USD 2 trillion. In addition, the BLUE Map/Shifts scenario described in Chapter 7 shows how changes in behaviour through modal shifts could deliver a further 1.5 Gt CO_2 in 2050.

Taking these potentials together, the faster and more widespread introduction of technologies already considered in the BLUE Map scenario could further reduce emissions to around 9.5 Gt CO_2 by 2050. This would entail considerable additional investment. Behavioural changes in the transport sector could reduce this further to 8 Gt CO_2. This is still more than 2 Gt higher than would be needed to meet an 80% reduction in 2050. Further reductions beyond this would seem to have to rely on completely new technologies not yet envisaged or on further behavioural and lifestyle changes.

Chapter 3 ELECTRICITY GENERATION

Key findings

- *Without a significant change in policies, global electricity generation will continue to be largely based on fossil fuels to 2050 and beyond. In the Baseline scenario, fossil fuels increase their share of electricity production slightly to reach almost 70% by 2050. Coal and gas both increase their share of generation over this timeframe. The shares of nuclear and hydro both decrease, but wind, biomass and solar all increase their shares, albeit from low starting points. As a result, CO_2 emissions from the electricity sector almost double between 2007 and 2050.*

- *Significantly decarbonising the power sector over the period to 2050 will need to be at the heart of any strategy to achieve deep CO_2 emissions reductions worldwide. Advances in low-carbon generation technologies and their widespread deployment will be essential. Renewable energy, fossil fuels used with carbon capture and storage (CCS), and nuclear power all have an important part to play. Each faces challenges. But if a near-zero carbon electricity supply can be achieved, it will open the prospect of demand-side electrification becoming a long-term emissions abatement solution in all end-use sectors.*

- *By 2050 in the BLUE Map scenario, the carbon intensity of electricity generation has been reduced by almost 90% compared to 2007 levels. Renewable energy accounts for almost half of total global electricity production, while nuclear energy's share is just less than one-quarter. The remainder is from fossil fuels, largely combined with CCS. While the optimum low-carbon generation mix in 2050 is subject to considerable uncertainty, the BLUE variants show that a range of low- or zero-carbon generation technologies will be needed to keep additional costs to a minimum.*

- *Significant investment will be needed in electricity generation over the next 40 years whichever pathway is followed. In the Baseline scenario, investment requirements in electricity generation, transmission and distribution to 2050 total USD 23.5 trillion. More than half of this (USD 15 trillion) is needed for new power-generation plants. The BLUE Map scenario requires the investment of an additional USD 9.3 trillion (40%) over the investment in the Baseline scenario, mostly in power generation.*

- *There are some promising signs of increased activity to develop and deploy low-carbon electricity generating technologies. Wind capacity is increasing rapidly in Europe, the United States and China. Photovoltaic (PV) capacity is also increasing in Europe. China has an ambitious programme of new nuclear build and a number of countries are actively considering new nuclear capacity additions. Several hundred CCS demonstrations are being planned at various scales and work on mapping storage sites and developing regulatory structures is being stepped up.*

- *It will not be possible to fully decarbonise electricity without greater policy intervention. Today, many low-carbon alternatives are considerably more expensive than traditional fossil-based technologies. Governments will need to continue and* *expand research, development and demonstration (RD&D) support, and to create market mechanisms to foster technological innovation and to move low-carbon technologies towards market competitiveness. These incentives should be tailored to the maturity of the technology and decrease over time. This should be accompanied by policies that encourage the closure of the dirtiest and least efficient plants at the earliest opportunity.*

- *Some low-carbon generation technologies have specific requirements that will need to be addressed. For example, system integration will be needed to support significant quantities of variable renewables such as wind, solar PV, run-of-river hydropower, wave and tidal power. Comprehensive regulatory approaches will be needed to enable the large-scale commercial deployment of CCS. For nuclear power, further progress needs to be made towards building and operating facilities for the disposal of high-level radioactive wastes.*

Introduction

Electricity production accounts for 32% of total global fossil fuel use and around 41% of total energy-related CO_2 emissions. Transforming the electricity generation sector will therefore need to be at the heart of any efforts to make substantial reductions in global CO_2 emissions. Improving the efficiency of production, switching to lower-carbon fossil fuels, increasing renewable and nuclear generation and the introduction of CCS will all need to play a part in this transformation.

The analysis in this chapter explores the possible future contribution of the most important electricity generation technologies and fuels in the Baseline scenario and in five variants of the BLUE scenario. These have the following characteristics:

- BLUE Map which is broadly optimistic for all technologies.
- High nuclear (BLUE hi NUC) which assumes nuclear capacity of 2 000 GW instead of the 1 200 GW maximum in the BLUE Map scenario.
- No carbon capture and storage (BLUE no CCS) which assumes that CCS is not commercially deployed.
- High renewables (BLUE hi REN) which assumes that renewables provide 75% of global electricity production in 2050.
- 3% discount rate (BLUE 3%) which uses a lower single discount rate for all electricity generating technologies.

The status and prospects for each of the key technology groups are also briefly discussed.

Achieving deep CO_2 reductions will also require changes in electricity transmission and distribution networks. These are discussed in Chapter 4.

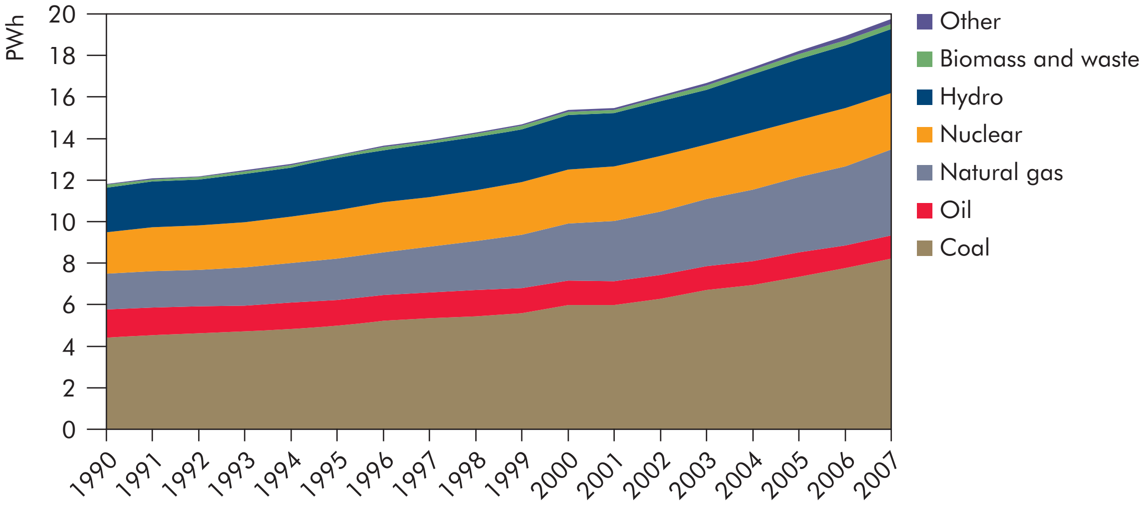
Recent trends

Generation mix by fuel

Global electricity generation[1] has increased by 67% since 1990, reaching almost 19 800 TWh in 2007 (Figure 3.1). Almost 70% of this electricity generation is from fossil fuels and this share has increased since 1990. Coal is the most important energy source for electricity production. Between 1990 and 2007, its share of total generation increased from 37% to 42%. The use of gas has grown rapidly over the same period, increasing from 15% to 21% of all generation. The share of oil has fallen to 6% of total electricity generation in 2007.

Total non-fossil fuel-based electricity generation has increased in absolute terms since 1990, but not fast enough to keep pace with rising electricity demand. As a result, the share of non-fossil fuels in electricity production has fallen. The contribution from nuclear power has fallen from 17% in 1990 to 14% in 2007. Over the same period hydropower has fallen from 18% to 16%. Electricity production from non-hydro renewable energy sources has increased markedly since 1990, but from a low base. The share of biomass and waste increased slightly from 1.1% in 1990 to 1.3% in 2007. Other renewables such as wind, geothermal and solar increased their share from 0.4% to 1.2% over the same period.

Figure 3.1 ▶ ***Historical trends in global electricity production***



Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

Electricity production has increased rapidly in recent years and continues to be dominated by fossil fuels.

The current electricity production mix varies considerably between countries, depending on their access to natural resources and their energy and environmental policies. The mix is a critical determinant of the level of CO_2 emissions per unit of electricity generated. On average, the share of electricity production from fossil

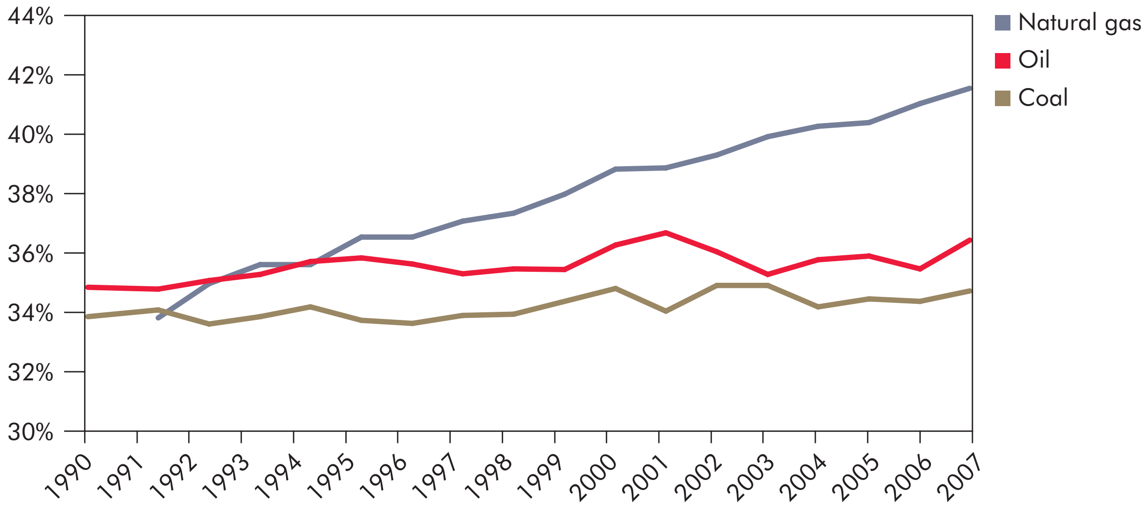
1. Global electricity generation includes production from public electricity and public combined heat and power (CHP) plants, as well as by enterprises that generate electricity primarily for their own use.

fuels in OECD countries was 63% in 2007. Non-OECD countries have a higher share, 74% on average. A number of individual countries also have significantly higher shares of fossil-fuelled electricity production than these average figures: Poland (98%), South Africa (94%) and Australia (93%) all generate more than 90% of their electricity from fossil fuels, mainly coal. In some other countries, electricity is mainly produced from non-fossil fuel sources. Electricity generation in Iceland (100%), Norway (99%) and Brazil (88%) is mostly based on renewable resources and in France (78%) is based on a high share of nuclear power.

Efficiency of electricity generation[2]

CO_2 emissions are also significantly influenced by the efficiency of fossil fuel electricity generation. In the case of coal-fired plant, the global average efficiency has remained broadly constant at around 35% between 1990 and 2007 (Figure 3.2). This is the result of a small upward trend in many countries, offset by a greater proportion of global coal-fired generation being in non-OECD countries that typically have lower generation efficiencies.

Figure 3.2 ▶ Efficiency of electricity production from fossil fuels



Key point

The efficiency of electricity generation from natural gas has increased steadily, but average coal and oil generation efficiency has not changed significantly since 1990.

The efficiency of coal-fired plants depends on a range of factors including the technology employed, the type and quality of coal used and operating conditions and practices. For example, average coal-fired generation efficiency in India in 2007 was 26% partly as a result of the widespread use of subcritical plants burning unwashed coal with high ash content, and of the use of coal-fired plants for peak load electricity production. By contrast, Denmark and Japan have some of the most efficient coal-fired power plants in the world, averaging efficiencies of almost 43% and 42% respectively, including a new generation of pulverised coal supercritical (SC) plants that were introduced in the 1990s.

2. All electricity generation efficiencies in this chapter are expressed on a gross output basis using net calorific values unless otherwise stated.

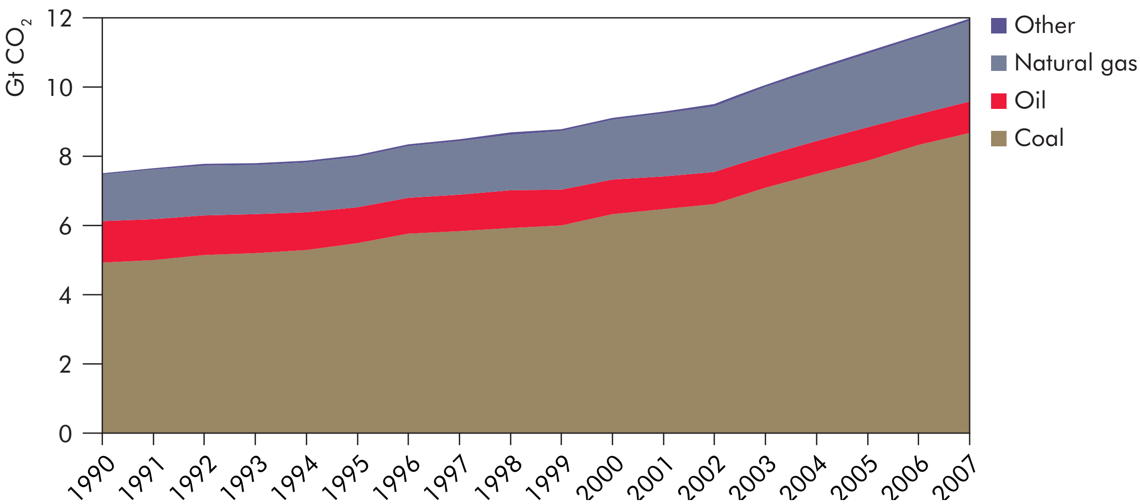
The average efficiency of natural gas-fired electricity production in 2007 was 47% in OECD countries and around 35% in non-OECD countries. The average efficiency of natural gas plants in individual countries varies considerably, with Luxembourg having the highest average efficiency of 55%. Since 1990, the efficiencies of natural gas-fired plants have risen significantly in many OECD countries and as a result the average has increased by almost 8 percentage points. In contrast, non-OECD countries have seen only a 1 percentage point rise. The widespread introduction of successively more efficient natural gas combined-cycle (NGCC) plants in OECD countries has been the main driver behind the increase in both the use of natural gas for electricity production and the average generation efficiency. The latest NGCC plants have efficiencies approaching 60%.

The use of oil in electricity production is declining, but it is still important in a few countries. The current average efficiency of oil-fired electricity production in OECD countries is 37%. In non-OECD countries the average efficiency is 35%. Average efficiencies for oil-fired electricity production in most countries and regions have not changed much in recent years.

CO_2 emissions

Between 1990 and 2007, CO_2 emissions from global electricity production increased by 59% to reach 12 Gt (Figure 3.3). Most of the rise in CO_2 emissions was driven by increases in electricity generation from coal. In 2007, coal-fired power plants accounted for 73% of total emissions from the sector, up from a share of 66% in 1990. Total CO_2 emissions from natural gas-fired plants are around only 25% of those from coal, despite the fact that they generate nearly half as much electricity. This is due to gas having a lower carbon content than coal per unit of delivered energy, together with the higher average efficiency of gas-fired electricity generation compared to coal plants.

Figure 3.3 ▶ **CO_2 emissions from global electricity generation**



Note: Other includes industrial waste and non-renewable municipal waste.

Key point

Electricity production from coal is the main source of CO_2 emissions from the sector.

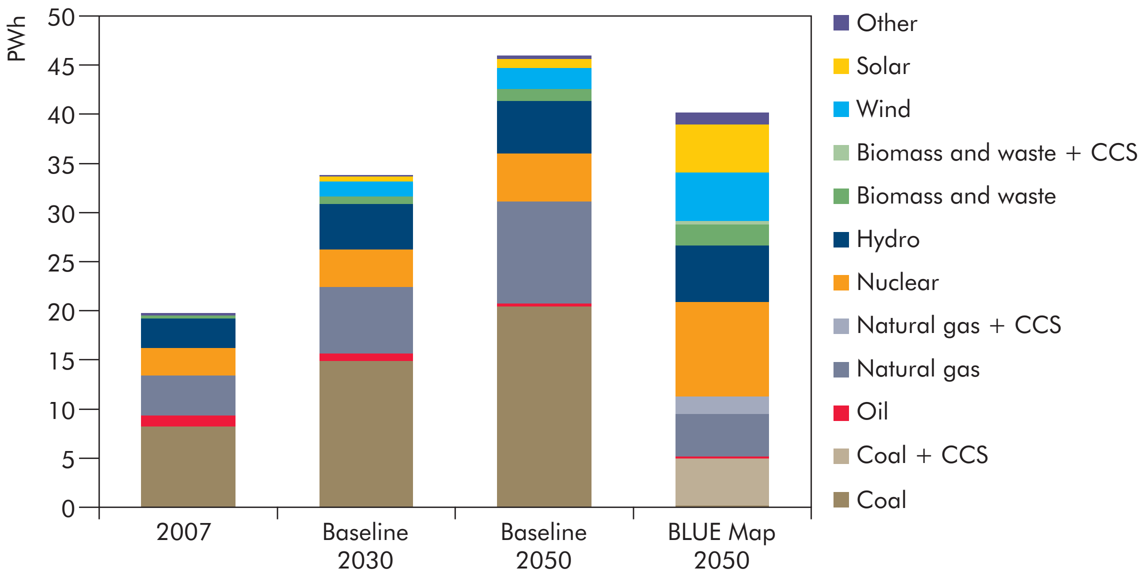
Future scenarios

Baseline scenario

In the Baseline scenario, global electricity production increases by 134% between 2007 and 2050 (Figure 3.4). Fossil fuels maintain their high share in the electricity generation mix, accounting for two-thirds of the total. In 2050, coal-based generation is 149% higher than in 2007, accounting for 44% of all power generation. The share of gas-fired power generation increases slightly to 23%, while oil is almost completely phased out. Nuclear decreases to 10%, hydro decreases to 12%, and wind increases to account for 5% of all power generation. As a result of the continued dependence on fossil fuels, CO_2 emissions from electricity generation almost double between 2007 and 2050.

In the Baseline scenario, investment in the electricity sector, including for generation, transmission and distribution, is USD 23.5 trillion between 2010 and 2050.[3] More than half of this (USD 15 trillion) is needed for new power generation plants, with USD 5.8 trillion for maintaining and expanding the electricity distribution network and USD 2.5 trillion for the electricity transmission network. Investment in gas, coal, biomass, hydro and nuclear technologies dominates the total for the power generation sector. Over 3 800 gigawatts (GW) of gas-fired capacity is added in the Baseline scenario between 2007 and 2050, and just over 3 200 GW of coal-fired capacity.

Figure 3.4 ▶ ***Global electricity production by energy source and by scenario***



Note: Other includes electricity generation from geothermal and ocean technologies.

Key point

There is a major shift from fossil fuels to low-carbon alternatives in the BLUE Map scenario.

3. All costs in this chapter are expressed in 2008 USD.

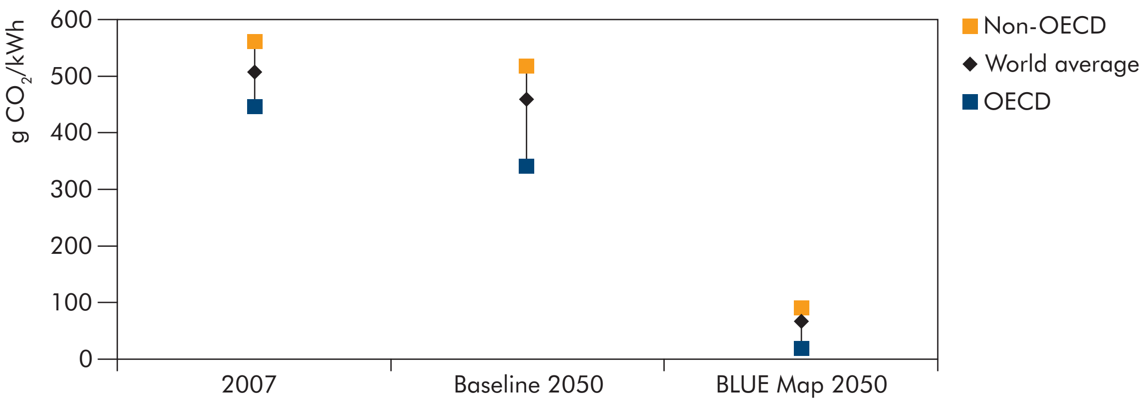
BLUE Map scenario

Electricity demand in 2050 in the BLUE Map scenario is 13% lower than in the Baseline scenario owing to increased energy efficiency in the end-use sectors. This is despite the fact that some of the increased efficiency in industry and buildings is offset by higher demand for electricity for additional uses, such as heat pumps and plug-in hybrid vehicles (PHEVs) and electric vehicles (EVs).

As well as reducing electricity demand, the CO_2 emissions reduction incentives and other measures introduced in the BLUE Map scenario radically change the electricity generation mix relative to the Baseline scenario. Low-carbon energy sources, such as nuclear and renewables, become more attractive compared to fossil-fuelled power. By 2050, a variety of renewables generate almost half the electricity in the BLUE Map scenario and nuclear increases its share to 24%. Coal-fired generation reduces to 12% by 2050, more than 90% of which is combined with CCS. Gas-fired generation is also much lower than in the Baseline scenario with a 15% share, of which almost one-third is fitted with CCS.

By 2050, these changes lead to CO_2 emissions reductions of just over 14 Gt in the BLUE Map scenario compared with the Baseline scenario, and the power sector becomes virtually decarbonised. In 2007, the average emissions intensity of electricity production was 507 grammes of CO_2 (g CO_2) per kilowatt-hour (kWh). By 2050, this reduces to 459 gCO_2/kWh in the Baseline scenario. In the BLUE Map scenario, the emissions intensity in 2050 falls dramatically to 67g CO_2/kWh with OECD countries having lower emissions intensity than non-OECD countries (Figure 3.5). Different supply-side measures play a role in achieving this emissions abatement (Figure 3.6).

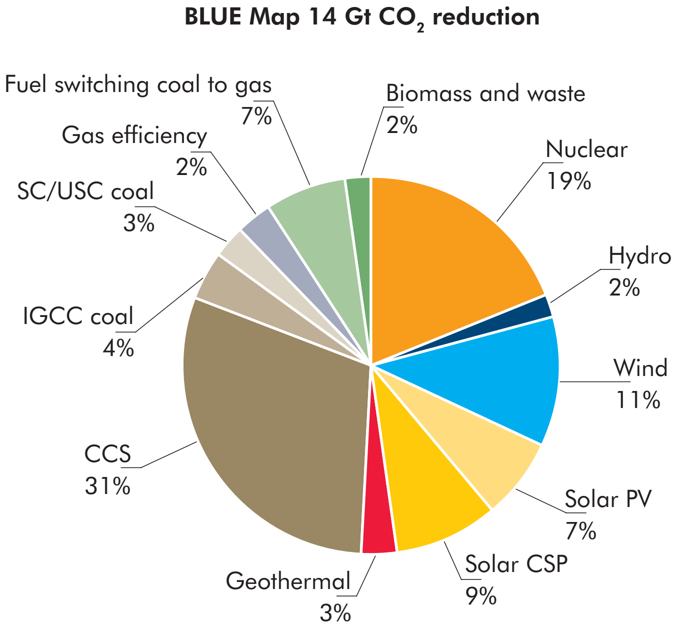
Figure 3.5 ► ***CO_2 intensity of electricity production by scenario***



Key point

The power sector is virtually decarbonised by 2050 in the BLUE Map scenario.

Figure 3.6 ▶ **The contribution of different power sector technologies to reductions in CO_2 emissions in the BLUE Map scenario**



Note: Excludes the impact on CO_2 emissions of changes in the level of electricity generation between the two scenarios.

Key point

Reducing CO_2 emissions from the power sector will require a mix of generation based on renewables, nuclear and fossil fuels with CCS.

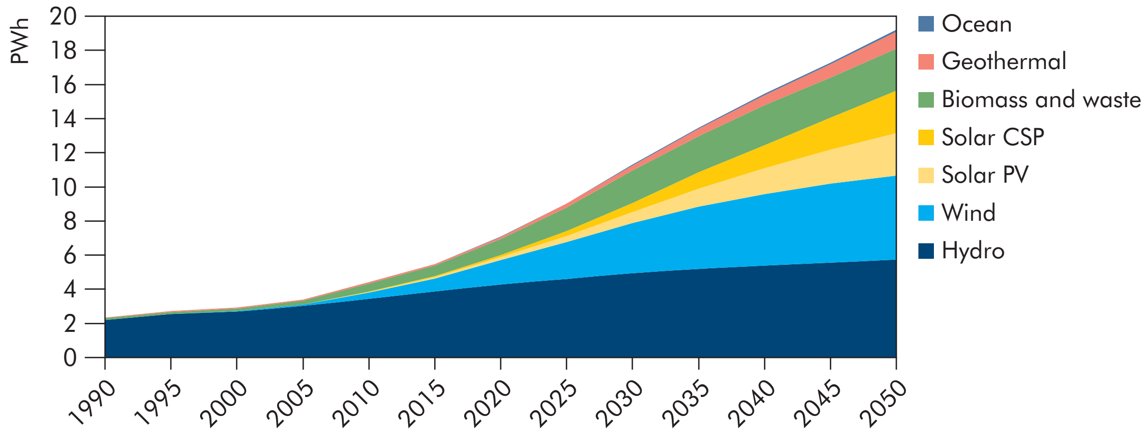
The share of all electricity generation from renewables increases from 18% in 2007 to 48% in the BLUE Map scenario (Figure 3.7). This results in CO_2 emissions reductions of 4.7 Gt in 2050 compared to the Baseline scenario. Variable renewable generation (wind, PV and ocean) produces almost 19% of electricity worldwide in 2050 from a capacity of about 3 160 GW. The integration of a large volume of variable capacity in grids will need careful management and will require electricity systems to become more flexible through the use of smart grids and greater electricity storage capacity.

Biomass and wind constitute the bulk of new renewables capacity up to 2020. After 2020, solar power starts to make a more significant contribution. Hydro grows continuously over the whole period, but this growth levels off in later years for lack of suitable new sites. By 2050, hydro, wind and solar each make similar contributions to total electricity production in the BLUE Map scenario.

By 2050, biomass is mostly used in dedicated plants, including those employing combined heat and power (CHP). Co-firing with coal increases significantly, particularly in the period to 2020. Most of the increase in electricity from wind is from onshore turbines. Electricity generation from offshore turbines grows very rapidly, but from a low starting point. In 2050, about two-thirds of total electricity production from wind still comes from onshore plant. Around 75% of the anticipated solar capacity is based on PV, with the balance coming from concentrating solar power (CSP). On average, the capacity factor for CSP is significantly higher than that of PV, thanks to the use of thermal storage. As a result, CSP generates more than 50% of total solar power generation.

3

Figure 3.7 ▶ **Growth of renewable power generation in the BLUE Map scenario**

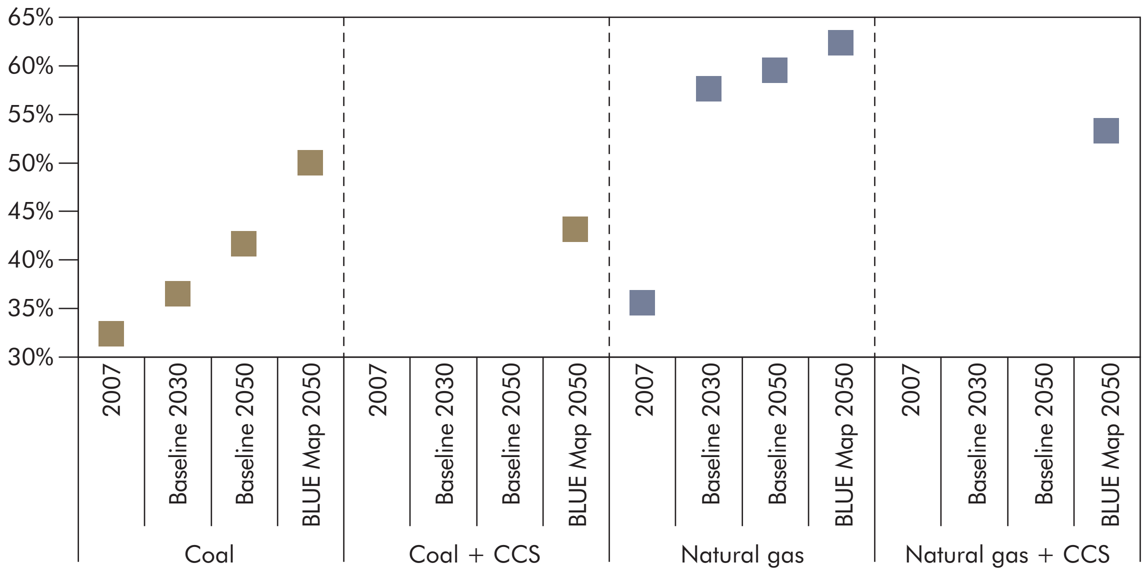


Key point

Electricity generation from renewables grows strongly in the BLUE Map scenario with hydropower, wind and solar being the most important technologies by 2050.

The underlying average efficiency of fossil-fuel power plant increases substantially in all the BLUE scenarios, as the efficiencies of coal-fired and gas-fired plants without CCS are higher than in the Baseline scenario (Figure 3.8). Integrated-gasification combined-cycle (IGCC) and ultra-supercritical steam cycle (USCSC) plants both play a role in achieving this outcome. However, the use of CCS incurs a significant energy penalty. As a result, efficiencies in 2050 are reduced by between 6 and 8 percentage points, depending on the plant.

Figure 3.8 ▶ **Net electricity generation efficiencies of fossil-fuelled power plants by scenario**



Note: Data refer to the average efficiency of the installed capacity in each year.

Key point

The efficiencies of power plants increase in the BLUE Map scenario, but the fitting of CCS reduces the gains significantly.

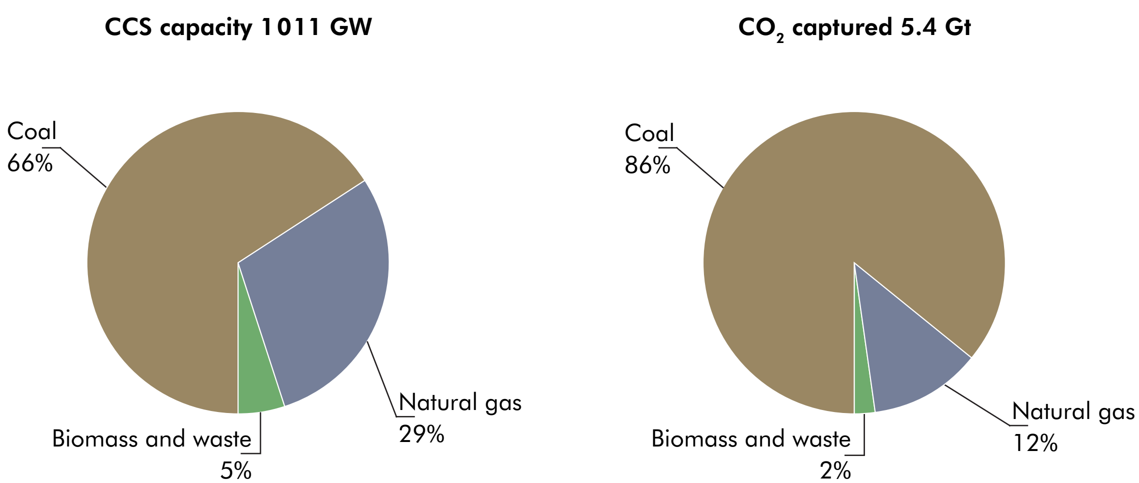
The use of CHP approximately triples in the BLUE Map scenario in absolute terms between 2007 and 2050. The share of CHP in power generation increases to 13% over this period, up from 10% in the Baseline scenario.

The efficiency improvements from new fossil-fuelled technologies and the greater use of CHP, combined with fuel switching from coal to gas, result in CO_2 emissions reductions of 1.9 Gt in 2050.

By 2050, the use of CCS in electricity generation accounts for a reduction of 4.4 Gt CO_2 in the BLUE Map scenario. More than 90% of the electricity generated by coal-fired power plants, and 30% of the gas-fired power generation, comes from plants equipped with CCS (Figure 3.9). In the BLUE Map scenario, 340 GW of coal-fired power plant capacity without CCS is retired early. By 2050, 75% of the 728 GW of coal-fired plant is equipped with CCS from the outset and 16% retrofitted with CCS. The remaining 9% of capacity continues to operate without CCS.

Additional CO_2 emissions reduction is achieved in the BLUE Map scenario by using biomass generation fitted with CCS. By 2050, 13% of electricity from biomass is generated in plants using CCS, which results in net negative emissions of CO_2. But this approach is costly. Biomass transportation costs limit the size of plant that makes economic sense and so combining CCS with biomass plant does not result in the same economies of scale as when used with fossil fuels.

Figure 3.9 ▶ **Global deployment of CCS and CO_2 captured in the power sector in the BLUE Map scenario in 2050**



Key point

In the power sector, CCS is mostly used to abate emissions from coal-fired plants.

In the BLUE Map scenario, increased energy efficiency in the end-use sectors lowers electricity demand compared to the Baseline scenario, thereby reducing the need for new capacity. But there is also significant new investment in more capital-intensive renewables, nuclear and CCS-equipped thermal generation. As a result, overall investment needs in the electricity generating sector between 2010 and 2050 are USD 9.3 trillion (40%) higher than in the Baseline scenario. USD 6.0 trillion additional investment is made in power generation plants, plus USD 1.7 trillion extra for transmission systems and USD 1.6 trillion more for distribution. The additional investment in transmission is to provide transmission lines that connect more remote renewables to the grid and to reinforce grids to handle the connection of variable renewables.

BLUE scenario variants

The future electricity mix is highly uncertain, being subject to a wide range of factors. Some of these factors have been explored through variants of the BLUE scenario (Table 3.1). The variant scenarios explore the effect of flexing the contribution of particular technologies under two different conditions. First, by using the same marginal carbon price of USD 175/t CO_2 as in the BLUE Map scenario and letting the amount of emissions abatement vary and, second, by examining the marginal carbon price that is necessary to achieve the same level of CO_2 emissions abatement as in the BLUE Map scenario.

Among the BLUE variant scenarios, *BLUE no CCS* results in the highest emissions when the BLUE Map carbon price is applied. Emissions are 4.2 Gt CO_2 higher in 2050 than in the BLUE Map scenario. In this variant, the share of coal-fired generation drops to 3%. Total electricity demand is 4% lower and the share of renewables increases to 54%. Nuclear power does not increase its share because of the assumption of a 1 200 GW limit on capacity in 2050 that is retained from the BLUE Map scenario. CO_2 emissions increase not only in electricity generation, but also in industry and in the fuel transformation sector. This scenario requires additional investments of USD 4.7 trillion compared to the BLUE Map scenario, and leads to the highest average electricity generation costs, increasing by 38% in 2050 compared to the Baseline scenario. These high costs demonstrate the importance of the availability of CCS as an option for mitigating CO_2 emissions, particularly if large-scale investment in nuclear power proves unachievable.

In the *BLUE hi NUC* variant, where the maximum allowed nuclear generation capacity is increased to 2 000 GW in 2050, almost all of the nuclear potential is used and the share of nuclear generation increases to 39%. The increase in nuclear generation is at the expense of coal with CCS and renewables, whose shares both decrease: from 12% to 8% for coal with CCS and from 48% to 42% for renewables. Total global emissions in this variant are around 1 Gt CO_2 lower in 2050 than in the BLUE Map scenario. This variant reflects a world in which nuclear power has greater public and political acceptability. However, it would require average reactor construction rates of 50 GW per year between 2010 and 2050, significantly higher than those achieved historically. It would also imply a much larger increase in the supply of nuclear fuel than the BLUE Map scenario. As well as greatly increased uranium production, this would probably require large-scale recycling of spent nuclear fuel and hence the earlier introduction of advanced nuclear systems. In this scenario, investment costs rise by USD 0.3 trillion. But average generation costs are lower than in the BLUE Map scenario and only 6% above those in the Baseline scenario.

Table 3.1 ▶ **Global electricity production by energy source and by scenario**

	2007	Baseline 2050	BLUE Map 2050	BLUE no CCS 2050	BLUE hi NUC 2050	BLUE hi REN 2050	BLUE 3% 2050
Production (TWh)							
Nuclear	2 719	4 825	9 608	9 608	15 859	4 358	9 608
Oil	1 117	311	226	148	170	197	290
Coal	8 216	20 459	238	1 164	211	330	236
Coal + CCS	0	0	4 746	0	3 395	910	4 463
Gas	4 126	10 622	4 283	6 939	2 840	2 983	2 184
Gas + CCS	0	0	1 815	0	1 536	771	1 440
Hydro	3 078	5 344	5 749	5 582	5 747	6 043	5 919
Biomass/waste	259	1 249	2 149	2 703	2 044	2 488	2 105
Biomass + CCS	0	0	311	0	251	146	278
Geothermal	62	297	1 005	1 007	932	1 411	1 137
Wind	173	2 149	4 916	5 589	3 943	8 193	6 267
Ocean	1	25	133	274	99	552	408
Solar	5	905	4 958	5 512	4 113	9 274	7 608
TOTAL	**19 756**	**46 186**	**40 137**	**38 526**	**41 139**	**37 656**	**41 944**
Share (%)							
Nuclear	14	10	24	25	39	12	23
Oil	6	1	1	0	0	1	1
Coal	42	44	1	3	1	1	1
Coal + CCS	0	0	12	0	8	2	11
Gas	21	23	11	18	7	8	5
Gas + CCS	0	0	5	0	4	2	3
Hydro	16	12	14	14	14	16	14
Biomass/waste	1	3	5	7	5	7	5
Biomass + CCS	0	0	1	0	1	0	1
Geothermal	0	1	3	3	2	4	3
Wind	1	5	12	15	10	22	15
Ocean	0	0	0	1	0	1	1
Solar	0	2	12	14	10	25	18
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Share of renewables (%) in 2050	18	22	48	54	42	75	58
Total CO_2 emissions (Gt CO_2/yr)	28.9	57.0	14.0	18.2	13.1	12.9	13.2
Additional investment cost compared to the Baseline (2010-2050) USD (trn)			6.0	10.7	6.3	12.1	
Average generation cost increase from Baseline (2050)			19%	38%	6%	31%	
Marginal cost in 2050 to meet target (USD/tCO_2)			175	293	159	153	

Notes: The CO_2 emissions, additional investment costs and increase in average generation costs of the BLUE variants are all calculated assuming the same marginal carbon price as in the BLUE Map scenario. The marginal costs of the BLUE variants are calculated using the same CO_2 emissions target in 2050 as in the BLUE Map scenario.

In the *BLUE hi REN* variant, the share of renewables in total electricity generation is set at 75% in 2050. While such a high proportion of renewables is not economically optimal from a CO_2 reduction perspective, it could be driven by the use of renewables to pursue other policy goals such as energy security and local environmental benefits. The increased generation from renewables is mostly at the expense of coal with CCS and nuclear, whose respective shares in the total electricity supply become 2% and 12%. CO_2 emissions in 2050 are slightly lower than in the BLUE hi NUC scenario. The BLUE hi REN scenario requires additional investments of around USD 6.1 trillion compared to the BLUE Map scenario, and results in an increase in average electricity generation costs of 10% over the BLUE Map scenario and 31% over the Baseline scenario.

The *BLUE 3%* variant is used to explore the impact on the electricity sector of using a single lower discount rate to reflect social time preferences, rather than the market rates of between 8% and 14% used in the BLUE Map scenario. With the same carbon price as in the BLUE Map scenario, this assumption results in much higher levels of renewables and in fossil fuels in end-use sectors being replaced increasingly by electricity. There is no increase in nuclear power because of the assumed capacity constraint. CO_2 emissions in this variant fall compared to those in the BLUE Map scenario.

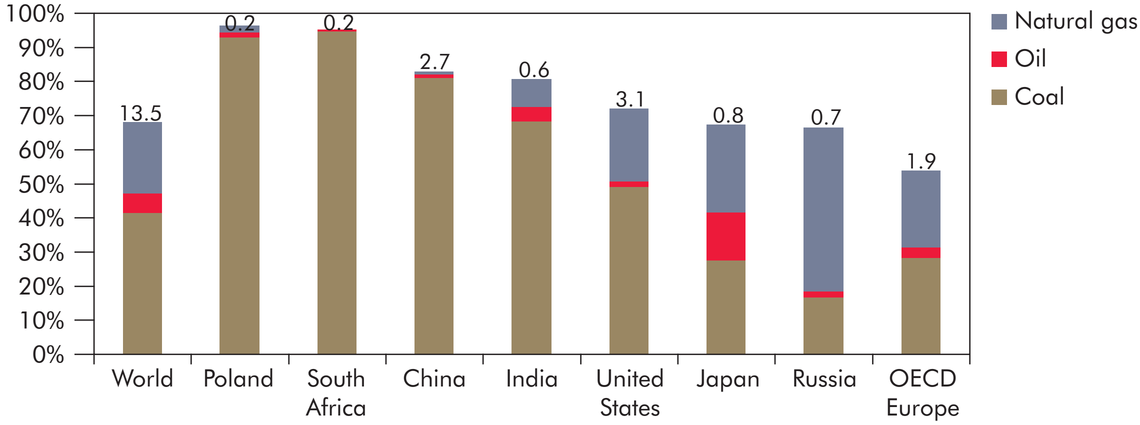
A second way to use these scenario variants is to assume a constant level of CO_2 reduction and to compare the impact on marginal costs. The highest marginal costs are observed in the BLUE no CCS variant, where they increase by 75% to just less than USD 300 per tonne of CO_2 saved. In the BLUE hi NUC variant, marginal costs are USD 16/tCO_2 less than in the BLUE Map scenario as the constraints on economically attractive nuclear power are relaxed. In the BLUE hi REN variant, the marginal cost of CO_2 reductions is reduced by USD 22/tCO_2 as higher cost renewable generation is forced into the mix, causing lower-cost CO_2 reduction options to be the marginal technology.

Fossil fuel power plants

Overview

Electricity generation is currently largely based on fossil fuels in many countries and regions (Figure 3.10). In the Baseline scenario, in the absence of new policies, coal use in electricity generation increases significantly. By 2050, 44% of the world's electricity comes from coal, slightly higher than its current share. The contribution from gas increases to 23%, while that from oil dwindles to almost zero. Pulverised coal combustion (PCC) remains the dominant technology for coal. From 2015, the output from subcritical PCC plant begins to reduce, while the role of SC and ultra-supercritical (USC) PCC plant in the mix grows, and they become the prevailing technologies from 2030. Fluidised bed combustion (FBC) plant contributes in niche applications, *e.g.* in the combustion of poorer-quality fuels. There is also a small contribution from IGCC from 2020. For gas, NGCC remains the technology of choice for electricity generation, with its capacity growing consistently to 2050. Some natural gas open-cycle (NGOC) plant is also used to meet peak electricity requirements.

Figure 3.10 ▸ Share of fossil-fuelled electricity generation in selected countries and regions, 2007



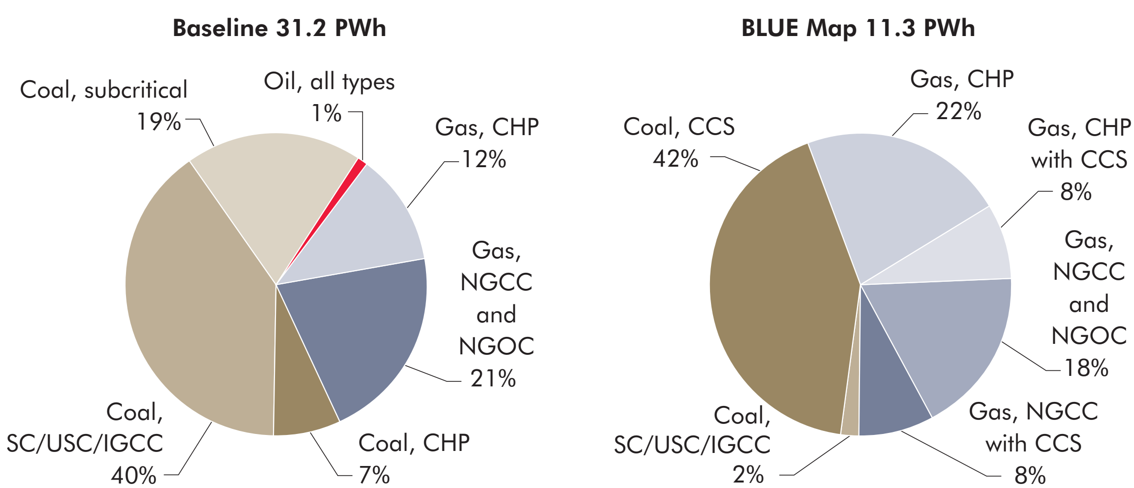
Note: Values above the columns are the absolute level of generation in PWh.

Key point

Many major countries and regions rely on fossil fuels for their electricity generation.

In the BLUE Map scenario, fossil fuel use reduces significantly. By 2050, coal and gas together contribute around 28% of total electricity generation, compared to around 67% in the Baseline scenario. By 2050, much of the remaining fossil fuel generation capacity is equipped with CCS. Generation from coal plants without CCS declines steeply after 2015. As a result of its slightly lower cost, IGCC with CCS predominates over PCC with CCS. Oxyfuel combustion is also introduced into the mix from 2020, and within 15 years is generating more electricity than PCC with CCS. The role of NGCC, though much reduced from that in the Baseline scenario, remains significant to 2050. CCS applied to NGCC plants begins to grow from 2025 (Figure 3.11).

Figure 3.11 ▸ Electricity generation from fossil fuels by technology type and by scenario, 2050



Key point

The fossil fuel generation mix changes radically between the Baseline and BLUE Map scenarios.

Technology status and prospects

There are essentially three ways to reduce CO_2 emissions from fossil fuel-fired plants:

- by improving the stock of operational plants, *e.g.* by closure of the most inefficient plants, modernising and refurbishing existing plants or improving their operation and maintenance, and by deploying best available technologies in new plants;
- by switching to lower-carbon fuels, *e.g.* by switching from coal to natural gas or by co-firing coal with biomass; or
- by employing CCS.

In practice, the choice will depend on the degree of CO_2 mitigation required, on the price of competing fuels and the cost of alternative technologies.

A number of factors influence the efficiencies of coal-fired power plant. Efficiencies may be improved by the closure of poorly performing plant, by upgrading existing plant or by installing new generation technology. Operating procedures and fuel quality are also important to good performance. Running plants below their rated output substantially reduces their efficiency.

Pulverised coal combustion

PCC is currently the predominant technology for generating electricity from coal. It accounts for more than 97% of the world's coal-fired capacity. Most existing plants operate at less than SC steam conditions, with the best examples reaching 39% efficiency. In recent years, a substantial number of plants employing SC steam conditions have been constructed. These are capable of reaching significantly higher efficiencies. This has been made possible largely through progress in materials development which has enabled SC plants to operate at high temperatures with steam pressures greater than 221 bar. Such plants are often sub-divided into two categories, SC and USC, depending on the temperatures at which they operate. Although there is no agreed definition, some manufacturers refer to those plants operating with steam temperatures in excess of 600°C as being USC. The efficiencies of SC and USC plants installed in recent years range from 42% to 47%, depending on the actual steam values, the quality of the coal and the ambient conditions. Advances in materials have paved the way for larger unit capacities, with single units of 1 000 MW now in commercial operation. Further developments in materials are under way to permit the use of steam temperatures at 700°C and higher. This requires the use of nickel-based super alloys, which would offer the potential to raise net efficiencies to 50% and beyond.

The average global efficiency of PCC plant has been broadly static at around 34% over the past decade or longer. In recent years, substantial capacity has been added, particularly in the larger developing economies of China and India. Given the long lifespans of coal plant, even with the majority of new capacity comprising well-performing plants, there is a considerable complement of underperforming existing plants. A number of countries have policies to close the smallest, least efficient plants. Even then, a large amount of inefficient current plants may continue to generate for many years to come.

A programme to refurbish these plants could lead to large reductions in emissions. For example, raising the efficiency of a plant with 35% efficiency by one percentage point would reduce its CO_2 emissions by about 3%. Such a programme would include the retrofitting of components by replacement and upgrade, installing more advanced control systems and improving operation and maintenance (O&M) procedures.

Some countries have large resources of brown coal (or lignite). Given its higher moisture content and lower heat content, the use of this coal may restrict technology choices and result in lower thermal efficiencies. Recently developed coal-drying techniques could have the potential to significantly improve the efficiency from such plants.

Technologies have been developed to reduce the emission of particulates, sulphur dioxide (SO_2) and nitrogen oxides (NO_x) from PCC plants to extremely low levels. These technologies are mature, with a competitive market. In practice, the levels of emissions reductions achieved are more often a function of the requirements of national legislation or local regulations rather than of the capability of modern pollution control technologies.

Fluidised bed combustion

FBC offers an alternative to PCC for generating electricity from coal. Today it is most often employed in particular or niche applications, for instance where fuel flexibility is required. FBC deals effectively with low-quality coals, biomass and general waste. Worldwide, there are several hundred FBC plants in operation. There are two main technology variants, bubbling bed (BFBC) and the more common circulating bed (CFBC). Both BFBC and CFBC offer the potential for integrated in-bed sulphur reduction and, as a result of the lower operating temperatures, lower NO_x emissions than PCC.

FBC plant is generally smaller than PCC plant, although a number of FBC plants of between 250 MW and 300 MW are in operation. In June 2009, a 460 MW CFBC plant at Lagisza in Poland began its commissioning programme. The plant will burn domestic bituminous coal and has a design efficiency of 43%. In the future, manufacturers hope to scale up designs to offer units within the range 500 MW to 800 MW.

Natural gas combined cycle

Natural gas-fired power generation has been the preferred power generating technology over the past two decades in many OECD countries and some non-OECD countries. Exhibiting higher efficiencies, lower capital costs, shorter construction times and lower CO_2 emissions, NGCC potentially offers a number of advantages over coal-fired power generation. The availability and relative costs of coal and gas have largely determined technology choices. Evolving gas turbine technology has led to efficiencies approaching 60%, with further developments in hand.

Integrated gasification combined cycle

Integrated gasification combined cycle plant has inherently lower emissions of some pollutants than PCC and the potential to achieve levels of efficiency as high as those of PCC plants. A fuel gas mainly comprising carbon monoxide and hydrogen is generated by partially combusting coal in air or oxygen at elevated pressure. Following cooling, the fuel gas is treated to reduce the concentration of particulates, sulphur and nitrogen compounds to extremely low levels before it is burned in the combustion chamber of a gas turbine. Electricity is produced through the combined cycle of gas and steam turbines. There are a number of variants of the technology depending, for example, on whether air or oxygen is used as the oxidising medium and whether the coal is fed to the gasifier dry or as slurry. Future designs offer the potential for efficiencies of over 50%.

The 1970s and 1980s saw a surge of interest in the development of IGCC plants, particularly in Europe, Japan and the United States. Concerns relating to the cost and reliability of IGCC plant meant that the technology fell out of favour towards the end of the 1990s. Of the plants that were commissioned in the 1990s, only four continue to operate on a commercial basis, two in Europe and two in the United States. The capacity of each of these plants lies in the 250 MW to 300 MW range and their net efficiencies are between 40% and 43%.

Interest in IGCC technologies has recently revived. By adding a water-gas shift reactor, additional hydrogen can be produced and carbon monoxide can be converted to CO_2 for capture and storage. The hydrogen that remains can be used to generate power through a gas turbine or a fuel cell. Alternatively, the fuel gas could be used to synthesise substitute transport fuels or a range of other chemicals. The flexibility for an IGCC plant to generate a range of products, electricity, hydrogen transport fuels and/or chemicals, is commonly referred to as polygeneration.

Given the attraction and flexibility of an IGCC plant, significant effort is being devoted to the development of IGCC technologies, particularly in China, the United States, Japan and Europe. However, a number of technical obstacles will need to be overcome if IGCC is to become widely deployed.

Combined heat and power

By making use of both heat and power, CHP plants generally convert 75% to 80% of the input fuel energy into useful energy. Many modern plants reach efficiencies of 90% or more. CHP plant tends to be situated close to end-users as the heat output from electricity production is often used for space heating or other heat applications in industry. This also helps to reduce electricity transmission and distribution losses.

Almost any fuel is suitable for CHP, although natural gas and coal currently predominate. Some CHP technologies can be fired by multiple fuel types, providing valuable flexibility at a time of growing fuel choice. CHP plant sizes range from 1 kW to 500 MW. For plants larger than 1 MW, equipment is generally tailored to the individual site, but smaller-scale applications can often utilise pre-packaged units. CHP plants are usually sized to meet the required heat demand, selling the excess electricity produced back to the grid.

The amount of electricity produced globally from CHP has been gradually increasing, and has now reached more than 1 970 TWh per year, or more than 10% of total global electricity production. The amount of heat that is co-generated is in the range of 120 million tonnes of oil equivalent (Mtoe) to 360 Mtoe per year, representing an important share of industrial, commercial and residential heat supply.

The penetration of CHP in the power generation sector varies widely from country to country. Denmark, Finland and the Netherlands already have high penetration rates. Russia and China have substantial lower-efficiency CHP capacity that offers significant opportunity for efficiency improvement. China also has very significant potential for growth in CHP given its increased attention to energy efficiency and its rapidly growing industrial base. Many other countries have significant potential to expand their use of CHP, if they take steps to address barriers such as unfavourable regulatory frameworks in the form of buy-back tariffs, exit fees, and backup fees, challenges in locating suitable heat users, and the relative cost-ineffectiveness of CHP units of less than 1 MW capacity.

Costs

The costs of coal and gas plants can vary substantially from country to country. Variations depend largely on the competition for power plant design and construction resources, commodities, equipment and manufacturing capacity. Fuel availability and costs, and the time needed for construction, are the major determinants of choices between coal or gas plant. With the increasing focus on reducing CO_2 emissions, there is significant ongoing effort to raise the efficiencies of both coal and gas plants. There have been significant developments in SC coal technologies in recent years, although the potential cost savings arising from more efficient SC and USC plants are offset by the need for more expensive materials, more complex boiler fabrication and the more precise control systems required. Costs for both coal and gas technologies are expected to fall in the future. For other technologies such as IGCC, improvements resulting from experience and learning will lead to lower costs, as will the development of innovative technologies to replace those available at present.

The assumptions about investment and O&M (excluding fuel) costs for new plant used in the scenarios are summarised in Table 3.2.

Table 3.2 ▶ ***Cost assumptions for hard coal- and natural gas-fired electricity generation***

	Investment cost USD/kW		O&M cost USD/kW/yr		Net efficiency %	
	2010	2050	2010	2050	2010	2050
SC PCC	2 100	1 650	42	32	42	42
USC PCC	2 200	1 700	44	34	46	52
IGCC	2 400	1 850	72	56	42	54
NGCC	900	750	27	23	57	63

Note: Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to US levels by 2050.

3

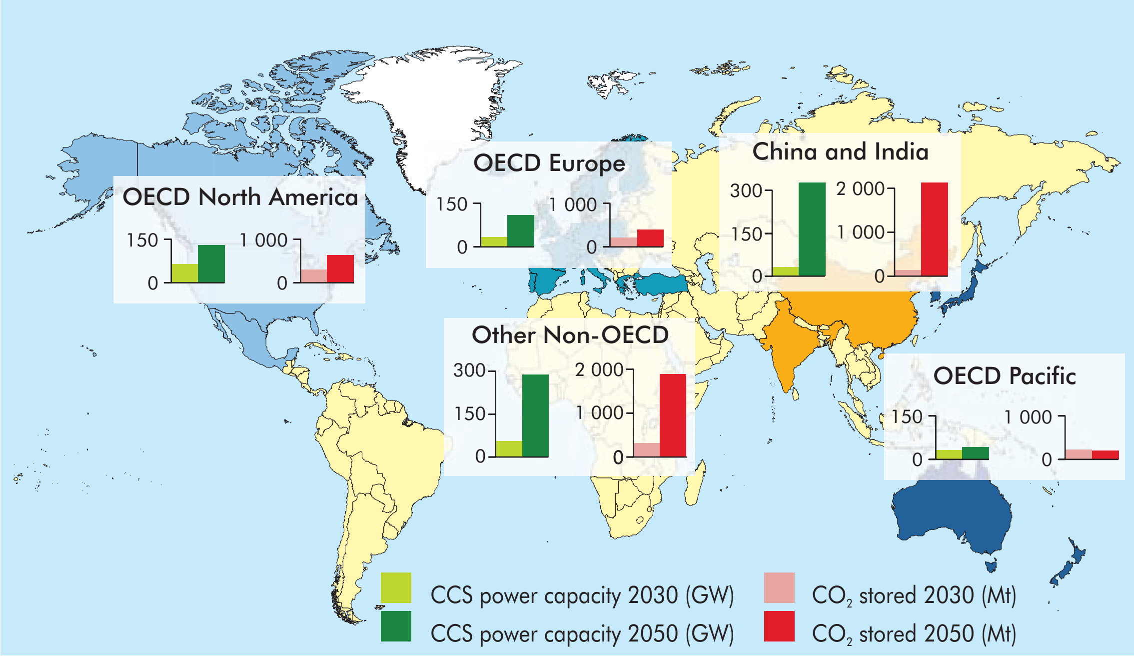
Carbon capture and storage

Overview

In the BLUE Map scenario, almost two-thirds of all fossil-fuel electricity is produced from plants which incorporate CCS. Most of the remainder comes from high efficiency NGCC. Over 20% of all electricity produced from biomass and waste is from plants that incorporate CCS.

From 2010 to 2050, the use of CCS in power generation in the BLUE Map scenario results in cumulative capture and storage of some 79 Gt CO_2. By 2050, coal-fired plants account for around 87% (69 Gt) of the cumulative CO_2 captured from power generation. Capture from gas-fired plants accounts for 10% (8.2 Gt) and capture from biomass plants accounts for around 3% (2.0 Gt). Total global installed CCS capacity rises to over 1 000 GW by 2050, of which coal-fired CCS accounts for almost two-thirds. Realising this goal will present major development and investment challenges. CCS-fitted plants account for only 19% of total electricity generation in 2050 in the BLUE Map scenario.

Figure 3.12 ▶ ***Regional deployment of CCS in power generation under the BLUE Map scenario***



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Key point

CCS is initially deployed mostly in OECD countries, but by 2050 India and China have the largest share of any region.

Of the three methods of CO_2 capture relevant to power generation (post-combustion, pre-combustion and oxy-fuelling), the BLUE Map scenario envisages near-term projects mainly consisting of post-combustion capture technologies from coal-fired power plants in OECD regions with other capture technologies then taking an increasing share over time. Post-combustion capture is the most extensively demonstrated of the three capture options at present, and capture from coal-fired power plant is cheaper than from gas-fired power plant given coal's higher CO_2 intensity. Post-combustion capture is also seen as the technology most suitable for retrofit, which means it will have the greatest impact on existing plant and on plant that is currently under construction.

The BLUE Map scenario shows that the share of CCS deployment within non-OECD regions will need to increase very significantly around 2025 to 2030 and beyond if emissions from new coal-fired power plants built in emerging economies are to be tackled (Figure 3.12). To meet the emissions reduction objectives of the BLUE Map scenario, the capture and storage of emissions from plants in China and India alone will need to account for around 36% of global CCS deployment in power generation by 2050.

Technology status and prospects

Carbon capture and storage is a system of technologies that integrates three stages: CO_2 capture, transport, and geological storage. Each of these stages is technically viable and has been demonstrated individually in relation to electricity generation. But none of the five fully integrated, commercial-scale CCS projects in operation involves capture of CO_2 from power generation.

To catalyse the deployment of CCS in power generation, OECD governments will need to increase funding for CCS demonstration projects. In addition, mechanisms need to be established to stimulate commercialisation beyond 2020 in the form of mandates, greenhouse-gas reduction incentives, tax rebates or other financing mechanisms. Carbon capture and storage technology must also be spread rapidly to the developing world. There is a need to develop near-term regulatory approaches to facilitate CCS demonstration activities, while at the same time developing comprehensive approaches for the large-scale commercial deployment of CCS.

Carbon dioxide capture

Carbon dioxide capture technologies have long been used by industry to remove CO_2 from gas streams where it is not wanted or to separate CO_2 as a product gas. But these technologies have only been combined with power generation on a small scale. Carbon capture and storage from power generation has only been demonstrated with sub-commercial volumes of flue gas, from small pilot plant or from flue-gas slip-streams from larger plant. Challenges associated with scaling up and integrating these technologies at scale need to be overcome. This can only be achieved through the experience of building and operating commercial-scale CCS facilities in a variety of settings. The demonstration of CO_2 capture from power generation in the next ten years will be critical to accelerating wider deployment between 2020 and 2050.

There are currently three primary methods for CO_2 capture: post-combustion, pre-combustion and oxy-fuel. Currently all three capture options result in a significant energy penalty to the base plant. It is expected that this energy penalty can be reduced through continued R&D and experience in operating plants at scale. The clean coal roadmap from the IEA Clean Coal Centre suggests a target range for efficiencies of power generation technologies with CO_2 capture of 40% to 45%.[4] This assumes that performance approaches that of current non-capture systems, avoiding major impacts on fuel and other costs (Henderson and Mills, 2009).

Box 3.1 ▶ Recent developments in CCS

The IEA CCS Roadmap (IEA, 2009) concludes that 100 large-scale CCS projects should be in operation by 2020 to enable widespread deployment in the following decades. In 2008, there were just five large-scale CCS projects in operation and none of these was in electricity generation. In the last two years there has been extensive investment in the development of CCS. A recent snapshot indicates some 240 active CCS projects at some stage in the planning process (GCCSI, 2010). Of these, 80 were large-scale and would demonstrate the entire process chain, i.e. they would include CO_2 capture, transport and storage.

To implement large-scale CCS plant requires extensive additional funding that, in the present energy market, cannot be justified commercially. In recognition of this market failure, governments have been taking an active role to address the financial gap. Although more funding is needed for first-of-a-kind CCS plants to be built in the numbers required, collectively more than USD 26 billion has been committed by governments, including those of Australia, Canada, Norway, the Republic of Korea, the United Kingdom and the United States, as well as the European Union.

The identification of suitable CO_2 storage reservoirs is critical to CCS deployment. In the last few years, several countries/regions have embarked upon strategies to map CO_2 storage potential, including Australia, Canada, China, the European Union, Mexico and the United States. For CCS to meet its potential beyond 2020, such mapping will need to accelerate over the coming decade.

Establishing effective, comprehensive legal and regulatory frameworks is essential for the broad deployment of CCS in the future. For first-of-a-kind or demonstration plants to be constructed and operated, exemptions or derogations from existing processes or regulations may be possible; but these can only offer an interim solution. Until recently, progress on the development of legal and regulatory frameworks has been fragmentary. This is no longer the case. The IEA, through its "Regulators' Network", and others have been instrumental in driving change. For example, Australia, the European Union, Japan and the United States have each introduced integrated legislation to facilitate the deployment of CCS.

Carbon dioxide transport

CO_2 has been transported in pipelines for more than 30 years in North America. Over 30 Mt CO_2 from natural and anthropogenic sources is transported each year through more than 3 000 km of pipelines in the United States and Canada (CSLF, 2009). CO_2 is transported predominantly in high-pressure pipeline networks. Ships, trucks and trains have also been used for CO_2 transport in early demonstration projects and in regions with inadequate storage. Although CO_2 captured from power generation may have different minor constituents in it due to the capture process and fuel used, it should not require any significant modifications to the current methods for CO_2 transport.

4. Based on net output and net calorific values.

3

The challenge for the future of transport technology is to develop long-term strategies to cluster CO_2 sources and develop CO_2 pipeline networks that will optimise the source-to-sink transmission of CO_2. The development of appropriate pipeline routes presents a number of regulatory, access, public acceptance and planning challenges. To address these, governments will need to initiate planning at a regional level and develop incentives for the creation of CO_2 transport hubs.

Carbon dioxide storage

Carbon dioxide storage involves the injection of CO_2 into geological formations such as saline formations, oil and gas reservoirs, and deep unmineable coal seams.[5] Of these, it is expected that saline formations will provide the opportunity to store the greatest quantities of CO_2, followed by oil and gas reservoirs. Monitoring data from projects involving injection into depleted oil and gas fields and saline formations have shown that the CO_2 performs as anticipated after injection, with no observable leakage. A number of projects involving the injection of CO_2 into oil reservoirs have also been conducted, primarily in the United States and Canada. Most of these projects use the CO_2 for enhanced oil recovery (EOR), but some seek also to establish long-term storage.

There is an urgent need to advance the state of global knowledge of CO_2 storage opportunities. Although depleted oil and gas fields are well mapped and offer promising low-cost opportunities, deep saline formations are the most viable option for the long term. But only a few regions have adequately mapped the CO_2 storage potential of these formations. There is also a need to develop common international methods for CO_2 storage site selection, monitoring and verification, and risk assessment.

Box 3.2 ▶ CCS retrofit and capture-ready plants: avoiding lock-in of non-CCS plants

In the short term there is a risk that increased electricity demand in many countries will be met by building new fossil fuel power plants to which CCS cannot be retrofitted once it becomes commercially available. If so, the building of these plants will lock in a large amount of CO_2 emissions over their operational lives of 40 years or more. It is critical that, wherever practical, fossil-fuelled plants built over the next 10 to 20 years utilise technologies and practices that enable CCS retrofitting.

To demonstrate capture-readiness, plants need to ensure the provision of sufficient space and access for the additional capture facilities that would be required, and identify reasonable methods for storing CO_2 (IEA GHG, 2007). Pre-investment in addressing these issues is relatively inexpensive and could result in significant reductions in the costs and down time involved in retrofitting CCS in due course.

5. CO_2 storage in basalt formations is also a potentially important option for regions such as the Indian subcontinent.

In the BLUE Map scenario, 16% of the total coal capacity operating with CCS in 2050 are plants that have been retrofitted. If these plants were unable to be retrofitted it would result in a significant increase in CO_2 emissions or in the cost of achieving emissions reduction targets. This demonstrates the importance of ensuring new build plant over the next 10 to 20 years has CCS fitted from the outset or is ready for retrofitting as soon as it can be achieved.

Costs

The capture, storage and transport of CO_2 all add to the cost of generating electricity. Capture raises costs by reducing electric efficiency, which means that more gross power capacity is needed for the same output, together with the cost of the additional capture equipment and the cost of additional fuel. The relative importance of these three components depends on the fuel price and the particular power plant and capture technologies employed.

Carbon capture and storage is expected to be more expensive to apply to power generation than to some industrial processes such as chemicals and gas processing, but cheaper than to fuel transformation and cement production. Most of the additional costs of CO_2 transport and storage will occur in respect of capital investment. These costs will depend on a number of factors, including whether the storage site is onshore or offshore, the distance between sources and sinks, the extent to which different projects can share a common transport infrastructure and the number of wells that are needed to inject and store a given amount of CO_2. Although the initial investment in CO_2 transport and storage infrastructure may be significant, the cost of CO_2 capture will represent the major component of the total additional cost over the lifetime of a project (Table 3.3). The costs of capture technologies are forecast to fall over time with increased demonstration of integrated projects and technology cost reductions, while transport costs will decrease with progressive optimisation of regional pipeline infrastructure.

Table 3.3 ▶ Cost assumptions for fossil electricity generation with CCS

	Investment cost USD/kW		O&M cost USD/kW/yr		Net efficiency %	
	2010	2050	2010	2050	2010	2050
USC PCC+ post-comb capture	3 400	2 500	102	75	36	44
USC PCC + oxy-fuelling	3 700	2 700	111	81	36	44
IGCC + pre-comb capture	3 200	2 450	96	74	33	48
NGCC+ post-comb capture	1 450	1 100	44	33	49	56
NGCC + oxy-fuelling	1 650	1 350	50	41	47	54

Note: Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to United States levels by 2050.

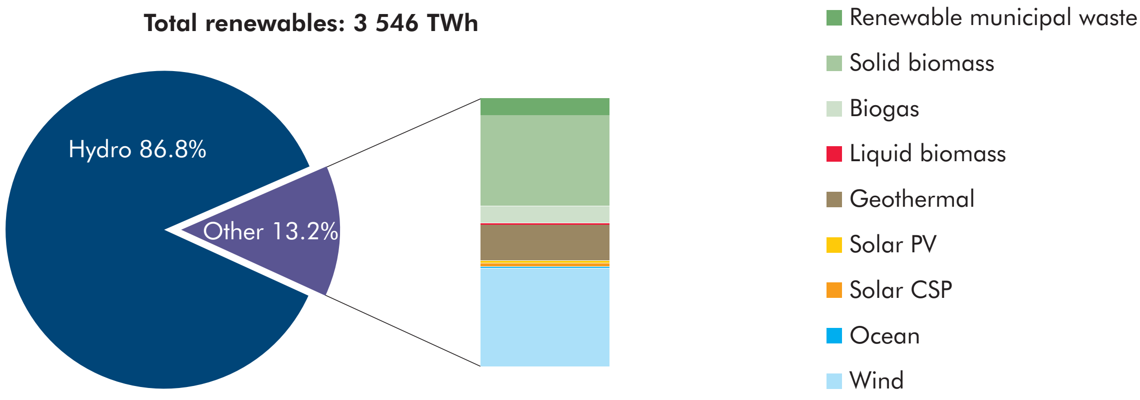
Renewable energy

Overview

Renewable energy sources can generate electricity with low or very low net CO_2 emissions over their lifecycle. They therefore have the potential to make a significant long-term contribution to decarbonising the power sector. The local availability of many renewable energy sources can also help decrease energy dependence and increase the energy security of countries.

In 2007, renewable energy sources represented 18% of power generation worldwide. This share has been decreasing for several years, mainly because of the slow growth of the largest renewable power source, hydro, compared to the growth of fossil-based power. The mix of renewables is also changing. For the first time in 2007 more electricity was produced from wind than from solid biomass (Figure 3.13).

Figure 3.13 ▶ Composition of renewable power generation, 2007



Key point

Hydro power is currently the most important renewable energy source for electricity generation.

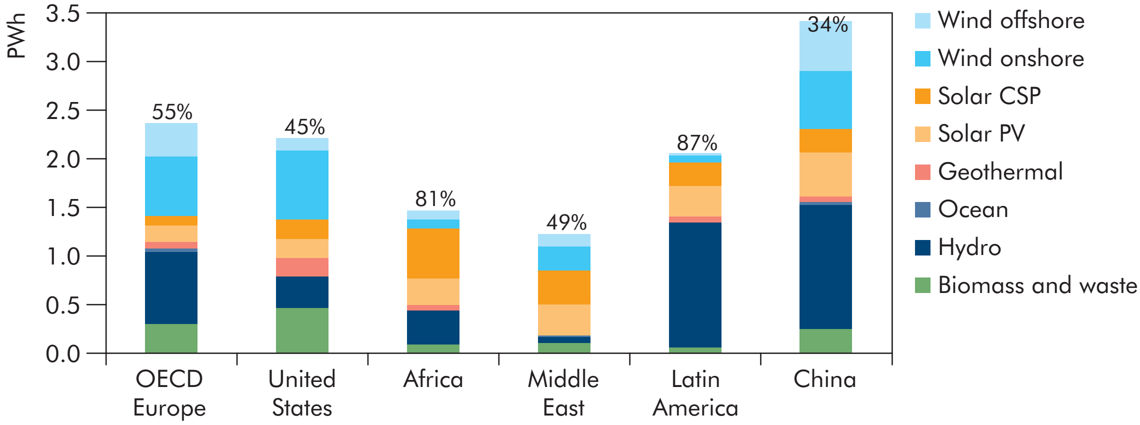
Wind power has grown at an average rate of almost 30% per year over the last ten years. In terms of installed capacity, solar PV has grown even faster. The overall contribution of solar PV to total power generation remains small and, in many countries, hard to measure as many systems are off-grid.

In 2007, OECD Europe produced more than 20% of its electricity from renewable sources. Central and Latin America produced almost 70%. In the BLUE Map scenario, these regions are projected to retain a lead in generating electricity from renewables up to 2030. By 2050, Africa overtakes OECD Europe, with more than 80% of electricity coming from renewables, and Latin America generates 87% of its total electricity from renewables.

China generates about 34% of its electricity from renewables in 2050. Although the lowest share among the ten regions, this is very significant in absolute terms.

Electricity generation in the Middle East is projected to undergo major changes between 2007 and 2050. In 2007, about 3% of the electricity generated in the region came from renewables. By 2050 the development particularly of solar and wind power results in just over 50% of the total electricity in the region coming from renewables in the BLUE Map scenario (Figure 3.14).

Figure 3.14 ▶ Renewable electricity generation in the BLUE Map scenario for key countries and regions in 2050



Note: Percentages above columns show the share of renewables in total electricity generation.

Key point

In the BLUE Map scenario, renewable energy makes a significant contribution to electricity generation in many countries and regions.

Compared to the BLUE Map scenario, overall electricity demand in 2050 is about 6% lower in the BLUE hi REN scenario. Wind, solar and ocean energy all have a higher share of electricity generation, at the expense of coal with CCS and nuclear. Solar energy is the largest source of electricity generation, accounting for almost 25% of the total. Solar generation comes about equally from CSP and PV technologies. Wind has the next largest share, followed by hydro. A high penetration of variable renewables, such as solar, wind and ocean, is complemented by the availability of flexible hydro and gas-fired capacity. These plants can provide backup in the absence of suitable conditions for electricity generation from variable renewables. A high share of variable renewable power will also require a number of other actions to increase the overall flexibility of power systems, including the development of smart grids, international interconnections, storage and demand-side response measures.

By 2050, all world regions produce at least 50% of their electricity from renewables. Africa and Central and South America achieve shares of more than 90%. China has the highest generation from both onshore and offshore wind. The deployment of solar CSP is significant in all regions with good resource conditions, *i.e.* Africa, Middle East, India and the United States. By 2050 the United States is the region with the highest electricity generation from CSP. Solar PV develops across all world regions, with the Middle East and the United States having most generation.

Ocean energy increases fourfold in the BLUE hi REN scenario compared to the BLUE Map scenario. More than half of total ocean-based electricity generation is in OECD Europe.

Technology status and prospects

Renewable energy technologies have a long history. Hydro and traditional geothermal and biomass technologies have been around for many decades and were first built in locations with abundant resources. In recent years, wind and solar technologies (both PV and CSP) have developed rapidly. These technologies are still subject to significant learning which, together with economies of scale, should contribute to significant cost reductions in the future. In recent years, their deployment has been subject to a range of incentive schemes that have helped to speed up learning. Ocean and enhanced geothermal technologies are in the demonstration stage and need further RD&D.

To achieve the BLUE Map scenario objectives, significant action is needed in renewable technology innovation and RD&D, policy frameworks, and infrastructure and energy system integration. Government budgets for renewable energy RD&D have increased moderately over the last 20 years in those OECD countries for which data are available, but are still lower than they were 30 years ago. To achieve the deployment of renewables envisaged under the BLUE Map scenario, RD&D priorities will need to be clearly set and additional long-term funds guaranteed. International collaboration will be crucial to maximise impacts, increase the efficiency of national programmes and avoid wasteful duplication.

Policy frameworks also need to be improved. Achieving a stable carbon price through a global carbon market will be an important element in fostering the deployment of renewable technologies in the longer term. But it is likely to take some time to achieve. In the meantime, national policies supporting renewables will be crucial. In 2008 and 2009, the governments of many countries committed additional funds for renewable energy through economic recovery and stimulus packages. These short-term measures need also to be coupled with more long-term oriented policy action to tackle non-economic barriers to the wider deployment of renewables. As technologies mature and renewable deployment increases, so incentive policies will need to evolve and become more market-oriented.

With the rapid deployment of additional renewables, system integration issues will become more important. The output from variable renewable energy such as wind, solar PV, run-of-river hydropower, wave and tidal power, requires greater power system flexibility than is the case with most conventional sources in order rapidly to supplement periods of low output and to manage production peaks. Modest shares of variable renewables have been shown to have little or no impact on power system operation. But larger shares will present new challenges. A number of options and technologies including smart grids and additional electricity storage capacity will need to be developed to increase the flexibility of electricity systems and allow the integration of larger proportions of variable renewables (see Chapter 4).

Hydropower

Hydropower is the largest source of renewable electricity today. It has a particular advantage in that it can adjust quickly and flexibly to sudden load changes. Hydro reservoirs serve as a means of storage in power systems and therefore play an important role in helping to cover peak loads and sudden losses of power from other sources, for example variable technologies such as wind. Hydro is also cheap to operate and maintain and produces no waste or CO_2 emissions. In some circumstances it can lead to methane emissions which need to be monitored and managed. Initial costs are relatively high but hydro plants have a very long lifespan. Existing hydropower plants are therefore often the cheapest means of generating electricity because once the initial construction costs are amortised, the electricity is produced with very little cost.

Hydropower is divided into large and small systems with the cut-off point between 10 MW and 50 MW, depending on the country. Small systems are usually run-of-the-river designs. These are normally environmentally benign as they do not alter river flows. They often provide an alternative to diesel generators in rural areas. Small hydro still has a huge potential for deployment especially in Africa, Asia and Central and South America. Large hydropower plants can be more controversial. They often alter water availability downstream, can cause the relocation of populations, and have a significant impact on existing ecosystems. The further development of large hydropower systems may be constrained by public concerns and by the availability of less environmentally damaging alternatives.

Hydropower is also susceptible to constraints resulting from climate change. Rainfall patterns are changing in some cases with consequences for electricity production from hydro sources. Efforts to improve hydro technology focus primarily on improving efficiency and sustainability. Refurbishing existing plants with modern turbines often offers a relatively cheap way to increase hydro capacities.

Bioenergy

Bioenergy is a renewable resource that can be converted to all final energy uses, *i.e.* to produce electricity, heat, or fuels for the transport sector. The term bioenergy encompasses a number of feedstocks together with several technologies that can convert these feedstocks into electricity. Bioenergy feedstocks include solid biomass, wood wastes, agricultural wastes, wastes from the paper and pulp industry, energy crops, biogases, landfill gases, biodegradable components of municipal solid waste, and liquid biofuels. Typical conversion technologies for electricity purposes are combustion, co-firing, gasification, and anaerobic digestion.

Steam turbines and steam piston engines have been proven with biomass feedstocks. They can be operated in electricity mode or in CHP mode. For smaller plants of 5 MW to 10 MW capacity, electricity efficiencies are around 25%. Larger plants of at least 50 MW capacity can achieve electricity efficiencies of more than 30% in CHP mode and about 40% in electricity-only mode. For small applications there are several other options, including the organic rankine cycle (ORC) which uses oil as the working fluid instead of water. Another option, although not yet commercially viable, is to use an externally fired Stirling engine.

Biomass is an interesting option for electricity production in parts of the world where supplies of residues from agriculture or the forest products industry are abundant. But the rapid development of second-generation liquid biofuel technologies to produce transport fuels may create competition for feedstocks between the two uses.

The co-firing of biomass with coal is becoming increasingly popular because it offers CO_2 and local pollutant emission benefits without requiring the modification of existing coal-fired plants and with only a small reduction in plant efficiency. Co-firing can also add economic value to agricultural or forestry residues that would otherwise often be disposed of through burning. Developing countries can use co-firing as a low-cost option to reduce their emissions.

Biomass, like coal, can be gasified. The resulting gas can then run an engine, steam or gas turbine to produce electricity, heat or steam. This technology is used, for example, with the waste from agriculture and the paper and pulp industry.

Anaerobic digestion is another way to convert organic wastes into a biogas, primarily methane. The gas can then be used to run an engine to produce electricity. This technology is particularly valuable in some developing countries for small-scale rural electrification.

Biomass technology improvement efforts are primarily focused on the improvement of the reliability, economic viability and efficiency of gasification systems. Other objectives include improving efficiencies, increasing yields for feedstocks, and the optimisation of production and logistics chains.

Solar photovoltaic

Photovoltaic (PV) cells are semiconductor devices that convert solar energy into direct-current electricity. Photovoltaic cells are interconnected to form PV modules with a power capacity of up to several hundred watts. Photovoltaic modules are then combined to form PV systems. Photovoltaic systems can be used for on-grid and off-grid applications. They are highly modular, *i.e.* modules can be linked together to provide power in a range of from a few watts to several megawatts.

Commercial PV technologies can be divided into two groups: wafer-based crystalline silicon and thin films. A separate range of technologies, including concentrating PV or organic solar cells, is emerging with significant potential for performance increases and cost reductions. The technologies differ in their costs as well as their performance. Thin films currently represent a low-cost, lower-efficiency technology, while concentrating PV offers high efficiency but at a high cost. The biggest share of the market is currently taken by crystalline silicon technologies that have mid-range efficiencies and costs.

Photovoltaic technologies can be applied in a very diverse range of applications, including in residential systems, commercial systems, utility-scale systems and off-grid applications of varying sizes. Different PV technologies may suit different uses. Off-grid applications offer the potential for the electrification of remote areas.

Photovoltaic module costs have decreased in the past with a learning rate of between 15% and 22%.[6] System prices fell by 40% in 2008/09 (IEA, 2010a). The installed worldwide capacity of PV has been growing on average by 40% per year for almost 10 years, and with incentive schemes in several countries encouraging PV deployment, this trend is expected to continue. This will help bring costs down further and should allow PV to achieve grid parity with electricity retail prices in many countries over the next decade. Deployment incentives need to be balanced with RD&D supporting measures, in order to allow for optimal technology progress, cost reduction and the ramp-up of industrial manufacturing.

The various photovoltaic technologies are at differing levels of maturity. All of them have a significant potential for improvement. Increased and sustained RD&D efforts are needed over the long term in order to accelerate cost reductions and the transfer to industry of the current mainstream technologies, to develop and improve medium-term cell and system technologies, and to design and bring novel concepts to industrialisation.

Other priorities for PV include developing technical solutions to enable the integration of PV systems in electricity grids. RD&D is also needed on the use of PV as a building material and architectural element. This will help respond to a range of technical, functional and aesthetic requirements and help reduce costs.

Concentrating solar power

Concentrating solar power (CSP) systems use concentrated solar radiation as a high-temperature energy source to produce electrical power and heat and to drive chemical reactions. A CSP plant comprises a field of solar collectors, receivers, and a power block where the heat collected in the solar field is transformed to run a turbine and produce electricity. Wet or dry cooling systems can be used. In some cases CSP plant incorporates heat storage devices or is backed up by power systems using a combustible fuel.

Concentrating solar power requires clear skies and strong sunlight because only direct insolation, *i.e.* parallel sunrays, can be transformed into useful energy. In practice this means that CSP will be most effective in areas such as North Africa, the Middle East, southern Africa, western India, the south western United States, Mexico, central Asian countries, Australia and some parts of South America.

Currently there are four major CSP technologies. Troughs and Fresnel reflectors track the sun along one axis, while towers and dishes track the sun along two axes.

Troughs are the most mature technology. They concentrate solar rays on long heat collector pipes. Synthetic oils are used as a heat transfer fluid that is circulated through the pipes then passed through heat exchangers where water is preheated, then evaporated, then superheated. The superheated steam runs a turbine, which drives an electric generator. Some recent plants have several hours of storage capacity, and most existing plants use some combustible fuel as a backup.

6. The learning rate describes how costs reduce with increased deployment of a technology. It is defined as the percentage cost reduction associated with a doubling of cumulative installed capacity.

Linear Fresnel reflectors (LFR) approximate to a parabolic shape with long ground-level rows of flat or slightly curved mirrors reflecting the solar rays onto a downward-facing linear fixed receiver. Saturated steam is directly generated in the receiver tubes.

Towers, also called central receiver systems, concentrate the sun rays on top of a fixed tower. This allows for higher temperatures and efficiencies than linear systems. Towers can generate saturated or superheated steam directly, or use molten salts, air or other media as heat transfer fluids. Molten salts can also be used to store heat for several hours.

Parabolic dishes concentrate the sunrays on a focal point that moves together with the dish tracking the sun. Dishes have an independent engine/generator at the focus point, usually an external combustion Stirling engine, although Brayton micro-turbines could be used as well. These systems offer the highest conversion performance at capacities of tens of kilowatts or less. Mass production may allow them to compete with larger systems that benefit from economies of scale. But the size of solar dishes, their absence of water needs, and their low compatibility with thermal storage and hybridisation, put them in competition with PV modules as much as with other solar thermal technologies.

Concentrating solar power technologies are still developing. Improvements can be expected in all aspects of CSP plants (mirrors, receivers, working fluids, power blocks, and cooling systems) as well as in automated control and maintenance systems (IEA, 2010b). Special attention needs to be paid to storage designs. With storage available for even only a few hours, CSP plants can offer a very interesting option in countries with good direct insolation for covering evening peak loads. With larger storage, CSP could become an option for firm baseload power.

Wind

Wind is the second-largest contributor to renewable electricity today after hydro. The average newly installed grid-connected turbine has a rated capacity of about 1.6 MW. It extracts energy from the wind by means of a horizontal rotor, upwind of the tower, with blades that can be pitched to control the rotational speed of a shaft linked via a gearbox to a generator, all housed in the nacelle on top of the tower. Today's offshore wind turbines are essentially large land turbines with, for example, enhanced corrosion protection. However, an offshore wind industry is developing, particularly in Europe, and a specific offshore supply chain is emerging.

Wind turbines generate electricity from wind speeds ranging from around 15 km/h to 90 km/h. Wind power output varies as the wind rises and falls. Even when available for operation, wind plants will not operate at full power all of the time. This variability will become increasingly significant as wind generation rises above around 10% of grid totals, at which level management of the power system may need to be improved to maintain reliability. Substantially higher wind penetrations will require additional system flexibility through some combination of quickly dispatchable generation, demand-side response, interconnection, and/or storage.

Technology improvements in the past have focused primarily on the scaling-up of turbines, an important driver for cost reductions. The largest turbines now have a rated capacity of 7 MW and even larger ones are under development. Materials with higher strength to mass ratios are important to enable the continued cost-effective development of very large turbines. Technological innovation should continue to improve energy capture by the rotor, particularly at low speeds, in complex terrains and under turbulent conditions, to increase the time offshore plants are available for operation, to reduce O&M requirements, to extend turbine lifespans, and to reduce the cost of components. In addition, RD&D needs to improve transmission technology and design and to develop enabling technologies including smart grids that will enhance the overall flexibility of power systems and allow for their operation with large shares of wind power.

Geothermal

Geothermal energy is heat extracted from the earth. It can be used for several energy purposes. Electricity generation from geothermal energy mainly uses high-temperature heat, for example in tectonically active regions near plate boundaries or rift zones, and mantle plumes or hot spots. These include the countries around the "Ring of Fire" (Indonesia, the Philippines, Japan, New Zealand, Central America, and the western coast of the United States) and the rift zones of Iceland and East Africa. The penetration of large-scale geothermal power installations is currently relatively limited.

Geothermal energy is independent of season, and immune to weather effects and climate change impacts. It is therefore a reliable source of baseload electricity. Geothermal power can be produced in steam plants, binary cycle plants or by enhanced geothermal systems. Conventional steam plants use steam separated from hot geothermal fluid to drive turbine generators to produce electricity. Binary plants often use lower temperature (<180°C) fluid in a heat exchanger to boil a secondary fluid to create a gas that drives the turbine generators. The separated water and condensate are typically reinjected back into the ground, although the separated water can first be used in binary plants to generate more electricity. Enhanced geothermal systems circulate water from the surface down wells into deep enhanced permeable volumes of hot rock in a closed loop. The water heats up, is brought up to the surface through other wells, and then is sent to binary plants to produce electricity.

Recent improvements in technology, especially for binary plants, have resulted in electricity production from fluids with temperatures as low as 73°C. This theoretically allows electricity production using enhanced geothermal systems almost anywhere in the world. But environmental concerns, including those relating to induced seismicity, land subsidence and water use, need to be resolved if such enhanced geothermal systems are to spread more widely.

Further technology advances are expected in terms of better methods for more accurate estimates of resource potential prior to drilling, better drilling methods and equipment, more reliable high temperature and pressure downhole pumps and logging tools, better methods for creating deep hot reservoirs, and better control or mitigation of induced seismicity.

Ocean

Ocean energy technologies are in the early stages of development compared with other renewable technologies. There are only a few tidal barrage installations operating in the world on a commercial basis. Ocean energy technologies can be divided into the following categories: tidal rise and fall, waves, tidal currents, ocean currents, thermal gradients and salinity gradients.

The technology required to convert the energy in the rise and fall of tides into electricity is similar to that used in hydropower plants. Electricity is generated in turbines by water flowing in and out of a dam or a barrage built across a tidal bay or estuary, ideally where there is a height difference of at least five metres between high and low tides. Tidal barrages can face considerable environmental challenges because they are potentially intrusive to the area surrounding the catch basins.

The kinetic energy associated with tidal and other marine currents can be harnessed using devices which generate energy from the flow of water. Technologies for extracting energy from marine currents include horizontal and vertical axis turbines or oscillating foils. These technologies are at, or near, full-scale development and undergoing sea trials.

There is a wide variety of methods for extracting energy associated with ocean waves, including oscillating water column systems, absorber systems (point, multi-point and linear) or overtopping devices. These devices and systems use different techniques for "capturing" the wave energy and employ a variety of different methods for converting it to electricity.

The temperature difference between surface seawater (at 20°C to 25°C) and deep water (at 4°C to 5°C) can be harnessed using ocean thermal energy conversion (OTEC) processes. Prototype technologies and test facilities were constructed in the 1970s but R&D was later abandoned. There has been a resurgence of interest recently in OTEC, with new R&D being undertaken in several countries.

Where fresh water mixes with salt water, the energy associated with the resultant salinity gradient can be harnessed, using a pressure retarded reverse osmosis process and associated conversion technologies. The world's first prototype plant was commissioned in October 2009.

Ocean energy technologies still need to overcome some technical barriers. An issue specific to these technologies is that pilot projects need to be relatively large scale in order to withstand offshore conditions. Such projects are costly and at the same time carry high risks. They therefore need government support. After successful pilot projects, the confidence of investors grows and commercial financing becomes easier.

Non-financial barriers include the need for resource assessment, setting performance assessment guidelines and standards, and developing energy production forecasting. Environmental effects are expected to be low but are still uncertain. Electrical connection may present similar challenges as for offshore wind.

Box 3.3 ▶ Recent developments in renewable electricity generation

Despite the economic crisis, significant amounts of new renewable energy were deployed in 2008 and 2009, especially wind and solar technologies. Investment in renewable power reached an all time high in 2008, and remained at a similar level in 2009. Investment levels were mainly boosted by rapid increases in capacity in Asia, and particularly in China. Stimulus packages played only a minor role in maintaining levels of investment. It is estimated that only about 9% of the total funds available were spent in the year 2009.

Renewable power installations represented 61% of all new power generation capacity in the European Union in 2009, the second successive year that renewable investment exceeded 50% of the total. More wind capacity was installed in 2009 than any other electricity generating technology, comprising 39% of all new EU installations. Although smaller in absolute terms, solar PV technology also expanded very rapidly in Europe during 2008 and 2009. Germany, Spain and Italy are the main PV markets. Europe is also showing renewed interest in CSP, mostly in Spain. Several projects started operation in 2008 and 2009 and many others are under construction.

In 2009 in the United States, almost 10 GW of wind capacity was installed. The solar market also seems to be taking off in the United States with several CSP projects under construction and important developments in the PV market during 2009. The United States is likely to become the leading PV market outside Europe in 2010, outperforming Japan. High gas prices in 2007 and 2008 and the American Recovery and Reinvestment Act (ARRA) helped to drive these developments. The expenditure of ARRA funds will be spread out over several years and therefore their impact should continue for this period. But renewables in the United States are likely to face competition from cheap unconventional gas.

Renewable power is growing not only in OECD countries. Emerging economies are becoming increasingly important players. China was the world's largest wind market in 2009. Solar programmes in China and India have stimulated a significant pipeline of PV projects. The development of non-OECD markets is mostly target-driven but some emerging economies, such as South Africa, are starting to introduce incentive schemes to support the development of renewable energy.

Costs

The costs of renewables vary between technologies. They are often highly site-specific. Costs are influenced by natural resource (e.g. wind speeds, global or direct normal insolation, the availability of biomass), the size of the plant, distance to the grid, commodity prices (e.g. steel, silicon) and many other factors. With RD&D, technological learning, mass production and economies of scale at both manufacturer and plant levels, the cost of renewables is expected to fall in the future.

Investment and O&M costs in the BLUE Map scenario are summarised in Table 3.4. Bioenergy electricity generation technologies vary in size as well as in technologies and the feedstocks used. Costs are dependent on all these factors. Bioenergy is the only renewable power source that is subject to fuel costs. Geothermal costs depend heavily on the costs of exploration and well-drilling but also on the local resource system and reservoir. Exploration and drilling costs can account for as much as

50% of the total cost of a geothermal project. Solar PV costs consist of the costs of modules, which are roughly 60% of the total cost with mounting structures, and inverters and cabling, which account for the rest. Costs are dependent on the price of commodities such as silicon.

Table 3.4 ▶ ***Cost assumptions for renewable electricity generation***

	Investment cost USD/kW		O&M cost USD/kW/yr	
	2010	**2050**	**2010**	**2050**
Biomass steam turbine	2 500	1 950	111	90
Geothermal	2 400-5 500	2 150-3 600	220	136
Large hydro	2 000	2 000	40	40
Small hydro	3 000	3 000	60	60
Solar PV	3 500-5 600	1 000-1 600	50	13
Solar CSP	4 500-7 000	1 950-3 000	30	15
Ocean	3 000-5 000	2 000-2 450	120	66
Wind onshore	1 450-2 200	1 200-1 600	51	39
Wind offshore	3 000-3 700	2 100-2 600	96	68

Note: The upper bound of the investment cost range represents the costs for enhanced geothermal systems. Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to United States levels by 2050.

Solar CSP investment costs differ considerably between plants with and without storage. But in terms of the cost of the energy they produce, they are broadly comparable because the presence of storage increases the capacity factor of plants. For ocean systems, the numbers in the table reflect the costs of existing tidal barrage systems. The costs of all other technologies are still very high.

For onshore wind, the turbine cost typically represents about 75% of the total cost, with infrastructure, grid connection and foundations accounting for the rest. Costs are linked to the price of commodities such as steel and copper. The costs of offshore turbines take account of additional factors such as the water depth and distance to the coast. In terms of the cost of the energy produced, the additional costs of offshore wind turbines are partly balanced by increased electricity production due to higher wind speeds for longer periods.

Nuclear power

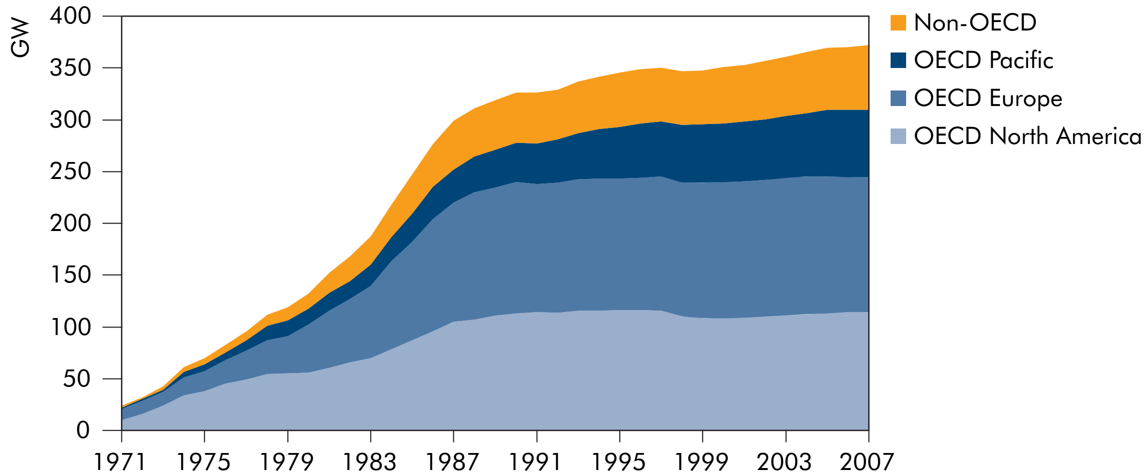
Overview

Nuclear power has the capacity to provide large-scale electricity production with very low net CO_2 emissions over the plant lifecycle. The technology is already proven, although new designs hold out the prospect of better levels of performance and reliability, as well as enhanced safety systems. Nuclear power is already in use in 30 countries and provides around 14% of global electricity supply. The share of nuclear energy in countries with operating reactors ranges from less than 2% to more than 75%. Nuclear power has the potential to play a very significant role in the decarbonisation of electricity generation in many countries.

Nuclear capacity grew rapidly in the 1970s and 1980s as countries sought to reduce dependence on fossil fuels (Figure 3.15). In most countries, growth stagnated in the 1990s. Reasons for this included increased concerns about safety, higher than expected costs and poor performance in some cases, and low fossil fuel prices.

In the Baseline scenario, installed nuclear capacity increases to 610 GW in 2050, compared to 374 GW at the beginning of 2010. In the BLUE Map scenario, nuclear capacity rises further to 1 200 GW, a level that is constrained by the assumptions in the scenario, in 2050. This nuclear capacity provides around 9 600 TWh annually by that date, or around 24% of the electricity generated worldwide and constitutes the single largest source of electricity. In the BLUE hi NUC scenario, the installed nuclear capacity reaches significantly higher levels of 2 000 GW in 2050.

Figure 3.15 ► ***World nuclear generating capacity***



Key point

Nuclear generating capacity grew rapidly in the three decades from its first commercial deployment in the 1960s, but the rate of growth has since slowed.

Although the installation of 1 200 GW of nuclear capacity by 2050 would be an ambitious goal, it appears achievable from a technical and industrial perspective. Assuming that by 2050 all reactors in operation today will have been decommissioned, some 30 units of 1 GW each would need to be connected to the grid on average each year between 2010 and 2050. Similar or higher rates of construction were achieved in the 1980s, even though a smaller number of countries were implementing nuclear programmes and industrial capabilities were less developed at that time.

In practice, the required construction rate to achieve the BLUE Map scenario is likely to be lower. Many existing units are licensed for up to 60 years of operation and plant-life extensions are being approved in many countries. So some existing plants are likely to remain in operation in 2050. In addition, many current reactor designs have a capacity larger than 1 GW, typically in the range 1.2 GW to 1.7 GW, and these are likely to be chosen in countries where electricity demand is high enough and grids are adapted to large units. Taking these factors into account, an average of about 23 nuclear units per year would need to be constructed over a 40-year period to achieve the levels of nuclear capacity in the BLUE Map scenario, with the rate of construction gradually increasing over the period.

As a result of higher nuclear power production in the BLUE Map scenario, uranium consumption will amount to about 5.6 million tonnes between 2010 and 2050, 70% higher than in the Baseline scenario.[7] This is roughly equivalent to current known conventional uranium resources of about 5.5 million tonnes, although so-called unconventional resources in phosphate rocks could amount to a further 22 million tonnes (NEA, 2008). Increased uranium demand can be expected to result in greater exploration efforts and the discovery of additional conventional resources to replace exploited resources. In the longer term, the commercial deployment of advanced nuclear reactor and fuel cycle systems could permit much greater amounts of energy to be obtained from each tonne of uranium. It seems probable that the increase in nuclear capacity in the BLUE Map scenario by 2050 could be achieved without the large-scale deployment of advanced nuclear systems, although achieving the capacity growth seen in the BLUE hi NUC scenario would most likely require the earlier introduction of such systems.

Technology status and prospects

The low level of orders for nuclear power plants since the 1980s has resulted in the contraction of the nuclear industry in most parts of the world, and in a series of industry consolidations over the last 15 years. The latest designs available from each of the main suppliers offer a comparable level of technology, sometimes known collectively as Generation III or III+. In developing Generation III reactors, the aim has been to design out many of the issues that were encountered in the construction and operation of the existing Generation II plants, and to offer better levels of performance and reliability as well as enhanced safety systems. Design simplification is an important theme, with the aim of reducing construction times. The intention is to offer, as far as possible, a standardised design worldwide to reduce the risk of construction delays caused by design changes. The plants are designed from the outset to operate for up to 60 years at high capacity factors.

Existing designs being built today are highly developed, and evolutionary improvements can be expected to continue over the coming decades. Significant RD&D efforts in the field of advanced nuclear systems are also continuing in several countries, to prepare the next generation of nuclear systems which will compete with alternatives mainly in the second half of the century.

7. This calculation assumes no recycling.

The main challenges facing accelerated deployment of nuclear energy are policy issues that need to be addressed in a timely manner in order to enable the growth of nuclear energy's contribution to the world energy supply mix. Political support and public acceptance are key to the implementation of nuclear energy programmes. A clear and stable definition of the role of nuclear energy in national energy policy is a prerequisite for investors to embark on nuclear projects and for the nuclear industry to maintain and develop capabilities and competitiveness.

Industrial capabilities and human resources need to be adapted to higher demand for the construction and operation of an increasingly large fleet of nuclear power plants. Fuel cycle capacities, including for uranium production, also need to be increased. Such increased capacities will take some years to implement.

The management and disposal of radioactive wastes is an essential component of all nuclear programmes. Progress needs to be made towards building and operating facilities for the disposal of high-level wastes. Although technological solutions are available, it is often difficult to gain political and public acceptance for these.

The international system of safeguards on nuclear technology and materials, designed to avoid its misuse for non-peaceful purposes, must be maintained and strengthened. Ensuring that countries relying on nuclear power have access to reliable supplies of nuclear fuel while avoiding the spread of sensitive technologies will be a challenge for the international community.

Box 3.4 ▶ Recent developments in nuclear power

At the end of 2009, 56 new power reactors were under construction in 14 countries. Of these, China had the largest programme, with 20 units under construction. Russia also had several large units under construction. Among OECD countries, Korea had the largest expansion under way, while Finland, France, Japan and the Slovak Republic were each building one or two new units. In the United States, a long-stalled nuclear project has been reactivated. In total, these new units can be expected to add around 50 GW of new capacity to the existing capacity of 374 GW. A few gigawatts of older capacity are expected to close over the next few years. The process of planning, licensing and building new nuclear power plants takes typically at least seven to ten years. So most of the nuclear capacity that is likely to be in operation by 2020 will already be in operation or in the planning and licensing processes.

Some countries with active nuclear construction are expected to continue their nuclear expansion with further construction starts in the next few years. In particular, major expansion of nuclear capacity is planned in China, India and Russia. Several other countries with existing nuclear plants but where no new construction has been launched in recent years are also actively considering new nuclear capacity, with final decisions expected to be taken in the next few years. These include Canada, the Czech Republic, the United Kingdom and the United States.

Future nuclear technologies

Nearly all nuclear units in operation or under construction are based on light or heavy water-cooled reactors. These proven technologies and designs will remain dominant up to 2050, although a few advanced systems such as sodium fast reactors and high-temperature gas reactors are likely to be built and operated before 2050. In the second half of the century, advanced nuclear systems are expected to be available on the market as the result of RD&D already being pursued in many countries and within international endeavours. Advanced nuclear energy systems, including so-called Generation IV systems, aim at an improved response to evolving technical, economic, environmental and social requirements.

Box 3.5 ▶ Nuclear fusion

Fusion is a nuclear process that releases energy by combining light elements – it is essentially the direct opposite of fission. In principle, fusion holds the promise of a long-term, sustainable, economic and safe energy source for electricity generation, with relatively inexpensive fuel. The amount of radioactive waste produced from fusion devices is hundreds of times less than that of a fission reactor, the fusion process produces no long-lived radioactive waste and it is impossible for any fusion reactor to undergo a large-scale runaway chain reaction.

Over the past two decades, the operation of a series of experimental devices has enabled considerable advances in this technology. However, the plasma created in current prototype devices is not significant enough to achieve sustained power. The International Thermonuclear Experimental Reactor (ITER) is a new, significantly larger, prototype fusion device designed to demonstrate the scientific and technological feasibility of fusion energy on a large scale. Seven partners are involved in the ITER project: the European Union, China, India, Japan, Korea, Russia and the United States. ITER is planned to be the bridge towards a first demonstration plant of large-scale production of electrical power.

If work with ITER goes as planned, then a first demonstration plant will start operations in the early 2030s, with fusion power into the grid expected in the 2040s. As fusion is not likely to be deployed for commercial electricity production until at least the second half of this century, it is not considered in the ETP 2010 scenarios.

Costs

Three main factors contribute to the direct costs of nuclear power: construction costs, O&M and fuel costs, and back-end waste management and decommissioning costs. Four variables primarily control construction costs: the length and complexity of the pre-construction period, capital costs (excluding interest), construction time, and the cost of capital (interest rates).

The pre-construction period is the time taken to secure permits and planning approvals. Historically, this process has been lengthy in many countries. Governments can reduce the length and, therefore, the cost of the pre-construction period through improvements in planning and licensing regimes.

Reliable capital cost data are difficult to obtain. Most nuclear power cost studies base capital cost estimates on recent new-build experience or on vendor estimates. However, there is no internationally agreed definition of capital cost, and opinions vary on the subject. Vendors have a commercial interest in minimising the apparent cost of new plants, and turnkey prices are inevitably commercially sensitive. The assumptions on capital costs used in the scenarios are derived from data in IEA/NEA 2010 (Table 3.5). Long construction times increase interest costs. Since the 1980s, average worldwide construction times have steadily increased. Recent experience from Asia, however, where average construction times of 62 months are being achieved, has shown a marked reduction in time from construction start to commercial operation. The cost of capital, which depends on aspects of the financing scheme such as the ratio between debt and equity, the interest rate of the debt, and the internal rate of return required by shareholders, has a major impact on construction costs.

3

Table 3.5 ► ***Cost assumptions for nuclear electricity generation technologies***

	Investment cost USD/kW		O&M cost USD/kW/yr		Net efficiency %	
	2010	2050	2010	2050	2010	2050
Gen III+	3 000 – 3 700	2 700 – 3 300	90 – 111	81 – 99	36	37

Note: Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to United States levels by 2050.

Operation and maintenance costs are incurred in the safe running and upkeep of a power station during its lifetime. They generally include the costs of safety inspections and safeguards as well as labour, insurance, and security costs, corporate overheads, and the costs of maintaining a level of spare generation capacity. Extensive data are available on these costs. These show a wide degree of variability that reflects, for example, differences in labour costs, plant sizes and age distributions in different countries, as well as differences resulting from government versus private security. Nuclear O&M costs are particularly influenced by changing regulatory requirements.

Waste management and decommissioning liabilities are regarded by some stakeholders as major impediments to nuclear power generation. For the first-generation reactors, many of which were effectively prototypes with little if any provision for back-end costs, these costs are potentially significant and subject to considerable uncertainty. The back-end costs for future nuclear plants should be predictable, provided that radioactive waste disposal facilities are available and that regulatory requirements are stable. In the scenario analysis, fuel cycle costs including fuel production, disposal and storage are assumed to be around USD 9/MWh (IEA/NEA, 2010). Decommissioning and the majority of associated waste management costs are not incurred until the end of the reactor's life, allowing the operator to accumulate funds from revenues. As a result, electricity generating costs are not particularly sensitive to back-end costs.

Chapter 4 ELECTRICITY NETWORKS

Key findings

- *Demand for electricity will continue to rise between now and 2050 in both the Baseline and BLUE Map scenarios. Together with changing demand and generation profiles, this will require changes in the design, operation and deployment of electricity networks.*

- *Regional characteristics such as increases in electricity demand, regulatory structures and the maturity of the existing electricity infrastructure will need to be considered in deciding how best to develop electricity networks to meet future needs.*

- *Smart grids have the potential to address many future electricity network challenges. This would include the ability to increase system flexibility to enable the balancing of variable generation and demand, the better management of peak loads and assisting in the delivery of energy efficiency programmes. But technical work is still required, especially to demonstrate such grids at system scale.*

- *Combined with smart grids, a range of electricity and thermal storage technologies can contribute to increasing the system flexibility that will be needed as a result of the expected increase in variable generation and demand.*

- *For developing countries, the deployment of smart grids could bring significant benefits over traditional technologies in the strengthening or expansion of their electricity grids, while addressing specific needs. The potential of smart grids to reduce transmission and distribution losses is especially relevant for these countries, where they can be very high.*

- *Smart grids can contribute directly and indirectly to CO_2 emissions reductions from electricity generation and use. Under the BLUE Map scenario, the global deployment of smart grids is estimated to reduce CO_2 emissions by between 0.9 gigatonnes of carbon dioxide (Gt CO_2) and 2.2 Gt CO_2 annually by 2050. More work is needed to develop quantified methodologies in this area.*

- *The cost of smart grids has not been examined in detail on a global level. A better understanding of costs will be needed to evaluate technologies, policy and regulatory approaches and the most appropriate market models to support deployment.*

- *A number of regulatory, policy and market barriers stand in the way of the most effective deployment of smart grids. Significant effort is required to develop well-informed and technically appropriate recommendations for change. Solutions must be developed with input from all electricity system stakeholders to ensure that creative and practical approaches and technologies are deployed.*

- *Skill constraints in the power industry are predicted to be severe in the near future. This could become a significant barrier to the deployment of needed power system investments. A detailed assessment of the skills required, considering regional situations to best fit human resource availability, must be carried out along with recommendations on how to fulfil these needs.*

4

Introduction

The availability of reliable supplies of electricity has become increasingly essential for daily living for most people in both developed and developing countries. It lights homes and work places, powers computers and enables industrial activity. Most electrical power, regardless of how it is produced or used, is transferred from generation plant to consumers through electricity networks, known as electricity grids or the grid.

To meet the demand for reliable supply, the grid must operate 24 hours a day, 365 days a year, meeting and balancing ever-changing levels of demand and supply. And it must do so in a cost-effective way, often using an ageing infrastructure. The complexity of this operation will be further complicated by steps to increase the use of electricity for both public and private transportation, the bringing on stream of greater amounts of renewable energy and other distributed generation, and increasing demand for electricity in general.

In the developing world and emerging economies, electricity demand is increasing at significant rates in response to economic and social development. Development and growth vary between regions and there continues to be a need to address energy poverty in many areas. Existing electricity systems are insufficiently flexible or robust for today's needs in many parts of the world, let alone those of the future. Change and investment will be required to enable further development and growth.

The changes projected in electricity generation and demand, both in the Baseline scenario and still more to achieve the ambitions of the BLUE Map scenario in 2050, will require an enormous investment in the electricity grid. Investment choices will have long-term implications. Investment in so-called smart grid technologies will be fundamental to enabling these changes, and will in parallel offer many other additional benefits.

History of the grid

The electricity grid has traditionally been developed, designed and implemented in such a way that electricity flows one-way from large generators to widely distributed loads. This highly structured and centralised approach has drawbacks at three distinct levels in the system:

- **Distribution system operators** have little or no detailed information on the demand from different sectors or nodes on the grid. So, for example, when a residential power outage occurs, the supply utility typically only becomes aware of it when consumers phone to ask what is happening.
- **Transmission system operators** have more intelligence about changes in demand and supply on the network. But this is still insufficient at times to allow utilities to anticipate or receive prior warning of developing problems. This limits the extent to which generators can proactively dispatch grid support or isolate minor problems so as to prevent the sort of large-scale outages that have been seen in the United States, Canada and Italy in recent years.

- Many **end users** are billed according to the amount of electricity they have used over an extended time period. They, therefore, have no access to detailed information on how or when they are using electricity. So they have no means of readily identifying ways of reducing or shifting their electricity use to minimise their demand and costs.

In OECD member countries, as already old grid infrastructure ages, significant investment is required to update and maintain it in order to ensure reliability. Power generation is increasingly becoming dispersed, *e.g.* in the form of combined heat and power (CHP) systems, in response to efforts to improve fuel usage or to take advantage of changing market structures. There has also been an increase in the amount of variable generation[1] being brought on line.

These changes are all challenging weaknesses in the traditional electricity grid. They need to be met by the implementation of new technology and methodologies for the design, maintenance and operation of electricity distribution systems. These need to be better adapted to modern circumstances, such as the emerging growth in consumers wanting to generate their own electricity with the option to sell any excess generation back to the grid.

Developing countries may have the opportunity to make early technological leaps to the implementation of smart grids, without going through the extensive development of traditional grids. This will enable them to benefit from these new technologies early in the implementation of a more widespread electricity infrastructure.

Electricity demand

Electricity demand by region

Worldwide electricity demand is expected to more than double between 2007 and 2050. In the Baseline scenario, demand increases by 151% and in the BLUE Map scenario it increases by 117%. This increase is not spread equally across regions. Those regions that currently have small electrical demands will see the largest growth between 2007 and 2050 (Table 4.1).

The need for grid maintenance and expansion will be different for those regions with high growth than for those with low growth. The three areas with projected low growth (OECD North America, OECD Europe and OECD Pacific) are areas that have a large legacy infrastructure that is ageing, the replacement of which is constrained by regulatory regimes which set limits on capital expenditure. In areas with greater growth, primarily non-OECD member countries, ageing infrastructure and reliability are also of concern. But these regions will also be committing to new construction, providing an opportunity to deploy modern electricity grid technology and to learn from the experience of other regions. The best way forward in some cases may be to render existing unreliable or inflexible infrastructure redundant.

1. Examples of variable electricity generation include wind, solar photovoltaics, tidal and combined heat and power in which generation is dependent on variable external resources such as insolation, local wind speed, tidal flows or heat demand in the case of CHP.

Table 4.1 ▶ ***Regional electricity demand and future growth***

	2007 electricity demand [TWh]	2050 BLUE Map electricity demand [TWh]	BLUE Map percent growth 2007 to 2050
OECD North America	4 664	6 252	34%
OECD Europe	3 136	4 071	30%
OECD Pacific	1 681	2 311	37%
Economies in transition	1 149	2 348	104%
China	2 856	9 500	233%
India	567	3 453	509%
Other Asia	853	2 822	231%
Africa	521	1 691	225%
Latin America	808	2 062	155%
Middle East	594	2 437	310%
World	16 999	36 948	117%

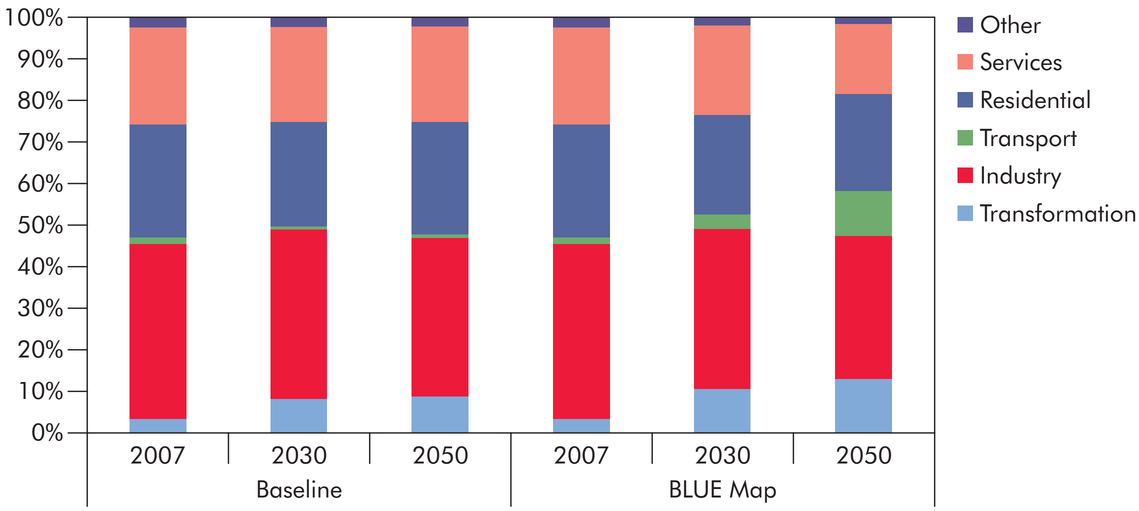
Note: Electricity demand equals generation minus losses.

China is currently making large investments in electrical infrastructure and technology in response to its past, current and anticipated growth. China's electricity demand is nearly the same as OECD Europe and its growth rate is much higher. This is expected to result in the highest regional electricity demand by 2050, at 26% of world electricity demand.

Electricity demand by sector

In addition to the increase in absolute electricity demand, electricity is also expected to continue to increase as a percentage of final end-use energy. Electricity represented 17% of total final energy use in 2007. By 2050, this increases in the Baseline scenario to 23% and in the BLUE Map scenario to 28%. In the BLUE Map scenario, electricity demand increases at a slower rate than in the Baseline scenario, and with a different distribution by sector (Figure 4.1).

Figure 4.1 ▶ ***Global electricity demand by sector***



Key point

The share of electricity demand from individual sectors changes in the BLUE Map scenario over time.

In the Baseline scenario, there is a broadly commensurate increase in electricity demand across all sectors. In the BLUE Map scenario, overall electricity consumption reduces by over 12% by 2015 compared to the Baseline scenario. This becomes a 17% reduction by 2030, coupled with changes in the sector shares of overall demand. By 2050, electricity use in the transport sector is 11% of overall electricity demand. This increased use of electricity in the transport sector offsets some of the otherwise much greater reduction of electricity use as compared with the Baseline scenario. The residential and service sectors, despite significant efficiency improvements, will also use more electricity *e.g.* for space heating with heat pump technology.

It is expected that the demand for electricity from transport will continue to increase beyond 2050. This demonstrates the importance of designing grid solutions in the short term which are capable of responding to the longer-term features of this load and its impact on the grid. The approaches used for grid to vehicle (G2V) charging will have significant impacts on the electrical system.[2] Generating electricity from electric vehicles (EVs) when they are parked could also be used to support the grid in a way that would not significantly impact on driver needs. This is sometimes referred to as vehicle to grid (V2G) generation.

Demand profiles

The amount of instantaneous electrical power required on any system fluctuates throughout the day. It also varies over the course of the year between a minimum base load and peak load. This aspect is demonstrated by load duration curves that show the number of hours that a given average hourly load occurs in an electricity system over the course of a year (Figure 4.2).

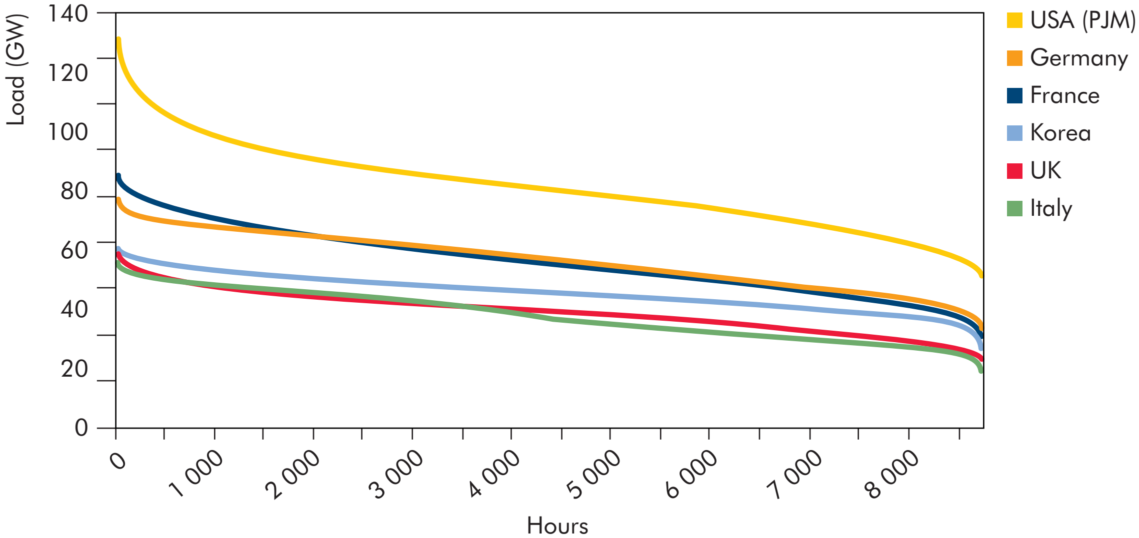
These data show that the minimum demand on the system in selected countries and regions is less than half of the peak demand. The generation, transmission and distribution infrastructure must be designed in a way that it can work reliably within this entire range. In France, for example, the peak 10% of generating capacity is only required 3% of the time. And about 20% of the total demand over a year is supplied by plants that operate just over 15% of the time. Securing private funding for investment in generation capacity to meet peak demand can be difficult if market structures do not provide revenue security for such high value, low call-off generation.

Baseload considerations are also becoming more important for system management, especially in the light of increases in the regional trading of electricity. For many years, base load was supplied by large fossil or nuclear plants from which output remained virtually constant throughout the year. Recently, fluctuations in electricity supply and demand have required large-scale base load plants to curtail and then increase their generation output. As a result, there is new interest in developing technologies that can enable these plants to provide responsive and flexible generation.[3]

2. Jan Peters from Enexis estimates that in Holland the use of smart approaches in the electrification of transportation will reduce enabling grid infrastructure costs by 60% compared to using non-intelligent approaches. www.mobilesmartgrid.eu/index.php?id=16.

3. Schmitt (2009).

Figure 4.2 ▶ **Load duration curves for several countries in 2008**



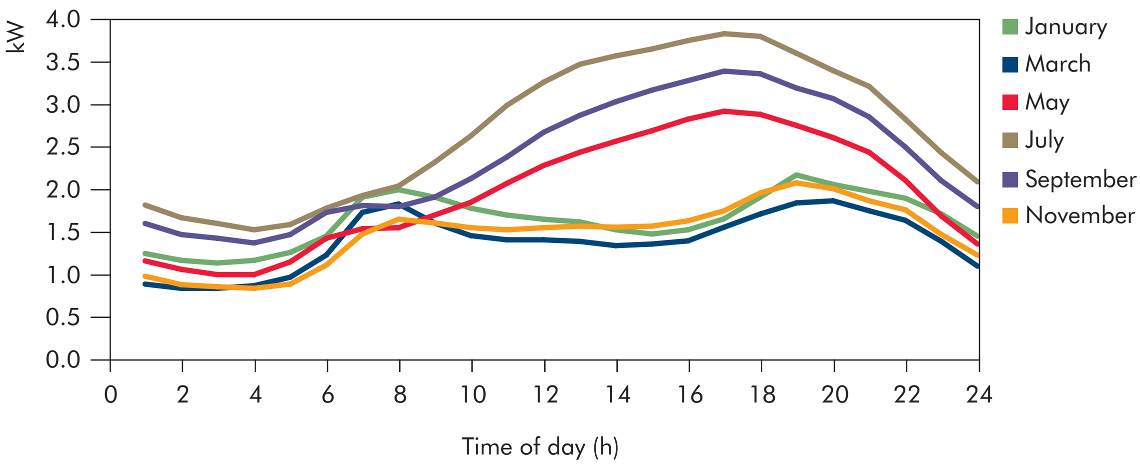
Note: PJM is a Regional Transmission Organisation which is part of the Eastern Interconnection Grid in the United States.
Source: Data from ENTSO-E, PJM, Korea.

Key point

Annual electricity demand on the overall systems varies significantly across the year.

The understanding of sector-specific demand profiles can enable solutions to be developed to reduce overall system peak demand. Residential and service sector demand varies over the course of the day and between seasons (Figure 4.3).

Figure 4.3 ▶ **Daily average residential electricity demand in a sample of homes in Florida, United States with a high penetration of central air-conditioning load**



Source: Parker (2002).

Key point

Residential electricity demand varies over the course of the day and on a seasonal basis.

The curves in Figure 4.3 represent a region with large amounts of residential central air-conditioning. It would not be representative of many areas in Europe that have much lower levels of central air-conditioning. This illustrates the importance of identifying sector-specific load profiles in a given region as a basis for determining appropriate ways to improve demand profiles.

The degree to which sector-specific peak demand affects overall electrical systems is dependent on its share of the overall electricity power demand. Industrial sectors, for example, often make up a large percentage of the electricity demand and contractual arrangements are often put in place to curtail their demand in circumstances where the grid needs to reduce peak demand. As sector demand patterns change in future, with increased residential loads and/or the wider electrification of transportation, peaks may become more difficult to manage.

Electricity generation

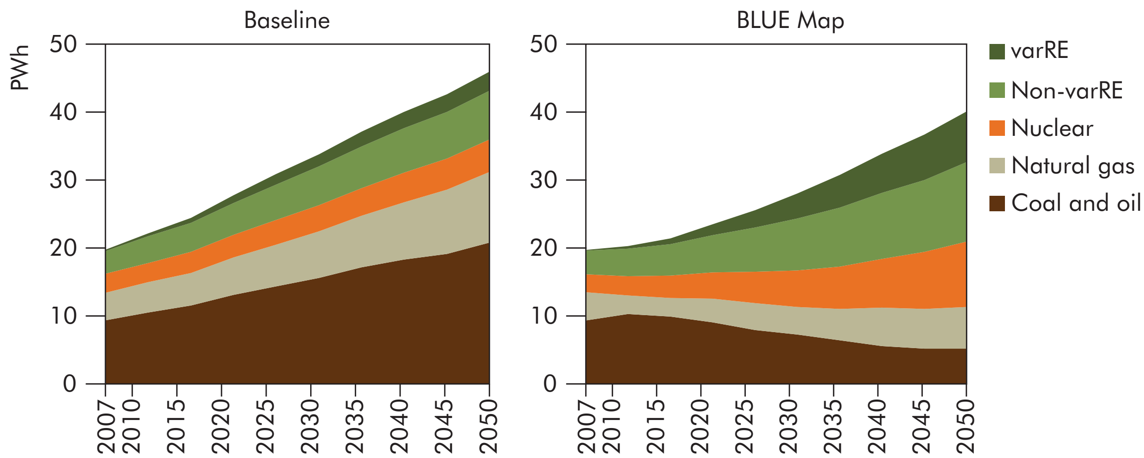
There will be significant changes in the way electricity is generated in the future. In addition to large centralised power plants, distributed generation in the form of both renewable and non-renewable generation is increasing, including plants connected directly to the distribution system and micro-generation at the household level.

Electricity generation aspects of the Baseline and BLUE Map scenarios have been discussed in previous chapters. In examining issues related to the grid, the most significant factor is the extent to which power generation is variable. CHP and variable renewable energy (varRE) technologies such as wind, solar PV, run of river hydro and tidal,[4] present particular challenges to the transmission system (Figure 4.4). Unlike non-variable power generation, where the generation can be contracted and dispatched with high degrees of certainty over long time frames and where the fluctuations can be managed in a controlled manner, varRE generation is difficult for system operators to predict both in terms of the uncertainty of its availability and the short time frame in which the speed and magnitude of any fluctuations can be predicted (Boyle, 2009).

In many electricity systems, merit orders require that all available renewable power is used at all times in order to minimise generation emissions or variable costs. This means the grid operator needs to manage the available non-variable generation to respond to changes in supply from the varRE generation and to meet a constantly changing level of demand, so as to maintain grid stability and reliability of supply.

4. Bioenergy, hydropower with water storage, geothermal and concentrating solar power generation with thermal storage would be considered as non-variable forms of renewable energy.

Figure 4.4 ▶ Global electricity generation mix

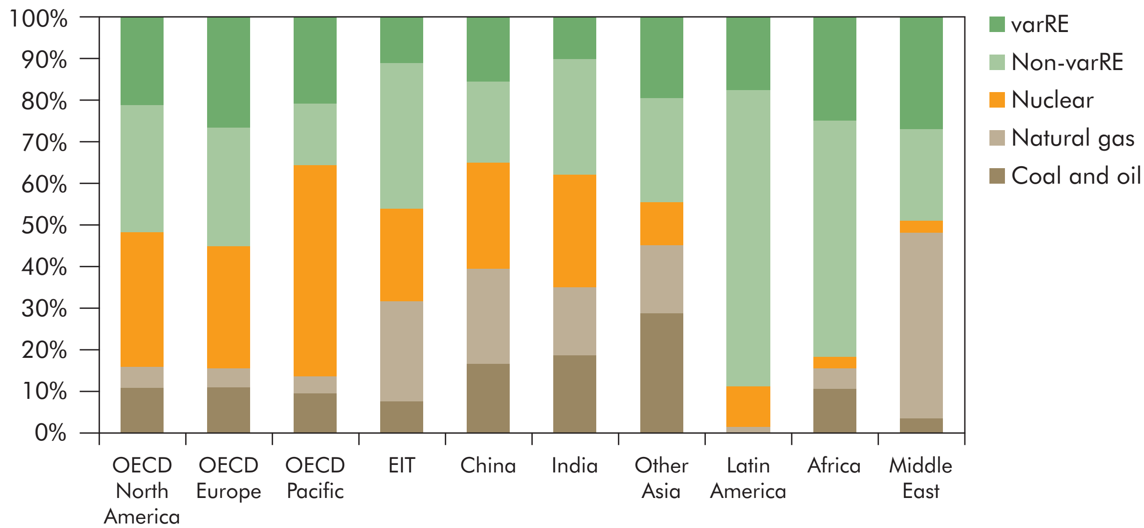


Key point

The BLUE Map scenario projects much more varRE generation than the Baseline scenario in both absolute and relative terms.

In the Baseline scenario, varRE generation in 2050 makes up 6% of all generation worldwide. Variability up to this level[5] can be readily managed using conventional technology currently employed in electricity systems. In the BLUE Map scenario, the progressive decarbonisation of electricity generation leads to varRE generation making up 19% of all generation. This proportion ranges from 10% to 27% by region by 2050 (Figure 4.5).

Figure 4.5 ▶ Regional generation mix in 2050, BLUE Map scenario



Key point

By 2050, all regions will have increased amounts of both variable and non-variable renewable generation compared to both 2007 levels and the Baseline scenario levels.

5. Some regional systems are already more variable than this.

Areas with higher amounts of varRE will need grid systems designed to handle their variability. Regions that may intend to move to higher levels of varRE will need to plan for that as they upgrade and develop their grid systems. In some countries and regions, other forms of variable generation such as CHP will also need to be taken into account. In CHP plants, operation is typically dictated by the demand for heat from the system rather than by the demand for power. In the absence of some form of thermal storage to enable constant generation, CHP generation is variable rather than non-variable.

Power system flexibility

A flexible power system can both rapidly supplement periods of low variable generation to meet demand as required, and manage large surpluses when demand is low. A flexible system is one which is able to transport, store, trade and consume electricity to maintain reliable supply in the face of rapid changes and potentially very large imbalances in supply and demand.

Power systems worldwide vary enormously in terms of scale, interconnection, generation, storage, transmission and distribution, demand behaviour, and market rules. The most appropriate way to handle large-scale varRE shares will depend on the specific characteristics of the overall system into which the varRE is being supplied. Power systems can be adapted in a number of ways to provide more flexibility to balance variable generation including:

- **Increasing the size of balancing areas** – to enable a geographically larger area to rely on a smaller proportion of reserve generation capacity to maintain system reliability, to enable imbalances to be resolved where they cost least, and to take advantage of the smoother average generation that is likely to result from a large geographic spread of varRE.
- **Demand shaping through demand-side management** – using prices to move some demand from peak to off-peak periods.
- **Improving output forecasting and intra-hour RE dispatch** – to allow more efficient scheduling of flexible reserves.
- **Increasing control of transmission and distribution assets** – to increase transmission capacity and reduce congestion during key periods and over critical line lengths.

Once all the options for optimising the use of existing flexibility resources of a system have been exhausted, still larger amounts of varRE generation will need to be balanced by increased capacity of these resources. Such measures may include additional flexible power plant capacity; additional storage capacity, *e.g.* through pumped hydro or new storage sources such as EVs; the reinforcement and expansion of transmission and distribution networks; and interconnection between adjacent grid areas.

Electricity network losses

In the electricity system, more electricity is produced than is actually consumed by end users. The balance is lost primarily through direct use in generation plants, through transmission and distribution (T&D) losses and through electricity storage inefficiency (Table 4.2).

Table 4.2 ▶ ***Regional electricity system use and loss of electricity, 2007***

	Direct use in plant	T&D losses	Pumped storage	Total
OECD North America	4%	7%	1%	12%
OECD Europe	5%	7%	1%	13%
OECD Pacific	4%	5%	1%	10%
Economies in transition	7%	12%	0%	20%
China	8%	7%	0%	15%
India	7%	26%	0%	33%
Other Asia	4%	9%	0%	13%
Latin America	3%	17%	0%	20%
Africa	5%	11%	1%	17%
Middle East	5%	13%	0%	18%
World	5%	9%	1%	15%

Note: At pumped storage plants, electricity is used during periods of low demand to pump water into reservoirs to be used for electricity generation during times of peak electricity demand.

Electricity used in generation plants ranges from 3.0% to 8.3%. It can be reduced by system improvements and modernisation at the plant level. Carbon capture and storage (CCS) technology will increase direct use in plant. T&D losses are larger, accounting for more than 9% of all generation worldwide, and vary much more between regions. OECD countries and China have the lowest percentage T&D losses, ranging from 5.0% to 7.2%. Even so, these losses represent a large amount of electricity, equivalent to more than the T&D losses from all other regions combined. In non-OECD countries T&D losses are higher as a percentage of total generation. A large portion of these losses are often attributed to non-technical losses,[6] *i.e.* theft. For example, in India some regions experience losses as high as 35% due to theft (IEA, 2007).

Many of these losses can be reduced by the modernisation of the electricity grid. Better system level and end-use metering in particular will enable the losses to be identified and resolved.

Vision for the grid of the future

Growth and change in the electricity system over the next 50 years will require major investment both of financial resources and in the development of expertise and know-how. The electricity grid of the future will need to demonstrate the same primary functional characteristics as today. But it will need to accomplish this with added flexibility in order to enable an environment with a different mix of both centralised and distributed, non-variable and variable generation and new demand profiles. In order for the grid to operate optimally in this environment,

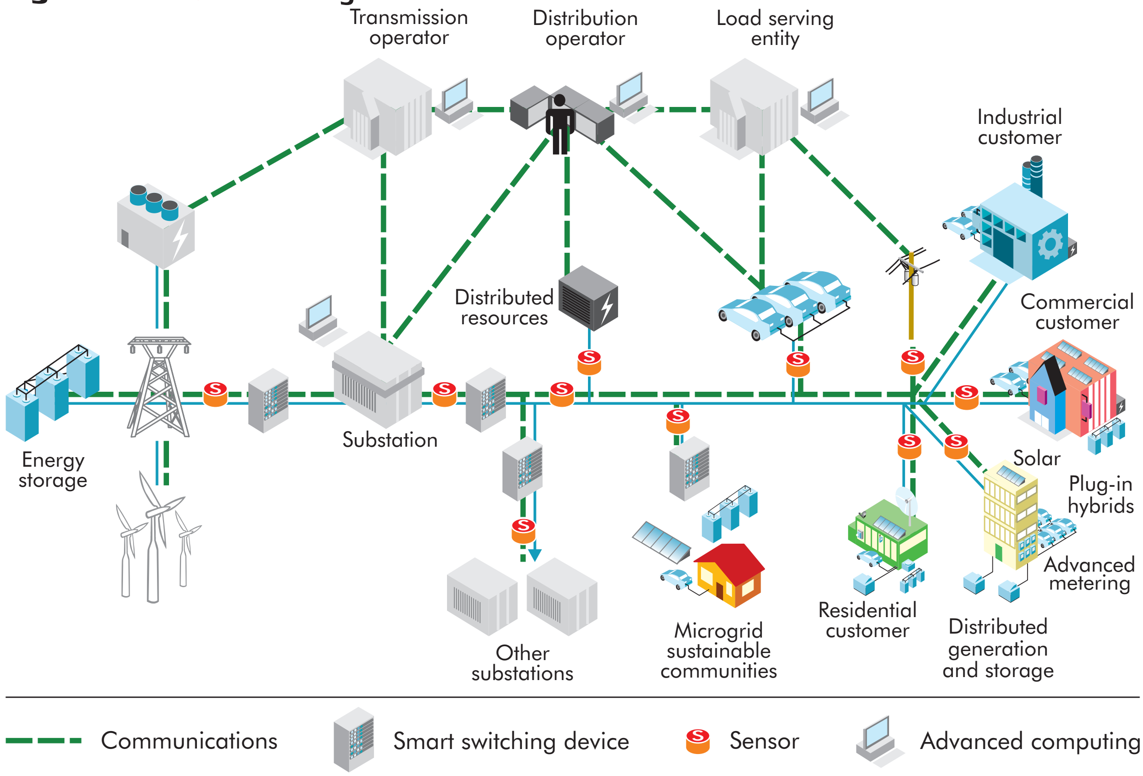
6. The electricity is technically not lost, but its use is unmetered. As a result, it is not possible for suppliers to manage, plan or recover system costs.

utilising both existing and new assets, there will be a need for the grid to become more intelligent, *i.e.* to become smarter.

Box 4.1 ▶ What is a smart grid?

A smart grid is an electricity network that uses digital technology to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Such grids will be able to co-ordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders in such a way that it can optimise asset utilisation and operation and, in the process, minimise both costs and environmental impacts while maintaining system reliability, resilience and stability (Figure 4.6).[7]

Figure 4.6 ▶ A smart grid



Source: Wang (2009).

Key point

A smart grid includes generation, transmission, distribution and end-use technology and stakeholders, connected by integrated information, communication and control technology.

Smart grid technology

The grid is an enabler. It enables sources of generation to be linked to consumers. A range of technologies are primarily grid related, as distinct from being generation related or consumer related (Table 4.3).

7. Various definitions of smart grids can be found in publications at the following links: http://ec.europa.eu/reearch/energy/pdf/smartgrids_en.pdf, www.weforum.org/pdf/slimcity/SmartGrid2009.pdf, www.nist.gov/smartgrid/Report%20to%20NISTlAugust10%20(2).pdf.

Table 4.3 ▶ ***Functional smart grid technology areas***

Technology areas	Description
Electricity generation control, automation and power electronics	Communication with, and the intelligent control of, generation sources are part of a smart grid, but not the generation itself. For example, power electronics technologies that allow wind generation to supply reactive power are essential to the smart grid. The wind turbine is not.
Advanced computing and grid control software	The data created from embedded sensor and metering technology will require significant computing and system control software to enable the use and management of the grid and to meet stakeholder needs.
Embedded grid sensing, automation, measurement and control technology	This technology provides the information and control capability to optimise grid operation and manage power flows within the constraints of the grid technology. Flexible alternating current transmission systems, phasor measurement units and automated switch gear are examples.
Communication infrastructure	The infrastructure required for two-way communication including wireless, internet and satellite communications may use existing or specialised methods.
Conductor technology and approaches	Advanced conductor technology such as high temperature superconductors (HTSs) can enable electricity systems to respond to operating changes more quickly, benefiting automated control, which will be especially important with the increase in remote variable renewable generation. High voltage direct current configurations can also offer management and control benefits to the grid.
Electrical load control and advanced meters	Advanced metering at residential, commercial and industrial levels can give customers and electricity providers the information they need to be able to respond to operational signals either by choice or automatically. Smart meters* can enable demand response initiatives.
Energy storage	Energy storage can be used as a load or as a generation source to help peak load management. Storage could also be used to provide ancillary services such as reactive power for frequency and voltage support.
EV charging infrastructure	The EV charging infrastructure will have an impact on grid operation. It must be capable of being managed intelligently.

* The European Smart Meters Industry Group (ESMIG) defines four minimum functionalities of a smart meter: remote reading, two-way communication, support for advance tariffing and payment systems and remote disablement and enablement of supply.

Benefits of smart grids

Smart grids will offer the capability:[8]

- **To reduce peak demand by actively managing consumer demand:** more appliances and equipment are expected to come onto the market that can respond to both consumer and utility operator priorities. As they do, the ability to manage power requirements in both directions – to the utility as well as from the utility – will reduce the need for power. For example, during high-use periods such as hot summer afternoons when the cost of producing and delivering power is extremely high, the system will enable consumers more directly to be informed of those costs and to reduce their demand, or increase their local generation output, accordingly.
- **To balance consumer reliability and power quality needs:** although some uses of electricity require near perfect reliability and quality, others are almost insensitive to these needs. A smart grid will be able to distinguish differences in demand and, where appropriate, to provide less reliable and lower quality power at a reduced cost.

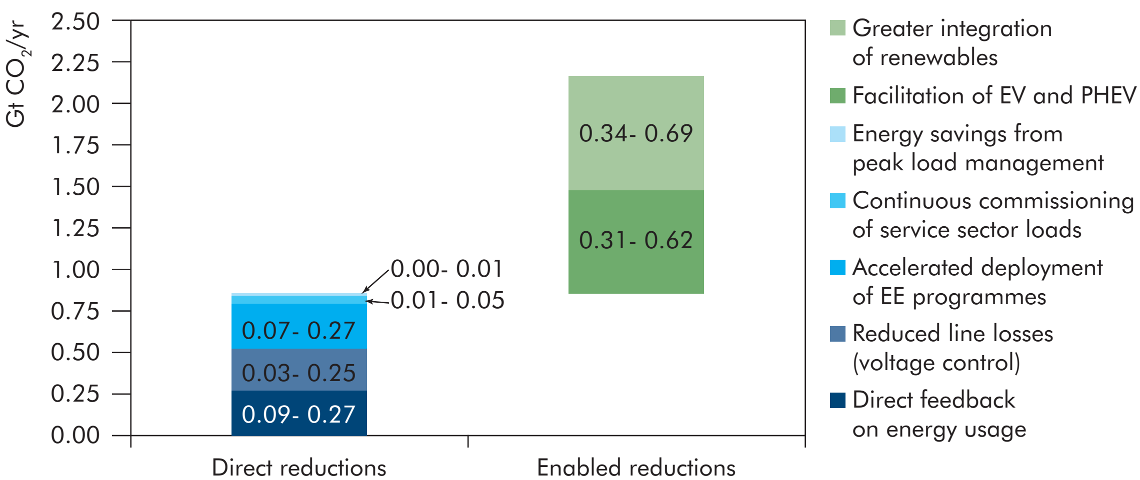
8. Adapted from Gridwise Alliance (2010).

- **To encourage the proactive application of energy efficiency opportunities:** a smart grid will furnish consumers and utilities with accurate, timely and detailed information about energy use. Armed with this information, consumers will be able to identify ways of reducing energy consumption with minimal impacts on safety, comfort and security.
- **To improve overall operational efficiency:** smart grids will become increasingly automated, and smart sensors and controls will be integral to their design and operation. Utility operators will be able more easily to identify, diagnose and correct problems, and will even have the capability to anticipate problems before they happen.
- **To integrate clean energy technologies:** EVs, roof-top solar systems, wind farms and storage devices will become essential parts of the grid, all contributing in a co-ordinated fashion to the achievement of economic and environmental goals.

Smart grid CO_2 emissions reduction

Although electricity consumption only represents 17% of final energy use today, it leads to 40% of global CO_2 emissions. This is largely due to the fact that almost 70% of electricity is produced from fossil fuels. In the Baseline scenario, this stays largely the same in 2050, but in the BLUE Map scenario, as a result of decarbonisation, power generation contributes only 21% of global CO_2 emissions, representing an annual reduction of 20.2 Gt of CO_2 compared to the Baseline scenario. Smart grids will be needed to contribute directly to these reductions and to enable some of the required technologies (Figure 4.7).

Figure 4.7 ▶ **Smart grid CO_2 reductions in 2050 in the BLUE Map scenario compared to the Baseline scenario**



Note: The methodology for calculating CO_2 reductions has been adapted from EPRI (2008).[9]

Key point

Smart grids have the potential to reduce CO_2 emissions in the electricity sector both directly and indirectly.

9. This methodology is preliminary in nature and provides a range for the quantification of CO_2 emissions reductions attributed to the smart grid. Using the *ETP 2010* analysis, this methodology has been modified to provide a first estimate of global emissions reduction attributable to smart grids. Actual regional CO_2 reductions depend on specific regional characteristics such as energy efficiency, demand structure and electricity generation mix.

Direct reductions are those that would only occur through the implementation of smart grid technologies or operating approaches. Indirect benefits are those that are the result of the deployment of other technologies, but require the capability of a smart grid to be fully realised. For example, smart grid technology will be needed to support the wider introduction of EVs and plug-in hybrid EVs.

Compared to the Baseline scenario in 2050, smart grids offer the potential to achieve savings of between 0.9 Gt CO_2 and 2.2 Gt CO_2 a year.

Benefits for developing countries

Smart grids could bring even more benefit to developing countries than to developed countries. Across the globe an estimated three billion people continue to lack access to sustainable and affordable modern energy (WEF, 2009). As developing countries respond to this, they may be able to implement smart grids from the outset, without going through the prior stage of increasingly outmoded technologies. A less carbon-intensive electricity generation infrastructure rather than one based on fossil fuels, along with demand control, could be used to reduce capital and operating costs while providing more robust operation.

Approaching electrification in this way has the potential to accelerate development and do so in a more sustainable way, reducing dependence on foreign sources of fuel. Many of the lessons learned both technically and economically by developed countries could be applied at the early stages of such development. Alternative approaches that may benefit given regions, such as micro grids and remote grids could take significant advantage of smart grid technologies in order to develop solutions that are tailored to specific needs.

Storage technology

With increasing variability of both generation and demand, storage will become increasingly important in enabling the grid to operate in a stable and reliable manner. Storage, by acting as both a load and a generation source, can play a major role in increasing system flexibility.

Storage technologies will be important in the development of smart grids in providing both grid support and enabling overall energy management. Direct electricity storage can, for example, decrease bottlenecks on both the transmission and distribution systems and be used to improve or maintain the delivery of power during outages. The output of excess generation from varREs in periods of high output and low electricity demand can be stored for later use. Apart from pumped hydro, these technologies are not yet financially viable other than in very specific applications. But continuing development can be expected to improve both cost-effectiveness and reliability. A range of storage technologies has recently been reviewed by the IEA (Inage, 2009a).

Thermal storage is likely to become increasingly important in the long term as thermal loads begin increasingly to use electricity generated through heat pump technologies and as CHP plays a stronger role. Heat pump technology can reduce electrical load during both heating and cooling operations by utilising the thermal energy stored in the air or ground. Intelligent control of these heating and cooling loads can be used to manage peak demand with no noticeable impact on the end user. CHP units can be converted from variable generation to non-variable generation by responding to electricity system signals and storing excess heat energy for use at a later time in response to heat demand. Overall system efficiencies need to be better understood, so that they can influence technology choices and business cases to maximise the benefits for both system operators and end users.

Analysis of electricity storage needs

In 2009, the IEA estimated the global need for large-scale direct electricity storage technology in 2050 using the BLUE Map 2008 scenario with global wind and PV generation at 12% and 11% respectively of overall electricity generation (Inage, 2009a). The amount of storage has been estimated by modelling the storage required to balance the grid over a 24 hour period in response to 15% net variations in wind generation on the scale of seconds and minutes. Simplifications were made to yield initial results on which to build. These do not take into account regionally specific transmission or distribution bottlenecks that can increase the need for storage, or the smoothing effects of complementary generation technologies or the full deployment of smart grid technologies that could reduce the need for storage. The modelling was performed in three stages, first by using only electricity storage as a balancing mechanism, second by combining electricity storage and V2G input through EV technology, and third by modelling combined electricity storage and the impact of heat pump technology deployment (Table 4.4).

Table 4.4 ▶ ***Estimated global electricity storage needs in 2050 in the BLUE Map scenario, using different approaches***

	(GW)
Electricity storage (ES)	189
ES + V2G	122
ES + heat pump deployment	154

Sources: Inage (2009a and 2009b) and additional analysis.

The modelling indicates that different approaches lead to a need for different levels of storage capacity. Using several forms of storage technologies together may provide additional flexibility. At the upper bound, these estimates probably reflect an unlikely occurrence of very high generation and very low demand. But they may signal some important conclusions about the relationships between a range of technologies that can be used to increase the flexibility of the grid. Currently, approximately 100 GW of electricity storage is in use globally, primarily in the form of pumped hydro storage. Since not all regions have the natural resources to take advantage of pumped hydro, other technologies will need to be used, requiring continued investment and development. As smart grid concepts develop, and as implementation proceeds, more detailed modelling will need to be carried out to incorporate all demand and generation elements to improve the estimates of electricity storage needs and costs to determine the best technology solutions.

How much does the grid of the future cost?

Capital expenses

The *ETP 2010* scenarios calculate electrical system capital costs based on previous infrastructure investment data and future energy requirements. T&D investment is estimated to account for USD 8.4 trillion and USD 12.3 trillion in the Baseline and BLUE Map scenarios respectively. The increase in the estimated T&D investment in the BLUE Map scenario is due to increased demand for electricity for transportation, the increased deployment of varRE and smart grid costs, offset significantly by reductions in electricity demand through energy efficiency in all sectors. After 2050, it is expected that electricity demand in the BLUE Map scenario will eventually become greater than in the Baseline scenario, due to the further electrification of transportation and heating loads through technologies such as heat pumps which will impact on system costs further at the distribution level.

The detailed cost of smart grids compared to conventional grid designs is not fully understood. The total cost of smart grids may be lower than that of conventional grids as the ability to reduce peak loads and to increase energy efficiency may enable savings in infrastructure costs for T&D lines, transformers and switch gear. These cost reductions will be at least partially offset by increased costs for smart grid technologies such as smart meters, phasor measurement units and the information and communication infrastructure needed. A detailed analysis is required to estimate costs more precisely to determine the support needed at financial, policy and regulatory levels.

Operating expenditures

The use of digital technology has demonstrated opportunities for reducing operating expenditures in many industries. The same can be expected for the electricity sector, especially with respect to smart grids. Savings can already be seen in the use of automatic meter reading enabled by smart meters which in some applications have underpinned a business case to justify the required capital investment. The improved maintenance and utilisation of assets through the embedding of sensing equipment along with the potential for reductions in line losses could offer opportunities for additional savings. These savings in turn could defer and in some cases eliminate the need for infrastructure investments. It has not yet proved possible to estimate these savings quantitatively.

Barriers to electricity grid investment

Despite the benefits that the modernisation of the electricity grid will bring, there are many barriers to its achievement (Figure 4.8). These barriers must be addressed by engaging the full range of stakeholders in both private and public sectors, including market participants from all parts of the system, e.g. generators, T&D system operators, regulators and consumers. It is only in this way that creative and practical solutions will be found.

Figure 4.8 ▶ **Barriers to electricity grid investment**

Market barriers	**Policy and regulation**	• Market uncertainty and unclear policy on market structure and rules • Revenue uncertainty due to regulatory structures
Market barriers	**Financing**	• Difficulties in defining priorities of technology investments • Business case fragmentation
Public barrier	**Consumer engagement**	• Low public awareness and engagement
Technology barriers	**Technology**	• Lack of R&D co-ordination • Lack of large-scale deployment projects
Technology barriers	**Standards**	• Interoperability and scalability assurance • Fragmentation and lengthy process for technology standards
Technology barriers	**Skills and knowledge**	• Insufficient skilled resources • Limited understanding of smart grids in public planning
Technology barriers	**Cyber security and data privacy**	• Threats to cyber security in networks and consumer information • Concerns about private data misusage

Source: MEF (2009).

Key point

Technology, public and market barriers must be addressed to enable smart grid deployment.

Priorities for next steps

The process for modernising the electricity grid as well as the transition to smart grids is already happening. It will continue as a transitional process rather than a step change. Grid investments tend to be very long term. They need to reflect deliberate and forward thinking that takes account of likely medium- and long-term changes in need. The IEA's planned development of a smart grid roadmap will help in this.

Regional assessment of grid needs

Regional needs, and the benefits that will result from meeting those needs through smart grid technologies, will differ. An assessment of needs and the grouping of regional needs will provide the opportunity for collaboration. This will also provide the opportunity to discuss what aspects should be addressed in what order. For example, in some regions, the need for the greenfield development of grid infrastructure may lead to the use of the latest conductor technology and controls which will provide flexibility in generation choice in the long term. Other regions, with mature markets and ageing infrastructure, may more appropriately focus on demand-side management and demand response to meet these medium-term needs while developing long-term upgrading plans.

Technology research, development and demonstration (RD&D) needs

RD&D is needed in the development of electricity systems. Priority should be given to:

- Advanced system level modelling for planning, building, operating and maintaining smart grids that include all related elements of generation, transmission, distribution, demand, electricity and thermal storage.
- System level demonstrations of smart grids of increasing scale, eventually to the city and country scale, incorporating a range of technologies in a variable generation and demand environment in both developed and developing country contexts. These demonstrators can undertake the real-world testing of concerns including cyber security, reliability and cost.
- Continued development in electricity storage technology to increase efficiency and longevity and to reduce costs.
- Power electronics technology development to provide more capability and flexibility for system components on the grid such as wind generation.
- Continued development in transmission technology to help achieve better interconnection between areas with different supply and demand characteristics. This includes high-temperature superconductors to reduce both cost and risk and provide real world demonstration of benefits.
- Increasing the reliability of cables, subsea grids and overhead lines and reducing their impact on the environment. The development of smart grids could be a catalyst for increased action in these areas.
- Standards development as an enabler for innovation through both RD&D and deployment. This must continue to ensure technologies will allow inter-operability to reduce supplier risk and allow new market entrants.

Markets

The structure of electricity markets influences the construction, maintenance and operation of the grid. Around the world there are a number of different market structures that include the range from vertically integrated state-run monopolies to structures with a mix of unbundled private sector operations and state-run monopolies. As changes occur to the generation and demand sides, new business models will be needed with the ability to provide new services such as grid balancing or the aggregation of demand side reduction. This can ensure that all stakeholders, including customers, are appropriately incentivised to make appropriate investments and changes to operating procedures.

Regulatory and policy needs

The electricity sector has seen significant changes in regulation over the last 20 years in many regions. Changes in the generation, transmission, distribution and retail businesses have brought both positive and negative consequences. From a customer point of view, the introduction of competition into parts of the electricity value chain have brought new service offerings and driven down prices. From a generation point of view this process has allowed new entrants into the market, bringing new capital for investment both in conventional generation technologies and also in distributed technologies such as CHP and renewables.

Transmission and distribution systems are often viewed as natural monopolies. Although they have not generally been opened to competition, they are now in many countries more heavily regulated to ensure that customers are treated fairly.

To ensure that a low carbon electricity system can be developed at least overall cost, policy makers and regulators will need to strike an appropriate balance between the various parts of the value chain. Investments in generation will influence grid costs, and grid investments may change the balance of advantage between different generation investment alternatives. Regulators and policy makers need to understand the long-term needs of the electricity system in the round, so that they can ensure that short- and medium-term investment needs in generation and in grids optimise outcomes.

Public education and public engagement

The understanding of the benefits of smart grids to the end user must be better analysed and understood. This needs to include studies to understand what benefits end users will value and what they will not. Listening to and addressing the questions and concerns will increase up take and minimise public resistance that may be founded on rational or irrational understanding.

Human resources

According to a Canadian study, it is estimated that over 28% of the current Canadian electricity workforce is expected to retire between 2007 and 2012 (ESC, 2009). Similar trends can be seen in many other OECD countries. In developing regions, the human resource challenge is based around the development of technical capacity from a relatively low level today. Human resource constraints could undermine the ability for the industry to respond to increased demand and development in the electricity sector. They need to be considered in long-term planning. As the resultant changes in planning, design, operation and maintenance of the electricity system occur, the skills and competencies needed will also change. A detailed skills assessment considering both near and long-term demands will be required, with recommended actions to deliver these skills over the appropriate time frame.

Chapter 5 INDUSTRY

Key findings

- *Energy efficiency in industry has improved significantly in the last decade, but additional improvements are still possible through the implementation of best available technologies (BATs). Efficiency measures offer some of the least-cost options to reduce carbon dioxide (CO_2) emissions in industry. Implementation of BATs could reduce current emissions by 12% to 26%. Greater implementation of many well-known, cost-effective policy instruments is needed to achieve this potential. The removal of energy price subsidies should be a priority in countries where they persist.*

- *For the industry sector to make its contribution to the halving of CO_2 emissions by 2050 envisaged in the BLUE scenario, it will need to reduce its direct emissions in 2050 by 24% compared to 2007 levels. This can only be achieved if all major industrialised countries and all industry sectors contribute.*

- *Efficiency measures alone will not be enough to offset strong demand growth. New technologies such as carbon capture and storage (CCS), smelting reduction, separation membranes and black liquor gasification will be needed to reduce direct emissions in industry.*

- *Indirect CO_2 emissions from the use of electricity currently represent 34% of total industry emissions. These emissions are nearly eliminated by 2050 in the BLUE Map scenario as electricity generation progressively decarbonises through a mix of renewable and nuclear energy, and fossil fuel generation coupled with CCS.*

- *A decarbonised power sector will offer new opportunities to electrify industrial processes further to reduce the CO_2 intensity of industrial production. Research and development (R&D) is needed in this area.*

- *CCS represents the most important new technology option for reducing direct emissions in industry, with the potential to save an estimated 1.7 to 2.5 gigatonnes (Gt) of CO_2 in 2050. Without CCS, direct emissions in 2050 could only be brought back to current levels. Urgent action is needed to develop and demonstrate CCS applications in industry. The large-scale demonstration of capture technologies in industry should be undertaken in parallel with demonstration projects planned for the power sector.*

- *Fuel and feedstock substitution with biomass and waste represents another important option to reduce CO_2 emissions. There will be significant competition for limited biomass resources from the power, transport, pulp and paper and buildings sectors. This will increase cost and possibly make industrial applications less attractive. Policy design for biomass and waste use should support an optimum use of limited resources.*

- *Greater investment by both government and industry is needed to research, develop, demonstrate and deploy a wide range of promising new technologies and to identify and advance novel processes which allow for the CO_2-free production of materials in the longer term.*

5

- *Clear, stable, long-term policies that put a price on CO_2 emissions will be necessary if industry is to implement the technology transition needed to produce deep emissions reductions. The current situation, in which developed countries are subject to greenhouse-gas emission constraints while developing countries are not, gives rise to concerns about competitiveness and carbon leakage.*

- *A global system of emissions trading may eventually provide the most efficient way of achieving this. In the short to medium term, international agreements covering specific energy-intensive sectors may be a practical first step. Government intervention will also be needed in the form of standards, incentives and regulatory reforms.*

Introduction

Nearly one-third of global energy demand and almost 40% of worldwide CO_2 emissions are attributable to industrial activities. The bulk of these emissions are related to the large primary materials industries, such as chemicals and petrochemicals, iron and steel, cement, pulp and paper, and aluminium. If climate change is to be successfully tackled, industry will need to transform the way it uses energy and significantly reduce its CO_2 emissions.

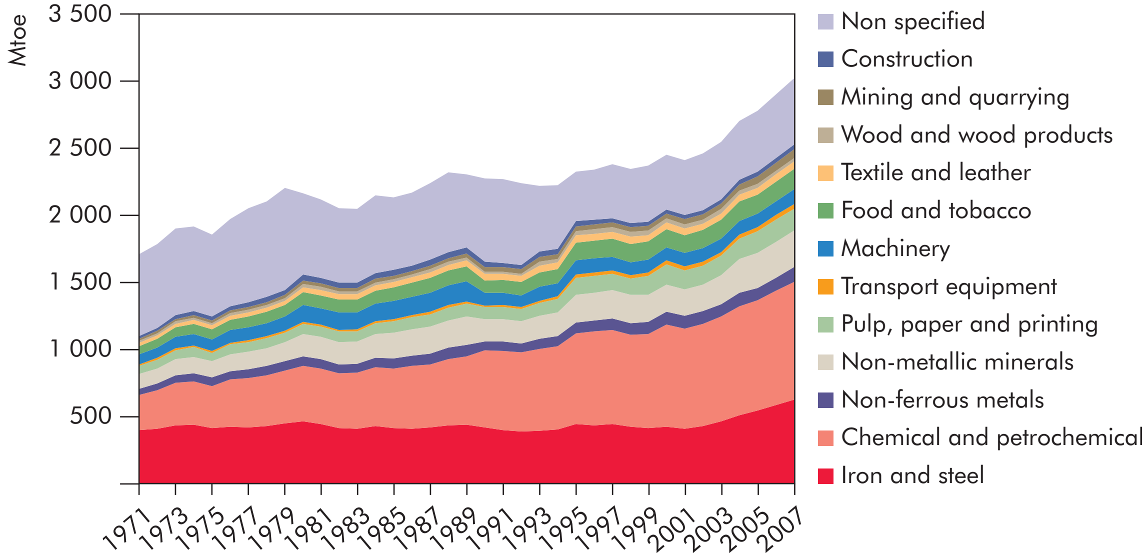
Although industrial energy efficiency has improved and CO_2 intensity has declined substantially in many sectors in recent decades, this progress has been more than offset by growing industrial production worldwide. As a result, total industrial energy consumption and CO_2 emissions have continued to rise. Over the next 40 years, demand for industrial materials in most sectors is expected to double or triple. Projections of future energy use and emissions based on current technologies show that, without decisive action, these trends will continue. This is not sustainable.

Making substantial cuts in industrial CO_2 emissions will require the widespread adoption of BATs and the development and deployment of a range of new technologies. This technology transition is urgent. Industrial emissions must peak in the coming decade if the worse impacts of climate change are to be avoided. Industry and governments will need to work together to research, develop, demonstrate and deploy the promising new technologies that have already been identified, and also to find and advance novel processes that will allow for the CO_2-free production of common industrial materials in the longer term.

Industrial energy use and CO_2 emissions

Total final energy use by industry reached 3 015 million tonnes of oil equivalent (Mtoe) in 2007, representing almost a doubling of energy use since 1971 (Figure 5.1). The five most energy-intensive sectors, namely iron and steel, cement, chemical and petrochemical, pulp and paper, and aluminium, together accounted for two-thirds of total industrial energy use and about 77% of total direct CO_2 emissions in industry. Energy intensity over this period has improved significantly in most sectors as a result of improvements in energy efficiency and material flow management. For example, in the cement sector, production since 1971 has risen 4.5 times. In the same period, energy use has risen only by a factor of 1.5 as technology advancement and higher rates of clinker substitution have helped to reduce the energy intensity of cement production by half. Higher recycling levels, together with a range of energy efficiency measures, have led to similar substantial improvements in energy use in the production of iron and steel, pulp and paper and aluminium.

Figure 5.1 ▶ ***World industrial energy use by sector***



Notes: Includes feedstock used in the production of chemicals and petrochemicals. Iron and steel includes coke ovens and blast furnaces. Unless otherwise indicated, all material derives from IEA data and analysis.

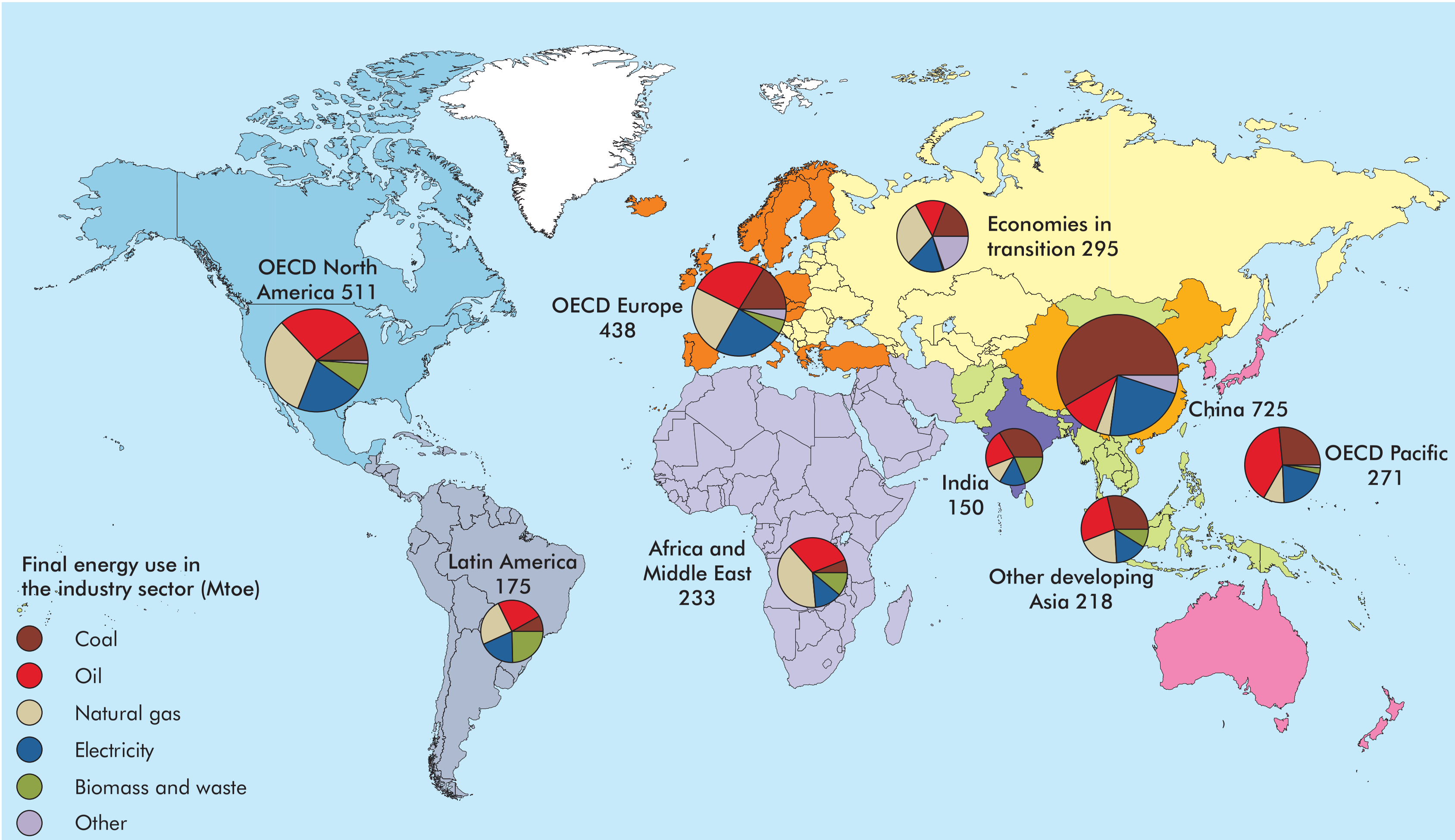
Key point

Energy use in industry has risen sharply since 1971, with strong growth seen in the chemical and petrochemical, iron and steel and non-metallic minerals industries.

China accounts for about 75% of the industrial production growth since 1971 and for a similar share of the increase in industrial energy use. As the country's energy base is dominated by coal, rapid industrial production growth has resulted in China becoming the largest emitter of CO_2 in the world, overtaking the United States in 2007. Approximately 60% of China's emissions are attributable to industry. In the United States, industry's share of total emissions is less than 20%, with the largest share (44%) of emissions coming from the buildings sector.

China, the United States and OECD Europe together accounted for over 50% of total global industrial energy use in 2007 (Figure 5.2). Action in these countries will be a major determinant of overall global industrial energy and CO_2 trends. In the United States and Europe, oil and gas represent the main sources of energy for industrial use. This is dominated by the feedstock needs of the chemical and petrochemical sector which account for 23% of total industrial energy use in these countries. In China, coal is the major source of industrial energy. As a result, China's share of global industrial CO_2 emissions (35%) is significantly higher than its share of industrial energy use (24%).

Figure 5.2 ▶ **Industrial energy use by region and by fuel, 2007**



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Key point

China, OECD North America and OECD Europe represent more than half of total energy use in industry.

Significant energy and CO_2 savings in industry are possible through the implementation of currently available BATs. The application of BATs in the five most energy-intensive sectors could reduce final energy use by between 10% and 26% according to sector (Table 5.1).[1] Total estimated savings for the five sectors analysed is 357 Mtoe per year, equivalent to 12% of energy use in industry and 4% of global energy consumption in 2007. In terms of CO_2 savings, the sector potentials vary from 12% to 26%, in total amounting to 1.3 Gt of CO_2. This equates to a reduction of 11% of total industry emissions and 4% of total global emissions in 2007.

Table 5.1 ▶ ***Potential savings from adopting BATs in industry***

	Energy savings potential Mtoe/yr	Share of current energy use in the sector	CO_2 savings potential Mt CO_2 /yr	Share of current emissions in the sector
Chemicals	121	15%	300	20%
Iron and steel	133	22%	420	19%
Cement	63	26%	520	26%
Pulp and paper	35	21%	80	20%
Aluminium	9.7	10%	45	12%
Total	**357**		**1 295**	
Potential as share of industrial energy and CO_2 emissions	**12%**		**11%**	
Potential as share of total energy use and CO_2 emissions	**4%**		**4%**	

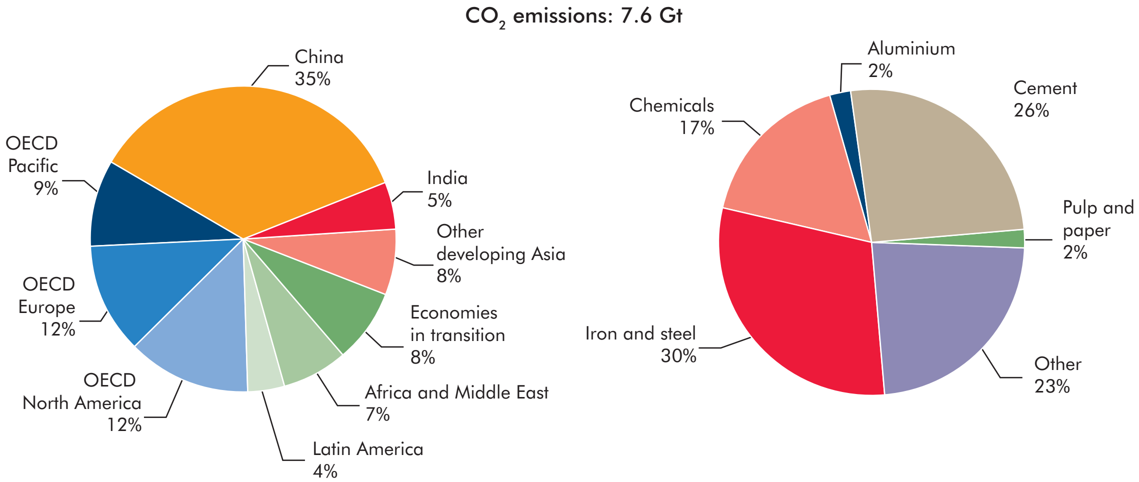
Note: Work at the IEA is seeking to improve the quality of the underpinning data and to refine the methodologies used in calculating the savings potential in the industrial sector.

It will take time to achieve these savings. The rate of implementation of BATs in practice depends on a number of factors, including capital stock turnover, relative energy costs, raw material availability, rates of return on investment and regulation. Energy subsidies undermine the ability of markets to signal least-cost options to maximise energy efficiency. Removing these subsidies will help to realise higher levels of energy efficiency.

CO_2 emissions reductions will be needed across all industry sectors. But action is particularly crucial in the five most energy-intensive sectors. Together, these sectors currently account for 77% of total direct CO_2 emissions from industry (Figure 5.3).

1. The potentials shown are technical. The economic potentials are substantially lower.

Figure 5.3 ▶ **Direct CO_2 emissions in industry by sector and by region, 2007**



Key point

Iron and steel, cement and chemicals account for almost three-quarters of emissions in industry.

Energy and CO_2 scenarios

Scenario assumptions

The BLUE scenarios enable the exploration of the technological options that will need to be exploited if global CO_2 emissions are to be halved by 2050 at least cost. Reaching the global CO_2 emissions objective in the most cost-effective way will require each economic sector to make a contribution according to its costs of abatement. Some sectors may, therefore, need to reduce emissions by less than 50% while others will have to reduce them by more.

Given the recent global economic crisis and uncertainties about projecting long-term growth in consumption, a low-demand and a high-demand case have been developed for each industry. In the five sectors covered in this analysis, demand is assumed to be between 15% and 30% lower in the low-demand cases than in the high-demand cases in 2050, depending on the sector. As the BLUE low- and high-demand scenarios are driven by the same level of CO_2 emissions in 2050, greater reductions in emission levels are needed in the high-demand scenario than in the low-demand one. As a result, costs are also higher in the high-demand case.

The scenarios take an optimistic view of technology development and assume that technologies are adopted as they become cost-competitive. The analysis does not assess the likelihood of these assumptions being fulfilled. But it is clear that deep CO_2 reductions can only be achieved if the whole world plays its part both in seeking to achieve that outcome and in engaging in the development and deployment of technologies that can help to bring it about.

Trends in materials production and demand projections for industry

Growth in industrial production since 1990 has been dominated by China, India and other developing Asian countries. Together, these countries accounted for over 80% of the increase in industrial production over this period. Today China is the largest producer of ammonia, cement, iron and steel, methanol and many other products. In OECD countries, industrial production since 1990 has increased only modestly. The IEA scenario analysis assumes that in the next twenty years, as industrial development matures, there will be another significant change in the pattern of industrial production growth (Figure 5.4). Production in China will flatten or, in cement production, decline as the economy matures and demand for materials levels off. But in India, other developing Asian countries, and Africa and the Middle East, industrial development will accelerate. Industrial production in these three regions is expected, in the low-demand scenario, to increase by over 150% by 2030 and by almost 300% by 2050 compared to 2007. OECD countries are expected to show relatively flat demand or only modest increases as consumption levels for materials in these countries are already mature and population growth is expected to be relatively flat or declining.

Scenario results

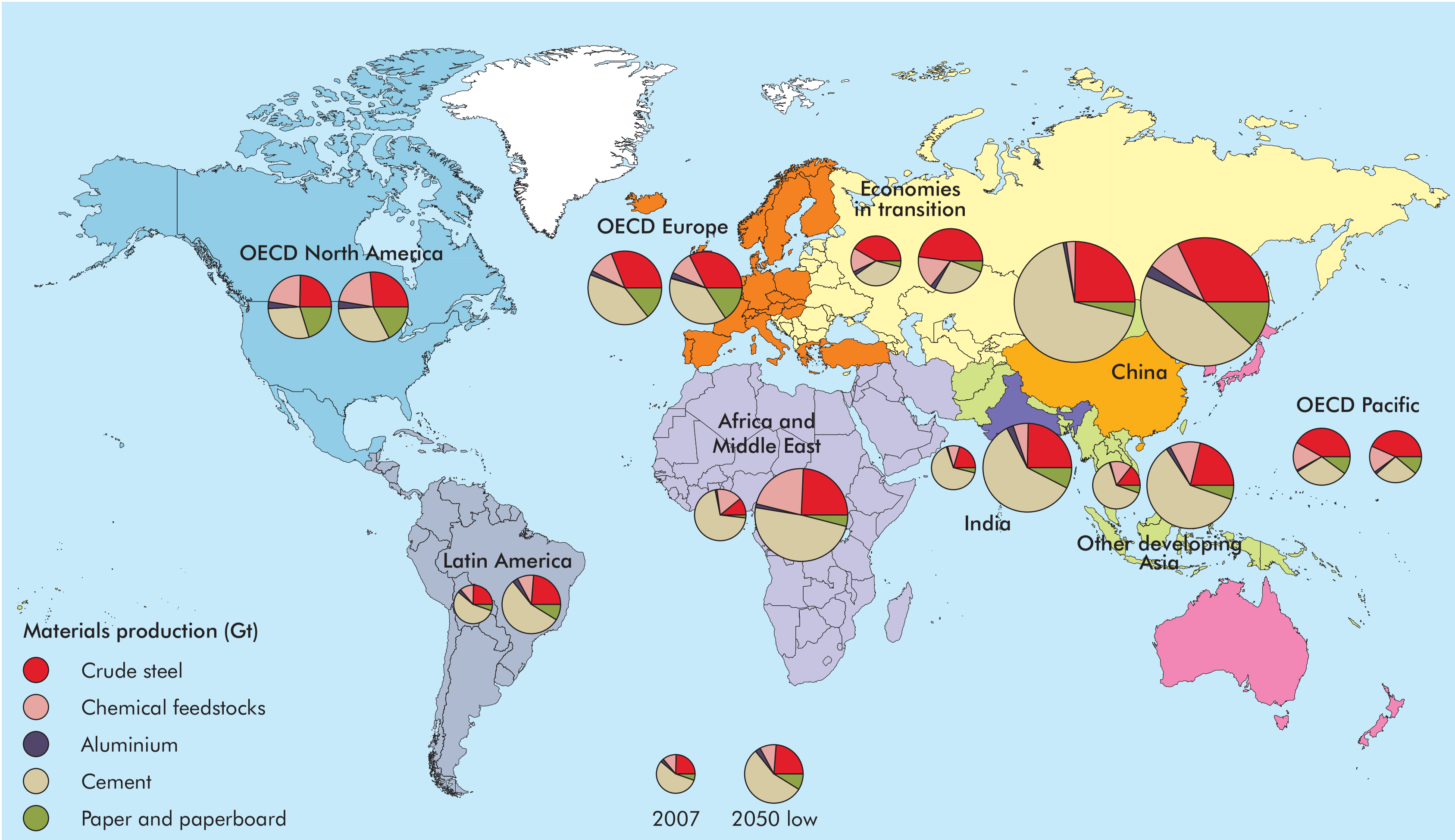
In the Baseline scenario, total direct and indirect emissions from industry rise between 2007 and 2050 by 74% in the low-demand case and by 91% in the high-demand case, reaching 19.9 Gt CO_2 and 21.9 Gt CO_2 respectively (Figure 5.5). In the BLUE scenarios, total industrial emissions would be 40% lower in 2050 than in 2007. Compared to the Baseline scenarios, industry emissions in the BLUE scenarios would be 66% lower in 2050 in the low-demand case and 68% lower in the high-demand case.

Direct process and energy emissions from industry are expected to reach 11.0 Gt CO_2 in the Baseline low-demand case and 12.5 Gt CO_2 in the high-demand case in 2050. In the BLUE scenarios, direct emissions fall from 7.6 Gt CO_2 in 2007 to 5.7 Gt CO_2 in 2050, a 24% reduction.

Indirect emissions from electricity use represent the largest increase between 2007 and 2050 in the Baseline scenarios, rising from 3.9 Gt CO_2 in 2007 to 8.8 Gt CO_2 (low-demand case) and 9.3 Gt CO_2 (high-demand case) in 2050. In the BLUE scenarios, as the power sector progressively decarbonises, indirect emissions show the largest decline, falling by 2050 to just 1.1 Gt CO_2 in low-demand case and 1.2 Gt CO_2 in the high-demand case.

The decarbonisation of the power sector accounts for the largest share (45% in the low-demand case and 42% in the high-demand case) of the reductions in total emissions in industry by 2050 in both BLUE scenarios (Figure 5.6). Energy efficiency, including electricity demand reductions, makes the next largest contribution, amounting to 34% and 32% of total reductions in the BLUE low- and high-demand scenarios respectively. The fitting of CCS to industrial applications, which accounts

Figure 5.4 ▶ **Materials production under the Baseline and BLUE scenarios**



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

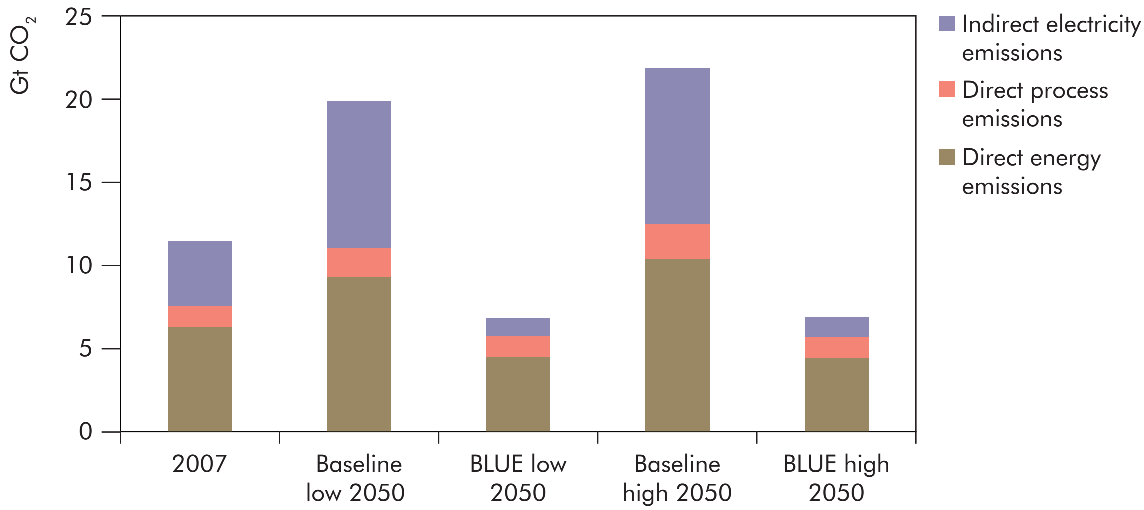
Note: Materials production is the same in the Baseline and BLUE scenarios.

Key point

Growth in industrial production will be strongest in India, other developing Asia and Africa and the Middle East.

for 13% and 17% of the total direct and indirect emissions reductions in the BLUE low- and high-demand scenarios respectively, will also be needed.

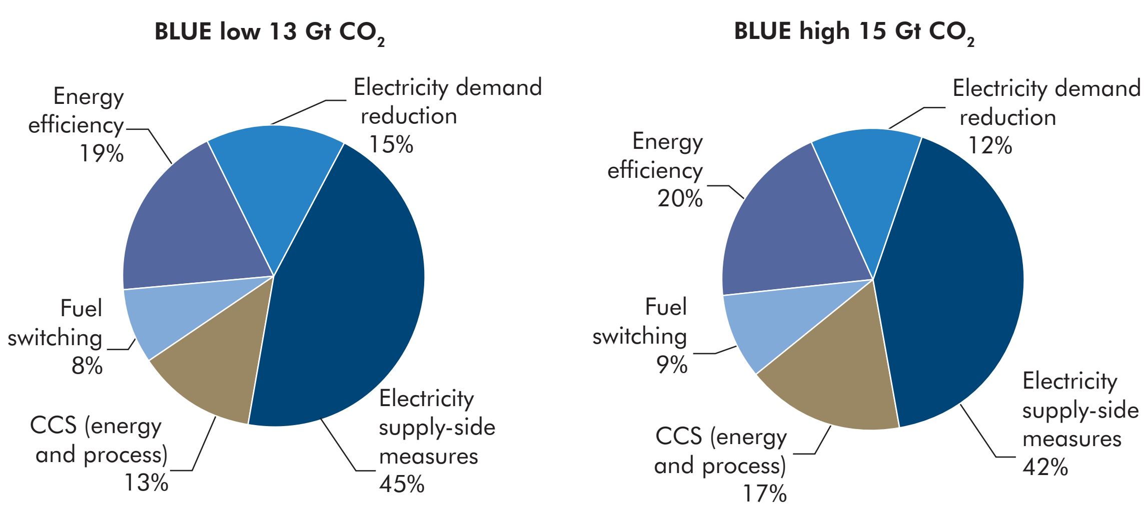
Figure 5.5 ▶ **Total industry CO_2 emissions in the Baseline and BLUE scenarios**



Key point

Total direct and indirect CO_2 emissions in industry fall by 40% in the BLUE scenarios compared to 2007 levels.

Figure 5.6 ▶ **Contribution to total direct and indirect CO_2 emissions reductions in the industry sector in the BLUE scenarios compared to Baseline scenarios**



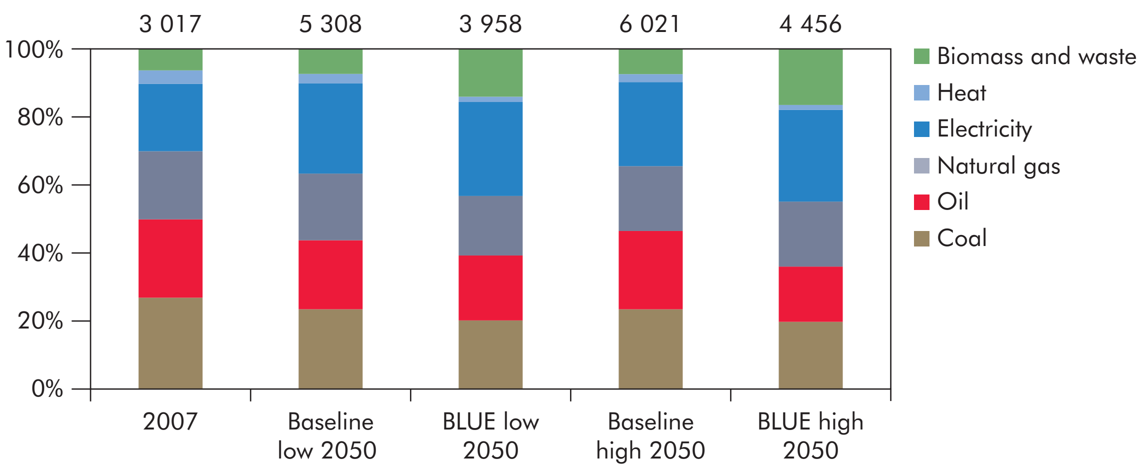
Key point

Measures in the electricity sector account for the largest reduction in total direct and indirect CO_2 emissions in industry.

Energy use

Total final energy use in the Baseline low-demand scenario increases from 3 017 Mtoe in 2007 to 5 308 Mtoe in 2050. It increases in the Baseline high-demand scenario to 6 021 Mtoe. Fossil fuels currently constitute 70% of the total final energy used in industry. In all scenarios, fossil fuel use will continue to dominate (Figure 5.7). But its share of final energy use will decline to 57% in the BLUE low-demand scenario and to 55% in the BLUE high-demand scenario. The remaining energy and feedstock will come from heat, biomass and waste and electricity. Coal currently accounts for over a quarter of total final energy use. In the BLUE scenarios, coal's share of final energy use falls to 20% by 2050.

Figure 5.7 ▶ Share of industrial energy use by fuel in the Baseline and BLUE scenarios



Note: Numbers at the top of the bars show total energy use in Mtoe.

Key point

The share of fossil fuels will decline significantly in the BLUE scenarios, offset by higher biomass and electricity use.

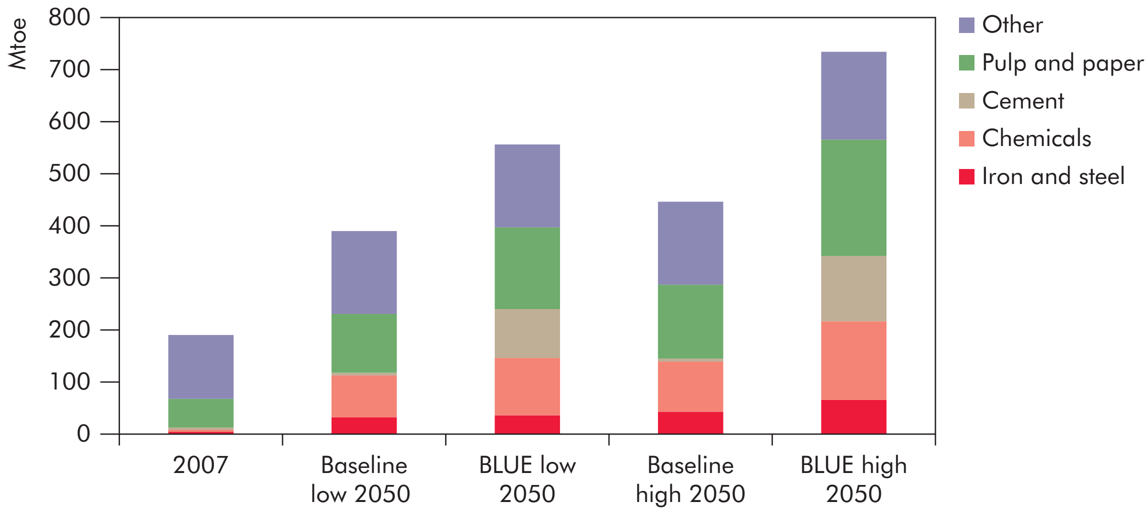
In the Baseline scenarios, the share of biomass and waste use remains similar to current levels. It increases sharply in the BLUE scenarios, rising from 6% of energy used in 2007 to 14% in the low-demand case and to 16% in the high-demand case by 2050. The switch from fossil fuels to biomass makes a significant contribution to CO_2 emissions reductions in all sectors except in aluminium production where electricity provides most energy. Applying CCS to biomass combustion will result in net emissions reductions as CO_2 from the atmosphere, initially captured in biomass, is sequestered. Industrial applications will have to compete with power generation for the available biomass. Significant improvements will be needed in agricultural yields if costs are to be contained and the negative impacts of land-use change and food availability are to be minimised.

In the BLUE scenarios, higher levels of energy efficiency will significantly reduce energy intensity, but total final energy use in 2050 will still rise by 31% in the BLUE low-demand scenario and by 48% in the BLUE high-demand scenario compared to 2007. This will be driven by strong production growth. The use of CCS in the BLUE scenarios to reduce CO_2 emissions increases energy consumption, offsetting some of the savings from higher energy efficiency that would otherwise be achieved.

Biomass use

In the BLUE scenarios, industry's use of biomass and waste increases from 190 Mtoe in 2007 to 556 Mtoe in the low-demand case or to 734 Mtoe in the high-demand case in 2050. The largest increase comes from the chemical and petrochemical sector, followed by the cement and iron and steel sectors (Figure 5.8). In the pulp and paper sector, biomass already represents 33% of total energy use and this share rises to about 60% in the BLUE scenarios in 2050. In the iron and steel sector, the use of biomass and waste rises to 36 Mtoe and 66 Mtoe in 2050 in the BLUE low- and high-demand scenarios respectively. Bio-based feedstock and biomass used as energy in the chemical and petrochemical sector represent between 8% and 10% of total energy used by the sector in 2050. In the cement sector, about 40% of the biomass and waste used in 2050 is assumed to come from combustible biomass, with the use of tyres, rugs and other waste accounting for the remainder.

Figure 5.8 ▶ **Use of biomass and waste in the industrial sector**



Sources: IEA (2009b and 2009c); IEA analysis.

Key point

Use of biomass and waste in industry will be three to four times higher in 2050 than in 2007.

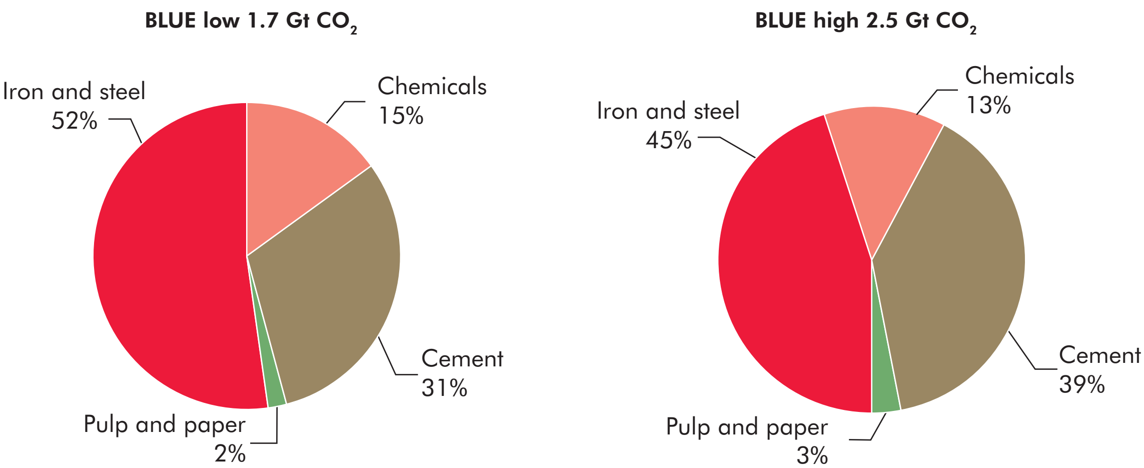
Achieving the high shares of biomass use in industry outlined in the BLUE scenarios will be challenging. The industrial sector will have to compete with other sectors of the economy for limited biomass resources. Growing demand could increase biomass prices, making fuel switching options in industry less economic. To assess whether or not the increased use of biomass by industry and other sectors is sustainable, it will be necessary to analyse at global, national and sub-national levels the use of biomass throughout the economy through a full life-cycle analysis.

Carbon capture and storage

Emissions reductions of between 1.7 Gt CO_2 and 2.5 Gt CO_2 need to be achieved through the application of CCS in industry in the BLUE low-demand and high-demand scenarios respectively, accounting for between 33% and 37% of the total direct emissions reductions needed as compared with the Baseline scenarios in 2050. Without CCS, direct CO_2 emissions in the industrial sector in 2050 come back to 2007 levels in the low-demand case; they would be 8% higher in 2050 than in 2007 in the high-demand case.

In the BLUE scenarios, CCS technology is applied in the iron and steel, pulp and paper, chemical and petrochemical and cement sectors. In the iron and steel sector, CO_2 is captured from blast furnaces, smelting reduction and direct reduced iron production plants. Capture in the cement sector is from rotary kilns for clinker production. In the chemical and petrochemical sector, capture is mainly in ammonia production and from large combined heat and power (CHP) units. In the pulp and paper sector, CO_2 is captured from large CHP units and black liquor gasifiers in pulp production (Figure 5.9).

Figure 5.9 ► ***Industrial CO_2 emissions reductions from CCS compared to the Baseline equivalent scenarios by sector, 2050***



Key point

There are important CO_2 reduction opportunities for CCS in the iron and steel and cement sectors.

Developing countries account for the bulk of the economic activity and for two-thirds of the CO_2 emissions in the Baseline scenarios in 2050. Spreading CCS technology to these countries will require international co-operation to maximise the impact of CCS as an abatement option.

If CCS is cost-effectively to play the role it needs to play in a number of sectors, the development of a CO_2 pipeline transportation and storage infrastructure will need to be actively co-ordinated between sectors. As CCS builds from demonstration to commercialisation, CO_2 transportation networks will need to be developed at regional, national and international levels to optimise infrastructure development and to lower costs.

The iron and steel and cement sectors have made some progress in advancing demonstration of CO_2 capture in industry. The United States government is providing USD 1.1 million to support the demonstration of a dry sorbent CO_2 capture technology at one of Cemex's cement plants in the United States. Discussions are currently under way between the cement industry and the European Commission to fund a CO_2 capture project in Europe. The Ultra-Low CO_2 Steelmaking (ULCOS) project, which is a joint public-private partnership in the steel industry in Europe, will soon move to the demonstration phase and a CO_2 capture demonstration plant at an ArcelorMittal plant in France is expected to be commissioned in 2015.

Industrial electrification

The decarbonisation of the power sector offers an attractive opportunity to reduce CO_2 emissions in industry through greater electrification, for example through the wider use of heat pumps instead of boilers (Box 5.1). R&D is needed to develop new electricity-based manufacturing processes. The widespread use of electricity in recycling suggests that increases in recycling rates would lead to higher levels of electrification in industry. There remains potential in many sectors to increase recycling, especially in developing countries. In the iron and steel sector, CO_2-free electricity could make production from hydrogen an attractive option. Research is also under way to produce iron by molten oxide electrolysis (MOE).

Box 5.1 ▶ Heat pump applications in industry

Heat pumps are already widely used in households and buildings. Recent technological advances that have enabled efficiency improvements, increases in capacity and output at higher temperatures offer the opportunity to replace boilers with heat pumps in a range of industrial applications. Heat pumps supplying heat at temperatures over 100°C are being commercialised. Additional R&D could help to make this technology more suitable for wider adoption in industry.

In the food and beverage sector, operating temperatures are often relatively low and, therefore, particularly appropriate to the use of heat pumps. An analysis of the CO_2 reductions from applying heat pumps with electric-drive compressors in the food and beverage industry in 11 countries has estimated that 40 Mt of CO_2 per year could be avoided (Table 5.2). This amounts to about 1.3% of CO_2 emissions in the industrial sector in the 11 countries analysed.

Table 5.2 ▶ **Energy and CO_2 emissions reduction from heat pump application in the food and beverage sector**

	Energy savings (Mtoe)	CO_2 savings (Mt CO_2)
China	3.57	3.0
France	0.47	2.0
Germany	0.53	1.3
Italy	0.44	2.2
Japan	0.57	0.5
Netherlands	0.18	0.1
Norway	0.04	0.8
Spain	0.24	0.2
Sweden	0.04	1.1
United Kingdom	0.42	13.7
United States	4.17	15.4

Source: Heat Pump and Thermal Storage Technology Center of Japan (2010).

Heat pump technology could be applicable to a range of other manufacturing processes in which relatively low temperatures are required, such as for washing, drying, air-conditioning and in the agricultural sector for horticulture and storage processes, etc. that are fundamental to the food sector. Using heat pumps can also cut energy costs, improve product quality and in some industries even shorten production periods.

The potential decarbonisation of the power sector in the future, combined with improvements in the efficiency of heat pumps, will also help to increase the CO_2 benefits of industrial heat pump applications. Heat pumps are a promising technology for industrial application and additional R&D is needed to allow for heat pump use at higher temperatures to enable wider adoption among industry sectors.

Recycling

The recycling of materials conserves energy, landfill space and raw materials. The use of recycled materials by industry, where appropriate, reduces energy needs and associated CO_2 emissions. Recycling is a particularly attractive option for the aluminium, iron and steel, paper and chemical and petrochemical industries. Although recycling rates could be increased in many sectors, achieving high rates of recycling might not be cost-effective. Many countries have already achieved high levels of recycling in some sectors and there is limited room for additional growth.

The proportion of recycled material relative to overall production is expected to increase by six percentage points (p.p.) in the aluminium sector, 19 p.p. in the iron and steel sector and three p.p. in the paper sector in 2050 compared to 2007, reducing energy use in these sectors by between 181 Mtoe and 240 Mtoe. The use of recycled materials will have an important contribution to make in achieving the 24% reduction in industrial direct energy use and process CO_2 emissions in the BLUE scenarios in 2050.

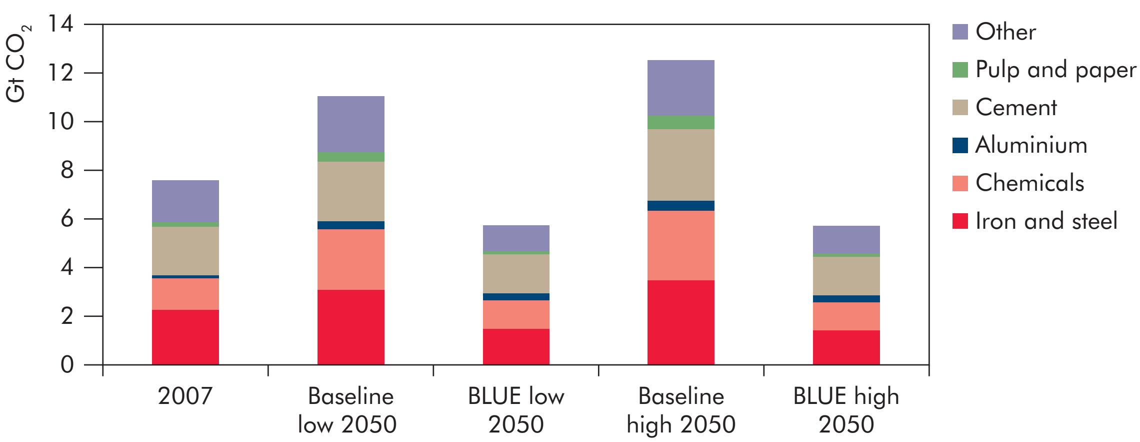
Sectoral results

Industry can significantly reduce emissions by 2050 only if all industrial sectors make a contribution. The projected direct emissions reductions between 2007 and 2050 in the BLUE low- and high-demand scenarios differ according to sector (Figure 5.10).

The aluminium sector shows an increase in direct emissions of 100%, offset by significant indirect emissions reductions from decarbonisation in the power sector. The iron and steel sector reduces its direct emissions by between 35% and 37%. Compared to the Baseline scenarios, total emissions fall in the BLUE low- and high-demand scenarios in 2050 in all five sectors.

In the BLUE low-demand scenario, the share of total CO_2 emissions from the chemical and petrochemical sector rises from 17% in 2007 to 21% in 2050 (Figure 5.10). The iron and steel sector, which is currently the largest emitter, shows the largest potential for reduction. The cement sector, which is currently the second-largest emitter, becomes the largest, accounting for 28% of total direct industrial emissions in 2050.

Figure 5.10 ▶ **Direct energy and process CO_2 emissions in industry by sector**



Key point

All sectors have the potential significantly to reduce emissions.

Iron and steel

The iron and steel sector is the second-largest industrial user of energy, consuming 616 Mtoe in 2007 and the largest industrial source of CO_2 emissions. The five most important producers – China, Japan, the United States, the European Union (EU) and Russia – account for over 70% of total world steel production.

Steel is produced through a dozen or so processing steps, which can take various configurations depending on the product mix, available raw materials, energy supply and investment capital. There are three principal modern processing routes:

- Blast furnace (BF)/basic oxygen furnace (BOF). This uses between 70% and 100% of iron ore, the balance being made up from scrap.
- Scrap/electric arc furnace (EAF). This uses between 70% and 100 % scrap material, with the balance being made up by ore-based materials.
- Direct reduced iron (DRI)/EAF. This uses DRI ore and scrap.

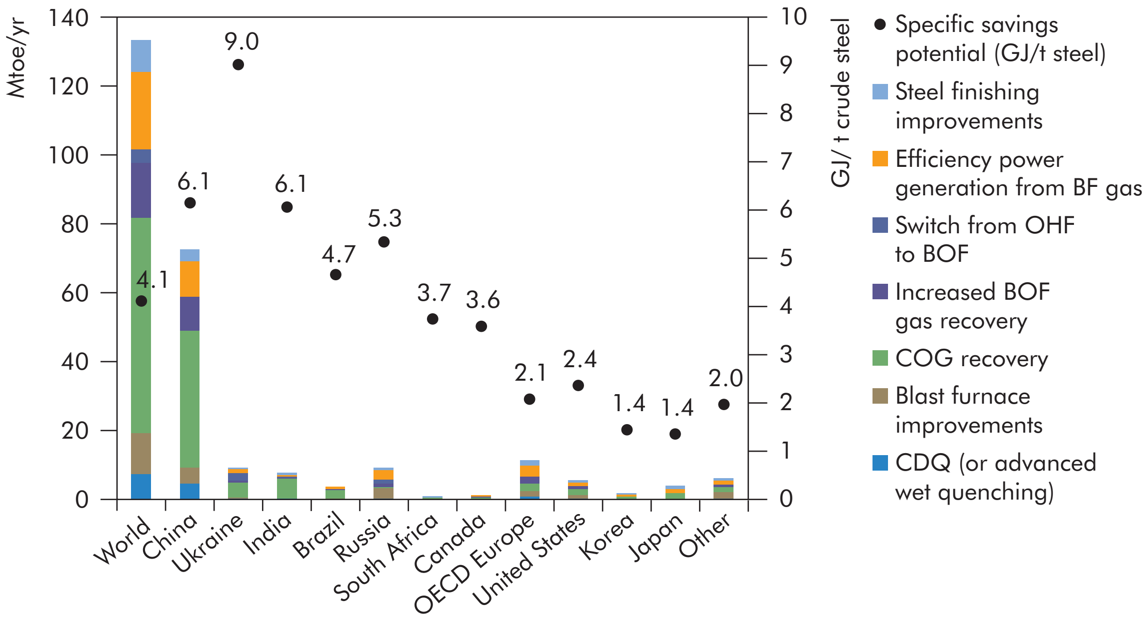
The scrap/EAF route is much less energy-intensive (using 4 GJ to 6 GJ per tonne of iron produced when using 100% scrap) than the BF/BOF route (which uses 13 GJ to 14 GJ per tonne of iron produced). For EAFs using higher levels of ore-based iron, energy use is higher. Significant energy savings can be achieved by switching from BF/BOF to scrap/EAF production, but such changes may be limited by barriers such as the availability of scrap and the demand for higher grades of steel. In China, India and other emerging industrial economies, the BF/BOF route will continue to dominate production.

Energy efficiency and CO_2 reduction potentials

Individual countries offer different technological efficiency potentials (Figure 5.11). The total potential energy saving in the iron and steel industry is 133 Mtoe, equivalent to 421 Mt CO_2 on the basis of current production levels. These potentials are technical and the economic potentials are significantly below these levels as achieving these savings will require re-build or major refurbishments. In some regions with small-scale production and low-quality indigenous coal and iron ore, the reduction potential will be particularly difficult to achieve. China accounts for 55% of the potential energy saving, although a number of other countries have higher potential in terms of energy reductions per unit of steel produced. The average global potential is 4.1 GJ per tonne of crude steel, equivalent to 0.3 tCO_2/tonne of steel produced.

The extensive use of BATs could result in energy and CO_2 reductions of around 20%. This is considerably less than the expected growth in energy demand that will result from production almost doubling in the low-demand case between 2007 and 2050. A net reduction in energy demand and emissions will, therefore, be dependent on significant innovation strategies bringing new technological solutions on stream well before 2050.

Figure 5.11 ▶ **Energy savings potential in 2007 for iron and steel, based on BATs**



Notes: OHF: open-hearth furnace; COG: coke-oven gas; CDQ: coke dry quenching.

Key point

The potential exists to save approximately 130 Mtoe of energy, with country-specific savings potentials of 1.4 to 9.0 GJ/t of crude steel.

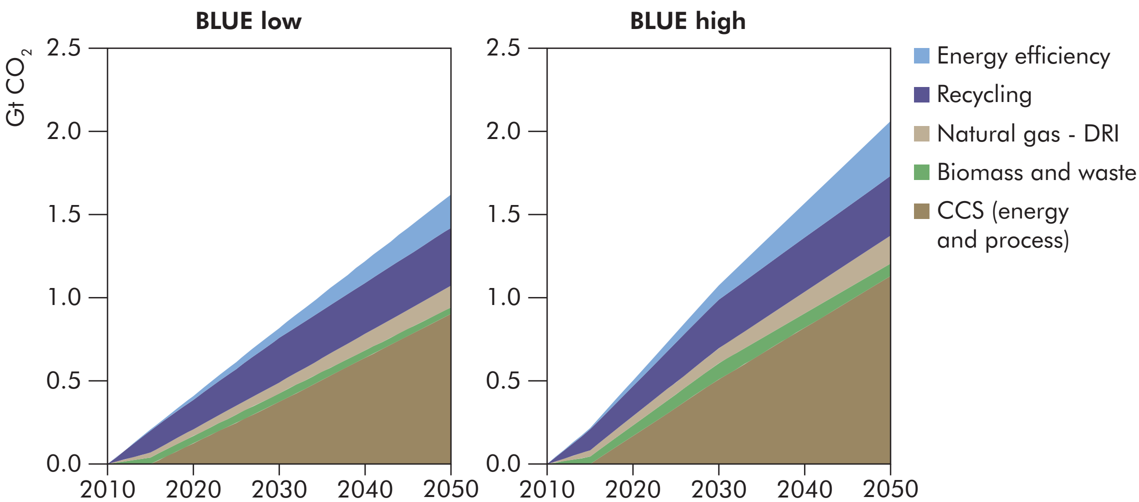
Scenario results

Improvements in materials flow management focus on the increased recovery of steel scrap, the development of new steel types and the design of new steel products. For example, more steel can be recovered from municipal solid waste through mechanical waste separation. For new steel types, significant developments will be needed in the design of alloys and testing procedures.

Crude steel production is estimated to increase from 1 351 Mt in 2007 to 2 408 Mt and 2 857 Mt in 2050 in the low- and high-demand cases respectively. In both cases, China will remain the main crude steel producer, accounting for about 30% of world production. India, other developing Asia, and Africa and Middle East will have the strongest growth rates, with the result that between 32% and 35% of all production in 2050 will be from those countries/regions.

Total direct CO_2 emissions in the iron and steel sector in the BLUE scenarios reach about 1.5 Gt CO_2 in both the low- and high-demand cases in 2050. This represents a decrease of about 35% to 37% in direct emissions compared to 2007. CO_2 intensity decreases by 63% to 70% between 2007 and 2050 in the BLUE scenarios, largely as a result of technological innovation, the introduction of CCS and efficiency gains (including recycling). Initially, recycling dominates (Figure 5.12). From 2020 onwards, fuel switching and CCS start to play a more important role. Total direct emissions reductions amount to 1.6 Gt CO_2 a year in the low-demand case and to 2.1 Gt CO_2 in the high-demand case in 2050. About 55% of this total reduction can be attributed to CCS and about 17% to 21% to increased recycling. Recycling levels in the BLUE scenarios are expected to rise from 444 Mt in 2007 to 1 200 Mt of steel in the low-demand case and to 1 470 Mt in the high-demand case in 2050.

Figure 5.12 ▶ *Direct emissions reduction by technology option for iron and steel*



Key point

Energy efficiency, recycling and CCS are the main options for emissions reduction in the iron and steel sector.

In the Baseline scenarios, energy use almost doubles to 934 Mtoe in the low-demand case and 1 045 Mtoe in the high-demand case. In the BLUE scenarios, energy use rises only to 757 Mtoe in the low-demand case and to 844 Mtoe in the high-demand case. This is 23% and 37% more than in 2007, with production growth being offset by the stronger uptake of energy efficiency measures and more efficient technologies. Coal use in the BLUE scenarios in 2050 is more or less the same as in 2007. All the growth in energy demand in the BLUE scenarios is met by other energy forms such as natural gas, electricity, biomass and waste. Compared to the Baseline scenarios, electricity, natural gas, biomass and waste use increases significantly in relative terms in the BLUE scenarios in 2050. These changes are underpinned by a range of structural changes (Box 5.2). For example, an increase in the use of natural gas for DRI production is offset by significant gas savings attributable to efficiency gains in steel finishing.

Box 5.2 ▶ Impacts of gas availability on use of gas-based direct reduced iron (DRI)

The results of the modelling are based on several assumptions on the production route that will be used to produce steel. Since in the BLUE scenarios the power sector is decarbonised, the model assumes a large increase in production from EAFs. As scrap availability is limited, large increases in gas-based DRI production are assumed in countries with large natural gas resources such as Russia, the Middle East and some South American countries. The increase is more moderate in regions where natural gas availability is more limited. Production from gas-based DRI increases from 51 Mt in 2007 to 329 Mt in 2050 in the BLUE high-demand scenario.

Recognising that the DRI option might be attractive only in locations with cheap stranded gas, a further analysis has been undertaken which limits production from gas-based DRI to no more than a doubling between 2007 and 2050. Initial analysis of the implication of this low growth in gas-based DRI, and the consequently lower levels of production of steel from EAFs, indicates that the large CO_2 savings implicit in the BLUE scenarios could only be achieved if there was particularly strong and fast technology development and deployment.

All new and refurbished units would need to be equipped with carbon capture starting in 2020 and new CO_2-free technologies, or a significant increase in the use of biomass and plastic waste would need to be implemented from 2020. Breakthrough technologies which are currently at the research stage, such as MOE, would need to be commercially available earlier than expected.

Preliminary analysis suggests that the incremental investment cost under this alternative scenario would be between USD 400 billion and USD 500 billion, compared to an investment of USD 300 billion to USD 400 billion if gas-based DRI were to be used, excluding any increased investment needed for the development and deployment of breakthrough technologies.

Technology options

A number of technology options need to be developed and deployed in the iron and steel sector (Table 5.3).

Natural gas-based DRI production enables the complete replacement of coal. It is a well-established technology. Such plants can use relatively small gas reserves, including those which may not be large enough to justify the development of liquefied natural gas (LNG) projects. New DRI projects should be equipped with CCS, the cost of which is highly sensitive to the price of natural gas. Biomass, plastic waste, CO_2-free electricity and hydrogen are other future energy source options. Gas can also be injected into blast furnaces, but volumes are limited by process conditions.

Table 5.3 ▶ Technology options for the iron and steel industry

Technology	R&D needs	Demonstration needs	Deployment milestones
Smelting reduction	Improve heat exchange in FINEX* New configuration of HIsmelt** to lower coal consumption Integration of HIsmelt and Isarna*** processes (Hisarna). Pilot due to start in 2010 Paired straight hearth furnace	Demonstration plants already operational for FINEX and HIsmelt Demonstration plant for producing reduced pellets operational by 2015 Demonstration plant with smelter by 2020	Share rise from 3% in 2015 to 18% in 2030 and 31% in 2050
Top-gas recycling blast furnace	Trial on existing experimental furnace successful	Commercial scale demonstration – small blast furnace – by 2014 Full scale demonstration plant by 2016	Deployment in 2020
Use of charcoal and waste plastic	Proven technologies Research needs to focus on improving the mechanical stability of charcoal		
Production of iron by MOE	Assessment of technical feasibility and optimum operating parameters	If the laboratory-scale project is successful, demonstration may start in the next 15 to 20 years	Deployment after 2025
Hydrogen smelting	Assessment of technical feasibility and optimum operating parameters	If the laboratory-scale project is successful, demonstration may start in the next 15 to 20 years	Deployment after 2025
CCS for blast furnaces	Research focusing on reducing the energy used in capture	2015-2020	2030 all new large plants to be equipped with CCS
CCS for DRI		2015-2020	2030 all new large plants to be equipped with CCS
CCS for smelt reduction		2020-2030	2035 all new large plants to be equipped with CCS

Notes: * FINEX is a smelting reduction process developed by POSCO which consists of a melting furnace with a liquid iron bath where coal is injected and a cascade of fluidised bed reactors for the pre-reduction of iron fines.

** HIsmelt (high-intensity smelting) is an iron bath reactor process.

***Isarna is a smelting reduction technology under development by ULCOS. It is a highly energy-efficient iron making process based on direct smelting of iron ore fines using a smelting cyclone in combination with a coal-based smelter. All process steps are directly hot-coupled, avoiding energy losses from intermediate treatment of materials and process gases.

CCS can play an important role in reducing CO_2 emissions in the iron and steel industry. If 1.1 Gt CO_2 emissions are to be avoided through CCS in the iron and steel sector by 2050, significant deployment would need to be achieved by 2030. This requires that the technology has been demonstrated at plant level by 2020. Urgent action will be needed in the next ten years to demonstrate CCS for blast furnaces, smelting reduction plants and DRI. Government support for CCS, which has focused on the power sector, should also be extended to demonstration projects in the iron and steel sector.

Investment costs

Table 5.4 provides a breakdown of the investment needs implicit in the Baseline and BLUE scenarios. Total investments in the Baseline scenarios amount to between USD 2.0 trillion and USD 2.3 trillion between now and 2050. In the BLUE scenarios, these rise to between USD 2.3 trillion and USD 2.7 trillion. Total incremental costs for the iron and steel sector to reach the BLUE scenario outcomes are approximately USD 300 billion to USD 400 billion, roughly 15% to 20% higher than Baseline investment needs.

Table 5.4 ▶ ***Additional investment needs in the iron and steel sector to 2050: BLUE scenarios compared to Baseline scenarios***

USD bn	China	OECD Europe	India	United States	World
Total	130 to 160	20 to 25	90 to 115	10 to 15	300 to 400

Cement

China is by far the largest cement producer with 49% of world production in 2007. India, the second-largest producer, accounts for only 6% of global cement production.

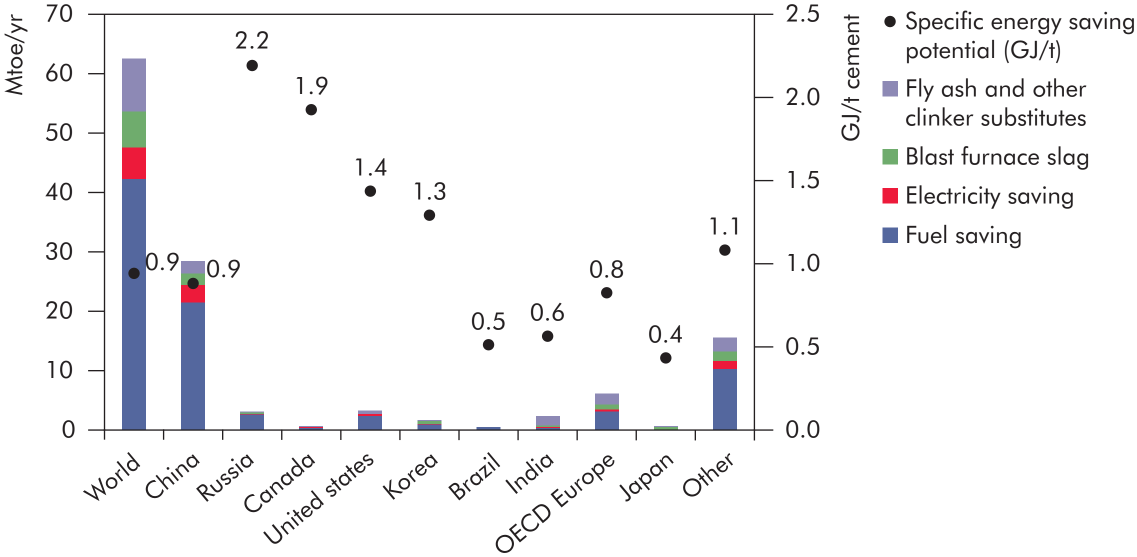
Cement production uses about 240 Mtoe of energy, equivalent to 80% of all energy used in non-metallic minerals production. The average final energy intensity for cement production for those countries with available data ranges from 2.9 GJ/t to 4.7 GJ/t cement, including electricity. The thermal energy needed ranges from around 3.2 GJ to 4.5 GJ/t of clinker produced. The cement industry has made significant strides in reducing energy consumption, with China reducing its thermal energy intensity per tonne of clinker by a quarter since 1990. The cement industry also uses significant amounts of electricity, equivalent to around 310 terawatt-hours (TWh) in 2007.

The industry is a significant source of CO_2 emissions. Coal accounts for around 60% of the fuel burned in cement kilns. Total direct CO_2 emissions from cement production amounted to 2.0 Gt CO_2 in 2007, with around 0.8 Gt CO_2 emitted from fuel combustion and 1.2 Gt CO_2 from processes.

Energy efficiency and CO_2 reduction potentials

The thermal energy consumption of the cement industry is strongly linked to the type of kiln used. The relatively efficient dry process with pre-heaters and pre-calciners is the technology of choice for new plants as shown by trends in the stock of plants in operation. The increasing share of dry-process kilns with pre-heaters and pre-calciners has had a clear impact on energy consumption in clinker production. The average thermal energy consumption per tonne of clinker has fallen by approximately 15% since 1990. The current average global intensity is 3.9 GJ per tonne of clinker.

Figure 5.13 ▶ Energy savings potential in 2007 for cement, based on BATs



Key point

China has the largest absolute potential for energy savings, but other countries have larger energy savings potential per unit of output.

A wet kiln can use between 5.9 GJ and 6.7 GJ/t clinker. Current BATs for six-stage pre-heater and pre-calciner kilns is in the range of 2.9 GJ to 3.3 GJ/t clinker. If all plants were BATs, assuming an average fuel need of 3.2 GJ/t clinker, 42 Mtoe a year of energy could be saved, equivalent to around 20% of current consumption. Shifting to BATs for electricity consumption would achieve savings of around 60 TWh (equivalent to around 5.2 Mtoe). The availability of clinker substitutes is sufficient to allow the cement-to-clinker ratio to be reduced to 0.7 globally, theoretically enabling a saving of a further 15 Mtoe of thermal energy. Taking into account all these potentials, the global intensity of cement production could be reduced by 0.9 GJ/t of cement produced, with significantly higher savings possible in many countries and regions (Figure 5.13).

CO_2 savings in cement production tend broadly to reflect the levels of energy saving. Shifting to BATs, maximising the use of clinker substitutes and increasing the proportion of alternative fuels could result in CO_2 savings of around 520 Mt CO_2 a year globally, including savings in process emissions.

Scenario results

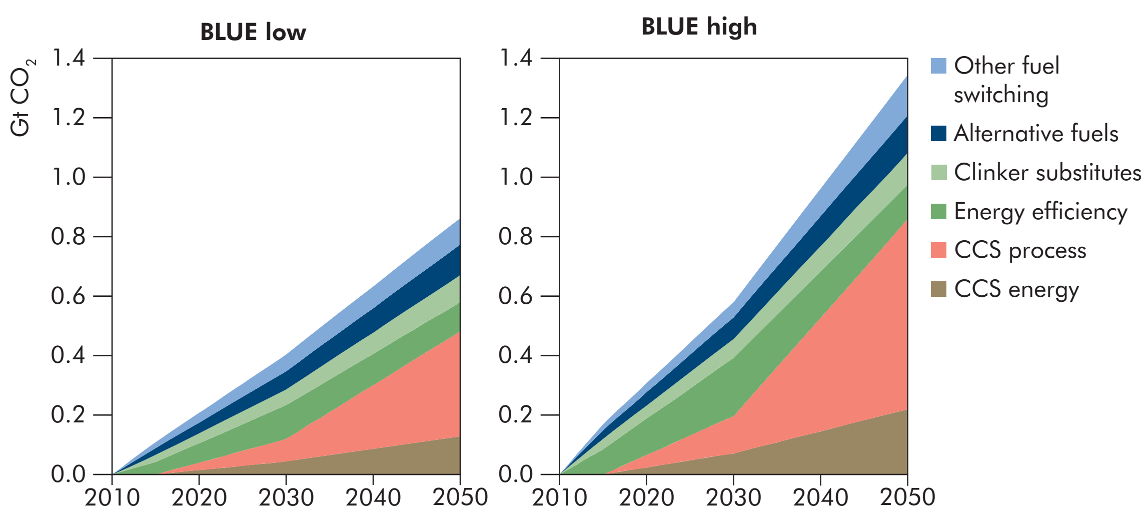
Cement demand is assumed to grow from around 2 774 Mt in 2007 to 3 817 Mt in the low-demand case or 4 586 Mt in the high-demand case in 2050. Demand in China peaks between 2015 and 2030 in both cases as per-capita cement consumption nears the levels in more developed countries. China's consumption is lower in both cases in 2050 than the 1 354 Mt it consumed in 2007, at 1 000 Mt in the low-demand case or 1 200 Mt in the high-demand case. Between 2007 and

2050, more than 95% of the growth in cement demand will come from non-OECD countries, reflecting the fact that many OECD countries are projected to experience declining populations between 2030 and 2050.

Total final energy consumption in the cement sector grows from 240 Mtoe in 2007 to 273 Mtoe in 2050 in the Baseline low-demand scenario and to 327 Mtoe in the Baseline high-demand scenario. In the BLUE scenarios, energy use is approximately 5% to 14% higher at 287 Mtoe in the BLUE low-demand case and 372 Mtoe in the BLUE high-demand case as an estimated 48 to 85 Mtoe of additional energy is needed for CCS.

The shift to BATs, the increased use of clinker substitutes and alternative fuels and the application of CCS reduce direct CO_2 emissions from the cement industry by around 20% below 2007 levels in the BLUE low- and high-demand scenarios (Figure 5.14). This represents a reduction from the Baseline level in 2050 of 0.85 Gt CO_2 in the BLUE low-demand scenario and 1.3 Gt CO_2 in the BLUE high-demand scenario. CCS is expected to contribute most of the savings, saving 0.5 Gt CO_2 in the BLUE low-demand scenario and 1.0 Gt CO_2 in the BLUE high-demand scenario. In both scenarios, CCS is essential to reduce emissions below today's levels. CCS dominates total savings by 2050, accounting for more than half the reduction below the Baseline scenarios by that time.

Figure 5.14 ▶ Direct emissions reduction by technology option for cement



Key point

CCS represents the largest share of CO_2 savings in the cement sector.

Technology options

A number of technology options need to be exploited to reduce emissions in the cement sector (Table 5.5). The four main options for the sector are increased energy efficiency and improvements in BATs; higher shares of alternative fuel use; the use of greater volumes of clinker substitutes; and CCS.

Cement companies should deploy existing BATs in new cement plants and retrofit energy efficiency equipment where economically viable. There is also a need to close down the remaining wet kilns which are almost twice as energy-intensive as current BATs. The use of less carbon-intensive fossil fuels and of more alternative fossil and biomass fuels also offers the possibility of reducing CO_2 intensity. Stronger policy support will be needed to reach the levels outlined in the BLUE scenarios. Further reductions in cement-to-clinker ratios will require additional R&D to assess substitution materials and to evaluate regional availability. The development and implementation of international standards for blended cements would also support greater use of clinker substitutes.

Table 5.5 ▶ ***Technology options for the cement industry***

Technology	R&D needs	Demonstration needs	Deployment milestones
Energy efficiency and shift to BATs	Fluidised bed technology Ongoing further improvements to BATs		Phase-out of wet kilns International standard for new kilns
Alternative fuels	Ongoing identification and classification of suitable alternative fuels		Share to rise from 5% in 2010 to 12% in 2020, 23% in 2030 and 37% by 2050
Clinker substitutes	Analyse substitution material properties and evaluate regional availability Develop and implement international standards for blended cements		Cement-to-clinker ratio falling from 77% in 2010 to 74% in 2020, 73% in 2030 and 71% by 2050
CCS post-combustion	Pilot plant needed by 2012	2015-2020	From 2020 for large new plants and retrofits
CCS oxyfuelling	Gas cleaning	2020-2030	All large new plants to be equipped with CCS from 2030

The widespread application of CCS is essential if the cement sector is to reduce CO_2 emissions below today's levels. In the BLUE low- and high-demand scenarios, 0.5 Gt and 1.0 Gt of CO_2 respectively are sequestered annually in 2050. Reaching these levels implies that CCS needs to be demonstrated at cement plants from around 2015 in order to ensure that a number of technology platforms are tested as early as possible. This would be an essential precursor to the beginning of commercial deployment in 2020 to 2025.

Such a rapid expansion of CCS will require between 20% and 30% of new plants to be equipped with CCS by 2030 and some retrofitting of post-combustion technology to existing plant. As with other sectors, this implies that there is a 10-year window in which CCS needs to be demonstrated if it is to be deployed at its lowest possible cost. If CCS were not commercially available until 2030, achieving the BLUE scenarios would require greater retrofitting of CCS to large or medium-scale plants after 2030 in order to ensure that between 26% and 40% of the stock of cement kilns in 2050 are fitted with CCS. This would significantly increase the marginal cost in the BLUE scenarios.

Investment costs

The additional investment needed to achieve the CO_2 reduction outlined in the BLUE scenarios is in the range of USD 350 billion to USD 840 billion (Table 5.6). Much of the additional investment will be needed in developing countries where CO_2 policies are now emerging. Overcoming the barriers in developing economies posed by limited capital and multiple demands for its use will be critical.

Investment needs for the cement industry are dominated by the additional upfront costs of CCS installations at cement plants. In Europe, CCS could double the capital cost of a cement plant (ECRA, 2009), as well as increase energy use and operating costs. The total investment needs and marginal abatement costs for the cement industry are critically sensitive to the future costs of CCS. In the short term, CCS development and demonstration will require strong government support as industry cannot bear these costs alone. An estimated USD 2 billion to USD 3 billion is required to fund CCS demonstration projects in the cement industry and an additional USD 30 billion to USD 50 billion will be needed by 2030 for deployment.

Table 5.6 ▶ **Additional investment needs in the cement sector to 2050: BLUE scenarios compared to Baseline scenarios**

USD bn	China	Europe	India	United States	World
Total	50 to 130	35 to 100	50 to 150	30 to 80	350 to 840

Chemicals

The chemical and petrochemical sector is by far the largest industrial energy user, accounting for almost 30% of all industrial final energy demand. It accounts for roughly 10% of total worldwide final energy demand, equivalent to 879 Mtoe/yr,[2] and is responsible for 7% of global CO_2 emissions. In 2007, the process energy requirements of the chemical and petrochemical sector emitted approximately 1 280 Mt CO_2, excluding indirect emissions from power use and from the treatment of post-consumer waste, *e.g.* from the incineration of plastics. Fossil fuels are used in the sector both for energy production and as feedstocks for the production of organic chemicals and a number of inorganic chemicals, including ammonia.

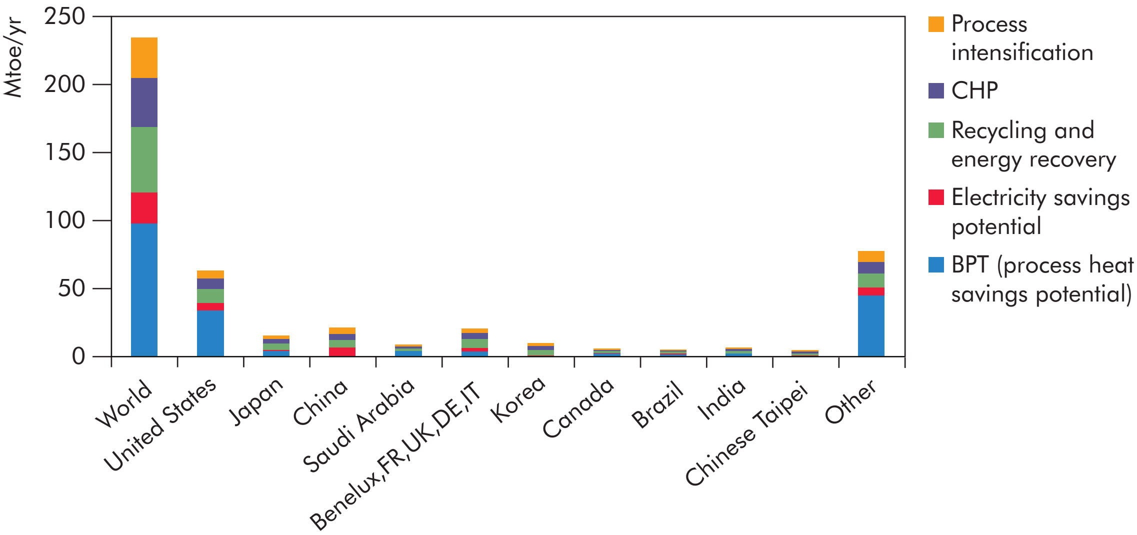
Energy efficiency and CO_2 reduction potentials

The global chemical and petrochemical sector has significant potential to improve its energy intensity through the implementation of best practice technology (BPT)[3] in core chemical processes (121 Mtoe) and other opportunities for energy

2. Final process energy is the total of demand of fuel (excluding feedstock energy), steam use and electricity. Final energy is the sum of final process energy and feedstock energy. Primary energy use is the sum of final energy and the conversion losses for producing steam and electricity.
3. In the chemical and petrochemical sector, given the scale of most plants, it is more appropriate to analyse potentials by reference to the most advanced technologies that are currently in use at industrial scale. This is known as best practice technology (BPT) as distinct from the best available technology (BATs) reference points used in other contexts.

saving (Figure 5.15). Process intensification/integration, CHP, recycling and energy recovery all offer opportunities for reducing the industry's energy use and CO_2 emissions. The total worldwide potential saving from these measures is approximately 235 Mtoe/yr in final energy and approximately 290 Mtoe/yr in primary energy use. The largest regional potential is in the United States.

Figure 5.15 ► ***Energy savings potential in 2007 for chemicals, based on BPT***



Key point

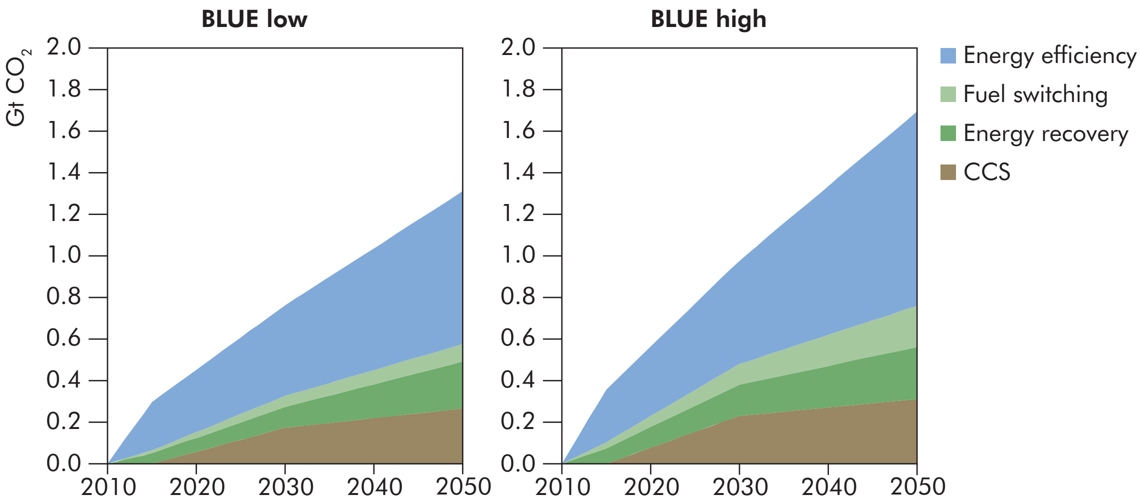
The current technical potential for global energy savings in the chemical and petrochemical sector is estimated at 235 Mtoe.

Scenario results

Worldwide production of high-value chemicals (HVCs) is projected to grow by 8 Mt to 14 Mt a year from 2007 to 2050. This is similar to the 10 Mt a year growth from 1990 to 2005. HVC production between 2007 and 2050 increases by 330 Mt to 600 Mt in the Baseline scenarios. It grows by a smaller amount, around 245 Mt to 340 Mt, in the BLUE scenarios as higher recycling rates reduce the need for HVC production. Ammonia production rises at a higher rate between 2007 and 2050 than in the last decade, increasing by 63% (100 Mt) in the low-demand case and almost doubling (increasing by 140 Mt) in the high-demand case. Methanol production is also projected to increase at a higher rate between 2007 and 2050 than in the last decade, more than tripling in both the high- and low-demand cases. Global growth in the chemical sector will be fuelled by China, the Middle East and other developing Asia, with production relatively flat in both North America and Europe.

In the Baseline scenarios, total final energy use increases by between 119% and 163% by 2050 compared to 2007. In the same period, the BLUE scenarios show an increase in final energy use of 59% to 75%. In the Baseline scenarios, total energy use in 2050 reaches 1 925 Mtoe in the low-demand case and 2 310 Mtoe in the high-demand case compared to 880 Mtoe in 2007. Energy use in 2050 in the BLUE scenarios rises much less, reaching 1 400 Mtoe and 1 540 Mtoe in the low- and high-demand cases respectively as greater levels of energy efficiency help to reduce energy intensity.

Figure 5.16 ▶ Direct emissions reduction by technology option for chemicals and petrochemicals



Key point

Energy efficiency offers the largest opportunities for CO_2 savings in the chemical and petrochemical sector.

Worldwide direct CO_2 emissions in the Baseline low- and high-demand scenarios are projected to more than double by 2050, increasing from 1.3 Gt in 2007 to 2.5 Gt and 2.9 Gt respectively in 2050. Worldwide direct CO_2 emissions by 2050 in the BLUE scenarios at around 1.2 Gt are about 7% lower than 2007 emissions and 52% (low-demand case) and 59% (high-demand case) lower than the Baseline scenario levels for 2050.

In the BLUE scenarios, the largest reductions in direct emissions come from energy efficiency improvements (Figure 5.16). These save an estimated 735 Mt CO_2 in the low-demand case and 935 Mt CO_2 in the high-demand case in 2050. In the BLUE high-demand scenario, fuel switching contributes emissions reductions of 200 Mt CO_2 in 2050, although in the BLUE low-demand scenario it contributes savings of only 85 Mt CO_2. CCS accounts for savings of 265 Mt CO_2 and 310 Mt CO_2 in 2050 in the BLUE low- and high-demand scenarios respectively.

Technology options

Developments in the last fifty years have seen the products of this sector, such as plastics, increasingly substitute for other engineering materials such as steel and glass.

Major productivity increases and improvements in material and process performance in other sectors, for example yields in the agricultural sector, have been enabled to a substantial extent by chemical products. The chemical and petrochemical sector continues to be very innovative. But it is unclear how it will develop in future, for example if the need to pass on substantially higher oil and gas prices slows down the demand for products of the industry. Even so, a growing world population is likely to require more fertilisers for food production and to help meet increased demand for biomass as a fuel and a feedstock. The chemical and petrochemical sector is also likely to play an important role in developing and supplying the materials needed to support growth in renewable energy and to enhance energy efficiency, such as lightweight materials for vehicles and more powerful batteries, and more effective agents for the removal of CO_2 from flue gases.

The implementation of BPT in the short term and of new technologies in the long term would enable the sector significantly to reduce both its energy needs and its CO_2 intensity. A wide range of technology options needs to be applied in order to reach the emission levels implicit in the BLUE scenarios. Ambitious R&D, spanning from basic to applied research, followed by strong and effective technology development is needed to reach these goals. New developments in catalysts, membranes and other separation processes, process intensification and bio-based chemicals could bring about very substantial energy savings. All countries should strive to achieve BPT levels by 2025. New technologies will need to be brought on stream from 2020 onwards. A number of technology goals will need to be met if the chemical and petrochemical sector is to contribute its full potential CO_2 emission savings (Table 5.7).

CCS can make an important contribution to reducing emissions in the sector. Early deployment should focus on implementation in ammonia plants. CCS in combination with large-scale CHP and in HVC production will also need to be developed for the sector to realise its full potential.

New investments are likely to remain in use for many decades. As companies make new investments in coming years, they will be making fundamental and in many cases irreversible choices about feedstocks. First-of-a-kind large-scale plants for the production of bio-based chemicals and plastics are currently being built. The experience gained by these plants and their products in the next 10 to 20 years will determine to a large extent the success or failure of bio-based chemicals and plastics. Policy support needs to extend over relatively long periods in order to be successful. Designing suitable and affordable policies for bio-based chemicals and plastics is a challenge given the complexity of the sector and its products, international trade agreements and the need to avoid displacing food production.

R&D on materials development and adapted design techniques that can, for example, maximise material efficiency and facilitate disassembly and separation is required to enable the potential of recycling fully to be exploited. Strong policy support is needed in order to expand collection schemes. Recycling can be optimised through the use of a portfolio of mechanical and chemical recycling steps, followed by highly efficient incineration with energy recovery.

Table 5.7 ▶ **Technology options for the chemical industry**

Technology	R&D needs	Demonstration needs	Deployment milestones
New olefin production technologies	Improve methanol-to-olefin (MTO) processes and oxidative coupling of methane (OCM)		Currently under way with greater penetration from 2020
Other catalytic processes	Improve performance and further reduce gap to thermodynamically optimal catalytic process by 65% to 80%	Under way	Starting in 2020 to 2025
Membranes	Develop other novel separation technologies		Expand use of membrane separation technologies
Bio-based chemicals and plastics	Develop bio-based polymers	Bio-based monomers	Wider use of bio-based feedstocks from 2025
CCS for ammonia		Two plants by 2012	20 plants by 2020 and 50 plants by 2030

Investment costs

In *ETP 2010*, the BLUE scenarios bring into effect technologies that are cost-effective with a carbon price of up to USD 175/tCO_2. Cumulative investment needs up to 2050 are estimated at USD 4.1 trillion in the Baseline low-demand case and USD 4.7 trillion in the Baseline high-demand case. In the same period, additional investment of USD 0.4 trillion is needed in the BLUE low-demand case and USD 0.5 trillion in the BLUE high-demand case (Table 5.8), resulting in cumulative investments of USD 4.5 trillion and USD 5.2 trillion respectively.

If successfully developed, membrane technology and catalysts could be implemented at very low or even negative additional cost. This may also be the case for some process-intensification processes. Additional investment costs could, however, be substantial for process integration and for CCS, especially in smaller plants. The capital cost of new olefin technologies could be substantially larger than that of current technologies because of the increase in the process steps involved. Additional investment costs for bio-based plastics and chemicals could also be substantial although some products are likely to be significantly less expensive to produce than others.

Table 5.8 ▶ ***Additional investment needs in the chemical sector to 2050:* BLUE scenarios compared to Baseline scenarios**

USD bn	China	Europe	India	United States	World
Total	60 to 100	50 to 70	15 to 25	60 to 80	400 to 500

Pulp and paper

The pulp and paper sector is the fourth-largest industrial sector in terms of energy use, consuming 164 Mtoe of energy in 2007, 5% of total global industrial energy consumption. The primary input for pulp and paper manufacture is wood. The industry, therefore, usually has ready access to biomass resources and it generates from biomass approximately a third of its own energy needs. It also produces energy as a by-product. The majority of the fuel used in pulp and paper making is used to produce heat. Just over a quarter is used to generate electricity.

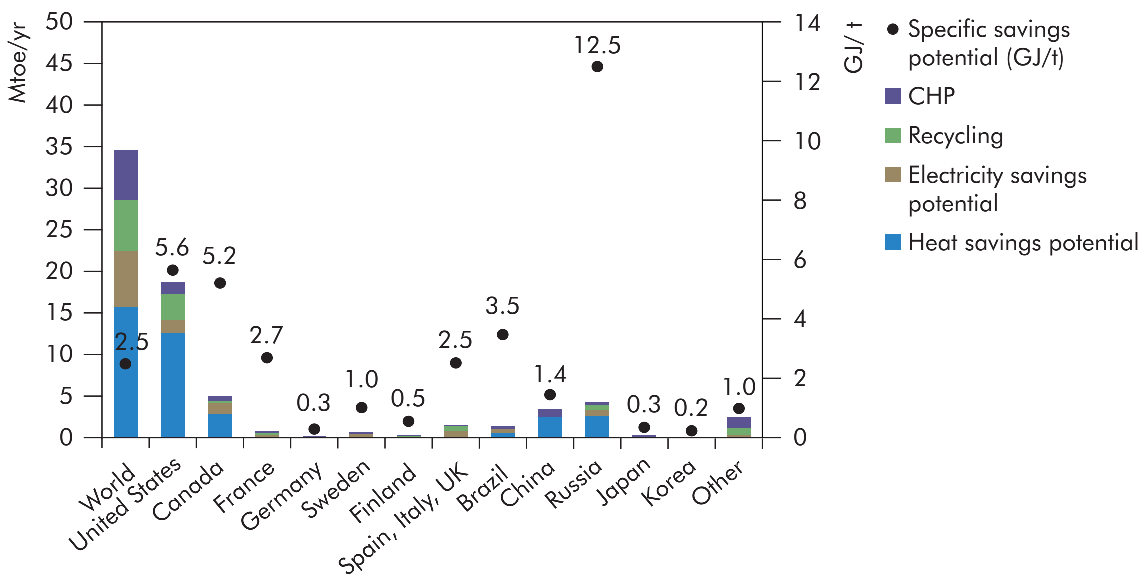
Its large use of biomass makes the sector one of the least CO_2-intensive, although large variations exist between different countries depending on biomass availability and industry structure. The sector emitted 183 Mt of CO_2 in 2007, representing 2% of direct emissions from industry.

Energy efficiency and CO_2 reduction potentials

The main production facilities are either pulp mills or integrated paper and pulp mills. An integrated mill is more energy-efficient than the combination of a stand-alone pulp mill and paper mill because pulp drying can be avoided. But integrated plants require grid electricity as well as additional fuel.

Most of the energy efficiency improvement that has so far been achieved has come from integrated pulp and paper mills in which recovered heat is used in the production process, for example to dry the paper. Investment in heat recovery systems in stand-alone mechanical pulp mills is not economically viable.

Figure 5.17 ▶ Energy savings potential in the pulp and paper sector in 2007, based on BATs



Key point

Global technical potential for energy savings in the pulp and paper sector is estimated at 35 Mtoe with the largest savings potential in Canada and the United States.

The application of BATs would yield total energy savings of 14% for heat and electricity use, equivalent to nearly 16 Mtoe of heat and 6.8 Mtoe of electricity (Figure 5.17). If global recycling was increased to the current EU level of 60%, another 6 Mtoe of energy could be saved. Higher CHP use could achieve an additional saving of approximately 6 Mtoe. Total savings for the sector are estimated at approximately 35 Mtoe, equivalent to 21% of total current energy use.

Scenario results

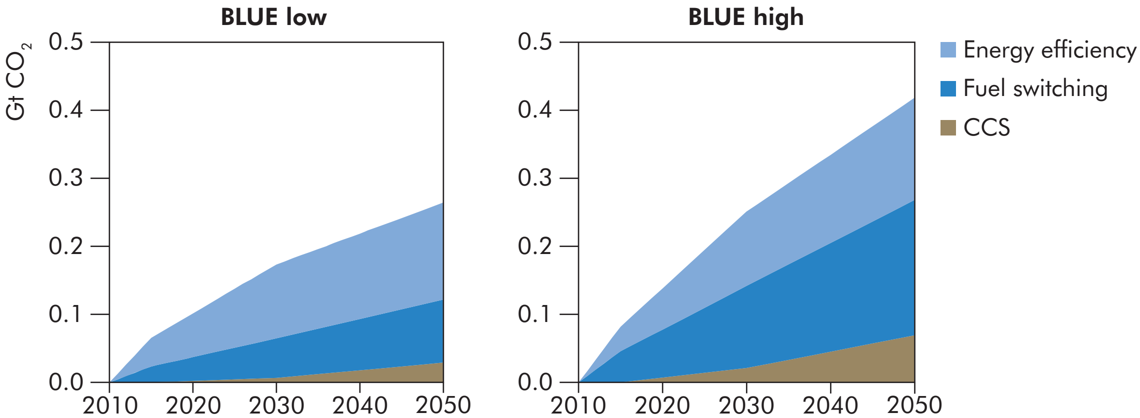
Paper and paperboard consumption is assumed to continue to grow most strongly in non-OECD countries, especially in Asia where demand from China is expected to increase fivefold from current levels by 2050 in the high-demand cases. As a consequence, the global share of paper and paperboard consumption shifts significantly from OECD to non-OECD countries with the share from the former falling from 65% today to between 32% and 24% by 2050. Consumption in China and India could match that of all OECD countries by 2050 in the high-demand case. World paper production is estimated to reach almost 800 Mt by 2050 in the low-demand case and over 1 100 Mt in the high-demand case.

Recycling levels are already relatively high with a global recycling rate of 50%. Many countries are already at or near their practical limits. But in others, especially developing countries, some growth can be expected in the future. In the Baseline scenarios, recovered paper utilisation is expected to reach 54% in 2050, while in the BLUE scenarios these levels are assumed to grow further, to 60%. Higher recycling levels can significantly reduce energy use as recovered paper pulp uses 10 GJ to 13 GJ less energy per tonne than the production of virgin pulp.

Energy use in the pulp and paper sector is expected to rise from 164 Mtoe in 2007 to 304 Mtoe in 2050 in the Baseline low-demand scenario. In the BLUE low-demand scenario, energy use will reach 270 Mtoe in 2050, 11% less than in the Baseline scenario, as higher energy efficiency reduces energy intensity. Biomass today represents 33% of total energy use. This is expected to rise to approximately 60% in 2050 in both the BLUE low- and high-demand scenarios as fuel switching takes place to reduce emissions. Electricity consumption in the sector in 2050 is expected to rise from 43 Mtoe in 2007 to 77 Mtoe in the Baseline low-demand case and to 105 Mtoe in the Baseline high-demand case scenarios and to 69 Mtoe and 94 Mtoe in the equivalent BLUE scenarios. In all regions, the share of fossil fuels will need to fall significantly to achieve the BLUE scenario outcomes, although fossil fuels will still represent a large share of total fuel use in China and India.

In the BLUE scenarios, where CCS is applied to black liquor gasifiers in regions with a high usage of biomass, the sector becomes a CO_2 sink, reducing overall global emissions. Total direct and indirect emissions in the BLUE scenarios fall by 56% from 405 Mt in 2007 to 175 Mt in 2050. The decrease in direct emissions is significantly less, at 30%. This reflects the extent to which the decarbonisation of the power sector impacts on overall emissions in the pulp and paper sector.

Figure 5.18 ▶ Direct emissions reduction by technology option for pulp and paper



Key point

Energy efficiency makes the largest contribution to CO_2 savings in the pulp and paper sector.

In the BLUE low-demand case in 2050, energy efficiency represents the largest share of savings as compared to the Baseline scenario, at 54%, followed by fuel switching which represents 35% (Figure 5.18). In the BLUE high-demand case, fuel switching plays the most important role in reducing emissions, accounting for 47% of the reduction, while energy efficiency contributes 36% of the reduction. By 2050, total emissions reductions in the sector are 264 Mt CO_2 in the BLUE low-demand scenario and 418 Mt CO_2 in the BLUE high-demand case. CCS, which is a later option for the sector, begins to have an impact by 2030 and accounts for 11% of the reductions in the BLUE low-demand scenario and 17% of the reductions in the BLUE high-demand scenario.

Technology options

The implementation of BATs and the future implementation of newly emerging technologies would enable the sector significantly to reduce both its energy needs and its CO_2 intensity. A wide range of technology options and opportunities need to be deployed if the outcomes implicit in the BLUE scenarios are to be achieved (Table 5.9). All countries need to try to achieve BATs levels by 2025 and to improve on BATs by 15% to 20% by 2035 through the wide deployment of black liquor and biomass gasification, increased waste heat recovery and new technologies in pulping and papermaking.

RD&D priorities should focus on improving biomass conversion technologies, more efficient water-extraction technologies and reducing the use of water in pulp washing and paper making. Improved reliability and gas clean-up for gasification is needed in the short term. Early commercial biomass-integrated gasification with combined cycle (BIGCC) plants need to be deployed within the next five to ten years and wider deployment should occur from 2015 to 2025. In addition to black liquor gasification, lignin production from black liquor and biomass gasification with synfuel production also offers attractive opportunities to increase biomass use in the sector and to raise the profitability of pulp and paper mills.

Table 5.9 ▶ Technology options for the pulp and paper industry

Technology	R&D needs	Demonstration needs	Deployment milestones
Black liquor gasification	Improved reliability and gas clean-up	Under way	Beginning in 2015 to 2025
Biomass conversion to fuels and chemicals	Efficient and low-cost removal of tar Production of high-value chemicals and liquid fuels	Under way	Beginning in 2015 to 2025
Advanced water-removal technologies	Enhance water-removal techniques		
CCS		Two plants by 2020 - 2025	Starting in 2030

In OECD countries, significant attention has been placed on developing biorefineries within the forest-based industries. The development of biorefineries within the pulp and paper industry could have positive impacts on the energy intensity, carbon intensity and profitability of the sector.

Additional CO_2 emissions reductions can be achieved if CCS is developed for BIGCC technology. The scenario analysis shows that an additional 30 Mt to 70 Mt of CO_2 can be saved in the sector with CCS. To reach this level of CCS, at least two demonstration plants would need to be on stream by 2020 to 2025, with more extensive deployment beginning by 2030. By 2050, approximately one-third of all CO_2 emitted from black liquor gasification would need to be captured and stored if the outcomes implicit in the BLUE scenarios were to be achieved.

Investment costs

Total investments in the Baseline scenarios amount to between USD 1.2 trillion and USD 1.35 trillion between now and 2050. In the BLUE scenarios, the additional investment costs over Baseline investments are USD 140 billion in the low-demand scenario and nearly USD 160 billion in the high-demand scenario (Table 5.10).

Table 5.10 ▶ Additional investment needs in the pulp and paper sector to 2050: BLUE scenarios compared to Baseline scenarios

USD bn	China	Europe	India	United States	World
Total	30 to 40	25 to 35	5 to 10	40 to 50	140 to 160

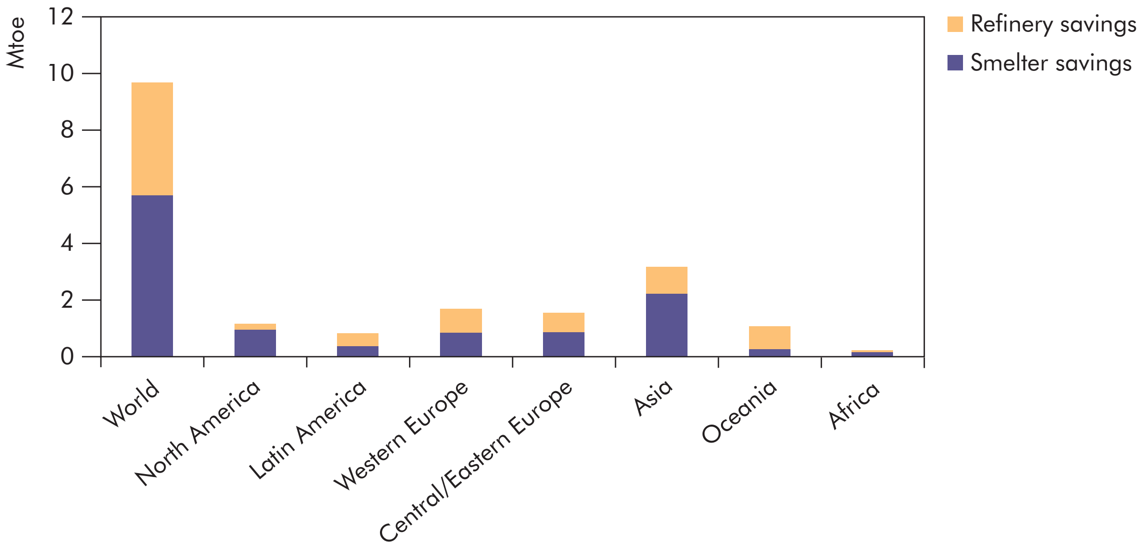
Aluminium

Final energy consumption in the global aluminium industry in 2007 was estimated to be 93 Mtoe. The industry is highly electricity-intensive. Primary aluminium smelters used just over 50 Mtoe of electricity in 2007,[4] equivalent to about 4% of global electricity consumption. In total, the aluminium industry emits 0.4 Gt CO_2-equivalent of greenhouse gases, including process emissions and indirect emissions from electricity production, equivalent to just under 1% of total global greenhouse-gas emissions.

Energy efficiency and CO_2 reduction potentials

The industry has steadily improved its energy efficiency in recent years. Globally, the electricity consumption of smelters has improved by an average of 0.4% a year since 1980. Smelters used 15.5 MWh/t of primary aluminium produced in 2007. China and Africa have the newest and most efficient smelters. Energy consumption in alumina refineries has also been reduced over time. The world average use is now around 17 GJ/t of alumina. China has the most energy-intensive alumina refineries because of the characteristics of its bauxite deposits.

Figure 5.19 ▶ Energy savings potential in 2007 in the aluminium sector, based on BATs



Key point

Implementation of BATs in aluminium refineries and smelters offers significant opportunities for energy savings.

4. IEA estimate based on International Aluminium Institute data for 2007 on the global average specific power consumption of smelters and global production of primary aluminium.

The CO_2 impact of aluminium production depends on the fuel mix of the electricity that is used to produce it. Countries such as those in North America that use significant amounts of hydropower can produce aluminium less CO_2-intensively than countries such as China that use significant amounts of coal in their electricity mix.

BATs offers the opportunity to reduce energy use in aluminium production by 10% compared with current levels (Figure 5.19). This is equivalent to final energy savings of about 9.7 Mtoe a year and direct and indirect emissions savings of 47 Mt CO_2.

Scenario results

Demand for aluminium is assumed to grow substantially up to 2050 because of higher consumption across a wide range of sectors, especially transport, buildings and engineering. World average per-capita demand almost doubles in the Baseline low-demand scenario and grows by more than 2.5 times in the Baseline high-demand scenario. To meet this increased demand, primary aluminium production reaches 95 Mt by 2050 in the Baseline low-demand scenario and increases to 127 Mt in the high-demand case. In both scenarios, most growth is outside the OECD, with strong increases in Asia, the economies in transition, and Africa and the Middle East.

Aluminium recycling is also expected to increase strongly. In the Baseline scenarios, recycled production rises to 47 Mt in 2050 in the low-demand case and to 63 Mt in the high-demand case, continuing to represent around one-third of finished products. In the two BLUE scenarios, total aluminium production is assumed to be the same as in the corresponding Baseline scenarios, but the recycled production increases to 56 Mt and 76 Mt in 2050 in the low- and high-demand BLUE scenarios respectively, representing about 40% of finished products.[5]

In the BLUE scenarios, energy use in 2050 is 14% (low-demand case) to 28% (high-demand case) lower than in the equivalent Baseline scenarios. In the BLUE low-demand scenario, these energy efficiency gains are largely achieved through further development of existing technology together with some deployment of new technologies. In the BLUE high-demand scenario, the widespread introduction of wetted drained cathodes and inert anodes from 2015 and of carbothermic reduction technologies from 2030 is assumed to reduce the global average electricity intensity of smelting in 2050 to 10.9 MWh/t of primary aluminium.

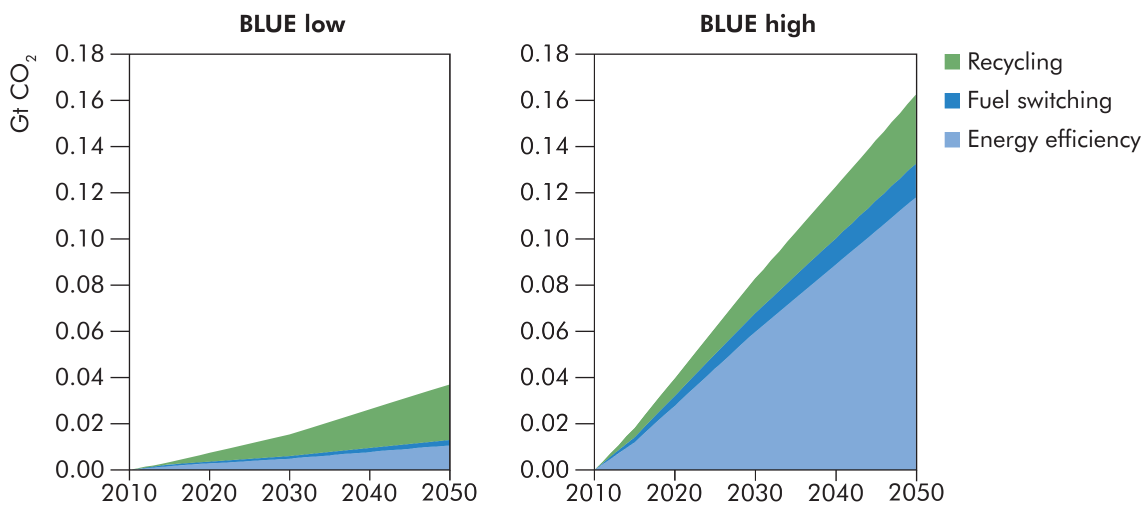
In the Baseline scenarios, total direct and indirect CO_2 emissions grow from around 0.4 Gt in 2007 to 1.0 Gt (low-demand case) and 1.3 Gt (high-demand case) by 2050.[6] Emissions grow less than final energy use as a result of the lower CO_2 intensity of the fuel mix in 2050 resulting from fuel switching. In the BLUE scenarios, total CO_2 emissions fall by 63% in the low-demand case or 72% in the high-demand case compared to the equivalent Baseline scenario cases, reaching 0.4 Gt in 2050, around 21% lower than current levels. Most of the CO_2 emissions reductions come from the use of low-carbon electricity rather than from the adoption of more

5. Production of aluminium is higher than demand as some of the aluminium is returned for recycling by customers before being made into finished products, and a small percentage is lost during the recycling process.

6. As indirect emissions account for 75% of total emissions in the aluminium industry it is important to look at total direct and indirect emissions for this sector.

expensive measures to reduce direct emissions from the aluminium industry itself. This suggests that an important part of the strategy for reducing emissions in this industry may lie in locating smelters close to sources of CO_2-free electricity such as hydro or nuclear power stations.

Figure 5.20 ▶ Direct emissions reduction by technology option for aluminium



Key point

Achieving deep cuts in CO_2 emissions in the high-demand scenario, requires significant reductions in direct emissions.

However, the decarbonisation of the power sector will not be sufficient to achieve the emissions reduction required in the BLUE scenarios. Additional CO_2 savings that are needed will have to come from direct emissions reductions. Reductions in direct emissions are, therefore, significantly greater in the BLUE high-demand scenario than in the BLUE low-demand scenario (Figure 5.20). In the BLUE low-demand scenario, about 65% of the direct emissions reductions come from recycling. In the BLUE high-demand scenario, recycling makes a much smaller contribution, with the largest share of reduction coming from improved energy efficiency.

Technology options

Reducing CO_2 emissions in the generation of the electricity that is used in smelters is the single largest opportunity for long-term emissions reduction in the aluminium sector. Currently, around 40% to 50% of the total electricity used by the aluminium industry comes from zero-carbon hydroelectric sources, often in remote locations where there are few competing uses for the electricity. Measures to create a global carbon price would encourage new aluminium plants to be sited where they have access to cheap, low-carbon electricity. In the longer term, the average CO_2 intensity of grid electricity is likely to decrease substantially in many countries so that by 2050 low-carbon grid electricity may become the norm.

Increasing the share of recycling in total production can help reduce energy use and CO_2 emissions. But given the long lifetime of aluminium in some markets and products, over three-quarters of the aluminium ever produced is still in use. Globally, recycled production accounts for around one-third of total aluminium production. In the BLUE scenarios, it is assumed that by 2050 this can be increased to 40% of total production. Although this is a relatively small percentage increase, in absolute terms it is very significant.

Future technological developments could also offer opportunities to reduce the direct emissions of CO_2 from aluminium smelting (Table 5.11). But although the two most promising technological developments – inert anodes and carbothermic reduction – have both been the subject of research for many years, neither has yet reached commercial scale. An alternative would be to combine conventional cell technologies with CCS, but this option is also still only at the research stage.

Table 5.11 ▶ *Technology options for the aluminium industry*

Technology	R&D needs	Demonstration needs	Deployment milestones
Wetted drained cathodes		Ready for demonstration	Deployment to start by 2015 with full commercialisation by 2020
Inert anodes	Extensive testing at laboratory and batch scale	Ready to be demonstrated at plant level	Deployment to start in 2015-2020 with full commercialisation by 2030
Carbothermic reduction	Extensive research under way	2020 - 2025	Deployment to start between 2030 and 2040 with full commercialisation by 2050
Kaolinite reduction	Research under way	2025 - 2030	Deployment to start between 2035 and 2045

Investment costs

Total investment costs over the period 2007 to 2050 in the Baseline scenarios are USD 840 billion in the low-demand case and USD 1 150 billion in the high-demand case. For the BLUE scenarios, the net additional investment costs are USD 60 billion in the low-demand case and USD 95 billion in the high-demand case, around 7% to 8% more than in the equivalent Baseline scenarios (Table 5.12).[7] This takes account of the additional investment costs of more efficient refinery and smelter technologies, plus some investment savings in anode production as carbon anodes are replaced by inert anodes.

Table 5.12 ▶ *Additional investment needs in the aluminium sector to 2050: BLUE scenarios compared to Baseline scenarios*

USD bn	China	Europe	India	United States	World
Total	20 to 30	7 to 10	3 to 6	5 to 6	60 to 95

7. The investment calculation excludes the additional costs of low- or zero-carbon electricity generating capacity.

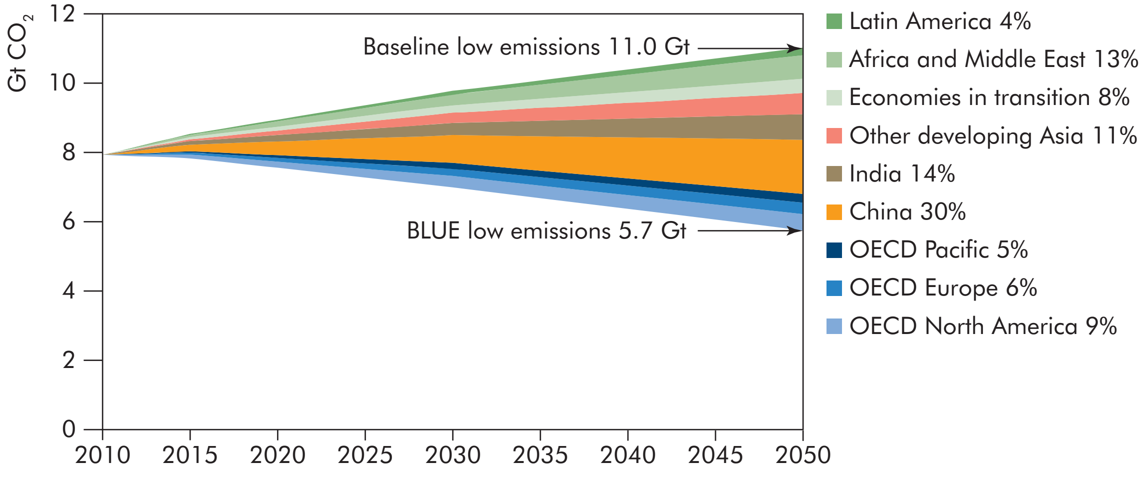
Industry-wide regional implications

A significant reduction in CO_2 emissions in industry will only be possible if all regions contribute. Actions in OECD countries alone, where emissions today represent 33% of total industrial emissions, would not be enough. Industrial production growth will continue to be strongest in non-OECD countries, with over 80% of total industrial emissions in 2050 expected in developing countries in the Baseline scenarios as compared to 66% today.

The BLUE scenarios examine the implications of a policy objective to halve global energy-related CO_2 emissions in 2050 compared with today's level. In the BLUE scenarios, all regions need to show a sharp decrease in emissions by 2050, ranging from 44% to 54% lower than in the Baseline scenarios (Figure 5.21). If industry is to contribute the 24% reduction in emissions that it needs to contribute to the achievement of the overall 50% reduction in emissions, all regions will need significantly to reduce the CO_2 intensity of their industrial operations.

In the Baseline scenarios, regional emissions grow fastest in India, other developing Asia and in Africa and the Middle East where current levels of industrial development are significantly below current global levels and where industrial production is expected to grow at the fastest rates. China's emissions will continue to rise rapidly in the next 20 years but then rise only moderately as the country's consumption of the most CO_2-intensive products, such as cement and iron and steel, begins to level off after 2030.

Figure 5.21 ▶ *Direct CO_2 emissions in industry by region in the Baseline and BLUE scenarios, 2007-50*



Key point

In the BLUE low-demand scenario, all regions will need significantly to reduce future emissions.

In the Baseline scenarios, emissions are expected to continue to rise year on year in all regions through to 2050. In the BLUE scenarios, emissions peak between 2015 and 2020 and then begin to decline as more efficient and cleaner technology is introduced. The largest contributor to the emissions reduction in the BLUE scenarios is expected to be China, given its dominant position in industry today.

Emissions from OECD countries decrease significantly in the BLUE scenarios, falling by more than half by 2050. With lower rates of production growth than China's, the OECD will contribute smaller reductions than China in all scenarios in 2050. Although it is important that OECD countries take the lead in terms of technology deployment and diffusion, measures in the OECD alone will not be sufficient to reduce global emissions from industry. Non-OECD countries also need to contribute.

As domestic consumption feeds demand, India's industrial CO_2 emissions in the Baseline scenarios grow the most of all countries. In the BLUE scenarios, India's emissions rise at a slower rate, but still almost double from today's levels by 2050. Industrial production in other developing Asia and in Africa and the Middle East is also expected to grow strongly. These three regions account for 23% of total global industry emissions by 2050, significantly surpassing total OECD industry emissions. Effort will also be required in these regions to reduce the CO_2 intensity of industrial production if global industry is to achieve significant reductions in emissions. Strong support for the poorest regions will be needed to promote technology transfer and deployment.

Table 5.13 ▶ Direct CO_2 reductions in industry by region in the Baseline and BLUE low-demand scenarios

	2007 Mt CO_2	Baseline low 2050 Mt CO_2	BLUE low 2050 Mt CO_2	Reduction Baseline 2050 vs BLUE 2050	Reduction BLUE 2050 vs 2007
China	2 650	3 545	1 981	–44%	–25%
India	413	1 563	828	–47%	100%
OECD Europe	932	648	316	–51%	–66%
OECD North America	906	884	404	–54%	–55%
OECD Pacific	635	480	229	–52%	–64%
Economies in transition	620	827	421	–49%	–32%
Other developing Asia	566	1 183	576	–51%	2%
Africa and Middle East	539	1 409	717	–49%	33%
Latin America	310	485	271	–44%	–13%
Total	**7 573**	**11 025**	**5 742**	**–48%**	**–24%**

Note: In the high-demand scenario, emissions reductions show a similar pattern.

Investment costs

The additional investment needs to achieve the results in the BLUE scenarios by 2050 are estimated to be between USD 2 trillion and USD 2.5 trillion higher than in the Baseline scenarios, with most investment being needed in the cement, iron and steel and chemical sectors (Table 5.14). These sectors account for the largest share of emissions in industry. Total additional investments in industry represent just 4% of the total incremental costs needed across all sectors to halve global CO_2 emissions. With the exception of cement, where investment needs in the BLUE scenarios are more than 50% higher than in the Baseline scenarios, investments in the other sectors are estimated to be 10% to 15% higher than in the Baseline scenarios.

The investment in new technologies will yield significant savings in fossil fuel consumption, but lead to increased biofuel and feedstock costs. Many of the energy efficiency investments are already competitive on the basis of life-cycle costs: total cumulative undiscounted fuel savings are estimated at USD 22 trillion. These savings are calculated on the basis of the difference between fuel costs in the Baseline and BLUE scenarios over the 2010 to 2050 period.[8] If the fuel savings are discounted at 10%, the cumulative fuel savings fall to just USD 2.3 trillion and discounted additional investment costs fall to USD 0.3 trillion, making the net savings for industry under the BLUE scenarios USD 2.0 trillion. These estimates do not include the extra costs of achieving a near-decarbonised power sector in the BLUE scenarios.

Table 5.14 ▶ ***Investment needs in industry in the Baseline and BLUE scenarios (USD bn)***

	Total investment needs Baseline 2010-2050	Total investment needs BLUE 2010-2050	Additional investment needs (BLUE scenarios compared to Baseline)
Iron and steel	2 000 – 2 300	2 300 – 2 700	300 – 400
Cement	760 – 970	1 200 – 1 640	440 – 670
Chemicals and petrochemicals	4 100 – 4 700	4 500 – 5 200	400 – 500
Pulp and paper	1 220 – 1 350	1 360 – 1 510	140 – 160
Aluminium	660 – 910	720 – 1 000	60 – 90
Total industry			**2 000 – 2 500**

Industry measures to reduce CO_2 emissions have different marginal abatement costs. Many energy efficiency options, for example, are cost-effective on a life-cycle basis provided they are introduced during the regular capital stock turnover cycle. For the most part, these options have negative or low marginal costs as the additional investment costs are largely or completely offset by fuel savings.

The industrial use of CCS is generally more expensive than CCS for coal-fired power plants, but is essential for deep emissions reductions in industries such as cement and iron and steel. CCS in industry falls within the range of USD 50/tCO_2 to USD 100/tCO_2 saved. Other more expensive options, costing up to USD 175/tCO_2 saved, include higher levels of recycling, and fuel and feedstock substitution, including switching to biomass feedstock in the chemical and iron and steel sectors.

8. In the Baseline scenario, Baseline fuel prices are used and in the BLUE scenario, BLUE fuel prices are used.

Policy changes needed to support technology transition in industry

Bringing about the technology transition that is needed to reduce emissions in industry will not be easy. It will require both a step change in policy implementation by governments and unprecedented investment in best practices and new technologies by industry. Engaging developing countries and their industries in this transition will also be vital, since most of the future growth in industrial production and, therefore, CO_2 emissions, will happen in countries outside the OECD region.

Given these considerations, a global system of emissions trading could eventually be crucial to create the conditions for global action to reduce CO_2 emissions from industry. But a worldwide carbon market is unlikely to emerge immediately. In the short to medium term, in order to encourage the urgent action that is required to stimulate the deployment of new technologies while addressing concerns about competitiveness and carbon leakage, it may be necessary as a first step to seek to secure international agreements covering some of the main energy-intensive sectors. Meanwhile, national energy efficiency and CO_2 policies will need to address specific sectors or particular barriers through standards, incentives and regulatory reform, including the removal of energy price subsidies.

Governments collectively and individually need to adopt challenging but achievable long-term greenhouse-gas mitigation goals and to allow flexibility to enable these goals to be met at least cost. This will facilitate and encourage the innovation of least-cost technologies to reduce greenhouse-gas emissions. Policy instruments can include market mechanisms, fiscal policies, regulatory measures and information schemes. Policies that foster increased recycling and/or changes in materials use can also play an important role.

To complement policies that generate market pull, many new technologies will need government support while in the RD&D phases before they become commercially viable. There is an urgent need for a major acceleration of RD&D in breakthrough technologies that have the potential to change industrial energy use or reduce greenhouse-gas emissions. Support for demonstration projects will be particularly important. This will require greater international collaboration and will need to include mechanisms to facilitate the transfer and deployment of low-carbon technologies in developing countries. Policy support to secure public acceptance of certain new technologies may also be important if they are to achieve more widespread deployment.

From sectoral agreements to global emissions trading

In any effective global emissions trading system, crediting mechanisms will need to encourage investments in emissions reductions where they are least expensive. In a number of cases, this will be in developing countries. The design of such approaches should ensure that in the long term they do not become a subsidy to developing countries at the expense of countries with carbon constraints.

The challenge for policy makers is to turn current concepts for sectoral agreements into effective international policy instruments which will foster the rapid, cost-effective deployment of BATs and provide a strong signal to make greenhouse-gas mitigation a priority for innovation.

Improving industrial data coverage should be a priority

The establishment of national sector-wide baselines requires statistical data that may not exist or be readily available in most developing countries. Even in the areas where international industry federations have been active, coverage is often limited to member countries and/or companies. In other cases, sectoral statistics may exist but they may need to be evaluated to establish confidence that they could form the basis of emission baselines and of measures of performance that could be used to determine emission credits on the international market. The collection of such data also raises issues of data confidentiality at the plant level.

Industry initiatives have also shown the importance of establishing clear sectoral boundaries. Major progress has been achieved, including through the Asia-Pacific Partnership on Clean Development and Climate (APP), to strengthen existing performance measurement practices (CCAP *et al.,* 2008). But there is also a need to allow for some flexibility in terms of the application of sectoral boundaries. One forum in which such methodological issues could be discussed with a view to developing standardised approaches is the International Organization for Standardization (ISO). The World Steel Association, for example, has already launched an initiative to standardise statistical approaches in the steel industry in co-operation with the ISO.

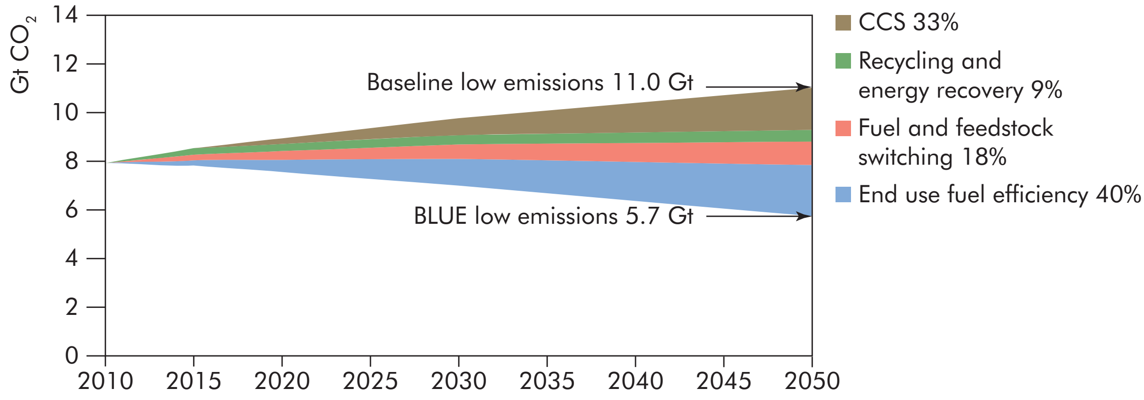
More work is also needed to establish the data that should underpin sectoral baselines. Countries may not be prepared to negotiate baselines without some knowledge of their own potential to reduce emissions and of the cost of achieving such reductions. Much is already known about mitigation technologies and best practices. But the cost of avoiding CO_2 emissions depends very heavily on national circumstances. Japan's submission to the United Nations Framework Convention on Climate Change (UNFCCC) illustrates how an inventory of existing practices and technologies, in addition to robust performance measurements, needs to be established if governments and/or sectors are to set ambitious but achievable targets.

Achieving significant reductions in greenhouse-gas emissions from industry will require costs to be attached to those emissions through policy measures. Existing schemes suggest that the system of caps and flexibility mechanisms embedded in the Kyoto Protocol architecture is not sufficient to trigger effective mitigation action. Sectoral agreements, which provide a means to engage effort in developing countries more effectively, could offer the promise of a "new deal" that would result in a more effective regime to reduce global greenhouse-gas emissions.

Pathway to the next Industrial Revolution

The implementation of current BATs could reduce industrial energy use by up to between 10% and 26%. This should be the first priority in the short term. But this will be nowhere near enough to achieve absolute reductions in CO_2 emission levels as production is expected to double or triple in many sectors. Continued improvements in energy efficiency offer the largest and least expensive way of achieving CO_2 savings over the period to 2050 (Figure 5.22). Energy efficiency gains will need to increase to 1.2% a year, double the rate seen in the Baseline scenarios. This will require the development of new energy-efficient technologies. Many new technologies which can support these outcomes, such as smelting reduction, new separation membranes, black liquor and biomass gasification, regenerative burner systems and advanced CHP, are currently being developed, demonstrated and adopted by industry.

Figure 5.22 ▶ Options for reducing direct CO_2 emissions from industry to 2050



Key point

Direct emissions in industry can be significantly reduced through a combination of energy efficiency, fuel and feedstock switching, recycling and energy recovery, and CCS.

New low-carbon fuels and technologies will also be needed, together with increased recycling and energy recovery. The use of biomass and electricity as CO_2-free energy carriers will make a significant contribution to industry's reductions in emissions. Although the technologies required are often sector-specific, the development and deployment of CCS will be critical for achieving deep emissions reductions in a number of sectors, particularly in the iron and steel and cement sectors.

Additional RD&D is needed to develop breakthrough process technologies that allow for the CO_2-free production of materials and to advance understanding of system approaches such as the optimisation of life cycles through recycling and the use of more efficient materials. These longer-term options will be needed in the second half of this century to ensure sustainability of industrial processes to the end of the century and beyond.

Technology development is fraught with uncertainties. Some of the technologies identified may never come to fruition, but future research may also deliver new technologies or breakthroughs that are not currently foreseen. A portfolio approach to the necessary RD&D can help to spread risks and help reduce the uncertainty of outcomes.

Chapter 6 BUILDINGS

Key findings

- *In the Baseline scenario, global final energy demand in buildings increases by 60% between 2007 and 2050. Carbon dioxide (CO_2) emissions from the sector, including those associated with electricity use, nearly double from 8.1 gigatonnes (Gt) of CO_2 to 15.2 Gt CO_2. This is driven by a 67% increase in the number of households, a near tripling of the service building area, higher ownership rates for existing energy-consuming devices, and increasing demand for new types of energy services.*

- *The BLUE Map scenario shows the part that the buildings sector can play in securing a more sustainable energy future. In this scenario, CO_2 emissions are 83% lower than in the Baseline scenario in 2050. Most of this saving comes from the decarbonisation of the electricity used in the sector (6.8 Gt CO_2), from energy efficiency and from the switch to low- and zero-carbon technologies (5.8 Gt CO_2).*

- *The additional investment needs to transform the buildings sector in the BLUE Map scenario are estimated to be USD 7.9 trillion in the residential sector and USD 4.4 trillion in the service sector. These investments achieve significant fuel savings, totalling USD 51 trillion between 2010 and 2050 at wholesale prices. Discounting the investment and fuel savings at 3% reduces the net saving to USD 18.6 trillion. Even at a 10% discount rate, these measures save USD 5.3 trillion net by 2050.*

- *The implementation of currently available low-cost energy efficiency options is essential to achieve cost-effective CO_2 emissions reductions in the short run. This will buy time to develop and deploy those technologies that are either currently more expensive, or not commercialised, and that can significantly improve efficiency or help decarbonise energy consumption in buildings in the longer term. These include highly efficient heat pumps for heating and cooling, solar thermal space and water heating, and combined heat and power (CHP) systems with hydrogen fuel cells.*

- *The main barriers are higher initial costs, lack of consumer awareness of technologies and their potential, split incentives and the low priority placed on energy efficiency, as well as the fact that the true costs of CO_2 emissions are not generally carried by consumers. Overcoming these barriers will require a comprehensive, sequenced policy package. This must target specific barriers with effective policy responses. These may include information campaigns, fiscal and financial incentives, and minimum energy performance standards. They must address financial constraints, develop industry capacity and boost investment in research and development (R&D).*

- *The policy challenge in the OECD and the economies in transition (EITs) is very different from that in developing countries. In the OECD and EITs, space heating in the residential sector results in very significant CO_2 emissions, while much of the current building stock is likely to remain in use for many decades. Most of the savings potential, therefore, lies in retrofitting technologies in existing buildings. In developing countries, where new building growth will be very rapid, opportunities exist to improve efficiency standards relatively strongly and quickly.*

- *In the service sector, improvements in the building shell of new buildings, together with highly efficient heating, cooling and ventilation systems will be needed to achieve the CO_2 emissions reductions in the BLUE Map scenario. Significant policy measures to improve the efficiency of energy use in lighting and other electrical end uses, such as office equipment, information technology equipment and refrigeration, will also be required given their larger share of total use compared to the residential sector.*
- *Reducing heating and cooling loads through building shell measures is not enough on its own to achieve the BLUE Map scenario outcomes. The deployment of low- and zero-carbon technologies, such as heat pumps, solar thermal, CHP and on-site electricity generated from renewables will also be required to improve efficiency and reduce CO_2 emissions.*

Overview of the residential and service sectors

Residential, service sector and public buildings[1] use a wide array of technologies. They are used in the building envelope and its insulation, in space heating and cooling systems, in water heating systems, in lighting, in appliances and consumer products, and in business equipment. From an energy perspective, buildings are complex systems in which the interaction of technologies almost always has an influence on energy demand. Occupancy profiles, the behaviour of occupants and the local climate all affect overall energy demand in a building.

Most buildings last for decades. Some last for centuries. More than half of the current global building stock will still be standing in 2050. In the OECD, this will be closer to three-quarters. Buildings are much more frequently refurbished than replaced. This has significant implications for policy makers. The very low retirement rate of the residential building stock in OECD countries is a significant constraint, particularly on reducing heating and cooling demand in the more ambitious CO_2 reduction scenarios. Service sector buildings are generally less constrained in this respect, as they are subject to much earlier retirement or to significant refurbishment.

Energy-consuming technologies and appliances are changed much more frequently than buildings. Heating, ventilation and air-conditioning (HVAC) systems are generally changed every 15 to 20 years. Roofs, facades and windows need renovation periodically. Office equipment is often changed after three to five years. Household appliances are changed every 5 to 15 years. Consumables such as light bulbs are changed in much shorter timeframes. Choosing the best available technology (BAT) at the time of renovation or purchase is important in reducing energy demand in buildings. It also has an impact on the costs and benefits associated with energy savings.

Buildings emissions are growing rapidly with the rapid expansion of both the built environment and the ownership of energy-consuming equipment. In the service sector, architectural trends are also increasing the energy intensity of new buildings

1. These are collectively referred to as the "buildings sector" in this chapter. It comprises residential buildings, plus those of the service sector. The service sector includes activities related to trade, finance, real estate, public administration, health, food and lodging, education and commercial services (ISIC codes 50-55 and 65-93). This is sometimes also referred to as the commercial and public service sector.

as large window surfaces become the norm. Policies to improve energy efficiency in new and existing buildings need to be designed to ensure that new structures are built to the highest standards of efficiency. Policies should foster new technologies both in buildings themselves and in the energy-using equipment inside them. Ensuring that these technologies are integrated into the smart energy network of the future will facilitate energy saving opportunities and unlock energy security benefits.

A wide range of technologies are already available that can significantly reduce CO_2 emissions in new and existing buildings. Many of these technologies are already economic on the basis of total life-cycle costs. But non-economic barriers can significantly slow their penetration. Government policies need to target these barriers. Additional R&D effort is also needed to expand the range of applications in which technologies can be deployed and to optimise their performance in a wider range of operating and climate conditions. Ensuring that these technologies are taken up will require strong policy action and integrated strategies on the part of the construction industry, developers, building owners, policy makers and building occupants (WBCSD, 2009).

Building stock turnover and heating and cooling

Achieving significant energy and CO_2 emissions reductions in the buildings sector is technically possible, but a challenging policy goal. Three fundamental issues need to be addressed by specific policies:

- Population, household numbers and service sector activity will grow significantly faster in developing countries to 2050, than in the OECD and EITs.
- Residential buildings, particularly in OECD countries, have very long life spans.
- Heating loads are large in the OECD and the EITs, while cooling loads are much more important in most developing countries.

The implications for policy makers of these issues are significant. The achievement of the deep emission cuts envisaged in the BLUE Map scenario will require a transformation of the current building stock in OECD countries by 2050. This is already technically achievable. But making it happen will require consumers to invest in technologies with potentially higher investment costs. And it will require unprecedented and well targeted policy direction and support. Policy efforts will need to be well tuned to local circumstances. For example, space heating is predominantly an issue for OECD countries. The issue for non-OECD countries will, more often, be to come to grips with the potentially very large growth in the energy demand for cooling.

Current building stock and energy consumption

Households: the residential building stock and its characteristics

The world's population was 6.6 billion in 2007 (World Bank, 2009). OECD countries had an estimated 425 million occupied households in 2005, although the total number of dwellings is around 10% higher than this. Data for non-OECD countries are not always available and household numbers have been estimated as a basis for the projection of future energy consumption.[2] China had an estimated 373 million households in 2005, with 190 million being in urban areas (LBNL, 2008). In India, total household numbers were estimated to be 219 million in 2006/07 with 58 million urban households (NSSO, 2008).

Even in OECD countries with very modest population growth rates, household numbers increased between 1990 and 2005.[3] The G7 countries accounted for around two-thirds of all households in OECD countries in 2005, down from around 70% in 1990.

The share of single-family buildings and multi-family buildings varies by country and region. Single-family buildings dominate in Brazil, India and the United States, whereas in Europe, China and India around 50% are multi-family buildings (WBCSD, 2009). In Europe, average area per dwelling is greater in single-family buildings, such that they account for around two-thirds of total built area.

The average number of persons per household in the IEA countries for which data are available was 2.9 in 1990 and 2.6 in 2006, a decline of 12%. In Finland, the number of persons per household dropped below two in 2006. In Korea, occupancy rates fell from 5.8 to 3.6 persons per household in 2006. In India, the average number of people per urban household dropped from 5.3 in 1990 to 4.3 in 2005, with a similar reduction from 5.6 to 4.9 people per rural household in the same period (de la Rue du Can *et al.*, 2009). In China, the average number of persons per household has fallen from 4.8 to 4.1 in rural areas and from 3.5 to 3 in urban areas between 1990 and 2006 (LBNL, 2008).

Since 1990, the average size of individual dwellings has generally increased in the countries for which IEA data are available, except in Greece, Italy, Korea and Sweden. Average dwelling size increased on average by eight square metres (m^2), or 9%, between 1990 and 2006. In OECD countries, the largest increase in absolute terms was in the United States, where the average dwelling size increased from 147m^2 to 172m^2 (17%). In China, urban households increased in size from 48m^2 in 1990 to 77m^2 (60%) in 2005, with the increase in rural households being from 86m^2 to 121m^2 (41%) over the same period.

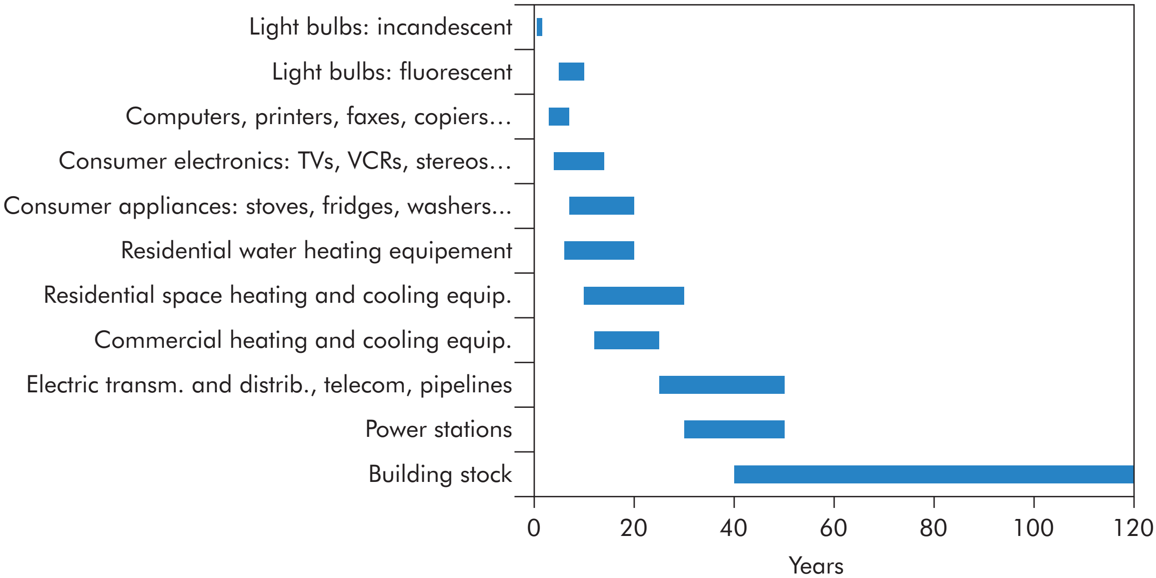
Although building shells have a significant effect on energy consumption, the total energy consumption of buildings is also determined by the appliances, fittings and heating and cooling systems inside them. These systems have very different, and generally much shorter, economic life spans than the buildings in which they are used (Figure 6.1).

The age of a building has a significant impact on its heating requirements. Data from Germany suggest that energy consumption per square metre for pre-1970s homes can be between 55% and 130% higher than that for more modern buildings. In the OECD countries, a significant share of the building stock was built before 1970 (Figure 6.2). It is only retired very slowly, with as little as 0.1% a year being retired in some OECD countries. Developing countries tend to have a higher building stock turnover rates, with average life spans often in the range of 25 to 35 years.

2. Analysis conducted in 2004 on the basis of UN Habitat data suggested that the estimated 1.56 billion households in the year 2000 would grow to 3.3 billion in 2050 according to 2002 population projections (Jennings Lloyd-Smith and Ironmonger, 2004).

3. Data in this section are based on the IEA's Energy Indicators Database, unless otherwise noted.

Figure 6.1 ▶ **Economic life spans of energy-consuming equipment and infrastructure**

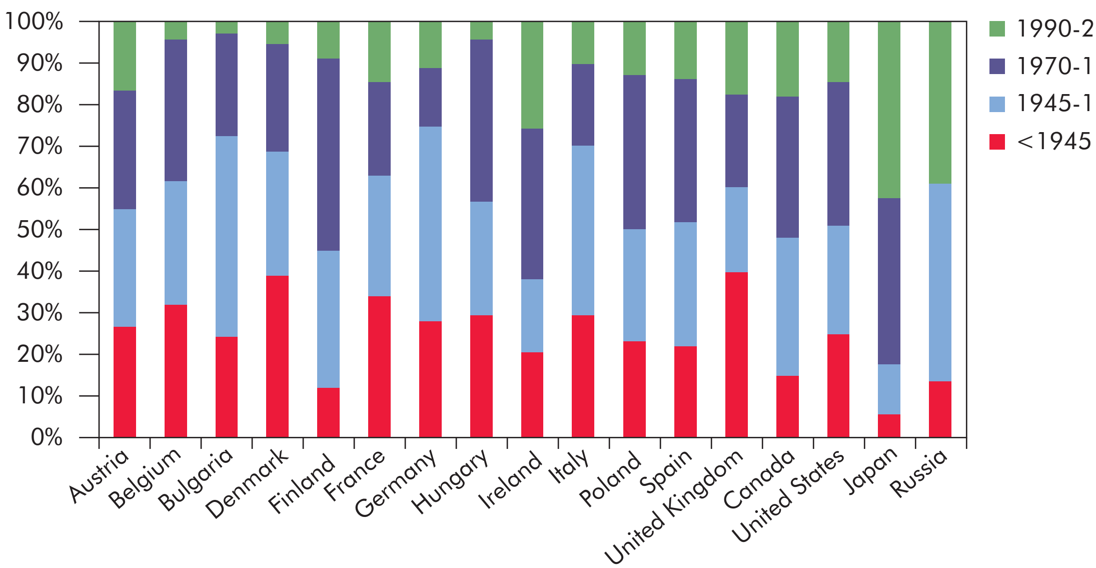


Source: Based on Philibert and Pershing (2002).

Key point

As the building stock is very long lived, action on appliances, fittings and systems is the key to achieving early low-cost CO_2 emissions reductions in the short run.

Figure 6.2 ▶ **Share of residential building stock in selected countries by vintage**



Notes: Final year varies by country. Some data sources are for slightly different periods.
Sources: Norris and Shiels (2004); NRCan (2007); Energy Information Administration (2007); UNECE (2004).

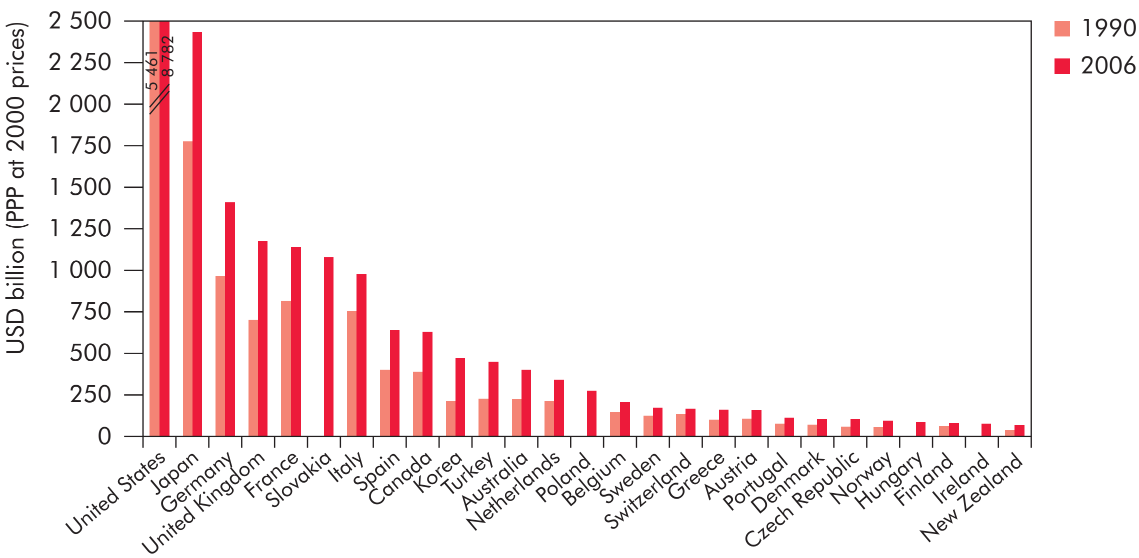
Key point

In many OECD countries, more than half of the housing stock was built before 1970.

The service sector building stock

Energy use in the service sector is primarily a factor of the level of economic activity in that sector. Between 1990 and 2005, the rate of growth in service sector value added[4] in 20 IEA countries for which data are available exceeded 2% per year in all countries except Finland, Italy and Sweden (Figure 6.3). The fastest growth occurred in Korea and Luxembourg, which averaged 5.1% and 5.2% a year, respectively.

Figure 6.3 ▶ Service sector value added by country



Source: IEA Indicators Database.

Key point

Service sector economic activity has grown rapidly in many OECD countries.

Reliable data on service sector floor area are only available for a smaller number of countries. At over 7 billion m^2, the United States has more service sector floor area than all of the other ten OECD countries for which data are available. Japan has the next largest area at 1.8 billion m^2. China is estimated to have around 11 billion m^2 of service sector floor area, while India is estimated to have anywhere between 400 million m^2 and 815 million m^2.

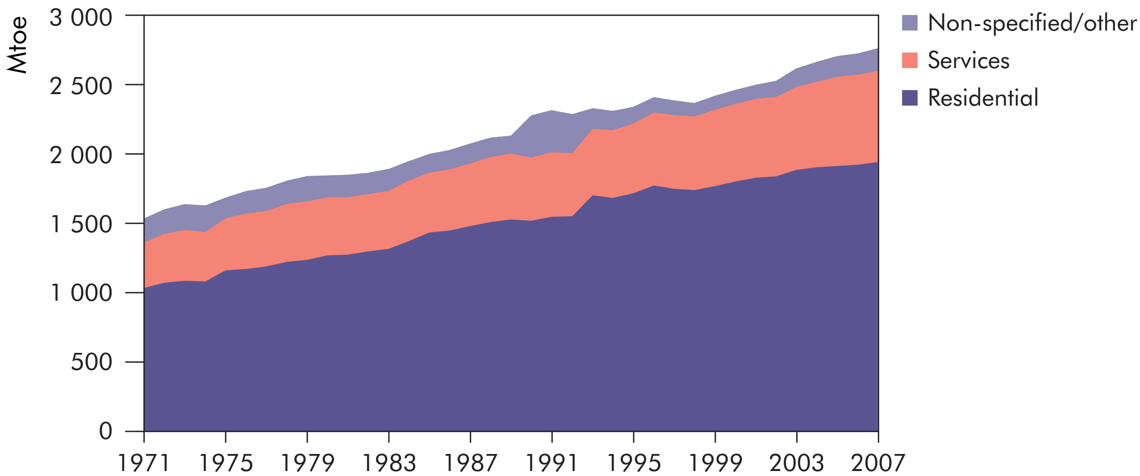
The relationship between floor area and value added has been relatively stable in most OECD countries since 1990. In 2005, the range for the OECD countries for which data were available was between 0.7m^2 and 1.2m^2 per USD 1 000 of service sector value added.

4. Value added of output expressed in constant USD (2000 prices) at purchasing power parity.

Global trends in buildings sector energy consumption

Between 1971 and 2007, total energy consumption in the buildings sector grew by 1.6% a year from 1 535 million tonnes of oil equivalent (Mtoe) to 2 759 Mtoe (Figure 6.4).[5] Overall growth has slowed over time, with energy consumption growing by 1.1% a year between 1990 and 2007. Energy consumption in the service sector grew more rapidly, at 2.2% a year, between 1990 and 2007 than for the overall period. Growth in energy consumption in the residential sector was 1.4% a year between 1990 and 2007. The residential sector remains the largest consumer of energy in the buildings sector, although the service sector has increased its share of the total slightly since 1990.

Figure 6.4 ▶ ***Energy consumption of buildings by sector***



Key point

The residential sector dominates total buildings sector energy consumption at a global level.

The OECD countries' share of total energy consumption in the buildings sector has declined from 55% in 1971 to 44% in 2007. China's share of total energy consumption has increased from 13% to 14% over that period.

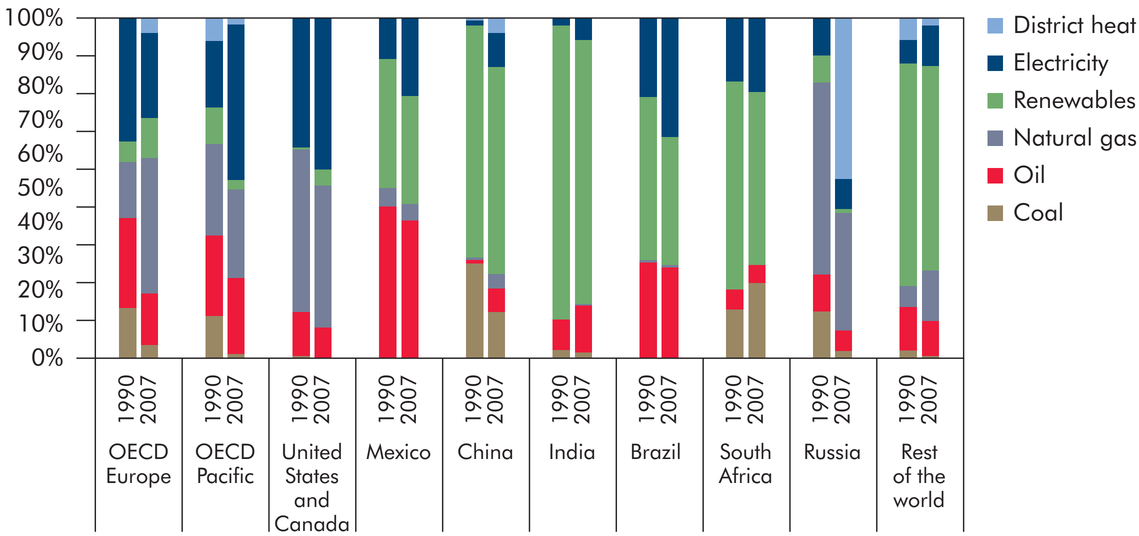
Residential sector

Global energy use in the household sector increased by 28% between 1990 and 2007 to 1 941 Mtoe. As is the case in the other major end-use sectors, energy consumption in households since 1990 has grown more in non-OECD countries (34%) than in OECD countries (17%).

5. In the presentation of the historical data for the buildings sector, the residential, "services" or "commercial and public service" sectors (these terms are used interchangeably in this chapter), and "non-specified (other)" sectors are presented separately. In the scenario analysis, however, the data for "other non-specified" (159 Mtoe in 2007), are included with services. This is in line with the treatment in *WEO* 2009 (IEA, 2009a).

Natural gas is the fuel used most in OECD countries, providing 265 Mtoe (38%) of household energy requirements in 2007 (Figure 6.5). Electricity use has been rising rapidly in OECD countries, largely because of the increased penetration of many different appliances. Electricity consumption increased from 169 Mtoe in 1990 to 248 Mtoe in 2007. In non-OECD countries, renewables, particularly traditional biomass, remain the largest source of energy, with consumption of 706 Mtoe in 2007.[6] Electricity use is by far the fastest growing energy commodity, its use increasing by 175%[7] since 1990 to reach 11% of total energy consumption. In Russia, district heating remains important in the household sector with heat consumption of 53 Mtoe in 2007, or 47% of total household energy consumption.[8]

Figure 6.5 ▶ Household energy use by energy commodity



Key point

Electricity, natural gas, oil products, district heat and biomass are of varying importance in different regions.

The service sector

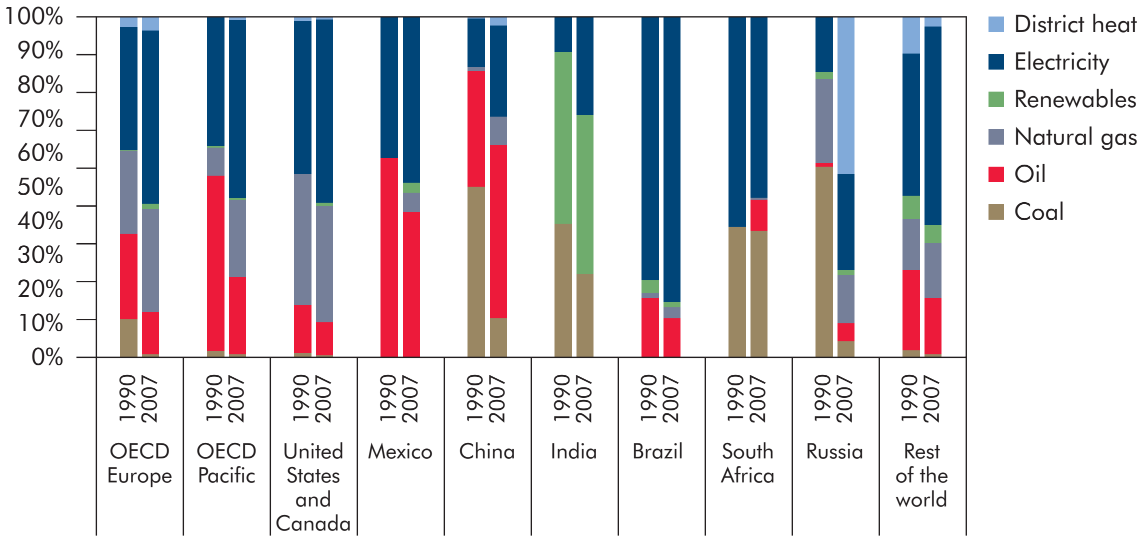
In 2007, final energy consumption in the service sector was 658 Mtoe, 46% higher than in 1990. In OECD countries, service sector energy consumption grew by 32%. It grew by 93% in non-OECD countries. Despite the slower increase in service sector energy use in OECD countries, in 2007 these countries accounted for 71% of global energy consumption in this sector.

6. The efficiency with which this biomass is used is typically very low (8% to 15% for traditional cook stoves is common). It has a wide range of negative impacts such as degraded indoor air quality and deforestation. Switching to alternatives will require a fraction of the energy, as alternatives are much more efficient, and have significant co-benefits.
7. The falling share of inefficient traditional biomass use in favour of electricity and commercial fuels is one of the main factors that has restrained the growth in energy use in non-OECD countries.
8. In IEA statistics for the residential and service sectors, "heat" refers only to purchased heat. It is not the total energy consumed for heating purposes.

Electricity is the largest energy commodity used in the service sector. Its use has increased by 91% since 1990. Its share of global service sector energy consumption increased from 38% in 1990 to 50% in 2007. This reflects the growing importance of electrical devices such as lighting, office equipment and air conditioning. Increased access to electricity and rising incomes have also played a role in the growth in electricity consumption in some developing countries.

There are substantial differences in the service sector energy mix between countries and regions (Figure 6.6). Electricity and natural gas are the dominant final energy commodities in many OECD countries, with oil also an important fuel in the OECD Pacific region, Mexico and China.[9] Biomass is still heavily used in India, accounting for 47% of total final consumption in services.[10] Direct coal use retains a significant share in both China and South Africa. In Russia, 46% of the service sector's energy demand is met by district heating.

Figure 6.6 ▶ Service sector energy use by energy commodity



Key point

Electricity is generally the largest source of energy in the service sector.

Buildings sector CO_2 emissions

The buildings sector's CO_2 emissions, including non-specified (other) and upstream emissions attributable to electricity consumption, grew by 2.2% a year between

9. Oil appears currently to account for 53% of final energy use in China, but this share may be inflated by a statistical convention that includes some commercial transportation in the service sector.
10. Some uncertainty surrounds service sector energy consumption statistics in India and these values should be treated with caution.

1995 and 2007. CO_2 emissions from the service sector grew by 3.1% a year, while those from the residential sector grew by 1.5% a year. The service sector's share of total buildings sector CO_2 emissions has grown from 32% in 1995 to 35% in 2007, while the residential sector's share has declined from 63% to 57%. Direct CO_2 emissions from fossil fuels accounted for 34% of the buildings sector's emissions in 2007 (2 768 Mt CO_2), with the upstream emissions attributable to electricity and heat consumption accounting for the remaining 66%. Household sector CO_2 emissions were around 4.7 Gt CO_2 in 2007, while they were around 2.9 Gt CO_2 in the service sector.

Global average emissions in the household sector were 0.7 tonnes (t) of CO_2 per person in 2006, slightly lower than in 1990. Per-capita emission levels differ widely between countries, being on average more than five times higher in OECD countries than in non-OECD countries. This results from a combination of lower per-capita household energy use and a higher share of renewable energy used in non-OECD countries, and from the very significant heating loads in OECD countries.

Demand drivers in the scenario analysis

Energy demand in the buildings sector is driven by population, climate, incomes, service sector value added and cultural factors. These factors have an impact on the number and size of households, the heating or cooling load, the number and types of appliances owned and their patterns of use.

The world's population will increase by around 40% to 9.1 billion in 2050 (UN, 2009), with Asia and Africa growing most. The population of the G8+5[11] countries will drop from 56% of the world's population today to 48% in 2050. Today, slightly more than half of the world's population lives in urban areas in developing countries (UN, 2008). By 2050, almost 85% of the world's urban population will be in developing countries.

The global number of households is projected to grow by 67% between 2005 and 2050. This is larger than population growth because of the continuing trend of fewer people per household. The recent trend towards larger floor areas per household is likely to continue, although this will be weak in many mature economies.

Service sector floor area is expected to continue to grow rapidly, with a projected increase of 195% between 2005 and 2050. In 2050, the global average per-capita service sector floor area will be around today's per-capita level in France, Japan and the United Kingdom. After rising initially, the global average floor area in the service sector per unit of GDP will decline slightly by 2050, as floor area growth begins to slow in the sector. Floor area is projected to expand most rapidly in developing countries, driven by the higher rates of growth in their economies and their service sector value added.

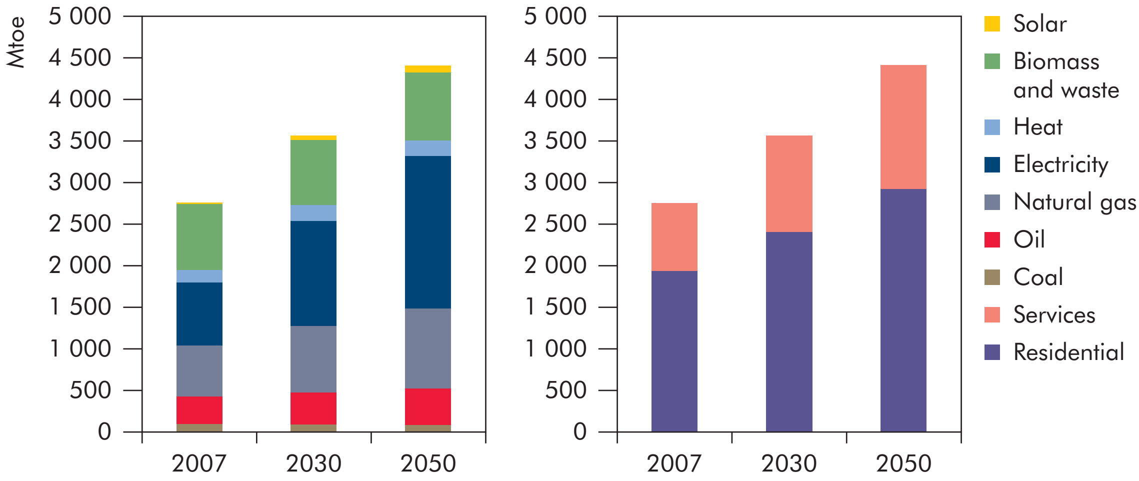
11. The G8+5 is defined as Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States, plus Brazil, China, India, Mexico and South Africa.

The Baseline scenario

Energy consumption by fuel and by sector

Total energy demand in the buildings sector increases from 2 759 Mtoe in 2007 to 4 407 Mtoe in 2050 in the Baseline scenario (Figure 6.7).[12] The residential sector accounts for 59% of this growth and the service sector for around 41%. The service sector grows the most rapidly at 1.4% a year between 2007 and 2050, with the residential sector growing by 1.0% per year. As a result, the service sector's share of energy consumption increases from 30% in 2007 to 34% in 2050, and that of the residential sector declines from 70% to 66%.

Figure 6.7 ▶ **Buildings sector energy consumption in the Baseline scenario by sector and by energy commodity**



Key point

The share of buildings sector energy consumption accounted for by electricity increases by 2050.

Non-biomass renewables use, predominantly solar,[13] grows the most rapidly in the buildings sector as a whole, by 4.5% a year between 2007 and 2050, although it still only represents 2% of the sector's energy consumption in 2050. The demand for biomass increases only slightly by 2050 compared to today, thanks to the improved efficiency of its use and the continued switch to fossil fuels in developing countries. Electricity demand grows by 2.1% a year. As a result, it not only remains the largest single source of energy, but also increases its share from 27% to 42% of total energy use in the sector by 2050. Heat consumption increases by 0.5% a year,

12. In line with the treatment in the *World Energy Outlook*, in this section the service sector total includes the projections for "non-specified (other)".
13. Unless explicitly noted, "solar" in this chapter refers to solar thermal energy.

gas consumption by 1.1% a year and oil consumption by 0.6% a year. Coal is the only fuel to experience a decline in use (of 0.2% a year) between now and 2050.

In the residential sector, total energy consumption grows by 1% a year between 2007 and 2050 to 2 920 Mtoe. Electricity demand in the residential sector continues to grow strongly, by 2.2% per year on average, increasing its share of consumption from 20% to 34% between 2007 and 2050. Non-biomass renewables, predominantly solar, grow rapidly by 5.4% a year on average. But this is from a low base, and they account for only 2% of total energy consumption in the residential sector by 2050. Gas consumption grows by 1.1% per year and oil consumption by 0.7% per year. Coal consumption is roughly flat between 2007 and 2050.

In the service sector, energy demand is projected to almost double between 2007 and 2050, growing by around 1.4% per year to 1 488 Mtoe in 2050. Non-biomass renewables, predominantly solar, are projected to grow the most rapidly, by 3.1% a year, between 2007 and 2050, albeit from a low base. In the Baseline scenario, the demand for electricity grows by 1.9% a year and remains the single most important source of energy in the service sector. The demand for biomass grows by 1.3% a year, gas by 1.0% a year, heat by 0.9% a year and oil by 0.5% a year. Coal demand declines by 0.8% a year.

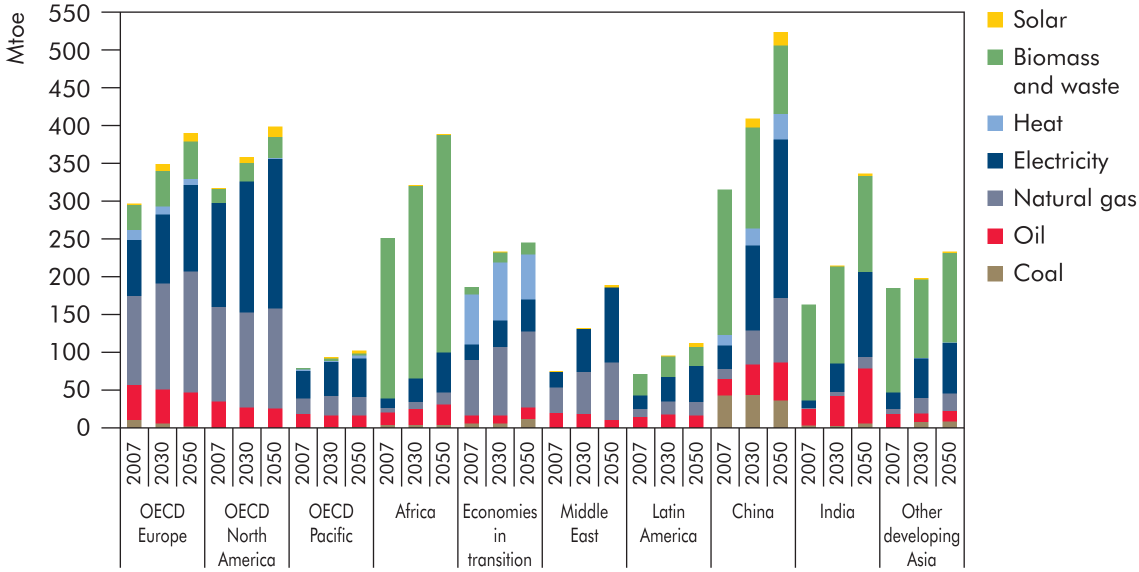
Energy consumption and CO_2 emissions by region and by sector

Energy consumption in the residential sector is dominated by the three OECD regions, China and Africa. Together these account for around two-thirds of all energy consumption in the residential sector. The OECD regions are expected to have only moderate growth in energy consumption before 2015 as a result of energy policies to tackle climate and energy security concerns. But growth picks up again after 2015 as the effect of currently enacted policies taper off, for example as already announced retrofit programmes reach a conclusion. The Middle East will experience the most rapid growth in residential sector energy consumption of 2.2% per year between 2007 and 2050 (Figure 6.8).

Energy consumption in the residential sector in India and China will grow by 1.7% and 1.1% per year respectively. The largest absolute increase in residential sector energy consumption will occur in China, where consumption will increase by 208 Mtoe from 2007 levels to 524 Mtoe in 2050. In the residential sector in non-OECD countries, there is a marked increase in the share of fossil fuels and electricity as traditional biomass becomes a relatively less important energy source. Distributed heat remains an important source of energy in the EITs, although significant improvements in the heat distribution network and renovations that improve building envelopes will mean that its share of energy consumption declines.

In the service sector, China is projected to experience the most rapid growth in energy consumption, with consumption growing by 3.3% a year between 2007 and 2050. India and the Middle East are also projected to experience rapid growth in energy consumption, by 3.1% and 2.9% a year respectively. OECD Europe and North America experience more modest growth rates, but their service sectors continue to consume the most energy, despite China's very rapid growth (Figure 6.9).

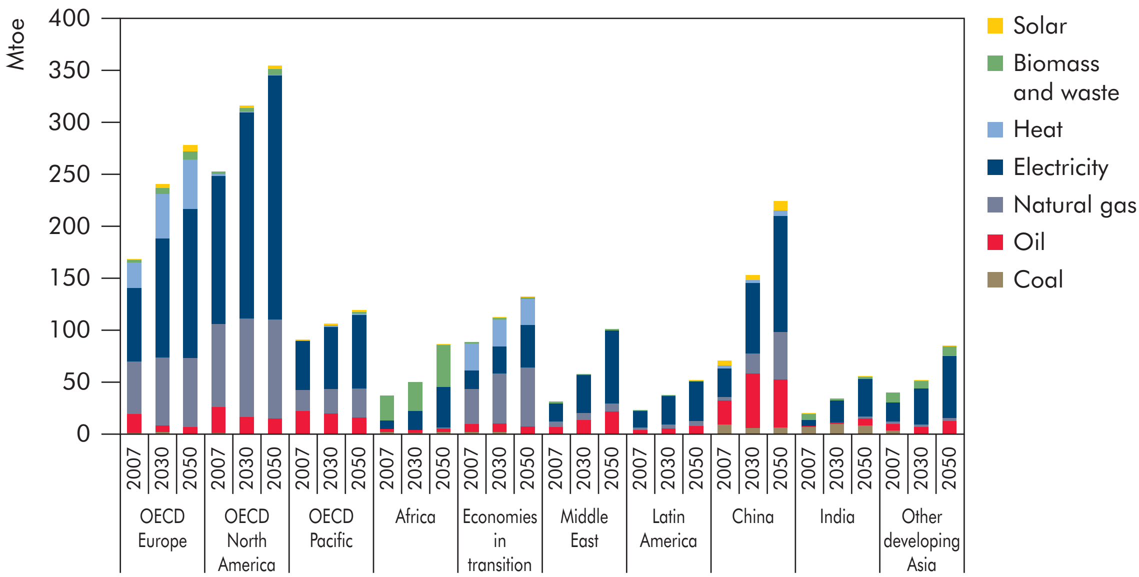
Figure 6.8 ▶ **Residential sector energy consumption by fuel and by region in the Baseline scenario**



Key point

Residential sector energy consumption grows by around 50% in the Baseline scenario.

Figure 6.9 ▶ **Service sector energy consumption by fuel and by region in the Baseline scenario**



Key point

Even by 2050, OECD regions still dominate service sector energy consumption.

6

Buildings sector CO_2 emissions increase by 87% between 2007 and 2050 in the Baseline scenario to around 15.2 Gt CO_2 in 2050. Service sector CO_2 emissions grow by 85% between 2007 and 2050, and residential sector emissions grow by 88%. The total buildings sector CO_2 emissions attributable to electricity consumption grow the fastest, by 2.1% a year between 2007 and 2050, while those of gas grow by 1.1% a year, purchased heat by 0.8% a year and oil by 0.7% a year. CO_2 emissions from coal are virtually unchanged between 2007 and 2050.

The BLUE Map scenario

The buildings sector has an important role to play in the BLUE Map scenario's overall goal of a 50% reduction in CO_2 emissions by 2050. Energy efficiency options are available in the buildings sector that can reduce energy consumption and CO_2 emissions from lighting, appliances and heating and cooling rapidly and at low cost. But achieving deep cuts in energy consumption and CO_2 emissions in the buildings sector is a challenge. The implementation of these technologies will require much more ambitious policies, particularly in relation to building shells in the existing stock of buildings in OECD countries, as well as decarbonising the energy sources used. These outcomes will be much more expensive to secure and their achievement will face significant barriers.

The most cost-effective approach to the transition to a sustainable buildings sector will involve three steps:

- First, the rapid deployment of existing low-cost technology options for energy efficiency and low-carbon fuel sources, while boosting R&D into new technologies and optimising existing technologies for new applications in the buildings sector.
- Second, the deployment of existing technologies into less economic end uses, efforts to address the existing building stock in OECD countries, and the deployment of emerging technologies at a modest scale.
- Third, maximising the deployment of energy-efficient technologies, substantially renovating 60% of today's OECD building stock by 2050 and ensuring the widespread deployment of new technologies, particularly those that decarbonise the fuel supply in the buildings sector.

Energy efficiency will not, by itself, be sufficient to meet ambitious climate change goals. It will need to be followed by significant fuel switching to low- or carbon-free fuel sources, including electricity and hydrogen after 2030 in the BLUE Map scenario. The low carbon content of gas, the high efficiency of gas-condensing boilers and the low cost of this incumbent technology means that fuel switching away from gas is likely to be expensive in many cases.

To achieve the transformation that is needed in the BLUE Map scenario will require significant policy action over a range of technologies and end uses (Table 6.1). Balancing the availability of technologies and their current costs with the rate of capital stock turnover means that some changes are more urgent than others. Some will achieve greater savings, over different time scales, than others.

The policy challenge facing OECD countries and the EITs is very different from that facing developing countries. OECD countries, and EITs to a lesser extent, are characterised by a large stock of residential buildings that is not growing quickly and that will be retired only slowly. So most of the CO_2 reduction potential is in the current stock of buildings. OECD countries and EITs also have significant heating loads, as does China. It is essential in OECD countries and EITs to achieve significant reductions in these heating loads in existing buildings through insulation and heating system retrofit packages. These actions are potentially expensive and are only likely to make economic sense during the scheduled refurbishments or maintenance activities which occur only every 20 to 30 years on average.

Table 6.1 ▶ ***Priority policy actions needed to deliver the outcomes in the BLUE Map scenario***

	Overall savings potential	Policy urgency	Bulk of savings available
Energy efficiency			
Lighting	Medium	Average	Quickly
Appliances	Large	Average	Short- to medium-term
Water heating systems	Medium to large	Urgent	Short- to medium-term
Space heating systems	Medium to large	Urgent	Short- to medium-term
Cooling/ventilation systems	Medium to large	Urgent	Short- to medium-term
Cooking	Small	Average	Quickly
Fuel switching			
Water heating systems	Medium to large	Urgent/average	Short- to long-term
Space heating systems	Medium to large	Urgent/average	Short- to long-term
Cooking	Small	Average/urgent	Short- to medium-term
Building shell measures			
New residential buildings	Medium to large	Average/urgent	Medium- to long-term
Retrofit residential buildings	Large	Urgent	Medium- to long-term
New commercial buildings	Large	Urgent	Medium- to long-term
Retrofit commercial buildings	Medium to large	Average	Medium- to long-term

Note: Overall savings potential is relative to their contribution to total savings in the buildings sector. Where two policy urgency ratings are given, it is for OECD/non-OECD.

In developing countries, buildings have much shorter life spans, commonly of 25 to 35 years. The rate of growth of the overall building stock is also very rapid. The priority for developing countries is, therefore, to address the energy consumption of new buildings, especially in respect of cooling loads, through building standards and codes. Building codes that reduce the cooling load of buildings through better design and building shell performance need to be implemented rapidly to avoid the building of very large numbers of high CO_2 emissions buildings in the short- to medium-term which will be around for decades to come.

The energy consumption of appliances and lighting can be reduced relatively quickly given their short economic lives. A wide range of technologies have lower life-cycle costs than the incumbent systems. But shifting to BAT can be an expensive abatement option until wider deployment begins to help to reduce costs.

Box 6.1 ▶ Recent trends in low-carbon technologies for buildings

There are some possibly encouraging signs of a shift in consumer behaviour in recent years towards new technologies which can reduce CO_2 emissions.

For example, the sales of heat pumps in a number of major European markets experienced double-digit growth from 2007 to 2008. In France, sales grew even more significantly, by 127%, and surpassed annual sales in Sweden, one of the most mature heat pump markets in Europe. Total annual sales in Austria, Finland, France, Germany, Italy, Norway, Sweden and Switzerland reached 576 000 in 2008, almost 50% more than in 2005 (EHPA, 2009). With estimated sales of 7.1 million boiler units (VHK, 2007a) and of 10.8 million dedicated water heaters in the European Union (VHK, 2007b), these data suggest that heat pumps may be beginning to achieve a critical mass for space and water heating in a number of European countries.

In addition, recent growth in sales of solar thermal systems, that can provide low-temperature heat for cooling and space and water heating, also highlights a growing shift towards renewable energy sources in buildings. Installed capacity of such systems in 2007 was 147 GW_{th}, 32% higher than in 2005. The number of systems installed each year is growing rapidly, increasing by 37% between 2005 and 2007: 19.9 GW_{th} of capacity was installed in 2007 alone (Weiss, Bergmann and Faninger, 2009).

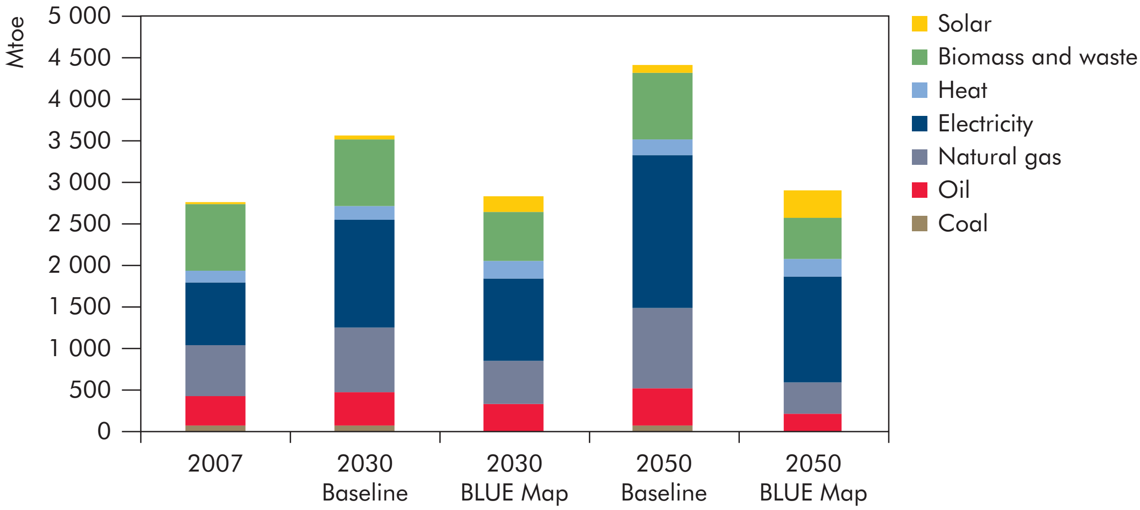
Energy consumption in the BLUE Map scenario

In the BLUE Map scenario, energy consumption in the buildings sector is reduced by around one-third of the Baseline scenario level in 2050. Energy consumption in 2050 is only 5% higher than in 2007, despite an increase in households of 67% and in service sector floor area of 195% over that time. The energy consumption of fossil fuels declines significantly, as well as that of traditional biomass. The residential sector accounts for 63% of the buildings sector's energy savings from the Baseline scenario in 2050.

The consumption of electricity, heat and solar is higher in 2050 than in 2005 in the BLUE Map scenario (Figure 6.10 and Table 6.2). Solar grows the most, accounting for 11% of total energy consumption in the buildings sector, as its widespread deployment for water heating (30% to 60% of useful demand depending on the region) and, to a lesser extent, space heating (10% to 35% of useful demand depending on the region) helps to improve the efficiency of energy use in the buildings sector and to reduce CO_2 emissions.

The level of energy savings and the percentage reduction below the Baseline vary significantly between regions (Figure 6.11). The largest percentage reductions occur in China (38%), the EITs (38%) and OECD Europe (37%). China's reduction in 2050 is a result of both improved efficiency and switching away from the inefficient use of traditional biomass to modern bioenergy (biofuels, biogas and bio-dimethyl ether) and commercial fuels. The smallest percentage reduction below the Baseline occurs in India and is due to a rebound effect in which some increased consumption is triggered by some of the energy efficiency measures in the period to 2050. The largest absolute reductions occur in China (286 Mtoe), OECD Europe (244 Mtoe) and OECD North America (230 Mtoe). In OECD regions and the EITs, it is projected that, with an abatement cost of USD 175/tCO_2, energy demand can be reduced below 2007 levels by 2050.

Figure 6.10 ▶ Buildings sector energy consumption by fuel and by scenario



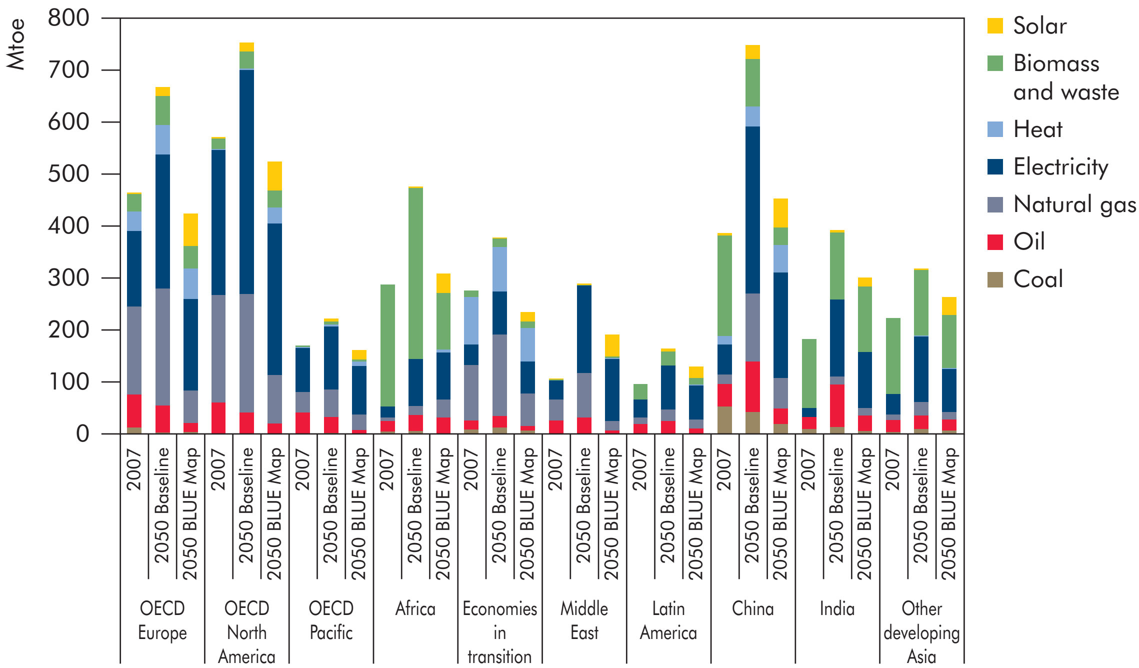
Key point

Energy consumption in the buildings sector is 5% higher in 2050 than in 2007 in the BLUE Map scenario.

Table 6.2 ▶ Buildings sector energy consumption by fuel in the Baseline and BLUE Map scenarios

		Baseline			BLUE Map		
	2007	2015	2030	2050	2015	2030	2050
Coal	96	104	94	88	97	66	44
Oil	336	344	382	439	321	283	182
Gas	608	661	796	958	597	502	366
Electricity	758	914	1 270	1 837	852	1 004	1 276
Heat	149	175	186	188	181	208	214
Biomass	799	779	787	816	721	586	491
Solar/other renewables	12	24	49	81	73	184	326
Total	**2 759**	**3 001**	**3 565**	**4 407**	**2 841**	**2 834**	**2 898**

Figure 6.11 ▶ Buildings sector energy consumption by fuel, by scenario and region



Key point

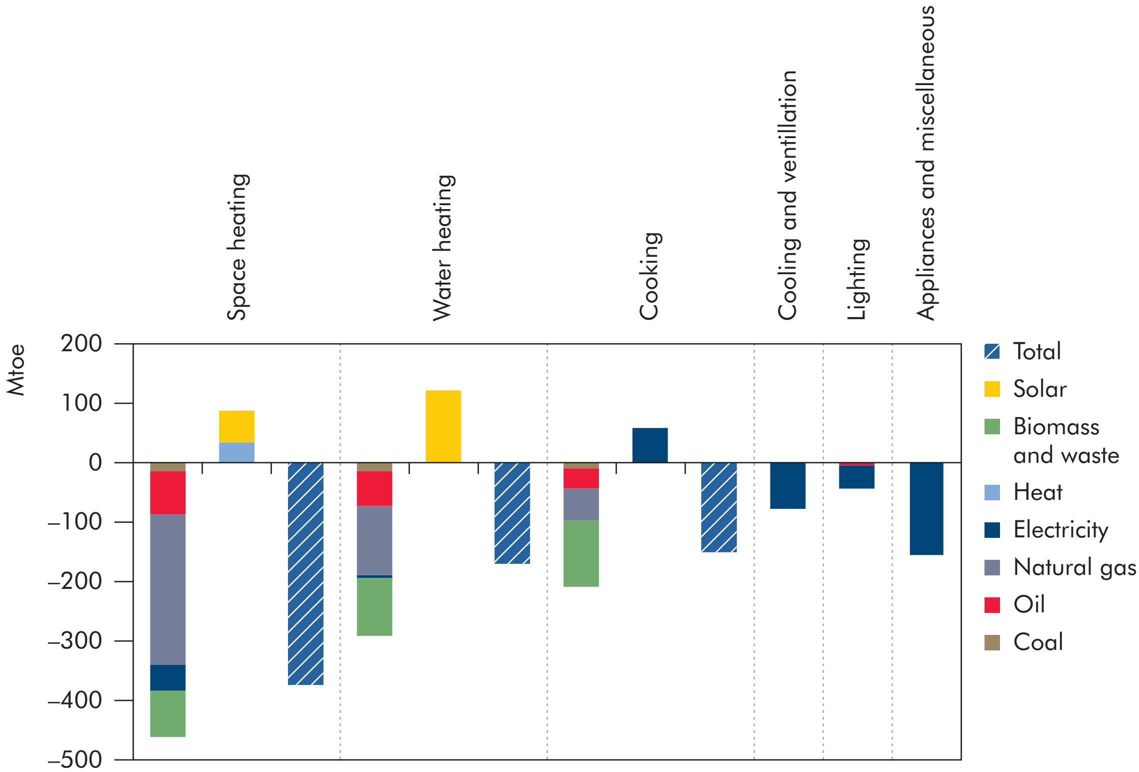
OECD regions reduce energy consumption below 2007 levels in the BLUE Map scenario by 2050.

The largest energy savings by end use in the BLUE Map scenario in the residential sector come from space heating. In the service sector, the largest savings come from lighting and miscellaneous energy use (Figures 6.12 and 6.13). In each sector, solar energy consumption for space and water heating is higher in the BLUE Map scenario in 2050 than in the Baseline scenario. Solar thermal energy is a particularly cost-effective abatement option in many countries. In addition, the projected availability of low-cost compact thermal storage systems enables a greater proportion of the annual space and water heating demand to be met by solar thermal systems in countries outside the tropics.

In the residential sector, total energy demand is reduced by 956 Mtoe. Globally, energy consumption for space heating is reduced by 374 Mtoe below the Baseline scenario in 2050, with a significant increase in the share of solar thermal and micro and small-scale CHP. Increased efficiency in space heating accounts for 39% of the total residential sector's energy savings with cooking (16%), water heating (18%), appliances and miscellaneous end uses (16%), cooling and ventilation (7%) and lighting (4%) all making significant contributions.

In the service sector, energy demand in the BLUE Map scenario is reduced by 553 Mtoe compared to the Baseline scenario in 2050. The pattern of savings is different from that in the residential sector. Space and water heating are still important sources of energy savings, but electrical end uses are just as important. Lighting and miscellaneous end uses account for 40% of the savings and cooling and ventilation for 19%. Space and water heating account for 27% and 14% of the savings, respectively.

Figure 6.12 ▶ ***Change in residential sector energy demand by end use in the BLUE Map scenario compared to the Baseline scenario, 2050***

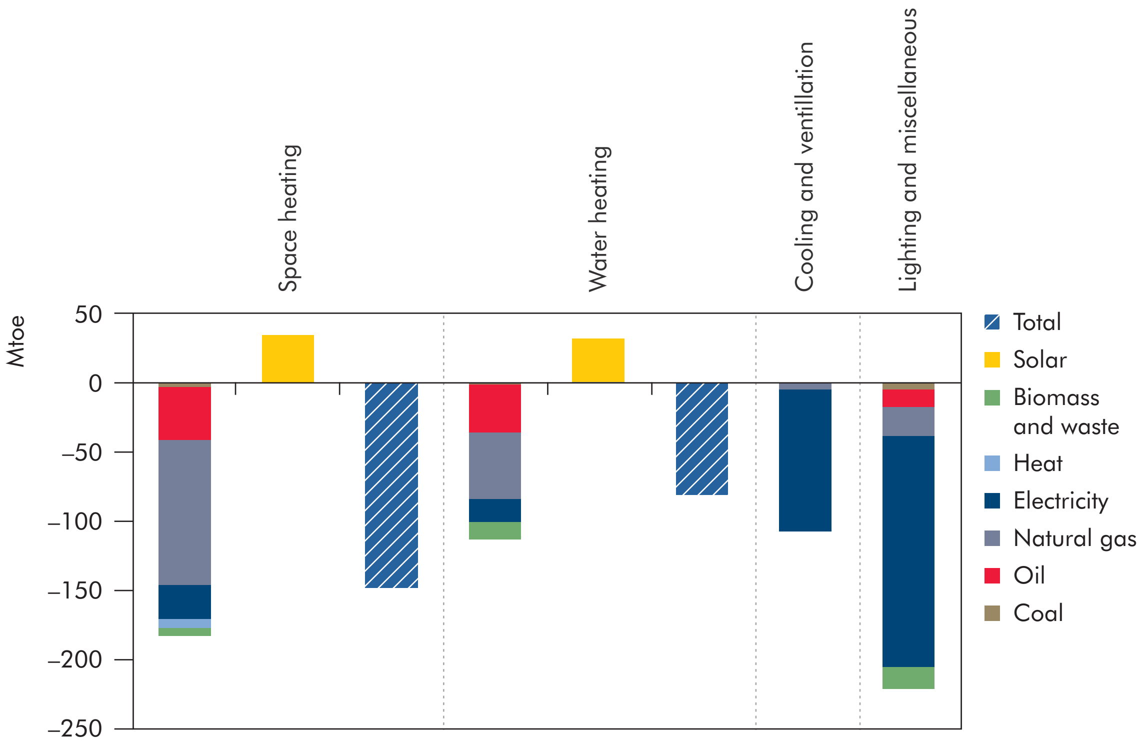


Key point

The BLUE Map scenario achieves significant savings in fossil fuels.

The total energy savings in the buildings sector in the BLUE Map scenario amount to 1 509 Mtoe in 2050 (Figure 6.14). Energy savings in residential space heating account for around a quarter of the savings. Space and water heating in the residential sector account for 36% of the total energy savings, and in the service sector for 15% of the total savings. End uses where the savings are dominated by electricity represent 39% of the savings. These will contribute an even larger share of the CO_2 emissions reductions as much of the savings occur in countries where electricity generation is CO_2-intensive.

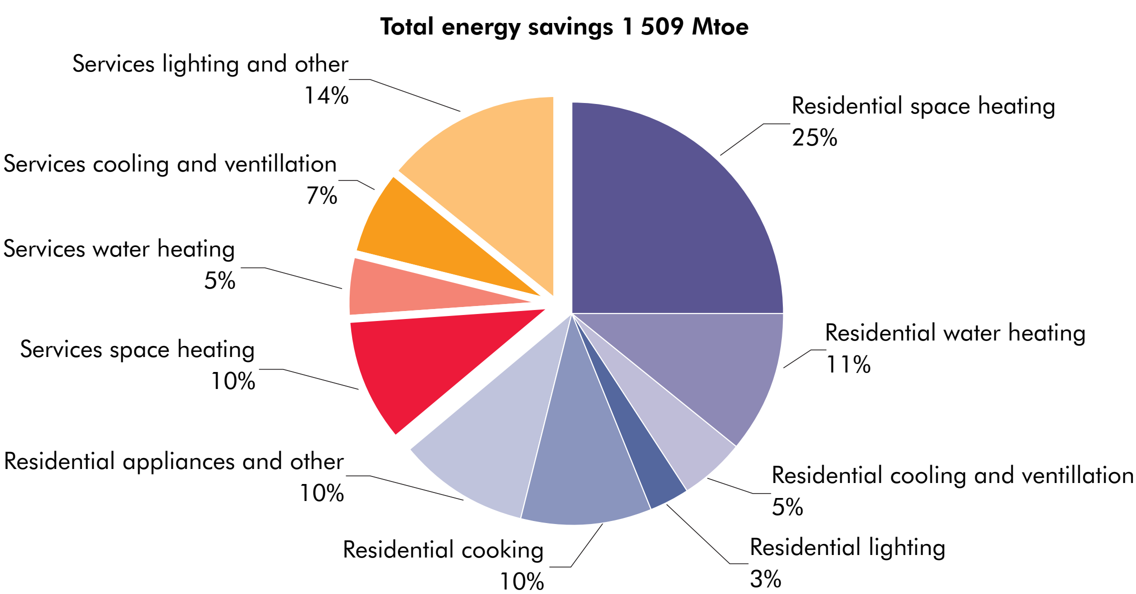
Figure 6.13 ▶ **Change in service sector energy demand by end use in the BLUE Map scenario compared to the Baseline, 2050**



Key point

In the service sector, savings in electrical end-uses are just as important as space and water heating.

Figure 6.14 ▶ **Buildings sector energy savings by sector and by end use, 2050**

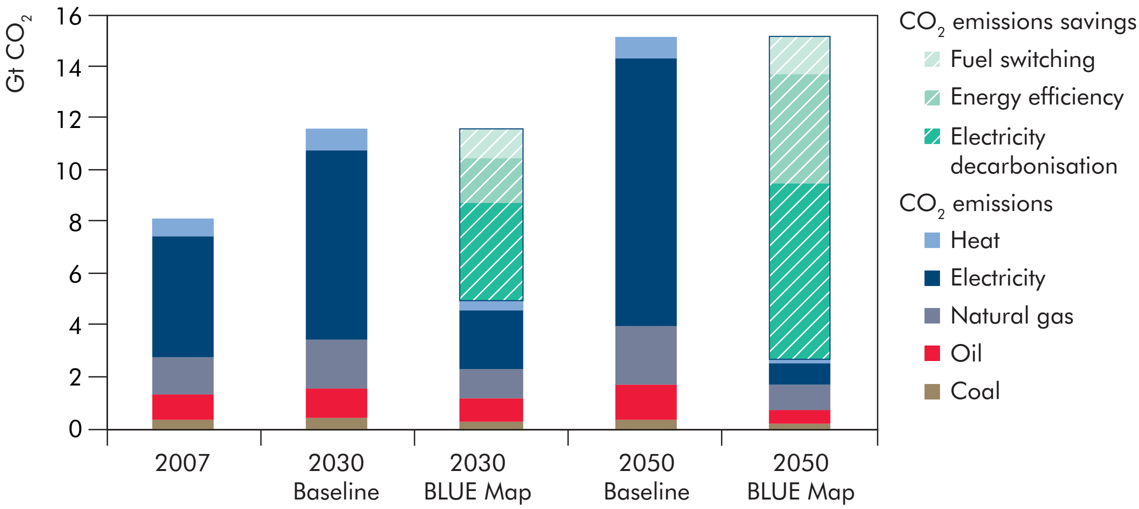


Key point

Two-thirds of the energy savings in the BLUE Map scenario come from the residential sector.

In the Baseline scenario, the buildings sector emits 15.2 Gt CO_2 in 2050, a 87% increase over 2007 levels.[14] The BLUE Map scenario reduces CO_2 emissions from the buildings sector by 12.6 Gt CO_2 from the Baseline scenario level in 2050, with 6.8 Gt CO_2 of this reduction being attributable to the decarbonisation of the electricity and heat sectors. As a result, buildings sector CO_2 emissions are 83% lower than the Baseline level in 2050. This reduces the direct and indirect CO_2 emissions attributable to the buildings sector to 2.6 Gt CO_2 in 2050, one-third of the 2007 level (Figure 6.15).

Figure 6.15 ▶ Buildings sector CO_2 emissions by scenario and by fuel



Key point

In the BLUE Map scenario buildings sector CO_2 emissions in 2050 are 83% lower than in the Baseline scenario and two-thirds lower than 2007 levels.

The BLUE Map scenario is based on the large-scale deployment of a number of technology options for the buildings sector, including:

- *Tighter building standards and codes for new residential and commercial buildings*. Regulatory standards for new residential buildings in cold climates are tightened progressively to between 15 and 30 kWh/m²/year[15] for heating purposes, with little or no increase in cooling load. In hot climates, cooling loads are reduced by around one-third. For commercial buildings, standards are introduced which halve consumption for heating and cooling compared to 2007. This will enable the downsizing of heating and cooling equipment.

14. Note that CO_2 emissions savings from electricity in this chapter have been calculated using the global CO_2 emissions factor for electricity. This is consistent with the approach taken in Chapter Two.
15. This is the useful energy demand. The actual energy consumption is a function of the fuel mix and the efficiency of the technology used.

- *Large-scale refurbishment of residential buildings in the OECD*. Around 60% of today's residential dwellings in the OECD which will still be standing in 2050 will need to be refurbished to a low-energy standard (approximately 50 kWh/m^2/year), which also enables the downsizing of heating equipment. This represents the refurbishment of around 210 million residential dwellings in the OECD between 2010 and 2050.

- *Highly efficient heating, cooling and ventilation systems*. Heating systems need to be both efficient and cost-effective. The coefficient of performance (COP)[16] of installed cooling systems doubles from today's level.

- *Improved lighting efficiency*. Notwithstanding recent improvements, many driven by policy changes, there remains considerable potential to reduce lighting demand worldwide through the use of the most efficient options.

- *Improved appliance efficiency*. Appliance standards are assumed to shift rapidly to least life-cycle cost levels, and to the current BAT levels by 2030.

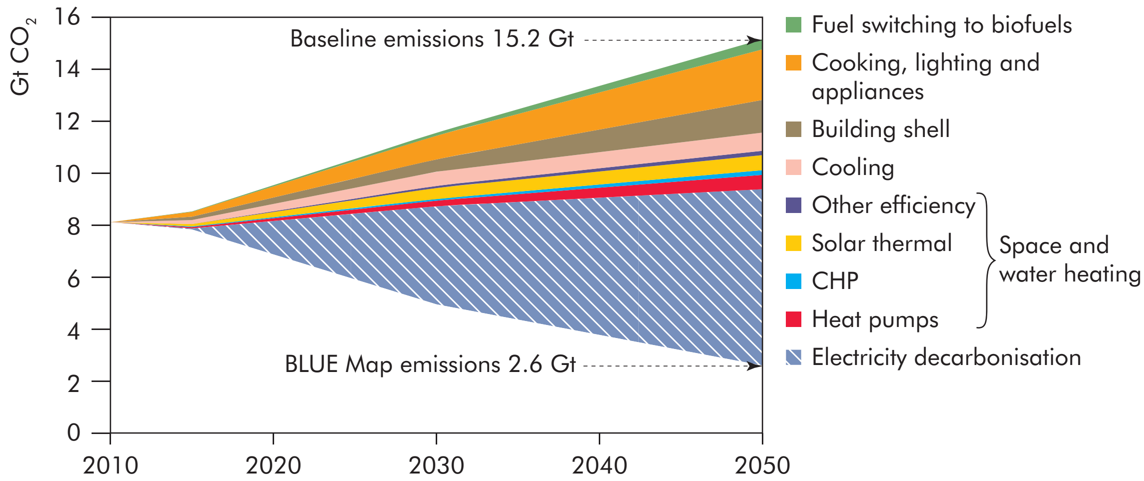
- *The widespread deployment of CO_2-free technologies*, including:
  - *Heat pumps* for space and water heating. This occurs predominantly in OECD countries, and depends on the relative economics of different abatement options.
  - *Solar thermal* for space and water heating. Often cost-effective today, further cost reductions for systems and the likely availability of low cost, compact thermal energy storage systems in the near future help increase deployment, especially in OECD countries.
  - *Micro- and mini-CHP* for space and water heating, and electricity generation. CHP can be an effective abatement option where power generation is CO_2-intensive. In the BLUE Map scenario in the buildings sector, all CHP deployed after 2030 is CO_2 free.

The CO_2 emissions savings that need to be delivered by the buildings sector in the BLUE Map scenario can only be achieved by undertaking all of these measures. Early improvements in the thermal envelope of buildings and other building shell improvements account for 22% of the total savings of 5.8 Gt CO_2 attributable to the buildings sector in 2050 (Figure 6.16) and enable the downsizing of heating and cooling equipment. Lighting and appliances, given the importance of electrical end-use growth and energy efficiency improvements in non-OECD countries, account for 32% of the total reduction.

The increased deployment of heat pumps for space and water heating, as well as the deployment of more efficient heat pumps for cooling account for 22% of the savings. Solar thermal systems for space and water heating account for around 12% of the savings. CHP plays a small but important role in reducing CO_2 emissions, as well as assisting in the balancing of the renewables-dominated electricity system in the BLUE Map scenario.

16. The COP of a heat pump is the ratio of useful energy output (heat or cold) to energy input (typically electricity).

Figure 6.16 ▶ **Contribution of CO_2 emissions reduction options**



Key point

Improvements in the building shell and energy savings in electrical end uses dominate total CO_2 reductions in the BLUE Map scenario.

Investment requirements in the BLUE Map scenario

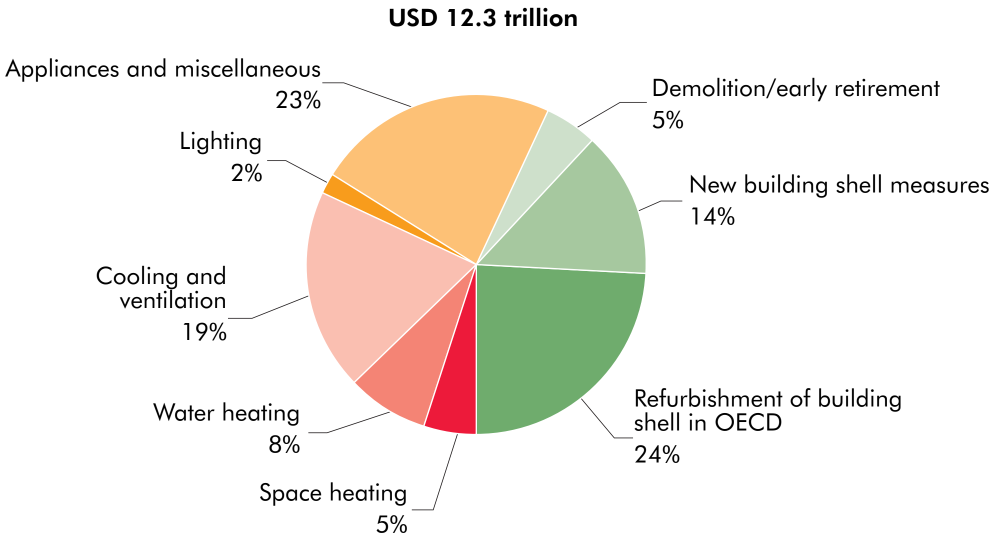
Additional investment needs in the BLUE Map scenario are estimated to be USD 12.3 trillion (constant 2007 USD), made up of USD 7.9 trillion in the residential sector and USD 4.4 trillion in the service sector.[17] The investment is required to ensure that new buildings meet more stringent building codes, to refurbish around 60% of the OECD building stock still standing in 2050 to a low-energy standard, and for additional investments in heat pumps, solar thermal systems, CHP systems, lighting systems and appliances.

The investment required in building shells, particularly in OECD countries for refurbishment of the existing building stock, dominates the total additional investment needs in the BLUE Map scenario over and above the Baseline by 2050 (Figure 6.17). The incremental investment needs for space heating are modest, because equipment size is reduced as a result of the building shell measures implemented, thus offsetting the shift to more capital-intensive options such as heat pumps, solar thermal and CHP.

In the residential sector, improvements in building shells account for just over half of the incremental investment needs. In the service sector, around 31% of all investment is required for this purpose. In the service sector, the electrical end uses of lighting, cooling and ventilation and miscellaneous plug loads dominate the incremental investment needs (Figure 6.18).

17. This is the total incremental investment over and above the Baseline scenario.

Figure 6.17 ▶ Incremental investment needs in the buildings sector in the BLUE Map scenario



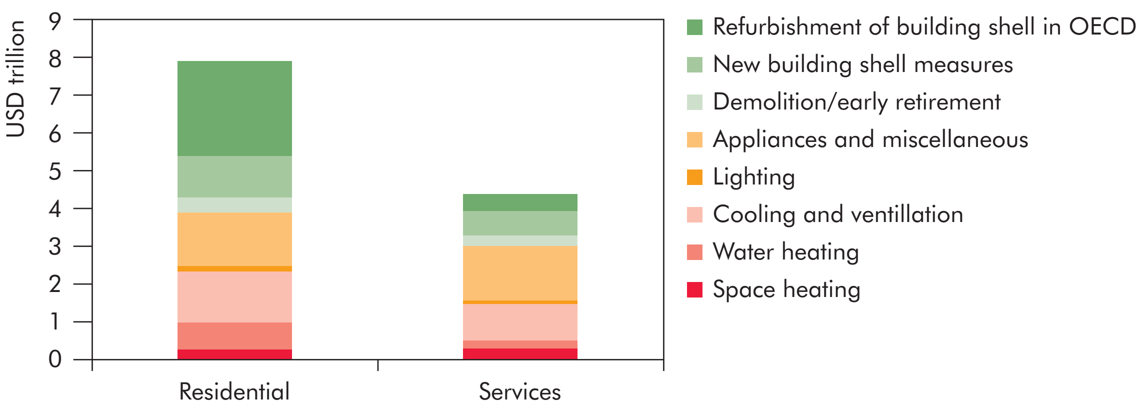
Note: Miscellaneous includes appliances, IT and office equipment, pumps and other small plug loads in the residential and service sectors. It also includes cooking in the residential and service sectors.

Key point

Investments in the building shell account for 43% of the additional investment.

Taken together, this investment of USD 12.3 trillion achieves fuel savings (including electricity) totalling USD 51 trillion between 2010 and 2050 when evaluated at wholesale prices. The net savings, undiscounted, are therefore around USD 39 trillion. Using a 3% discount rate reduces the net savings to USD 18.6 trillion; while at a 10% discount rate, the net savings are USD 5.3 trillion. On this basis, the net cost of investing in efficiency improvements in the buildings sector is relatively low.

Figure 6.18 ▶ Incremental investment needs in the residential and service sectors in the BLUE Map scenario, 2007-50



Key point

Additional investment needs in the residential sector are 80% higher than in the service sector.

BLUE scenario variants

Developing scenarios for the future is an inherently uncertain exercise. To explore the sensitivity of the results to different input assumptions, several variants of the BLUE Map scenario have been analysed. They are:

- *BLUE Heat Pumps*: this scenario looks at ultra-high efficiency heat pump air conditioners (COP of 9) for cooling and humidity control, and faster cost reductions for space and water heating applications.
- *BLUE Solar Thermal*: this scenario explores the situation where low-cost compact thermal storage is deployed on a large scale from 2025 and system costs come down more rapidly in the short term.
- *BLUE Buildings CHP*: this scenario explores the impact of more rapid declines in the cost assumptions for fuel-cell CHP units using hydrogen and their potential contribution to a higher penetration of distributed generation.

The main distinction between these scenarios is that in each case a specific technology is assumed to achieve significant cost reductions earlier than in the BLUE Map scenario. This technology, therefore, gains a higher share of installations than competing options. By 2050 this has a significant impact on the share of space and water heating demand that is met by the technology in question. In the BLUE Solar Thermal and BLUE Heat Pumps scenarios, each of these technologies becomes the dominant technology in 2050 for space and water heating. In addition, in the BLUE Heat Pumps scenario, heat pumps achieve higher efficiencies than in BLUE Map for cooling. In the BLUE Buildings CHP scenario, the share of useful energy for space and water heating provided by small-scale CHP in the buildings sector doubles.

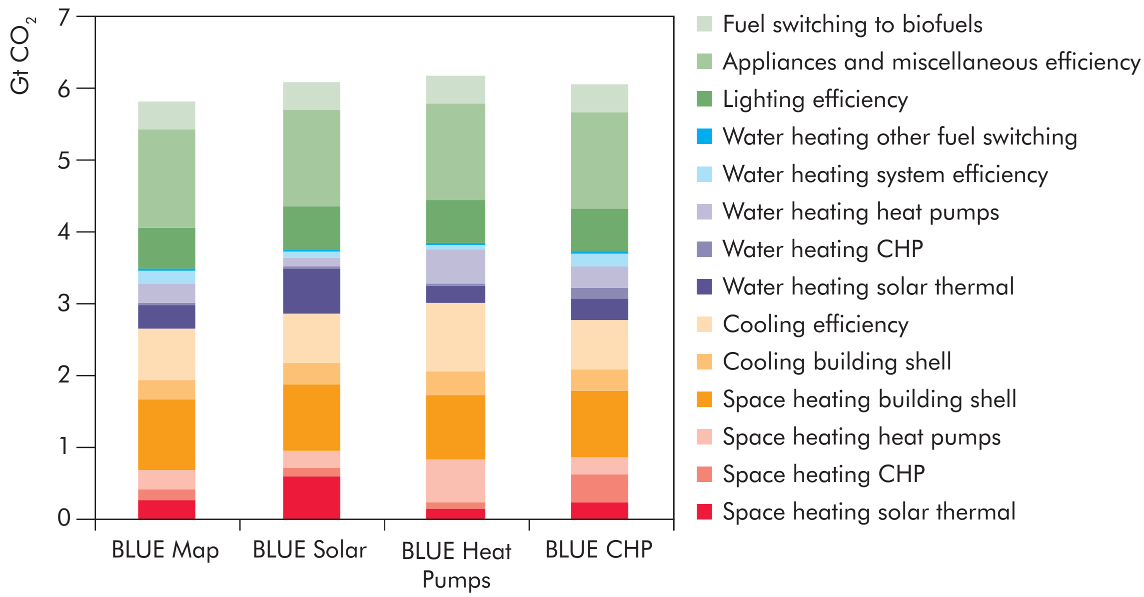
In each of the buildings sector BLUE scenario variants, additional savings are achieved below the Baseline scenario in 2050 compared to the BLUE Map scenario. These additional savings are modest because the BLUE Map scenario is already very efficient and has already resulted in a significant switch away from fossil fuels for space and water heating by 2050.[18]

In the BLUE Solar Thermal variant, total CO_2 reductions in the buildings sector are 5% greater than in the BLUE Map scenario. They reach around 6 083 Mt CO_2 (Figure 6.19). In this scenario variant, solar thermal accounts for 44% of the CO_2 reduction below the Baseline scenario from space and water heating in 2050. In the BLUE CHP variant, CO_2 emissions reductions are 4% more than in the BLUE Map scenario. CHP increases its share of CO_2 emissions reductions in space and water heating from 7% in the BLUE Map scenario to 19% in the BLUE CHP variant.

In the BLUE Heat Pumps variant, CO_2 emissions reductions are 7% higher than in the BLUE Map scenario. Heat pumps' share of the savings from space and water heating increases from 23% in the BLUE Map scenario to 40% in the BLUE Heat Pumps variant in 2050. In addition, highly efficient heat pumps for air-conditioning save an additional 155 Mt CO_2.

18. These BLUE scenario variants assume the same economy-wide marginal abatement cost of USD 175/tCO_2, and hence result in greater emissions reductions. An alternative approach would have been to keep the same abatement level as the BLUE Map scenario and to analyse the reduction in the marginal abatement cost for the sector of each scenario variant.

Figure 6.19 ▶ **Direct CO_2 emissions reduction below the Baseline scenario in the buildings sector BLUE scenario variants, 2050**



Key point

A range of outcomes are possible for the buildings sector depending on the rate at which technologies improve and reduce their costs.

Technology options in the BLUE Map scenario

Buildings are complicated systems and a wide range of factors affect their energy use. In OECD countries and the EITs, the biggest opportunities to improve energy use and reduce CO_2 emissions arise in the areas of space and water heating, lighting and appliances. In developing countries, lighting and cooking are relatively more important, and cooling will grow in importance. Other than in China, space heating is less significant for developing countries.

A number of technologies offer opportunities to significantly reduce energy use and emissions at low cost. Reductions in electricity consumption may be a higher priority than reductions in the direct use of fossil fuels in countries with CO_2-intensive electricity generation. In the buildings sector, the greatest opportunities for cost-effective CO_2 reductions will come from:

- *Intelligent building design* that makes the most of solar gains in the heating season and limits those gains in the cooling season.
- *High-performance building envelopes* that reduce heating and cooling loads, e.g. through shading, reflective surfaces and light coloured roofs, high levels of insulation and air tightness, and high-performance windows.

- *Highly efficient heating, ventilation and air-conditioning systems*. HVAC systems such as heat pumps for heating and cooling, ventilation systems, gas-condensing boilers and CHP need to be as efficient as is cost-effective.

- *Highly efficient water heating systems*. These may be dedicated systems or combined (integrated) with the space heating system and/or cooling system. Options include integrated heat pumps, solar thermal, CHP, and gas-condensing boilers.

- *Highly efficient appliances and lighting*. A rapid shift to least life-cycle cost standards and then to BAT is required.

- *Efficient cook stoves*. In developing countries, the use of more efficient biomass stoves and switching to commercial fuels will reduce energy consumption and deforestation and improve indoor air quality.

- *CO_2-free technologies*. The deep emission cuts envisaged in the BLUE Map scenario require not only efficiency improvements but also fuel switching. By 2030, increased electrification using electricity from decarbonised generation sources is an abatement option. Solar thermal is an important abatement option for space and water heating. Depending on technology developments, hydrogen in fuel-cell CHP units could also be an important option.

The BLUE Map scenario requires large contributions from all of these sources if energy consumption and CO_2 emissions are to be reduced.

The building envelope and good design

The building envelope and the design[19] of a building play a substantial role in determining the heating and cooling load for a desired indoor temperature. It is estimated that, in 2007, 39% of the residential sector's and 35% of the service sector's global CO_2 emissions stemmed from space and cooling needs. The largest total savings potential to 2050 is in new buildings in developing countries, because of the rapid growth in the building stock, and in existing buildings in the OECD.

In new buildings, significant savings are possible compared to common new building practices and codes in many countries (IEA, 2008a). Current codes and standards are in many cases a long way from being sufficient to achieve least life-cycle costs if energy savings are taken into account. Significant reductions can be achieved at relatively low CO_2 abatement costs.

In cold climates (predominantly in the OECD, EITs and China), the BLUE Map scenario envisages building standards for new residential buildings being progressively tightened. They reach between 15 and 30 kWh/m^2/year of useful energy for heating and cooling by 2030 for those countries with standards furthest from this level (greater than 150 kWh/m^2/year) and the same level by 2020 for those that currently have more stringent codes. This is similar to the passive house standard for Central Europe of around 15 kWh/m^2/year when normalised for climate. At the same time, building design will also need to evolve to more readily

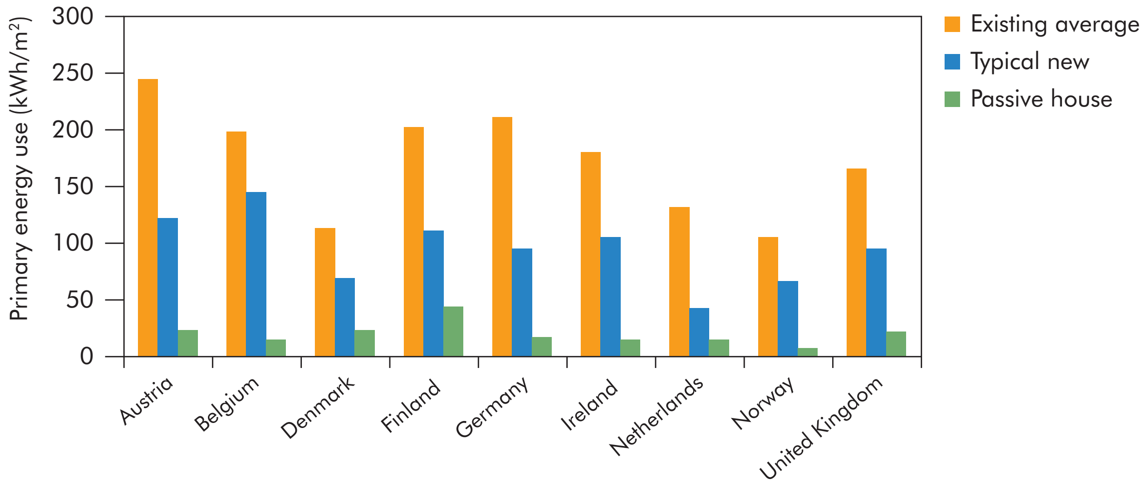
19. The term design is used here to encompass all of the architectural issues involved in buildings, as well as the integration of the building with its energy-using systems where appropriate.

incorporate solar thermal and photovoltaic (PV) systems. Governments will also need to do more to ensure compliance with building standards.

In OECD countries, most of the building stock was constructed before the 1970s and has very high space heating requirements (Figure 6.20). Refurbishment or renovation of these buildings will offer the largest abatement potential, given current low rates of retirement of the existing stock and modest additions of new buildings. But although many measures are cost-effective, comprehensive energy refurbishment to standards similar to those in new buildings will require significant upfront costs, and their economics will depend heavily on fuel prices.

The BLUE Map scenario assumes that this investment will only be economic when major scheduled refurbishments are undertaken, typically every 20 to 30 years, but sometimes after much longer periods. These measures are also relatively expensive in terms of their costs per tonne of CO_2 saved. The refurbishment of 60% of the existing OECD stock by 2050, as implied in the BLUE Map scenario, will only happen if urgent policy action is taken to make it happen.

Figure 6.20 ▶ Yearly primary space heating use per dwelling in selected European countries



Source: Kaan, Strom and Boonstra (2006).

Key point

The existing building stock in many European countries requires significantly more energy for space heating than could be achieved with today's technology (e.g. a passive house design).

Achieving these more rigorous standards for new buildings currently increases initial construction costs by around 2% to 7% on average, although higher values are possible in the early stages of deployment. This will decline over time as this standard becomes the norm and the required components such as high-performance windows and insulation achieve mass market deployment. Reducing the heating and cooling loads of new commercial buildings will be more difficult to achieve.

Building shell technologies and design

Building shells, including the external walls, floors, roofs, ceilings, windows and doors, are a critical factor in determining heating and cooling demand. Building heating loads constitute the largest energy end use in OECD countries.

Reducing heat losses in winter and heat gains in summer offers large opportunities to reduce energy consumption. The most important heat losses occur through roofs (30% to 35%), walls (25% to 30%), windows (15%) and ventilation (25%).[20] For renovations, these areas provide the best opportunities to reduce heating needs at least cost. In new buildings, they are the areas requiring most attention in energy-efficient design.

Energy-efficient designs are optimised to reduce heating and cooling needs and make the most use of the sun. Passive solar designs maximise the benefits of free solar radiation and light in cold climates to reduce heating and lighting needs. Similarly, in hot climates, the use of thermal mass, insulation, shading and reflective surfaces, and convection ventilation can help minimise heat gains in summer and, by providing naturally assisted ventilation, reduce energy needs for cooling and ventilation. Having significant thermal mass can also help reduce temperature fluctuations. Minimising heating and cooling loads generally requires the following to be incorporated into the building design:

- High levels of insulation in the walls, roof and floor in order to reduce heat losses in cold climates.
- Minimisation of design components that easily conduct heat/cold (known as thermal bridges).
- Use of high-performance windows with low U-values,[21] with low-emissivity coatings or even switchable coatings appropriate to the prevailing climate.
- Air tightness to reduce heat losses and latent cooling loads. This often then requires a mechanical system to ventilate the building. Such systems can also be used for heat recovery. In hot climates, air tightness may not be as important, and can even have a negative impact.
- Good passive solar design, including natural ventilation.

Existing standards offer minimum measures for efficient building. Guidance is often readily available to achieve designs that significantly exceed minimum standards (such as the ASHRAE Advanced Energy Design Guide series). Taking these design principles into account can significantly reduce heating and cooling loads in a new building at little or no additional cost when life-cycle costs are taken into account.

Building shell technologies: walls, floors, roofs and windows

Walls, floors and roofs represent the largest external area of most residential and commercial buildings. It is through these elements of the shell that most of the heat losses from the building occur. There are many types of insulating materials, including mineral wool, cellulose, polystyrene and polyurethane. Insulation is

20. Significant variations can occur depending on the design and construction of the home. These values are indicative only.
21. The U-value is the overall heat transfer coefficient for a given building element. It measures, for a given area (usually one m^2), the rate at which heat is transferred through a given building component under standardised conditions.

available for all parts of the building shell. Building insulation performance has more than doubled over the past 25 years. But super-insulation technologies that are already or will soon be on the market will be even more effective than today's technology. These include vacuum-powder-filled panels, gas-filled and vacuum-fibre-filled panels, structurally reinforced beaded vacuum panels, and switchable evacuated panels.

The IEA's Implementing Agreement on Energy Conservation in Buildings and Community Systems has a specific work programme on high-performance thermal insulation systems. Considerable attention is being paid to improving insulation quality as standards for buildings become more rigorous.[22]

Different types of insulation perform differently for a given level of thickness. If space is not a constraint, the cheapest and simplest solution to improve building envelope performance is to increase the thickness of the insulation installed as the additional material cost is usually only a fraction of the overall construction cost.

Although windows take up less area than the rest of the building shell in most cases, they have been an important source of heat losses because of the poor energy performance of conventional window systems compared to well-insulated walls. For windows, the resistance to heat flow is affected by a number of factors including the tightness of the window installation, the type of glazing material, the number of layers of glazing, the size of the air space between layers, the filling between the layers, the coating (if any), and the thermal resistance of the frame. In general, multiple layers of small areas of glass will typically perform better than larger windows with fewer layers.

Windows are available with heat losses of only 0.7 to 0.8 W/m^2 per degree Kelvin (K). This is around 30% to 35% less than coated double-glazed windows. The improvement in the thermal performance of windows is due to the use of multiple glazing layers, the use of low-conductivity gases such as argon between glazing layers, applying low-emissivity coatings on one or more glazing surfaces, and using very low-conductivity framing materials such as extruded fibreglass or PVC. Coatings that allow the inner glass layer to have a temperature much closer to that of the room also help improve indoor comfort. It is important that glazing with low-conductivity gases is well maintained, as a loss of filling can result in performance deterioration of up to 60%.

In hot climates, it is particularly important to keep heat out. Coatings on the glazing that reflect or absorb a large fraction of the incident solar radiation while maximising the transmission of visible sunlight can reduce solar heat gain by up to 75%. This reduces the need for cooling, particularly when combined with shutters or shading. The cost of glazing and windows, even with these technological improvements, has remained constant or even dropped in real terms (Jakob and Madlener, 2004).

Barriers to greater market penetration

A number of market and non-economic barriers mean that the building shells of new buildings are generally not designed to least life-cycle cost levels. Cost-effective refurbishments are also often not undertaken, even when other renovations are

22. For more information, see www.ecbcs.org

under way. Research, development and demonstration (RD&D) is needed to improve the cost and performance of current materials, and to develop their optimisation and integration into new building design and refurbishment designs. This RD&D is essential if large-scale reductions in energy consumption, particularly from existing residential buildings and new commercial buildings, are to be achieved.

Savings potential and abatement costs

The technical scope for energy efficiency improvements in the existing residential building stock is large. It is also large from an economic perspective. Some industry studies indicate that energy consumption in existing buildings in Europe could be reduced by more than 50%, more than three-quarters of which in some types of buildings could be achieved with increased insulation (European Mineral Wool Manufacturers Association, EURIMA). In new buildings, BATs could halve or quarter heating requirements compared to standard practice. This could be achieved at a cost of only a few per cent of the total cost of residential buildings, and at little or no net incremental cost in new service sector buildings (Demirbilek *et al.*, 2000; Hamada *et al.*, 2003; Hastings, 2004). In countries that have mild winters but still require heating, modest amounts of insulation can readily halve heating requirements, as well as substantially reducing indoor summer temperatures (Taylor *et al.*, 2000; Florides *et al.*, 2002; Safarzadeh and Bahadori, 2005). This includes many developing countries.

Retrofitting high-rise residential buildings with energy efficiency improvements when they are refurbished can yield energy savings of up to 80% and negative life-cycle costs.[23] The economics of retrofitting detached or terraced houses can vary widely. In the United Kingdom, for example, retrofitting ceilings and cavity walls with insulation has been estimated to range from a cost of USD 1 310/tCO_2 saved where insulation is already thick to a net saving of as much as USD 444/tCO_2 saved where this is not the case (Shorrock and Henderson, 2005).[24] For new houses in Canada, moving to a more energy-efficient design standard (the Canadian R-2000 standard) rather than the minimum standard can save significant amounts of energy at abatement costs in the range of net savings of USD 36/tCO_2 to costs of USD 228/tCO_2 depending on circumstances (Seeline Group, 2005 and IEA analysis). In the United States, the average abatement cost for building shell measures such as the tightening of new building standards and retrofits is estimated to be around a net saving of USD 42/tCO_2 abated (McKinsey, 2007a). In Germany, renovation to a low-energy standard is expected to have negative abatement costs, while renovation to passive house standards is currently estimated to be very expensive, with an abatement cost of at least USD 800/tCO_2 (McKinsey, 2007b).

Heat pumps for heating and cooling

Heat pumps are highly efficient technologies for providing cooling and space and water heating. They use renewable energy from their surroundings (ambient air, water or ground) and "high-grade" energy (*e.g.* electricity or gas) to raise the

23. Negative life-cycle costs are where energy savings exceed initial capital costs when evaluated at a 10% discount rate.
24. Caution needs to be used in interpreting energy and CO_2 emissions reduction costs that are not based on analysing whole building solutions, given the complexity of building systems and the potential synergies of a holistic approach.

temperature for heating, or lower it for cooling.[25] They achieve efficiencies greater than 100%, that is to say they provide more useful cold or heat (in energy terms) than the energy input.[26] The potential energy and CO_2 savings from the wider use of heat pumps are substantial, given their high efficiency and relatively low market penetration for space and water heating. Most air conditioners are heat pumps. The efficiency of today's BAT for air conditioners is considerably higher than average installed efficiencies, offering further scope for CO_2 emission savings. When combined with thermal storage, to enable load to be shifted out of peak periods, heat pumps could also help reduce the costs in the BLUE Map scenario of integrating a high share of intermittent renewables into the grid.

In OECD countries, most energy in the buildings sector is used for space and water heating. The energy consumption for cooling is generally modest. For example, in the residential sector in the United States, a mature air-conditioning market, energy consumption for cooling is only around 8% of the total energy consumption in the residential sector. In commercial buildings in the United States, cooling and ventilation accounts for around 13% of the total energy consumption for space and water heating.[27]

Air-conditioning systems, which are predominantly heat pumps, cool, ventilate, humidify and dehumidify buildings. Space conditioning, including controlling humidity, is an integral requirement of many buildings for human comfort, productivity and even safety, for example in hospitals and rest homes. In humid countries, the energy required for dehumidification can be as high as that for cooling. In the BLUE Map scenario, the buildings sector deploys heat pumps widely for space and water heating and very high-efficiency heat pumps for cooling. This, together with the decarbonisation of the electricity sector, results in very significant savings as against the Baseline scenario.

Heat pump technology and performance

Heat pumps for heating and cooling buildings can be described by the source of renewable energy they use (air, water or ground) and by the heat transport medium they use (air or water). They can also be described by the service that they provide, *i.e.* cooling, or space and/or water heating. The European Union, depending on certain criteria being met, credits heat pumps as using renewable energy.

The performance of heat pump systems has improved over time with the advances made in individual heat pump components (such as the use of inverters) and with efforts to achieve better overall system integration and performance. The efficiency of a heat pump depends on a number of different factors, specifically:

- the technical specifications of the heat pump;
- whether the heat pump is operating at full load or not;

25. The European Union credits the heat pumps use of "aerothermal", "hydrothermal" and "geothermal" energy as part of its Directive to promote the use of renewable energy (EU, 2009).
26. Heat pump efficiencies can be described by the "coefficient of performance" (COP). For example, a heating COP of three is equivalent to 300% efficiency, *i.e.* three units of useful heat for one unit of energy input.
27. United States Energy Information Administration's Residential Energy Consumption Survey (RECS) and Commercial Building Energy Consumption Survey (CBECS) (see www.eia.doe.gov).

- whether temperature is being increased or decreased;
- the desired indoor temperature and the existing or planned heat distribution system temperature;
- the temperature difference between the heat source and heat sink to be bridged by the heat pump.

The most critical factor is the temperature differential that is required to be bridged, *i.e.* the temperature lift or reduction that is being sought. The higher this is, the lower is the efficiency of the system. On a like-for-like basis, ground-source heat pumps (GSHPs) tend to have higher efficiencies than air-source heat pumps (ASHPs)[28] or air-to-air heat pumps, as ground temperatures are more constant throughout the year. The higher efficiency of GSHPs has to be considered in light of their higher installation costs. Typical COP values for air-to-air heat pumps are in the range of 2.5 to 3.5, while for ASHPs the range is similar. GSHPs tend to have COPs in the range of 3.5 to 5. [29] However, the best systems available can exceed these values by a significant margin.

Significant improvements in the average efficiency of new air conditioners have been achieved. The United States minimum energy performance standards and Energy Star programmes, the European labelling schemes, and Japan's Top Runner Programme have helped to raise COPs. The Japanese programme has resulted in impressive improvements in COPs. The COP of heat pump air conditioners in Japan increased from around 4.3 in 1997 to around 6.6 in 2008. Some air conditioners have achieved COPs of 9.0. In the United States, the minimum standard for new central air conditioners in the residential sector is a seasonal COP of 3.8, while models with a COP greater than six are available.[30]

Heat pumps for space heating can either use air or water as the distribution method. In hot climates, the availability of units that can both heat and cool offer a potentially very cost-effective means of producing hot water, heating it from the waste heat produced in the cooling cycle. If combined with thermal storage, this could dramatically reduce energy consumption for water heating. This technology is also suitable for buildings with simultaneous space heating and cooling loads, particularly in the commercial sector.

ASHPs are capturing an increasing share of the space and water heating market. They can operate down to temperatures of around -25°C and, by avoiding the need for ground or water loops, have significantly lower installation costs than GSHPs. Significant improvements in efficiency have also been achieved, with the COP of Japanese heat pump water-heating systems rising from around 3.5 in 2001 to around 5.1 in 2008. But they tend to be around 10% to 30% less efficient than GSHPs in cold climates.[31]

28. In this chapter, ASHPs are defined as air-to-water heat pumps to distinguish them from air-to-air heat pumps.
29. It should also be noted that in inter-country comparisons of heat pumps, higher COPs do not necessarily imply more efficient technology. Differences can be due to different climate and operating conditions.
30. The COPs of Japan and the United States are not directly comparable owing to different test standards.
31. This is due to the rapid fall in capacity and performance with decreasing outdoor temperature, the relatively high temperature difference in the evaporator and the energy needed for defrosting the evaporator and to operate the fans.

Barriers and R&D priorities

Heat pump technologies are proven and mature. But to achieve the goals in the BLUE Map scenario will require a number of current market and non-economic barriers to be overcome as well as additional R&D to improve overall system performance, particularly in a wider range of applications and climates.

For example, although there are many air-conditioning products on the market, users often lack an understanding of the most appropriate technology for a specific use. Some more efficient systems have high initial capital costs although they may be cheaper to run on a lifetime basis. The installation and operation of more advanced systems can be difficult as well, adding to costs. There has been a lack of good comparative information to help the consumer. Improvements in control systems have the potential to achieve additional savings by ensuring that coolers only run when necessary.

Similarly, more efficient heating systems suffer from relatively high first costs, a lack of consumer awareness of the often lower life-cycle costs and the lack of good comparative information and financing packages to help overcome these barriers.

The main R&D priorities for the future are:

- *Components*: More efficient components and systems for heating and cooling applications. Reduce costs and increase reliability and performance.
- *Systems/applications*: Optimise component integration and improve heat pump design and installations for specific applications.
- *Control and operation*: Develop intelligent control strategies to adapt operation to variable loads and optimise annual performance. Develop automatic fault detection and diagnostic tools.
- *Integrated and hybrid systems*: Develop integrated heat pump systems that combine multiple functions (*e.g.* space conditioning and water heating) and hybrid heat pump systems that are paired with other energy technologies (*e.g.* storage, solar thermal and other energy sources) in order to achieve very high levels of performance.

Integrated systems, such as those that integrate solar thermal technologies and heat pumps, have significant potential and would result in very high efficiency/low-carbon hybrid systems.

Heat pump system and abatement costs

Investment costs and delivered energy costs depend heavily on the system selected and the cost of electricity. In many cases, heat pump investment costs are higher than those of conventional boiler systems. Heat pump systems with borehole heat exchangers are expensive. Horizontally installed heat pump circuits are cheaper and can cost around the same as oil-fired boilers. In large systems in commercial buildings, the use of thermal ground storage offers the possibility of very low-cost cooling once the installation is paid for. Air-to-air systems have very low capital costs.

Systems that can be reversed, for heating or for cooling purposes, are economically attractive in temperate climates which may require both applications at different times of the year. The incremental cost of giving the possibility to reverse the cycle is very modest compared to the cost of installing separate heating and cooling systems.

Different regions deploy residential heat pumps with very different specifications and costs, as a result of the often very different sizing systems, local standards and consumer preferences (Table 6.3). GSHPs tend to be the largest and most expensive systems to install.

Table 6.3 ▶ Technology and cost characteristics of heat pumps for heating and cooling, 2007

	Single-family dwelling			
	North America	China and India	OECD Pacific	OECD Europe
Typical size (kW_{th})	2-19	1.5-40	2.2-10	2-15
Economic life (years)	15-20+	15-20	8-30	7-30
Costs				
Installed cost: air-to-air (USD/kW_{th})	475-1 250	180-225	400-536	558-1 430
Installed cost: ASHP (USD/kW_{th})	720-1 250	347	560-1 333	607-3 187
Installed cost: GSHP (USD/kW_{th})	905-1 700	439-600	1 000-1 400	1 170-2 267
Cost of delivered energy				
(USD/GJ) range for all	16-29	7-11	18-49	18-64

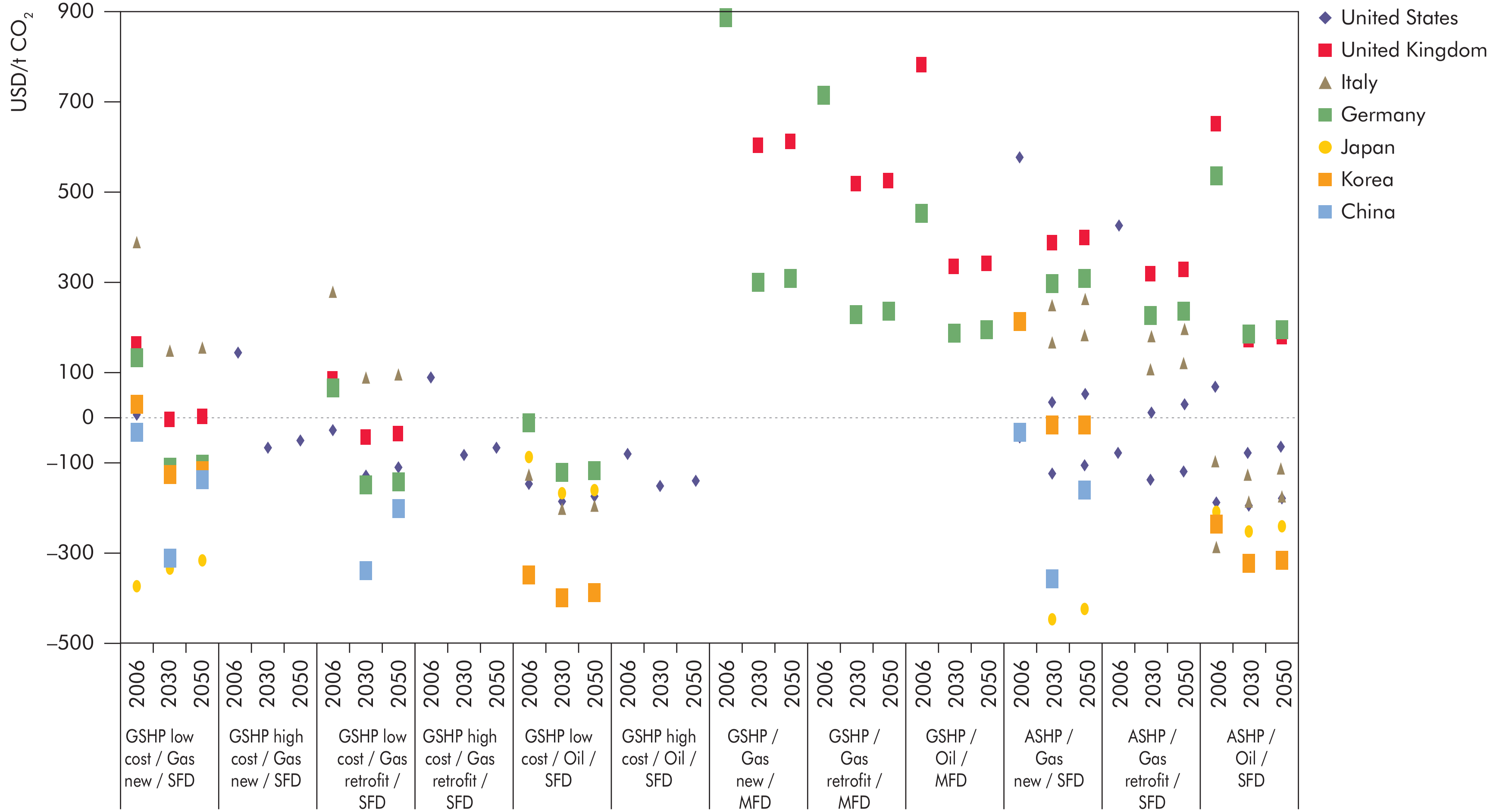
Note: The cost of delivered energy is an average for heating and cooling combined where appropriate; COPs used for calculating delivered energy costs are based on typical values provided by the IEA Heat Pump Programme. Economic life varies by technology.

Sources: IEA Heat Pump Programme; Navigant Consulting; VHK (2007c) and McNeil *et al.* (2005).

The cost of abating CO_2 through the use of heat pumps varies widely depending on the country and application (Figure 6.21). A number of options in the United States for the residential sector would deliver cost savings alongside emissions savings. Advanced unitary compressors for central air-conditioning units would save USD 95/tCO_2 abated. In humid climates, systems would save USD 80/tCO_2 abated (Sachs *et al.*, 2004). For the service sector, an advanced roof-top air conditioner unit could save over 4 000 kWh a year with a saving of USD 72/tCO_2 abated. In the European Union, the wider use of split air conditioners would reduce electricity consumption by 38% at a saving of between USD 117/tCO_2 and USD 600/tCO_2 abated (Riviere *et al.*, 2008).

In many cases, modest energy and CO_2 savings can be achieved with negative costs of abatement. But larger energy and CO_2 savings can only be achieved at a cost, and one which tends to become progressively larger for higher levels of abatement.

Figure 6.21 ▶ CO_2 abatement costs for heat pumps in heating applications



Note: "Gas new" and "Oil" denote a comparison to a gas and oil boiler respectively for a new installation. "Retrofit" denotes a comparison to a boiler replacement in an existing home. "SFD" is single-family dwelling and "MFD" is multi-family dwelling. Analysis undertaken for typical residential dwellings in North America, Europe, China and OECD Pacific.

Sources: Based on data in Table 6.3 and IEA databases and analysis.

Key point

Heat pumps are already an attractive abatement option in many applications and countries.

For example, in India today the electricity consumption of room air conditioners could be cut by around 10% at a saving of between USD 14/tCO_2 and USD 65/tCO_2 saved. But increasing the electricity saving to around 30% would result in costs of between USD 120/tCO_2 and USD 170/tCO_2 saved. This latter cost range could fall to between USD 50/tCO_2 and USD 100/tCO_2 saved by 2030, but will still even then be a cost rather than a saving (McNeil *et al.*, 2005 and IEA analysis).

For large service-sector buildings, GSHPs systems are likely to be economic and have negative abatement costs where they provide space and water heating as well as cooling in summer (Sachs *et al.,* 2004).

Combined heat and power in buildings

CHP technologies can reduce CO_2 emissions in the buildings sector today in a wide range of applications.[32] CHP can also potentially improve energy security and the reliability of energy supplies. It is a mature technology, capable of providing electricity, heat, cooling (using absorption cycles) and dehumidification. Newer CHP technologies that are not yet mature, such as fuel cells and stirling engines, are beginning to be deployed. In the BLUE Map scenario, given the decarbonisation of electricity generation, CHP will need to depend on carbon-free or largely carbon-free fuel sources if it is to avoid increasing CO_2 emissions. Building-scale CHP systems using fuel cells powered by CO_2-free hydrogen play a part in the BLUE Map scenario after 2030. But achieving such an outcome will depend on cost reductions, improved performance and durability improvements in the next 20 years.

Building-scale CHP can meet space and water heating demands, as well as cooling demands. In recent years, the use of CHP in commercial buildings and multi-residential complexes has increased steadily. This is due largely to technical improvements and cost reductions in smaller-scale, often pre-packaged, systems that can meet a wide range of thermal and electrical loads. Previously, CHP has been confined mostly to large institutional-type organisations that have large heat loads, or that need secure electricity supplies in the event of grid failure, such as hospitals, hotels, education facilities and large campus-style service parks. Installation in residential buildings is still at an early stage of deployment.

Selecting a CHP technology for a specific application depends on many factors, including:

- the annual electricity load profile;
- the annual thermal load profile;
- the relative timing of thermal and electric loads;
- despatch choice (either thermal or electric load following);

32. This chapter only discusses building- and "campus"- or "service park"-scale CHP technologies. Large-scale CHP and the distribution of heat to buildings through district heating networks is taken into account "upstream" in the modelling of electricity and heat generation and distribution.

- space constraints, if any;
- emission regulations;
- fuel availability;
- utility prices for electricity and other fuels;
- interconnection regimes/protocols with local electricity utilities for sale of surplus electricity;
- first cost and the cost of financing; and
- complexity of installation and operation.

The complexity of the design and operation of CHP systems is a significant obstacle to the exploitation of the potential of CHP to reduce costs and energy consumption. The development of small-scale CHP technologies with lower costs and improved performance and reliability means that their potential for deployment in the near future should grow, as building-scale CHP applications become attractive. Even so, there remain serious challenges to the widespread uptake of CHP technologies in the residential sector.

The most significant constraint is the wide variation in seasonal heat demand. For example, sizing for generally more constant water heating loads limits the benefits of CHP systems in the residential sector, while grouping water heating loads from several residential buildings is often difficult to manage. But the reduction of the relative importance of space heating in the BLUE Map scenario will allow a greater proportion of space heating needs to be met by CHP, as will the growing availability of low-cost compact thermal storage. In the service sector, many sub-sectors have proportionately larger and more stable water and space heating, and cooling loads. This significantly improves the competiveness of CHP solutions.

CHP technologies

A number of technological developments are being explored that offer the possibility of expanding the range of potential applications for CHP in buildings. These include the use of reciprocating engines including stirling engines, gas turbines, fuel cells, microturbines and fuel-cell/turbine hybrids.[33]

Most service sector applications demand 50 to 500 kW_e. In the residential sector, demand can be as low as 1 to 30 kW_e in an individual household. Gas turbines are available up to around 30 MW_e. Fuel cells could possibly reach up to 10 MW_e. Reciprocating engines and microturbines are available from around 5 kW_e and 25 kW_e respectively. Fuel cells and microturbines are commercially available, but are still in their infancy in terms of market deployment.

33. Other options not discussed in detail in this section include organic rankine cycles and steam boilers with heat capture downstream.

Reciprocating engines

Reciprocating engines in the form of spark- or compression-ignited internal combustion engines (ICE) are the most common CHP type. They are technically mature and often the most cost-effective small-scale CHP technology. They are used in a variety of applications because they have low costs, take up little space, have a useful thermal output and are available in a wide range of sizes from as little as 5 kW_e to as large as 7 MW_e. The efficiency of reciprocating engines for electricity generation is in the range of 25% to 45%, with the most advanced natural gas-fired engines reaching 48%. The total efficiency of reciprocating engines is between 70% and 80%. Reciprocating engines have a rapid start capability and a high tolerance of start/stop operations. Like car engines, they emit a range of local air pollutants, depending on the fuel used.

Stirling engines are external combustion engines, as opposed to ICEs. They are not yet widely available and still need development. They can use a wide range of fuel sources such as natural gas, biomass and solar energy. They are closed systems, so they require heat exchangers to transfer the heat to a working fluid. Stirling engines can have high overall efficiencies, low maintenance costs, and are quieter than reciprocating engines. However, they have relatively low electrical efficiency. Depending on development, stirling engines could become a potentially attractive technology for the buildings sector, but their low electrical efficiencies make their economics challenging.

Gas turbines

Gas turbines use high-temperature, high-pressure hot gases to produce electricity and heat. The combustion of natural gas or liquid fuels causes high-pressure, high-temperature gas to rush out of the combustor and rotate a set of turbine blades that can be used to run a generator. They can produce heat and/or steam as well as electricity. Their electrical efficiency ranges from 20% to 45%, while overall efficiency can range from 70% to 80%. Above an 80% load factor, gas turbines can operate within one or two percentage points of their design efficiency. They are among the cleanest fossil-fuelled generation equipment available. They are also quick starting, compact (relative to their output), lightweight, simple to operate and have high reliability and availability. But their output declines with altitude and with higher ambient air temperatures.

Microturbines

Microturbines have been around since the 1990s, but have not been widely deployed and are not currently a mature technology. They are similar to gas turbines although smaller, and they use recuperators to preheat combustion air. They are generally in the 25 kW_e to 500 kW_e power range, with the majority in the 30 kW_e to 100 kW_e range. Microturbines are lightweight and compact in size. They are generally designed to use natural gas but they can also use other fuels such as liquid petroleum gas and industrial waste gases if they are relatively pure. They are generally less efficient than their larger counterparts. Recuperated microturbines in the 30 kW_e to 100 kW_e capacity range typically achieve electrical efficiencies of about 23% to 27%, and overall efficiencies of between 64% and 74%. Simple-cycle microturbines achieve electrical efficiencies some 12% to 13% lower, with little change in overall efficiencies.

Fuel cells

Fuel cells use an electrochemical process which releases the energy stored in a natural gas or hydrogen fuel to create electricity. Heat is a by-product. Fuel cells that include a fuel reformer can utilise the hydrogen from any hydrocarbon fuel, including natural gas, methanol and gasoline. Local pollutant emissions from this type of system would be much lower than emissions from the cleanest fuel combustion processes.

Although fuel cells are available commercially, they are only at their infancy in terms of deployment and development. They will need to tackle significant cost and performance challenges, such as cell longevity and durability, before they will become attractive CHP options in the buildings sector.

There are four main types of fuel cell: molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), phosphoric acid fuel cells (PAFC) and polymer electrolyte fuel cells (PEMFC).[34] Of these, the most promising for CHP may be the SOFC. These operate at high temperatures, thereby obviating the need for precious-metal catalysts and external reformers. They could be paired with gas turbines or microturbines in a hybrid configuration, potentially achieving electrical efficiencies of between 58% and 70% and overall efficiencies of up to 80% to 85%.

PEMFCs operate at relatively low temperatures (80°C), have high power density, can vary their output quickly, and are suited for applications where quick start-up is required. They are likely to be the fuel cell of choice for the automotive market and are, therefore, attracting significant R&D efforts.

If fuel cells decline in cost in line with expectations, they could become a very attractive technology as their high power-to-heat ratios make them ideal for low base-heat loads. If hydrogen production costs come down and hydrogen distribution infrastructure is available, fuel cells will also have a significant role in decarbonising heat supply as well as in improving overall efficiency.

CHP characteristics and costs

The overall economics of CHP systems depend on a number of factors, including the technology, system configuration, the individual characteristics of the project and relative electricity and gas tariffs (Table 6.4). Large-scale systems tend to have lower unit costs and higher electrical efficiencies, although sometimes not higher overall efficiencies. The lower installed costs for larger systems are the result of proportionally lower equipment costs and lower installation costs. Small-scale CHP applications are generally expensive today, but are expected to become cheaper over time.

34. See IEA (2005) for a more detailed discussion of these fuel cell types.

Table 6.4 ► **Technology and cost characteristics of CHP technologies**

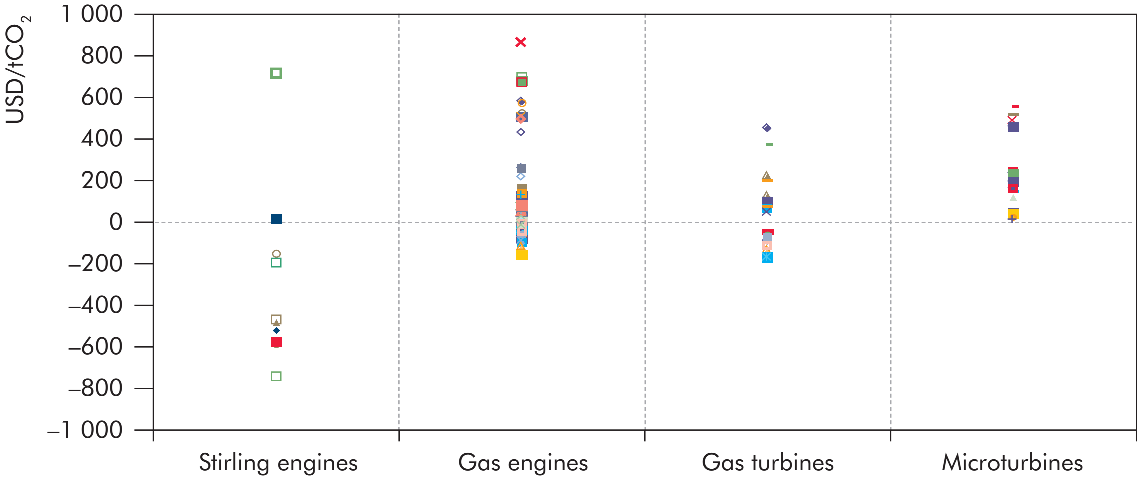
	Reciprocating engines			
	2006	**2050**	**2006**	**2050**
	Large-scale		Small-scale	
Size range (kW_e)	100-3 000	100-3 000	1-100	1-100
Economic life (years)	15-20	15-20	15-25	20-25
Electrical efficiency	30-40%	35-45%	20-40%	26-40%
Total efficiency	**75-85%**	**80-88%**	**80-85%**	**80-90%**
Installed cost (USD/kW_e)	1 000-1 600	800-1 100	1 500-12 000	900-7 000
Fixed O&M (USD/kW_e/year)	1.5-10	1-5	varies	varies
Variable O&M (USD/kWh)	0.008-0.017	0.006-0.012	0.011-0.017	0.01-0.013
	Gas turbines/microturbines			
	2006	**2050**	**2006**	**2050**
	Large-scale		Small-scale	
Size range (kW_e)	1 000-5 000	1 000-5 000	30-250	30-250
Economic life (years)	15-20	15-24	10-20	8-30
Electrical efficiency	25-40%	30-43%	25-30%	35-40%
Total efficiency	**70-80%**	**75-85%**	**65-70%**	**75-85%**
Installed cost (USD/kW_e)	1 050-2 000	800-1 350	2 000-2 700	1 000-1 500
Fixed O&M (USD/kW_e/year)	10-40	9-40	20-67	15-30
Variable O&M (USD/kWh)	0.004-0.005	0.004-0.0045	0.011-0.017	0.005-0.008
	Fuel cells			
	2006	**2050**	**2006**	**2050**
	Large-scale		Small-scale	
Size range (kW_e)	200-2 500	200-2 500	1-100	1-100
Economic life (years)	8-15	8-20	8-10	10-15
Electrical efficiency	40-50%	40-58%	30-37%%	35-45%
Total efficiency	**70-80%**	**80-85%**	**70-75%**	**75-85%**
Installed cost (USD/kW_e)	5 000-11 000	3 000-4 300	8 000-28 000	3 000-7 000
Fixed O&M (USD/kW_e/year)	2.1-6.5	2-6	varies	1 000-1 400
Variable O&M (USD/kWh)	0.03-0.04	0.02-0.025	varies	0.02-0.03

Note: O&M refers to operation and maintenance.
Sources: Discovery Insights (2006); Japan Gas Association (2009); Marcogaz (2009).

CHP abatement costs

The estimated CO_2 abatement costs for different CHP technologies in 2015 are shown in Figure 6.22. Stirling engines, although just being introduced to most markets, look to be an attractive small-scale technology in many regions given their cost profile. The CO_2 abatement costs of conventional gas engines and gas turbines depend significantly on the region and scale.

Figure 6.22 ▶ **CO_2 abatement costs for CHP in the buildings sector by technology, 2015**



Note: Analysis is based on data presented in Table 6.4 and the sources for that table, as well as IEA databases and analysis. Data points are for the G8+5 countries for small- and large-scale applications where appropriate.

Key point

CHP can be an attractive abatement option in buildings depending on the application and location.

In the BLUE Map scenario, electricity generation in OECD regions is substantially decarbonised by 2030, and the carbon intensity of electricity generation in developing countries is significantly reduced. At this point, the lowest emissions will be achieved by buying electricity from the grid and producing heat separately in highly efficient gas-condensing boilers, rather than by exploiting the efficiency gains of fossil-fuelled CHP. If CHP is to play a part in the post-2030 BLUE Map scenario, it will need to move to carbon-free fuel sources.

Larger-scale CHP could be equipped with CCS, and the heat generated could be distributed to the residential and service sectors through district heating networks. Alternatively, at the building scale, biomass or possibly hydrogen could be used by conventional and fuel cell CHP technologies respectively. If the capital costs of fuel cells come down and delivered hydrogen costs can be reduced to about USD 15/GJ, then hydrogen fuel cell CHP units could be a particularly attractive abatement option in many applications in the residential and service sectors.

Solar thermal heating and cooling

Solar thermal technologies provide heat that can be used for any low-temperature heat application up to 250°C, including space and water heating and cooling (with sorption cooling).[35] They are an important part of the transition to a sustainable energy profile for the buildings sector, as they offer a cost-effective, carbon-free energy source that can be used for space and water heating. But costs will need

35. Solar PV technologies are discussed in Chapter 3.

to continue to fall and low-cost compact thermal energy storage will be required if they are to provide a significant share of space and water heating needs globally.

Active solar thermal (AST) systems collect the incoming radiation from the sun by heating a fluid (generally a liquid, but occasionally air). The heated fluid in these collectors is used either directly, for example to heat swimming pools, or indirectly with the use of a heat exchanger to transfer the heat to its final destination, for example for space heating. The amount of heat energy provided per square metre of collector surface area varies with design and location but typically can range from 300 $kWh/m^2/yr$ to 900 $kWh/m^2/yr$.

The use of solar thermal energy varies significantly between countries depending on the maturity of markets, policy incentives and available solar resources. In 2007, China dominated total installed capacity with 79.9 GW_{th}. The United States has 21.2 GW_{th} installed capacity, the 27 European Union countries 17 GW_{th}, and Japan 5.2 GW_{th}. In China, Europe and Japan, solar thermal systems are used mainly to provide hot water and space heating, while in the United States and Canada swimming pool heating is still the dominant application.

Technology application, description and status

The majority of installed active solar thermal systems heat water for residential applications, as they are often competitive with conventional heating fuels. But they also have the potential to provide significant contributions to space heating and cooling in the buildings sector.

AST systems are either *thermosiphon* (natural) or *pumped* (forced) circulation systems. Thermosiphon systems are common in frost-free climates and rely on the fact that heated liquids are lighter than cooler ones in order to circulate the heat transfer fluid to the storage tank. Forced circulation systems allow the separation of the collector and the storage tank, but are more complicated systems with pumps and a control system to optimise operation. There are two main types of collectors: flat-plate collectors, which can be glazed or unglazed, and evacuated tubes.

Solar panels are mature technologies and at the upper end of the efficiency range for converting solar radiation into heat. Their efficiency is unlikely to improve very significantly. But design and cost parameters are complex and there can be significant differences between systems. The variation between the best and worse systems in Switzerland showed that the most effective flat-plate collectors produced more than twice as much energy as the least effective collectors for water heating (VHK, 2007c).

Thermal storage

The key to solar systems providing a larger share of a household space and water heating is the availability of low-cost compact thermal storage systems. These would enable much larger solar systems than are used today, with the surplus heat in summer months being stored until the winter, enabling 100% of space and water heating needs to be met.

The most common storage system today is a well-insulated tank containing either the working fluid or hot water. These systems are cheap and can store heat for days or even a week or two at acceptable cost. But they are bulky and not an ideal solution for long-term storage.

Current solar systems are relatively small and meet between 20% and 70% of average domestic hot water needs with a 150 to 300 litre storage tank. Solar combi-systems are larger, and with a 1 000 to 3 000 litre storage tank can meet 20% to 60% of the space heating and water heating needs of a single-family house.

The prospects for low-cost thermal storage solutions becoming available in the near future based on the latest heat-storage technologies (*sorption* or *thermochemical* heat storage) are good. The BLUE Map scenario assumes that these begin to be deployed beyond 2020 and that they enable solar thermal systems to become progressively larger to meet a growing share of space and water heating needs.

Solar thermal system and abatement costs

Solar systems can often provide space and water heating at competitive prices compared to conventional technologies using electricity or fossil fuels. Simple systems without freeze protection can provide hot water at very competitive prices. The more sophisticated flat-plate and evacuated-tube systems that characterise many markets, including the European and North American ones, are significantly more expensive. They are often more costly than conventional technologies. With wider deployment, these costs are expected to come down as solar sales grow and achieve critical mass in markets.

Solar water heating can abate emissions at very low, or even negative, costs where good insolation levels occur and cheap solar systems are available and appropriate. In China and India, for example, where systems are very cheap by OECD standards, starting from as little as USD 200 per system, the CO_2 abatement costs are often modest or negative. In Zimbabwe, solar water heating can yield discounted cost savings of USD 1 000 over 15 years (Batidzirai *et al*., 2008). Solar water heating is estimated to have an abatement cost of around USD 30/tCO_2 in South Africa. In Hong Kong, solar hot-water systems that replace gas-fired systems could save CO_2 at a negative cost of around USD 850/tCO_2 (Li and Yang, 2008). But in cold climates where freeze protection is necessary, abatement costs can be much higher. In the United Kingdom, for example, abatement costs could be over USD 1 000/tCO_2 (Shorrock and Henderson, 2005).

Installed system costs for solar thermal systems for water and space heating are expected to decline by 2050, at least in Europe, by around three-quarters for new multi-family buildings and by between 53% and 60% for refurnishing applications and new single-family buildings (ESTTP, 2007). Cost reductions will come from the use of cheaper materials, improved manufacturing processes, mass production, and the direct integration into buildings of collectors as multi-functional building components and modular, easy to install systems. Delivered energy costs are anticipated to decline by around 70% to 75% (Table 6.5).

Table 6.5 ▶ **Solar thermal system characteristics and costs for OECD Europe, North America and Pacific, 2006-50**

	Single-family building				Multi-family building			
OECD Europe	**2006**	**2015**	**2030**	**2050**	**2006**	**2015**	**2030**	**2050**
Typical size: water heating (kW_{th})	2.8-4.2	2.8-4.2	3.6-5.5	3.6-5.5	35	35	45	45
Typical size: combi systems (kW_{th})	8.4-10.5	8.4-10.5	17-21	25-32	70-130	70-130	140-260	210-390
Useful energy: water heating (GJ/system/year)	4.8-8	4.8-8	6.2-10.5	6.2-10.5	60-77	60-77	78-100	78-100
Useful energy: space and water heating (GJ/system/year)	16.1-18.5	16.1-18.5	32-37	48.2-55.6	134-230	134-230	268-463	402-690
Installed cost: new build (USD/kW_{th})	1 140-1 340	950-1 050	450-550	450-550	950-1 050	730-800	225-275	225-275
Installed cost: retrofit (USD/kW_{th})	1 530-1 730	1 200-1 300	700-800	700-800	1 140-1 340	950-1 050	450-550	450-550
OECD North America								
Typical size: water heating (kW_{th})	2.6-4.2	2.6-4.2	3.6-5.5	3.3-5.5	35	35	45	45
Typical size: combi systems (kW_{th})	8.4-10.5	8.4-10.5	25-32	25-32	70-105	70-105	140-210	210-315
Useful energy: water heating (GJ/system/year)	9.7-12.4	9.7-12.4	17-21	12.7-16.1	82-122	82-122	107-158	107-158
Useful energy: space and water heating (GJ/system/year)	19.8-29.2	19.8-29.2	39.6-58.4	59.3-87.6	165-365	165-365	330-730	495-1 095
Installed cost: new build (USD/kW_{th})	1 200-2 100	950-1 900	450-560	450-550	950-1 050	730-800	225-275	225-275
Installed cost: retrofit (USD/kW_{th})	1 530-2 100	1 200-2 000	700-800	700-800	1 140-1 340	950-1 050	450-550	450-550
OECD Pacific								
Typical size: water heating (kW_{th})	2.1-4.2	2.1-4.2	4.1-4.9	4.1-4.9	35	35	45	45
Typical size: combi systems (kW_{th})	7-10	7-10	15-18	22-28	70	70	210	315
Useful energy: water heating (GJ/system/year)	6.5-10.3	6.5-10.3	10.5-12	10.5-12	86	86	158	158
Useful energy: space and water heating (GJ/system/year)	17.2-24.5	17.2-24.5	36.8-44.2	54-68.7	172	172	730	1 096
Installed cost: new build (USD/kW_{th})	1 100-2 140	1 000-1 930	710-1 340	490-1 210	1 850-2 050	1 650-1 850	950-1 200	500-1 100
Installed cost: retrofit (USD/kW_{th})	1 400-2 140	1 300-1 950	1 000-1 350	700-1 250	1 950-2 050	1 750-1 850	1 150-1 250	950-1 150

Barriers and research, development and demonstration needs

Solar heating technologies are mature and reliable, and are already competitive with incumbent technologies in many applications. However, their often higher capital costs can make them appear more expensive to the potential purchaser compared to conventional heating systems, even when they are competitive on full-life costs. During the last decade, capital cost reductions of around 20% have been observed for each doubling of installed capacity of solar water heaters. Solar cooling technologies are at a much earlier stage of development.

More RD&D investment can help to drive AST system costs down further. Priority areas for attention include new flat-plate collectors that can be more easily integrated into building facades and roofs, especially as multi-functional building components. Photovoltaic-thermal combined collectors that can deliver warm water as well as generate electricity and advanced systems that can meet the specific needs for heating and cooling in single-family houses. Hybrid solar thermal/ heat pump systems are also a potentially interesting area of R&D. Larger-scale systems require further development if solar-assisted district heating schemes, with capacities in the megawatt scale are to be achieved. Concentrating solar heating technologies are at an early development stage, with several promising collector designs close to demonstration.

Architectural design will play a major role in the broader market penetration of solar heating and cooling options, as will the introduction of new standards, regulations and testing procedures, coupled with appropriate labelling.

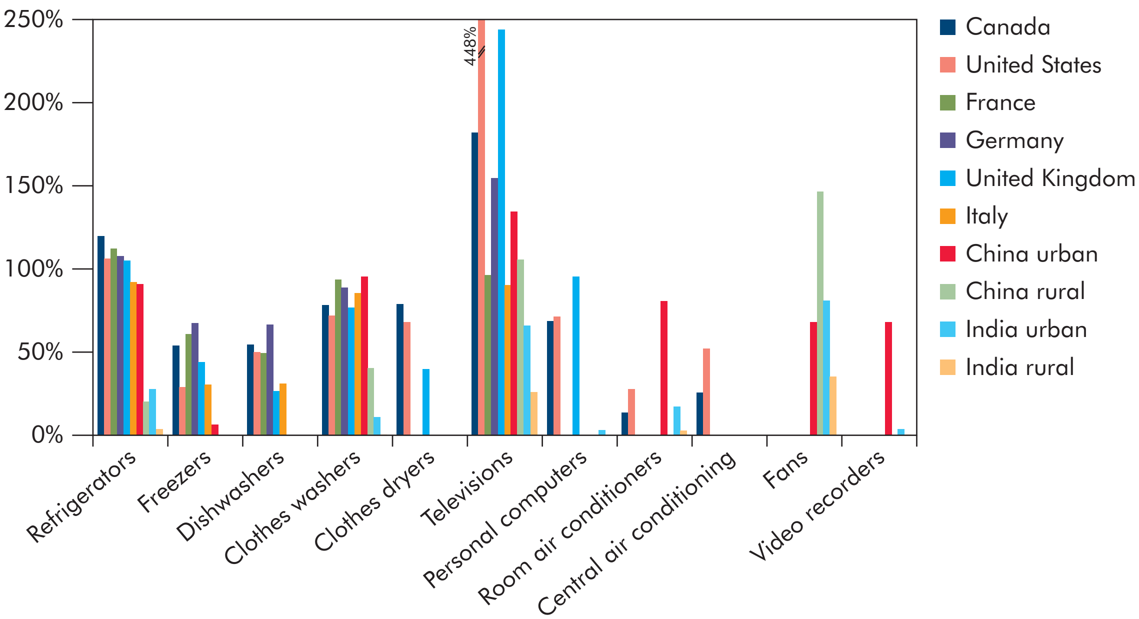
Lighting and appliances

Ownership and technology status

The continuing demand for new large and small appliances, often with new functionality, is resulting in rapidly increasing electricity consumption in both the residential and service sectors. Lighting demand is also growing, although new policies on residential lighting, such as the phase-out of incandescent bulbs, will help to slow demand growth in OECD countries. Given the high CO_2 intensity of electricity generation in the Baseline scenario in developing countries, and their rapid growth, energy efficiency for lighting and appliances will be an important abatement area.

Traditional large appliances are still responsible for most household electricity consumption for applicances. But their share is falling rapidly as electronic home entertainment and information and communications equipment now accounts for more than 20% of residential electricity consumed in most countries. This rapid technology penetration offers opportunities to roll out more efficient appliances, but this effect to date has been overwhelmed by the increased uptake of new devices. For example, flat-screen televisions are more efficient than the cathode ray tube technology they replaced. But sales have quickly shifted to much larger screens, eliminating any benefits. In developing countries, current ownership levels, even of major appliances, are often low and the potential for growth is significant. For instance, only 4% of rural households in India had refrigerators in 2002, compared to the norm of 95% to 100% in OECD countries (Figure 6.23).

Figure 6.23 ▶ Selected appliance ownership by country



Note: Room air conditioners include "air coolers" for India. Data for India are for 1999/2000 or 2002, for other countries they are for 2005 or latest available.

Sources: IEA databases; LBNL (2008); National Sample Survey Organisation (2005).

Key point

Appliance ownership in developing countries is generally very low compared to the norms in OECD countries.

Most large household appliances, such as residential refrigerators, have become more efficient in their use of energy over recent years and at the same time have become cheaper (IEA, 2009b). But the impact of these efficiency gains has been diminished by an increase in the size of products and the increasing range of products. This is true in developed and developing countries. For example, there has been a trend in India over time for people to buy larger refrigerators. The largest sales share now is for 185 litre to 225 L refrigerators, whereas in the past 165 L refrigerators dominated. This trend is unlikely to slow for some time, as the sales of even larger refrigerators (200 L to 300 L) are rising rapidly (TERI, 2006).

The life-cycle costs of new, efficient lighting systems are often the same as or lower than existing systems. Many new lighting solutions are so cost-effective that it makes sense to prematurely retire old inefficient lighting systems and to retrofit more efficient ones. Voluntary market transformation programmes, such as the European Greenlights programme, have shown that the retrofitting of lighting systems has a generally very short payback period. Some of these programmes have shown internal rates of return on investment of over 20%.

6

The demand for artificial light is far from being saturated. While an average North American consumes 101 megalumen-hours each year, the average inhabitant of India uses only 3 megalumen-hours (IEA, 2006). But lighting is currently used very inefficiently. Light is routinely supplied to spaces where no one is present. This could readily be reduced by the use of time-scheduled switching, occupancy sensors and daylight-responsive dimming technologies, all of which are mature and fully proven techniques with high savings returns.

Potentials and costs

In developed countries, energy efficiency policies for major appliances have achieved efficiency gains of 10% to 60% in most major economies in recent years while real consumer prices have fallen by 10% to 40% at the same time (IEA, 2009b). This has been due to a combination of factors, including the availability of low-cost electronic control technologies, improved materials and reduced manufacturing costs. Experience and economies of scale have also contributed.

There is still a potential for significant further savings. The household electricity consumption of a range of information and communications technology and consumer electronics appliances could be reduced by 30% by 2030 (IEA, 2009b). Shifting to BAT would allow a 50% saving by 2030, leaving electricity consumption more or less unchanged for these appliances between 2010 and 2030. The potential savings from all types of appliances in developing countries and EITs could be even greater than in developed countries because of their ability to leap-frog to more efficient technologies (IEA, 2006; WEC, 2006 and 2007). But cost barriers need to be addressed, as consumers in these countries are much more likely to be capital constrained.

The cost of current BATs is expected to reduce as they become more widely deployed. Life-cycle costs of these technologies could even become negative. For example, shifting to BAT for fridge-freezers in OECD Europe would initially cost between USD 171/tCO_2 and USD 411/tCO_2. After deployment these costs could fall to between a saving of USD 307/tCO_2 and a cost of USD 81/tCO_2 (IEA, 2008b). Given the high CO_2 intensity of electricity generation in China and India, abatement costs are already negative for a wide range of appliances. For example, for refrigerators efficiency could be improved for a cost saving in the range of USD 30/tCO_2 to USD 50/tCO_2.

A number of already fully commercialised technologies could significantly reduce lighting demand. These include fluorescent and high-intensity discharge lamps and modern ballasts and transformers, luminaires and controls. A shift from inefficient incandescent lamps to compact fluorescent lamps (CFLs) would cut world lighting electricity demand by 18%. If owners were to install only efficient lamps, ballasts and controls, global lighting electricity demand in 2030 would be almost unchanged from 2005, and it could even be lower than that between 2010 and 2030 (IEA, 2006). This could be achieved at a global average saving of USD 161/tCO_2 saved, but it would require strong policy action.

Solid-state lighting is emerging as a promising efficient lighting technology for the near future. Over the last 25 years it has undergone sustained and significant improvements in efficiency that hold the prospect of it outperforming today's mainstream lighting technologies in a growing number of applications. If current progress is maintained, solid-state lighting may soon make inroads into general lighting. Solar-powered solid-state lighting already offers a robust economic solution to the needs of households reliant on fuel-based lighting.

In the service sector, the use of high-efficiency ballasts, slimmer fluorescent tubes with efficient phosphors, and high-quality luminaires produces savings that are just as impressive. For street and industrial lighting, there are large savings to be had from discontinuing the use of inefficient mercury vapour lamps and low-efficiency ballasts in favour of higher-efficiency alternatives.

Barriers and policy options

The bulk of this savings potential could be achieved without major technological development (McKinsey, 2007c). Achievements to date have been largely policy-led. The primary concern is to create sufficient market pull to encourage widespread deployment of the best existing technologies. The further deployment of energy-efficient appliances continues to face many barriers. R&D effort will also be needed in order to go beyond existing BATs.

In most developed countries, low energy costs and rising affluence mean that the overall running cost of appliances is a small proportion of household incomes. Electricity expenditure represented only 1.6% of average household expenditure in 2006 in the United Kingdom and only 3.1% in Japan (IEA, 2009a). And it is an expenditure that remains largely hidden. In developing countries, the first cost of more efficient products represents a significant barrier.

Energy labels have become widespread for major appliances. But there is very little available public information on the running costs and savings potential of smaller appliances. In addition, labels do not usually specify the highest efficiency potential for each type of appliance. As a result, few consumers have the ability to make informed decisions about relative life-cycle costs. For example, consumers are largely unaware of the consumption of current TV technologies, and there is little market incentive for the commercialisation of liquid crystal display (LCD) televisions with back-light modulation or organic light-emitting diodes (LEDs), technologies that could reduce consumption by approximately 50%. Such information could provide a market pull for new, more efficient appliances. This is the case in Europe, where the intention to make labelling mandatory for televisions, perhaps in 2011, has already resulted in more efficient products entering the market.

To tap into the potential for low-cost energy and greenhouse-gas savings, policies are required that provide an incentive at all stages in the supply chain to bring energy-efficient technologies to the market. A broad range of policy measures is available, including regulatory and voluntary approaches, financial incentives, fiscal measures and procurement policies. Many have been tried successfully by some countries. These need to be replicated in more countries and regions, and applied to a wider range of appliances, particularly those in the area of home entertainment and information and communications technologies.

Policies need to be developed for small electronic appliances which will remain relevant despite the rapid evolution of products. For example, the IEA has proposed that a generic approach to stand-by power requirements should be applied to the majority of appliances so that product-specific definitions become unnecessary. In general, policies need to ensure that manufacturers design all their devices with the ability to move automatically to the lowest power needed for their required functionality. This will minimise the time that appliances that no one is using continue to consume unnecessary power.

Chapter 7 TRANSPORT

Key findings

- *Driven by increases in all modes of travel, but especially in passenger light-duty vehicles (LDVs) and aviation, the Baseline scenario projects a doubling of current transport energy use by 2050 and slightly more than a doubling of greenhouse-gas emissions to about 16 gigatonnes (Gt) of carbon dioxide equivalent (CO_2-eq).*[1] *In a transport High Baseline scenario, CO_2-eq emissions increase by 150% over 2007 levels to nearly 20 Gt in 2050. Greenhouse-gas emissions increase faster than fuel use increases in the Baseline scenarios as a result of the growing use of high-carbon fuels such as unconventional oil and coal-to-liquid (CTL) fuels after 2030.*

- *In the BLUE Map scenario, total transport fuel use rises much more slowly, reaching 30% above 2007 levels by 2050, with very low-carbon fuels such as biofuels, electricity and hydrogen (H_2) providing more than half of all fuel use in that year. This results in emissions reductions of 9.5 Gt CO_2-eq, about 60% below the Baseline scenario and nearly 20% below 2005 levels (base year for CO_2-eq emissions reduction target in the BLUE scenario).*

- *A BLUE Shifts scenario is also examined in which some of the expected future growth in passenger travel and freight transport is shifted from LDVs, trucks and air travel into bus and rail travel. In this scenario, emissions in 2050 are about 3 Gt CO_2-eq lower than in the Baseline scenario. Combining the BLUE Shifts scenario with the BLUE Map scenario achieves an overall reduction of about 11 Gt CO_2-eq in 2050 against the Baseline scenario.*

- *Both OECD and non-OECD countries reduce their greenhouse-gas emissions in 2050 by an average of about 60% in the BLUE Map scenario compared to the Baseline. This results in emissions in OECD countries on average about 60% less than in 2007. However, in non-OECD countries, emissions in BLUE Map in 2050 are still 60% higher than in 2007. Strong population and income growth in non-OECD countries will make the achievement of absolute reductions compared to today's emission levels extremely challenging.*

- *The prospects are good for cutting future fuel use and CO_2 emissions from LDVs, including via technologies to improve internal combustion engine (ICE) efficiency, through vehicle hybridisation and adoption of plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs) and fuel-cell vehicles (FCVs).*

- *With oil at USD 120 per barrel (bbl) and using a low discount rate, virtually all incremental efficiency improvements to gasoline and diesel vehicles are paid for by vehicle lifetime fuel savings. Plug-in hybrid electric vehicles (PHEVs) can also provide*

7

1. As described in IEA (2009a), the transport analysis includes three types of greenhouse-gas emissions: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Therefore, the results are expressed in tonnes of CO_2-equivalent emissions, on a well-to-wheel (WTW) basis, unless otherwise stated. Nearly all vehicle emissions are CO_2; and only for natural gas and biofuels are upstream emissions of CH_4 and N_2O significant. The transport totals reported in *ETP* combined results (e.g. Chapter 2) do not include CH_4 or N_2O.

relatively low-cost CO_2-eq reductions in the near term in areas with low CO_2-eq electricity generation. Pure EVs and FCVs remain relatively expensive in the near term even with oil prices at USD 120/bbl, but costs decline over time.

- *Advanced biofuels can also play an important role for light-duty ICE vehicles, with some cost-effective options already available and other options becoming more cost-effective over time. Demand for biofuels for LDVs in the BLUE Map scenario begins to decline after 2030 as a result of a strong shift towards electricity and hydrogen fuels. However, biofuel use continues to rise rapidly for trucks, ships and aircraft through 2050. This biofuel will slowly replace middle distillate petroleum fuels and to a large extent will need to be compatible with these fuels.*

- *Total additional investment costs for vehicles in the BLUE Map scenario to 2050, relative to the Baseline, amount to about USD 22 trillion. This is about 10% higher than the levels of investment in the Baseline scenario of around USD 231 trillion and reflects significant cost reductions over time. At a 2050 oil price of USD 120/bbl, fuel savings in the BLUE Map scenario reduce costs by around USD 20 trillion, nearly offsetting the higher vehicle costs. At USD 70 per barrel of oil in 2050 (as assumed under BLUE Map), fuel costs are reduced by USD 47 trillion. In that case, the total vehicle and fuel costs in the BLUE Map scenario are around USD 25 trillion less than those in the Baseline scenario. With a 10% discount rate, the vehicle and fuel costs in the Baseline drop to about USD 95 trillion, with the costs in BLUE Map about USD 1 trillion higher.*

- *Most OECD governments now have strong light-duty vehicle fuel economy standards in place that will influence LDV markets at least until 2015. Many governments have announced plans to support the wider use of EVs and PHEVs. Taken together, these commitments amount to more than 5 million EVs and PHEVs being in use by 2020. The United States and the European Union have implemented policies to encourage the greater use of more sustainable types of biofuels. But these measures constitute only initial steps towards the transport technology revolution that is needed if emission levels are to be halved by 2050. Much more effort is needed to increase research, development and demonstration (RD&D) and deployment funding and co-ordination. And measures need to be taken to encourage consumers to adopt the technologies and lifestyle choices that are the essential underpinning of a transition away from energy-intensive, fossil fuel-based transport systems.*

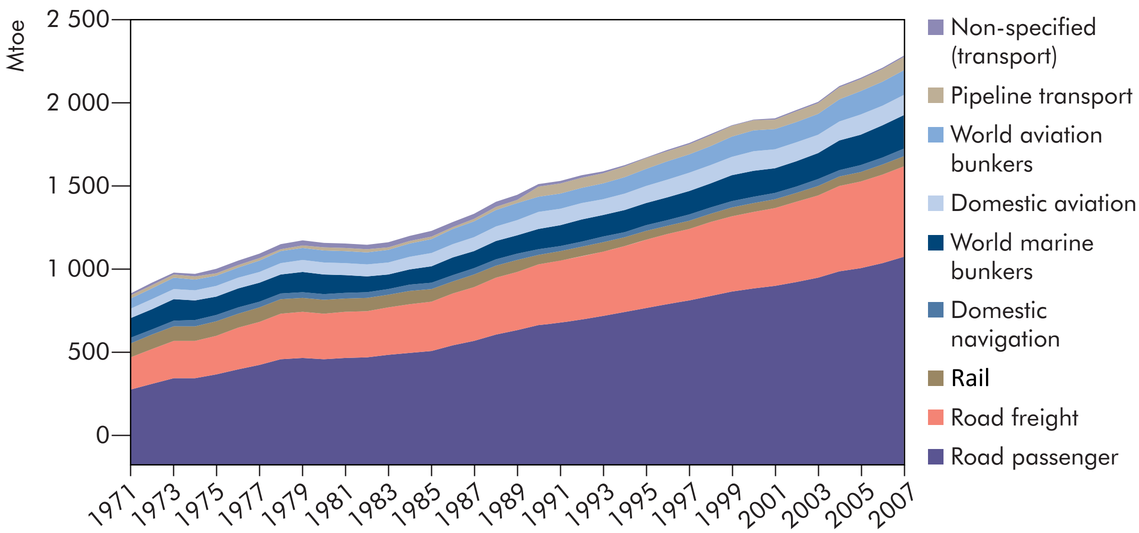
Introduction

Transport accounted for about 26% (IEA, 2009b) of all energy-related CO_2 emissions in 2007 and is likely to account for a higher share in the future unless strong action is taken. As discussed in *Transport, Energy and CO_2: Moving towards Sustainability* (IEA, 2009a), reducing the global use of fossil fuels in transport will be very challenging. If a halving of global energy-related CO_2 emissions is to be achieved by 2050, transport must make a significant contribution, moving well below 2007 emission levels by 2050.

Worldwide, transport-sector energy use and CO_2 trends are strongly linked to rising population and incomes. Transport continues to rely primarily on oil. Decoupling transport growth from income growth and shifting away from oil will be a slow and difficult process. Achieving large reductions in greenhouse-gas emissions by 2050 will depend on changes happening much more quickly in the future than in the past. Improvements in vehicle and transport system efficiencies of 3% to 4% a year will need to replace past improvement rates of 0.5% to 2% a year. New technologies and fuels will need to be adopted at unprecedented rates. But if significant decoupling can be achieved, the benefits will include not only CO_2 reductions, but also substantial energy cost savings and increased energy security, as well as reductions in pollutant emissions, such as nitrous oxides (NO_X) and particulate matter.

From 1971 to 2007, global transport energy use rose steadily by between 2% and 2.5% a year, closely paralleling growth in economic activity around the world (Figure 7.1). The road transport sector, including both LDVs and trucks, used the most energy and grew most in absolute terms. Aviation was the second-largest transport user of energy, and grew the most in percentage terms.

Figure 7.1 ▶ World transport final energy use by mode



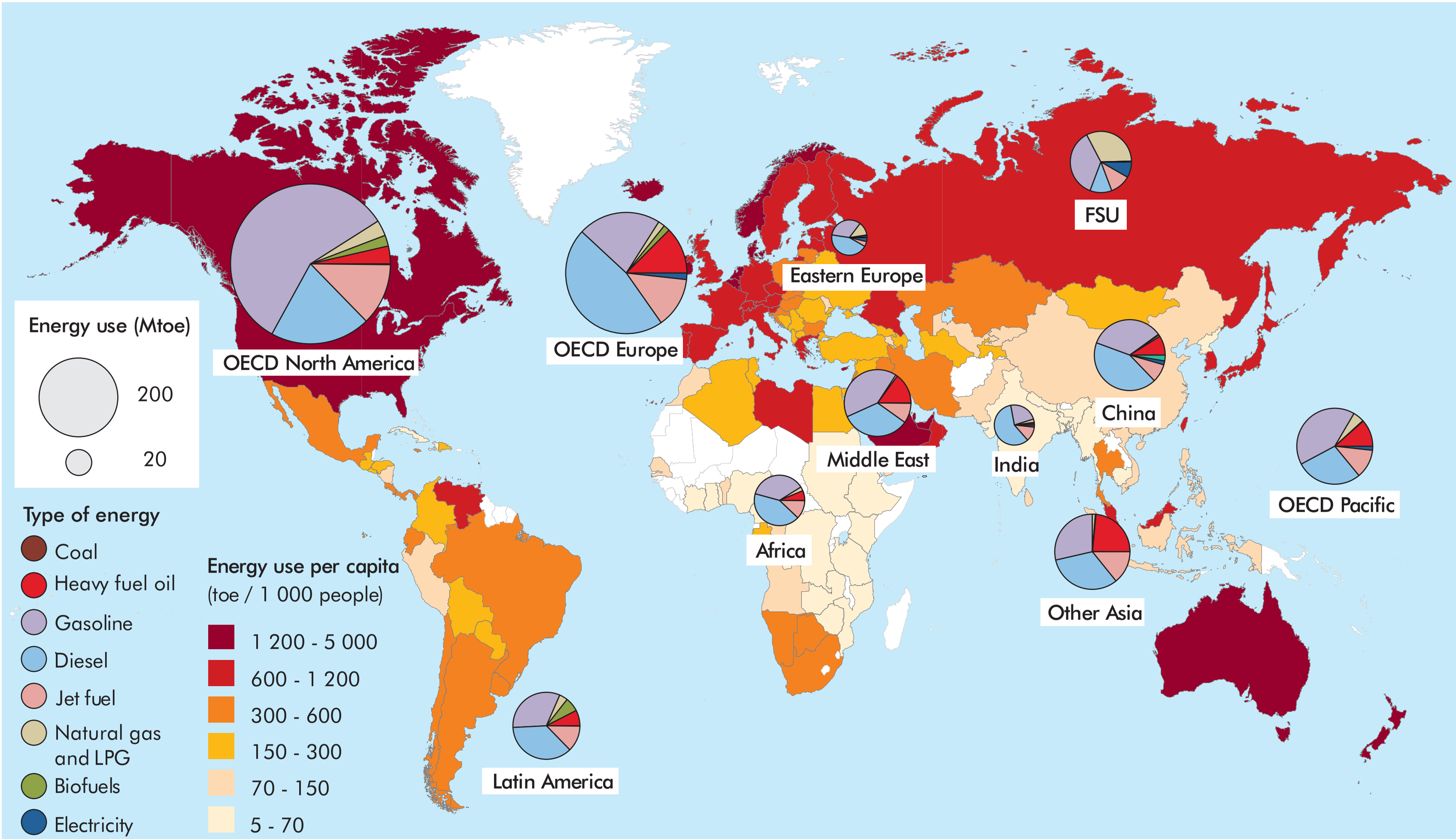
Source: IEA (2009b).

Key point

Transport energy use has more than doubled since 1971, and has been dominated by road transport.

Despite steady global growth, different regions and countries show very different patterns in terms both of energy use per capita and of the types of fuel used (Figure 7.2). Including the share of international transport energy use attributed to each region, some regions such as North America (except Mexico) consumed an average of over 2 300 tonnes of oil equivalent (toe) per thousand people in 2007. Others, such as parts of Africa, averaged less than 100 toe per thousand people.

Figure 7.2 ▶ **Transport sector energy use by region, 2007**



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Note: The figure reports final energy (end use), including the relevant allocation of energy use by international shipping, international aviation and pipeline transport. Pipeline is excluded in the rest of Chapter 7, unless otherwise stated.

Source: IEA (2009b).

Key point

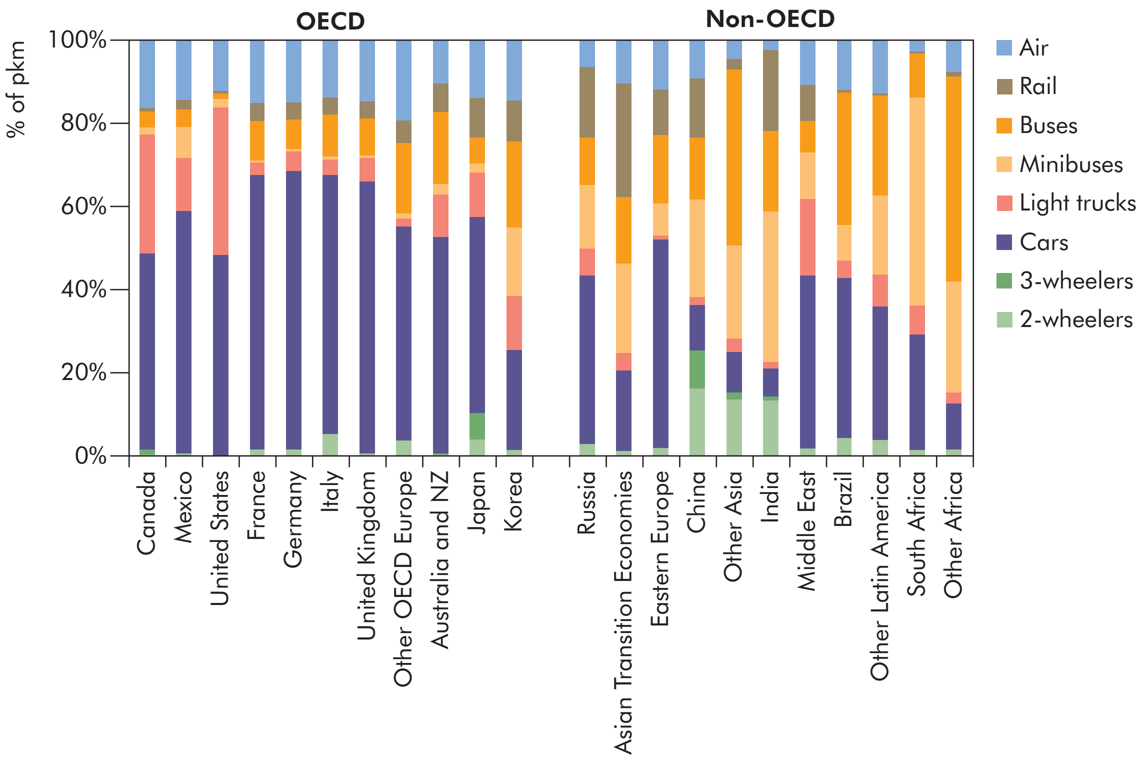
Different countries have very different patterns of energy use per capita and use very different types of energy.

These data reveal differences both in the amount of travel undertaken and in the types of vehicles and fuels used for that travel.

Transport fuel use worldwide is currently dominated by petroleum, with over 95% of fuel being either gasoline or distillate fuels such as diesel, kerosene or jet fuel. Some countries use significant amounts of natural gas, liquefied petroleum gas (LPG) or liquid biofuels such as ethanol.

Different regions use individual modes of travel to different extents (Figure 7.3). OECD countries rely on passenger LDVs (*i.e.* cars, sports utility vehicles and minivans) much more than non-OECD countries. People in OECD countries also undertake far more air travel per capita. Developing countries show far higher modal shares for buses and, in some regions, motorised two-wheelers, *i.e.* scooters and motorcycles.

Figure 7.3 ▶ Motorised passenger travel by mode, 2007



Source: IEA Mobility Model (MoMo) database estimates.

Key point

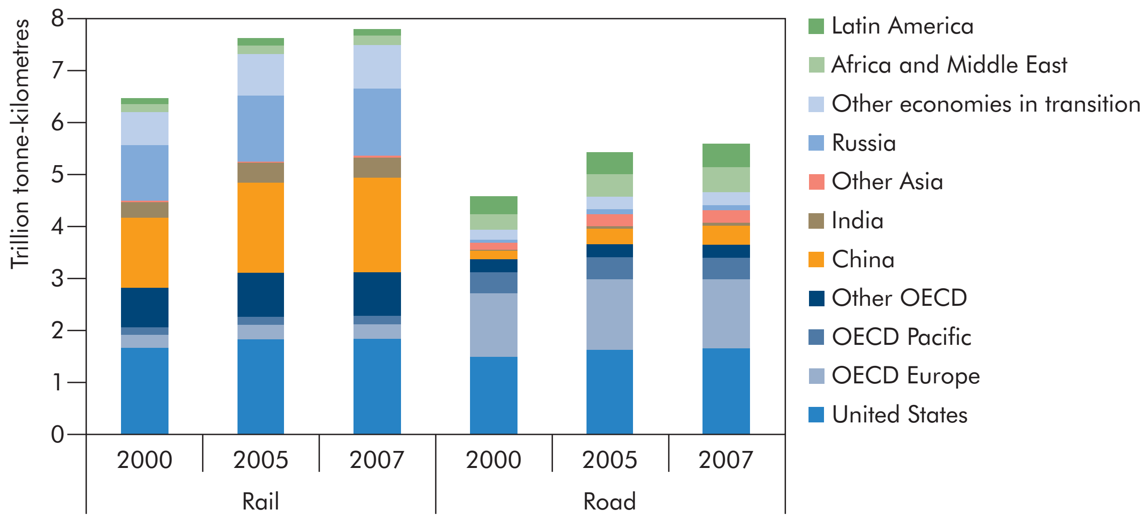
Passenger travel shares on a total kilometre basis in OECD regions are primarily met by passenger LDVs, while in many non-OECD regions buses provide a majority of passenger travel.

The total stock of passenger LDVs has grown steadily, reaching about 780 million worldwide in 2007. From 1990 to 2007, the stock of LDVs grew by about 60%, or about 3% per year, dominated by gasoline vehicles in most countries. In the same period, world population grew by 25%, from 5.2 billion to 6.5 billion. In wealthy countries, the rate of growth in passenger LDV stocks has declined in recent years.

This reflects a slowing in population growth. It may also signify a saturation of car ownership, reflecting the fact that in most OECD countries many families already own one vehicle per driver. In developing countries, rates of LDV ownership are growing rapidly. Many families purchase LDVs as soon as they can afford them. The emergence of low-cost LDVs such as the Tata Nano in India will probably further accelerate LDV ownership rates. The number of motorised two-wheelers also continues to grow rapidly.

In most regions, the total amount of road and rail freight has been increasing, although the rates of increase vary widely between countries (Figure 7.4). Even within Europe, growth rates vary considerably. Between 1999 and 2007, for example, road tonnage rose by 93% in Spain and fell by 7% in the Netherlands (Eurostat, 2009). Worldwide, total rail volumes are higher than total road volumes, but they are concentrated in a small number of countries, and are growing at a slower pace than road freight.

Figure 7.4 ▶ Freight activity trends by region



Sources: Country data and IEA estimates.

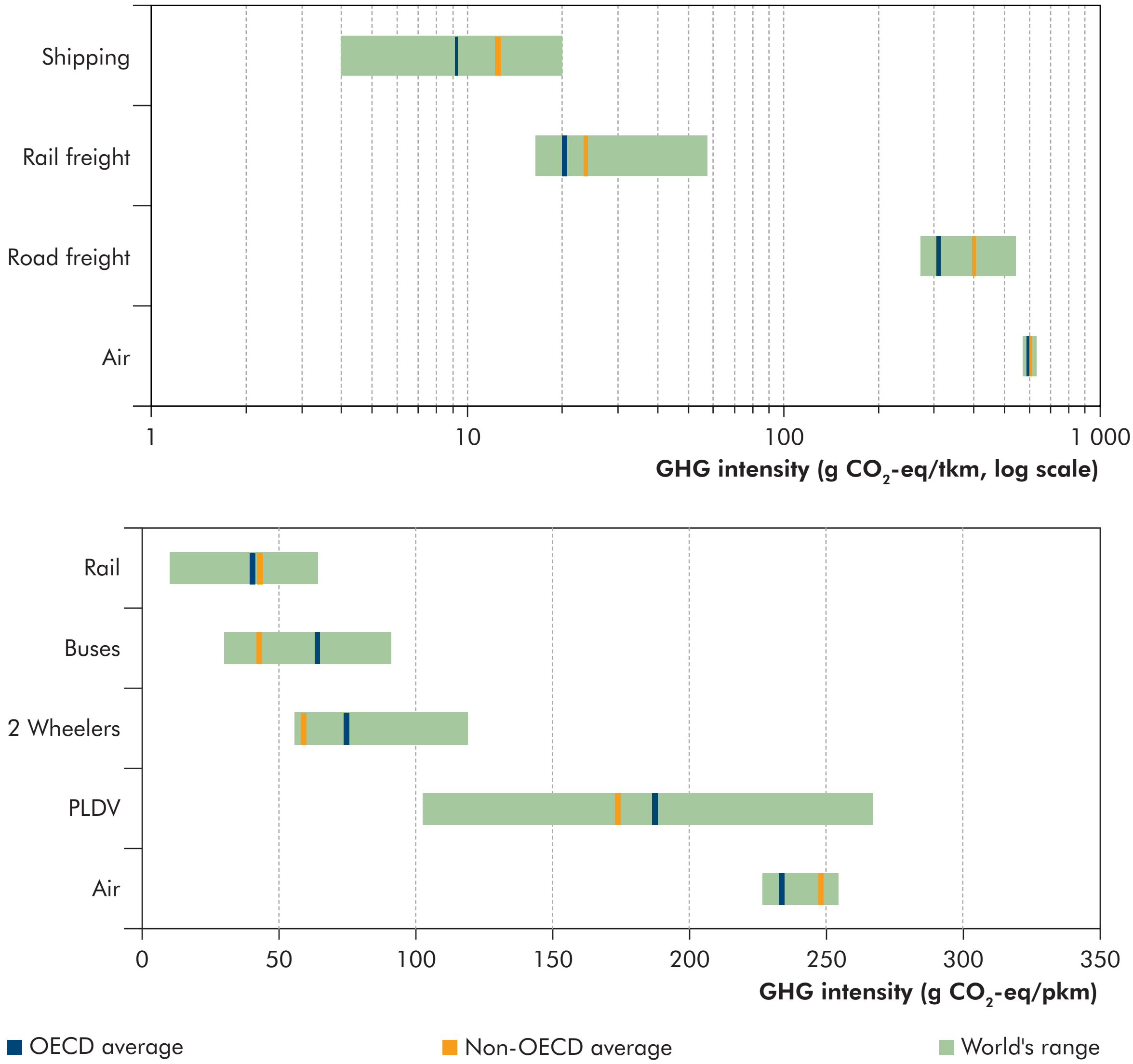
Key point

Freight trends for road and rail by region reveal that rail volumes are higher than total road volumes, but they are concentrated in a small number of countries.

Energy efficiency by mode

Estimates of recent average vehicle CO_2-eq intensity by mode in grammes (g) of CO_2-eq per tonne-kilometre (tkm) for freight modes and in grammes of CO_2-eq per passenger-kilometre (pkm) for passenger modes are shown in Figure 7.5. The figures reveal a wide range of values for each mode of transport. Some modes are generally less CO_2-intensive and also more efficient than other modes. For example, rail is less CO_2-intensive (more efficient) than air for both freight and passenger movement.

Figure 7.5 ▶ **Greenhouse-gas efficiency of different modes, freight and passenger, 2007**



Sources: IEA MoMo database; Buhaug *et al.* (2008).

Key point

The energy efficiency and CO_2-eq emissions of different passenger and freight modes vary widely; shipping is least CO_2-intensive (most efficient), air is usually the most CO_2-intensive (least efficient).

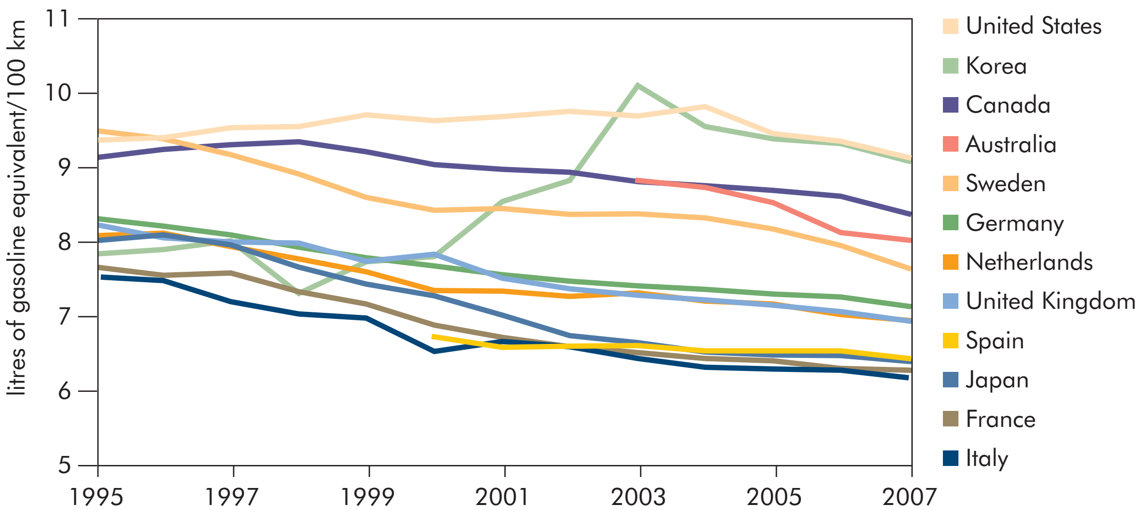
Large-scale shipping is generally the most CO_2-efficient way to move freight. Rail is the next most CO_2-efficient mode. Road and air freight movements tend to be much more energy-intensive. For passenger transport, rail, buses and two-wheelers show similar levels of average efficiency, but efficiency levels range much more widely for buses and two-wheelers than for rail. Passenger LDV efficiencies range even more widely, reflecting the fact that different regions have very different vehicle types as well as significant differences in average load factors. Air travel shows a narrower range but on average emits more CO_2-eq than any other mode.

On the basis of the limited data available, it appears that road freight transport is more efficient in OECD countries than in non-OECD countries. Road passenger transport in non-OECD countries is more efficient than in OECD countries, as non-OECD passenger travel happens mostly in smaller vehicles and at high load factors. Current estimates also indicate that passenger aviation is more efficient in OECD countries than in non-OECD countries. This could be due to a lower average age of airplanes and higher load factors. Passenger rail transport is also thought to be slightly more efficient in OECD countries than in non-OECD countries owing to the higher levels of electrification of the rail passenger infrastructure in the former. Accurate data on rail passenger travel levels in many developing countries are not however available.

Trends in light-duty vehicle fuel economy

Through much of the 1980s and 1990s, new LDV fuel economy remained fairly constant in many OECD countries. It began to show steady improvements in Europe and Japan in the mid-to-late 1990s in response to new national and regional policies, thereby increasing the disparity in fuel economy between North America and the European and Pacific OECD countries. Test values, although not fully comparable one with another, indicate wide variations in the average fuel consumption rates for new LDVs in IEA countries (Figure 7.6). Korea experienced a notable jump in average fuel consumption rates after 2000 primarily because of a rapid rise in sports utility vehicle (SUV) sales.

Figure 7.6 ▶ New LDV tested fuel economy in various OECD countries



Source: IEA MoMo database.

Note: European countries test with the New European Duty Cycle (NEDC); Canada and the United States use the CAFE test cycle; Japan uses the 10-15 test cycle; and Korea uses the US urban test cycle.

Key point

Steady improvements in LDV efficiency have occurred in many, but not all, OECD countries since 1995.

Transport scenarios

Five main scenarios are covered in this chapter. Two (the Baseline and BLUE Map scenarios) are consistent with the *ETP*-wide scenarios. Using the IEA Mobility Model (MoMo), three additional scenarios have been developed to show alternative possible futures for the transport sector. These scenarios represent just a few of many possible futures, selected to illustrate the impacts of specific assumptions and policy and technology developments. They are not predictions.

The main features of the five scenarios are:

- **Baseline:** In this scenario, vehicle ownership and travel per vehicle for LDVs, trucks and other modes are consistent with IEA (2009c) and a world oil price rising to USD 120/bbl by 2050. This scenario assumes greater urbanisation in developing countries and lower suburbanisation than in OECD countries, greater income disparities between the wealthy and the poor in non-OECD countries, and limits on the capacity of non-OECD countries to develop the infrastructure needed to support large numbers of vehicles. As a result, passenger LDV ownership is somewhat lower in the developing world at a given level of income than has occurred historically in many OECD countries. This scenario also assumes that the decoupling of freight travel growth from GDP growth that has clearly begun in OECD countries continues and that it spreads also to non-OECD countries.
- **High Baseline**: This scenario uses the same population and income assumptions as the Baseline scenario. It assumes growth in passenger LDV ownership in the developing world to levels similar to historical trends in OECD countries, and faster growth in vehicle travel and freight transport, especially trucking. This scenario results in about 20% higher fuel demand by 2050 than in the Baseline scenario and would probably require much greater use of more expensive fossil fuels such as unconventional oil and synthetic fuels such as CTL and gas-to-liquid (GTL) fuels.
- **BLUE Map**: This scenario reflects the uptake of technologies and alternative fuels across transport modes that are economic at a carbon price of up to USD 175 per tonne of CO_2-eq saved by 2050. New powertrain technologies such as hybrids, PHEVs, EVs and FCVs start to penetrate the LDV and truck markets. Strong energy efficiency gains occur for all modes. Very low greenhouse-gas alternative fuels such as hydrogen, electricity and advanced biofuels achieve large market shares.
- **BLUE Shifts**: This scenario envisages that travel is shifted towards more efficient modes and that total travel growth is restrained by better land use and the denser development of metropolitan areas, the greater use of non-motorised modes of travel and the substitution of travel by telecommunications technologies. Most of these policies will need time to be implemented and to have a wide impact. The scenario envisages that these effects reduce passenger travel in both LDVs and aircraft by approximately 25% compared to the Baseline scenario by 2050.
- **BLUE Map/Shifts**: This scenario combines the technology changes in BLUE Map with the travel pattern changes in BLUE Shifts, reaping the combined energy and CO_2-eq benefits of both. However, since in BLUE Map all vehicle types become significantly decarbonised by 2050, the benefit of modal shifting is somewhat lower than in the BLUE Shifts scenario. As a result, the combined effect of the two scenarios is much less than additive.

The specific assumptions and key results for each scenario are shown in Table 7.1

Table 7.1 ▶ ***Scenario descriptions, assumptions and key results***

	Baseline	High Baseline	BLUE Map	BLUE Shifts	BLUE Map/ Shifts
Scenario definition	Baseline projection	Non-OECD countries follow more closely OECD passenger LDV ownership trends	Maximum efficiency gains, greater use of advanced biofuels, deployment of EVs, FCVs	No advanced technology deployment, gain through modal shifting only	BLUE Map + BLUE Shifts
Passenger LDVs	Total vehicle travel more than doubles by 2050; fuel economy of new vehicles 30% better than in 2007	Total vehicle travel triples by 2050; fuel economy of new vehicles 30% better than in 2007	FCVs reach nearly 20% of market share in 2050, EVs/PHEVs reach nearly 50%	Passenger travel in LDVs 25% lower than Baseline in 2050. Ownership and travel per vehicle reduced	BLUE Map + BLUE Shifts
Trucks	Strong growth to 2050; 25% on-road efficiency improvement	Strong growth to 2050; 25% on-road efficiency improvement	Fuel cells reach nearly 20% of sales of large trucks by 2050; PHEVs constitute between 5% and 10%: CNG grows to about 15%	Baseline tkm growth between 2007 and 2050 cut by 50%, shifted to rail	BLUE Map + BLUE Shifts
Other modes	Aircraft 30% more efficient in 2050; other modes 5% to 10% more efficient; strong growth in air, shipping	Aircraft 30% more efficient in 2050; other modes 5% to 10% more efficient; strong growth in air, shipping	Aircraft 43% more efficient by 2050 than in 2007; improved efficiencies for other modes	Baseline air travel growth cut by 25% (from a quadrupling to a tripling compared to 2007); many short-distance flights replaced by high-speed rail	BLUE Map + BLUE Shifts
Biofuels	Reach 160 Mtoe in 2050 (4% of transport fuel) mostly 1st generation	Reach 230 Mtoe in 2050 (4.5% of transport fuel), mostly 1st generation	Reach 745 Mtoe in 2050 (27%); mostly 2nd generation biofuels growth after 2020	Reach 130 Mtoe in 2050 (4%), mostly 1st generation	Reach 600 Mtoe in 2050 (26%) mostly 2nd generation biofuels growth after 2020
Hydrogen	No hydrogen	No hydrogen	200 Mtoe in 2050	No hydrogen	150 Mtoe in 2050
Electricity	27 Mtoe (mainly for rail)	30 Mtoe (mainly for rail)	350 Mtoe in 2050 primarily for EVs and PHEVs	44 Mtoe (mainly for rail)	290 Mtoe in 2050 primarily for EVs and PHEVs

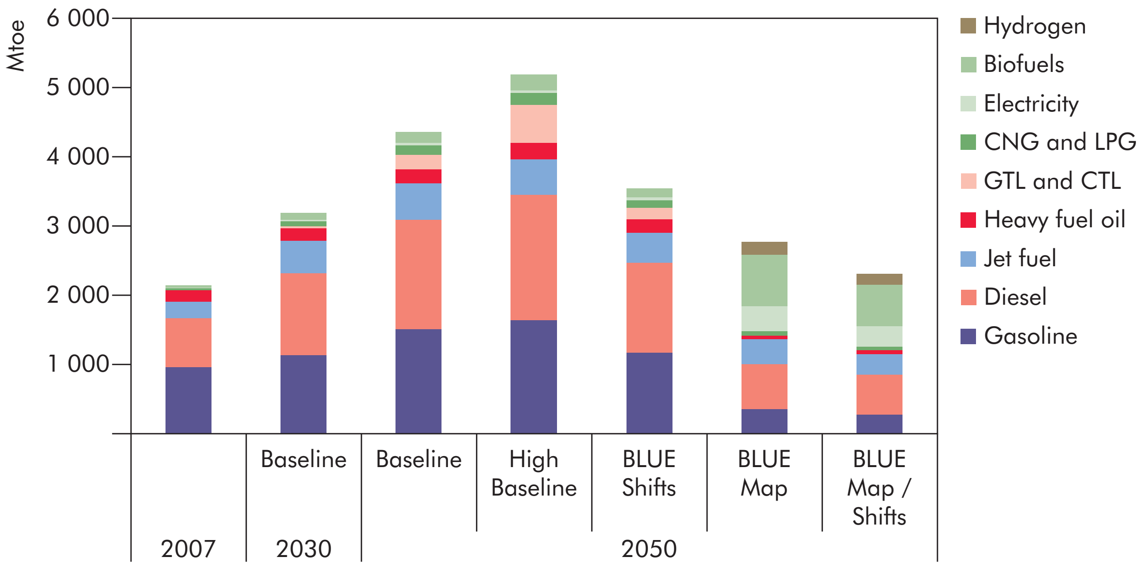
Scenario results

Energy use and greenhouse-gas emissions

The scenarios envisage very different results for energy use over time (Figure 7.7). In the Baseline scenario and even more in the High Baseline scenario, energy use grows substantially to 2050 as efficiency improvements are outweighed by growth in transport activity. There are also important differences between scenarios in the composition of fuels used. In the Baseline and High Baseline scenarios, little non-petroleum fuel is used even in 2050, although in the High Baseline scenario substantial amounts of synthetic fossil fuels and biofuels are used. As a result, fossil fuel use doubles in the Baseline scenario and increases by almost 150% in the High

Baseline scenario. The High Baseline scenario in 2050 would require an increase of more than 40 million bbl/d in liquid fuels from today's level just for the transport sector. That level would be very challenging from a supply perspective.

Figure 7.7 ▶ Evolution of energy use by fuel type, worldwide



Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

The BLUE scenarios cut energy use by almost half compared to the Baseline in 2050, and cut fossil fuel use to less than 50% of energy use.

In the BLUE Shifts scenario, the changes in travel patterns cut energy use in 2050 to about 10% above the Baseline scenario in 2030, suggesting a trend towards stabilisation. In the BLUE Map scenario, which retains the Baseline mode shares but with strong efficiency improvements, energy use in 2050 drops below the Baseline 2030 level. In the BLUE Map/Shifts scenario, energy use almost returns to the 2007 level.

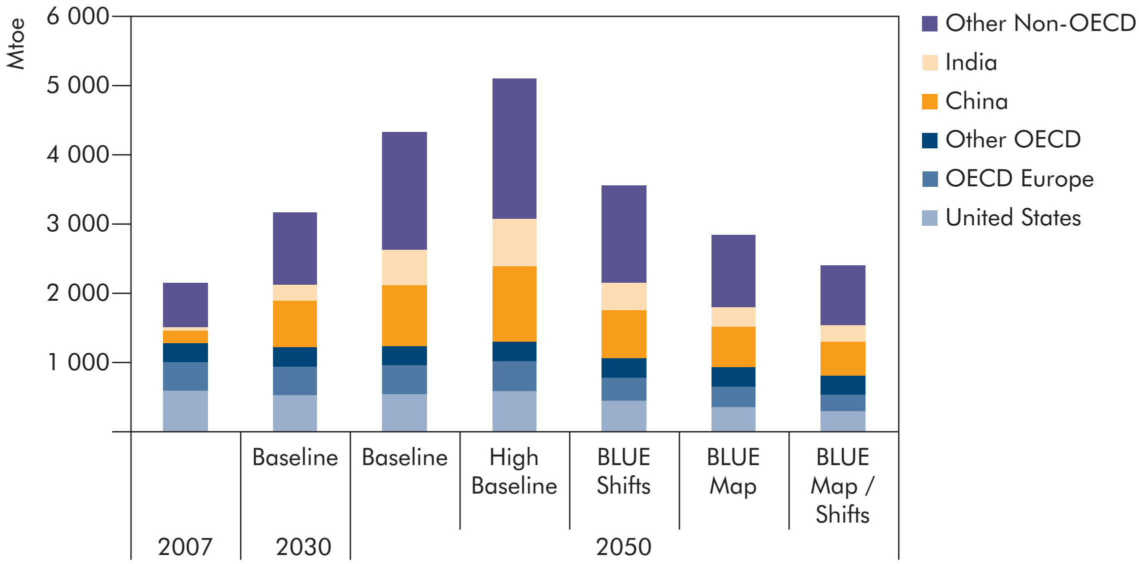
While in the BLUE Shifts scenario the share of different fuels is similar to the Baseline, in the BLUE Map scenario, the need for fossil energy for transport is cut by nearly half compared to 2007, given very large shifts to low-carbon alternative fuels such as low-CO_2-eq electricity, hydrogen and advanced biofuels. In the BLUE Map scenario, most conventional gasoline- and diesel-powered LDVs have been replaced by 2050, largely by hydrogen and electrically powered vehicles.

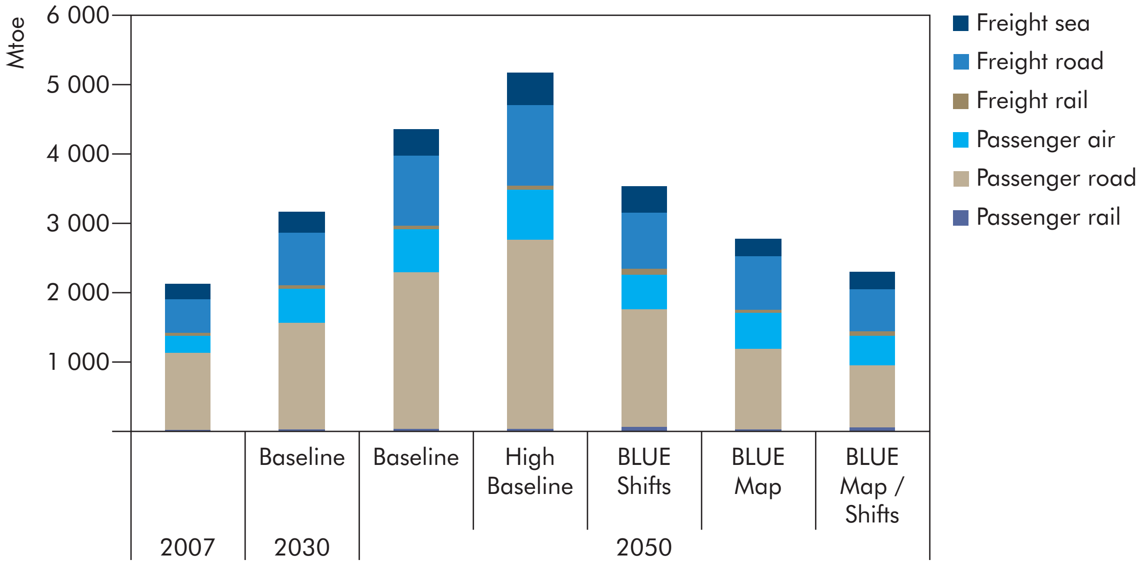
Fuels for heavier long-distance modes such as trucks, planes and ships, will continue to need to be energy-dense and to accommodate long-range travel. They, therefore, remain dominated by diesel fuel, jet fuel and heavy fuel oil (HFO) or marine diesel. Biofuels are likely to play an important role in decarbonising these modes. Biofuels reach about 27% of total transport fuel use in the BLUE Map scenario in 2050, including about 30% of truck, aircraft and shipping fuel and 24% of LDV fuel. The balance comprises nearly all electricity and hydrogen for LDVs and predominantly petroleum fuel for trucks, ships and aircraft.

7

Different scenarios also result in different levels of energy use by individual modes and in different regions (Figure 7.8). Passenger travel accounts for about two-thirds of total transport energy use in 2007. This proportion does not change significantly in the future in either the Baseline or the High Baseline scenarios. But in the BLUE scenarios, particularly in the BLUE Map scenario, more energy saving occurs in passenger modes than in freight modes. This is due mainly to LDVs, which achieve the biggest overall efficiency gains as a result of the increase in EVs and FCVs. So the overall balance of energy use shifts towards freight.

Figure 7.8 ▶ Energy use by transport mode and by region





Key point

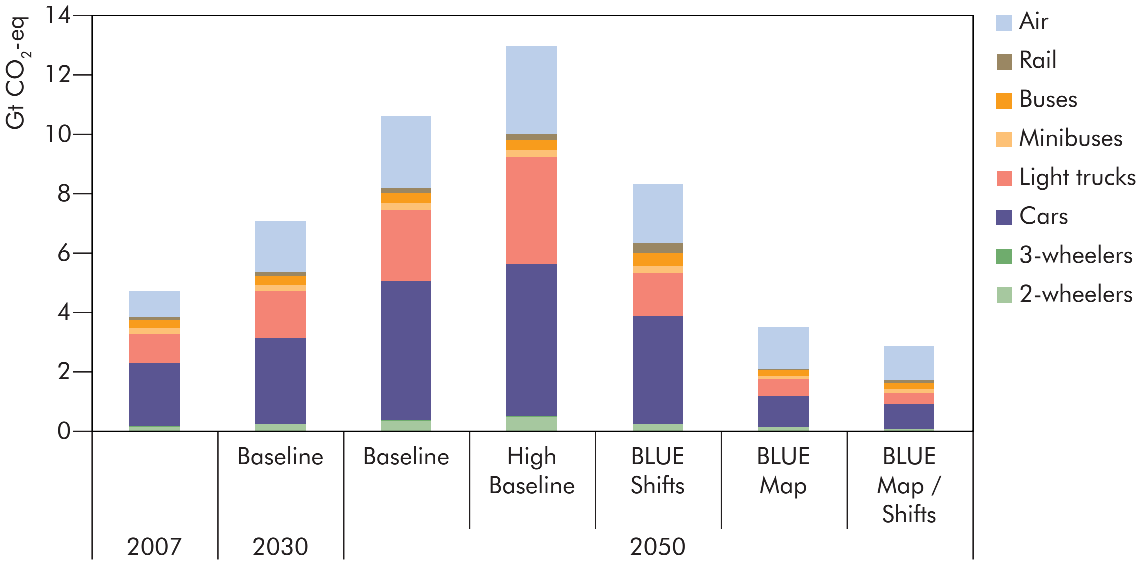
In the BLUE scenarios, more energy saving occurs in passenger modes than in freight modes. Regionally, most of the growth in energy use occurs in non-OECD countries.

In the Baseline and High Baseline scenarios, nearly all transport growth is in non-OECD regions. In the BLUE Shifts scenario, energy use in OECD countries drops significantly below its 2007 level, although energy use in non-OECD countries still grows significantly. The levels of travel and energy use per capita in 2050 remain much higher in OECD than in non-OECD countries, but are on a trajectory to converge some time after 2050.

The CO_2 intensity of the fuels in the BLUE Map scenario is largely dependent on the manner in which they are produced. For example, the electricity generation mix in the BLUE Map scenario becomes progressively less CO_2-intensive over time as fossil fuel generation is replaced by systems equipped with carbon capture and storage (CCS) and by nuclear and renewable energy. By 2050 it is nearly completely decarbonised. If this does not happen, then the CO_2-eq benefits of shifting to EVs will be far less than shown here.

Figure 7.9 shows passenger mobility greenhouse-gas (CO_2-eq) emissions by mode and scenario. In the Baseline and High Baseline scenarios, aviation grows fastest, increasing from about 10% of passenger transport greenhouse-gas emissions in 2007 to nearly 20% in 2050. In the BLUE Map scenario, aviation greenhouse-gas emissions reach nearly 40% as emissions from LDVs are greatly reduced by the switch to non-fossil energy sources.

Figure 7.9 ▶ Well-to-wheel passenger mobility greenhouse-gas emissions by mode



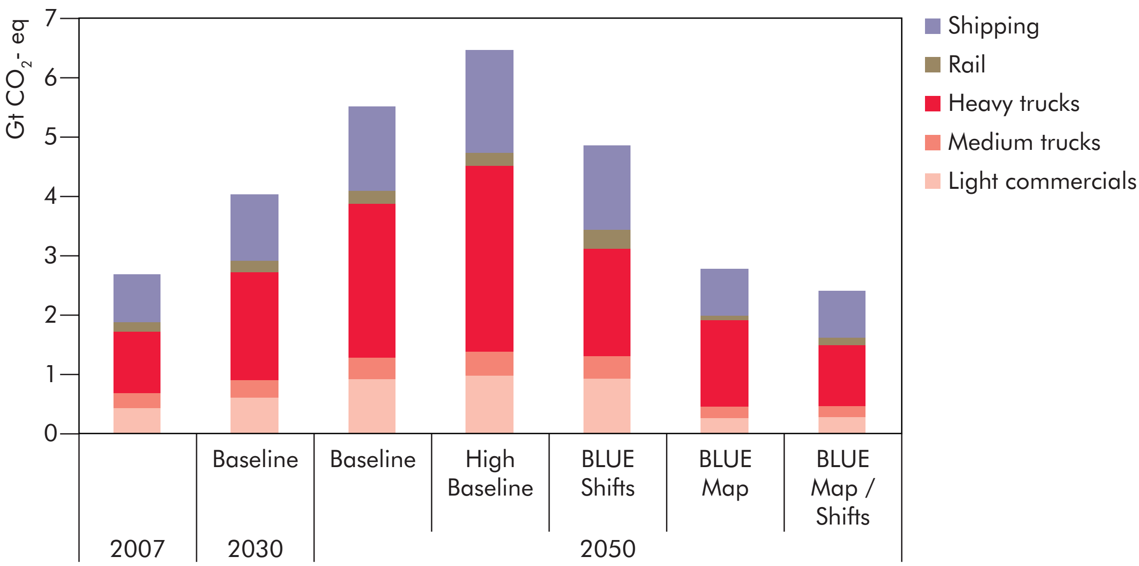
Key point

By 2050 in the BLUE Map scenario, passenger greenhouse-gas emissions are about 30% lower than in 2007 and are dominated by car and air travel.

In freight transport, heavy trucks will continue to emit more greenhouse gases than other modes, with a particularly high share of about 60% of all freight emissions in the High Baseline scenario (Figure 7.10). Significant efficiency improvements in all trucks are expected. Some shift to electricity for light commercial trucks is included in the BLUE Map scenario. But only a very small amount of electricity is assumed to be used by medium and heavy trucks. For these modes, natural gas (eventually partly substituted by bio-synthetic gas, bio-SG) gains some market share by 2050, as do hydrogen fuel cells. Diesel engines and diesel fuel remain dominant, particularly for long-haul trucks. For these trucks, refuelling needs to be high-capacity, quick and available on motorway networks. These factors limit the viability of fuels such as natural gas or hydrogen, given their low energy density and long refuelling times. Therefore, high-density, liquid diesel fuel substitutes such as advanced biodiesel are expected to play an important role in cutting truck CO_2-eq emissions.

Water-borne transport, including national and international maritime transport, also accounts for an increasing share of total emissions over time (Figure 7.10). As with heavy trucks, the options for CO_2-eq reductions in the future are limited. But many opportunities for efficiency improvements and use of biofuels could lead to potentially significant greenhouse-gas emission mitigation even in this mode.

Figure 7.10 ▶ Well-to-wheel freight mobility greenhouse-gas emissions by mode



Key point

For freight transport, emissions are cut by half in BLUE Map in 2050 compared to the Baseline scenario, but maritime transport and trucking continue to emit significant greenhouse gases.

The contribution of well-to-tank (WTT) and tank-to-wheel (TTW) CO_2-eq greenhouse-gas emissions varies over time and between scenarios. Until 2050, WTT emissions account for between 7% and 20% of the total well-to-wheel (WTW) greenhouse-gas emissions in the scenarios considered. As vehicles become more efficient, the proportion of WTT emissions may increase in some cases. In particular, zero tailpipe vehicle emission technologies such as FCVs and EVs shift CO_2-eq emissions from TTW to WTT. The decarbonisation of the energy production process may in many cases be less expensive in terms of costs per tonne of CO_2-eq saved than reducing CO_2-eq emissions from vehicles themselves.

Sources of greenhouse-gas reduction

Both technology innovations and modal shifts will help to achieve the strong reductions in greenhouse gases projected in the BLUE scenarios. The reductions achieved by different approaches will depend both on relative costs and on the ability of governments to implement effective policies relating to travel, efficiency and fuel use.

Greenhouse-gas reductions for transport will come from three main sources:

- **Modal shifts** in urban short-distance travel and in long-distance travel from, for example, the greater use of high-speed trains.
- **Efficiency improvements** from new technologies that allow vehicles to reduce their energy use and from operational changes in truck transport management.
- **Alternative fuels** which allow vehicles to emit less CO_2-eq per unit of energy used, for example through the use of less carbon-intensive energy sources.

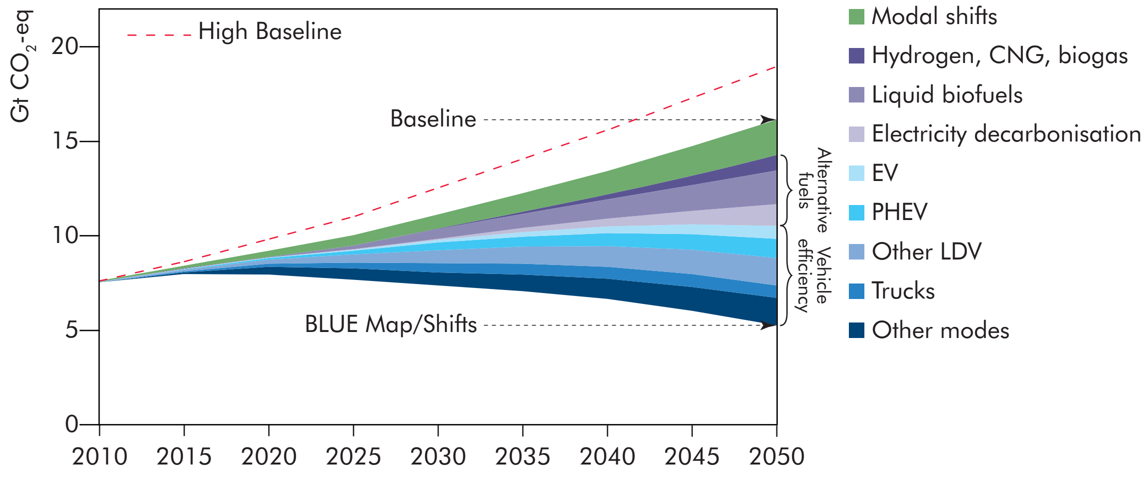
The BLUE Shifts scenario results in a saving of around 3 Gt of CO_2-eq compared to the Baseline scenario in 2050 and nearly 6 Gt of CO_2-eq compared to the High Baseline scenario in 2050. In the BLUE Map scenario, strong efficiency improvements and adoption of low-carbon fuels make similar contributions to a total CO_2-eq reduction of about 10 Gt relative to the Baseline scenario in 2050. This is more than a 60% reduction. It is also about 20% below 2007 levels.

Combining the assumptions in the BLUE Map scenario with those in the BLUE Shifts scenario into the BLUE Map/Shifts scenario results in reductions of nearly 11 Gt of CO_2-eq compared to the Baseline scenario in 2050. As shown in Figure 7.11, this comprises about 2 Gt of CO_2-eq from modal shifts, 4 Gt CO_2-eq from alternative fuels and 5 Gt CO_2-eq from vehicle efficiency improvements. In this scenario, each element contributes slightly less than in the two scenarios run separately, as the separate effects are not fully additive. Strong decarbonisation across all modes in the BLUE Map scenario reduces the differences in CO_2-eq intensity between different modes, thereby reducing the CO_2-eq benefits of shifting between modes. And with the lower levels of LDV and air travel in the BLUE Shifts scenario, the efficiency gains and lower-carbon fuels implicit in the BLUE Map scenario provide slightly smaller CO_2-eq reductions. But the combined effects are nonetheless quite large.

It is not clear that, in practice, the maximum potential impact of improved efficiency, fuel switching and modal shifts will all be achieved. But since there appear to be low-cost opportunities in all three areas, the optimum strategy is to pursue all of them vigorously. If for some reason one line of development plays a reduced role, then the others will tend to provide bigger CO_2-eq reductions than would otherwise be expected. In other words, if one "wedge" in Figure 7.11 is smaller than targeted, other wedges will likely become larger.

Each of the scenarios reaches different levels of CO_2-eq emissions and of CO_2-eq reductions for different regions over time (Figure 7.12). All regions reduce their emissions in 2050, compared to the Baseline, by more than 50% in the BLUE Map/Shifts scenario. Compared to 2007 emission levels, however, OECD regions make far bigger reductions than non-OECD regions. Most non-OECD countries, including India and China, show significant increases.

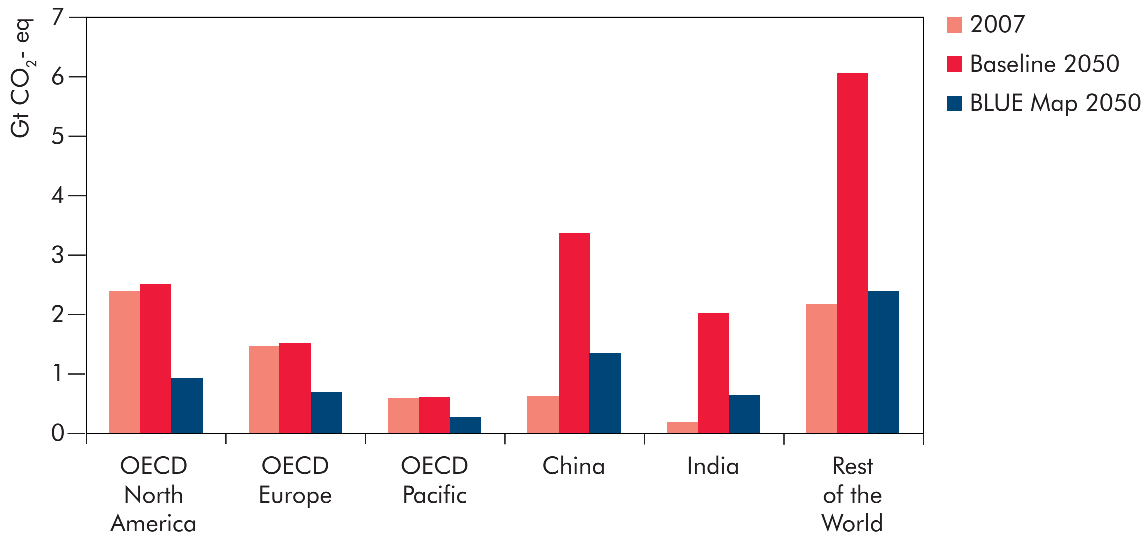
Figure 7.11 ▶ Sources of greenhouse-gas emissions reduction, transport sector



Key point

Modal shift, efficiency and alternative fuels all play significant roles in cutting greenhouse-gas emissions by 2050.

Figure 7.12 ▶ Well-to-wheel transport CO_2-equivalent emissions by region and by scenario



Key point

All regions achieve deep CO_2-eq reductions by 2050 in the BLUE Map scenario compared to the Baseline scenario.

In the BLUE Shifts and BLUE Map/Shifts scenarios, travel levels per capita begin to converge across all regions by 2050, especially for urban travel. Even so, non-urban travel levels in OECD countries remain far higher than those in non-OECD countries. The use of alternative fuels and advanced technology vehicles also begins to even out across regions after an assumed five- to ten-year head start in OECD regions in most cases. Accordingly, the CO_2-eq emissions in the BLUE Map/Shifts scenario in 2050 reflect both much more sustainable travel in all regions and more uniform travel patterns across regions than they are either today or in the Baseline scenario in 2050.

Investment requirements and fuel cost savings

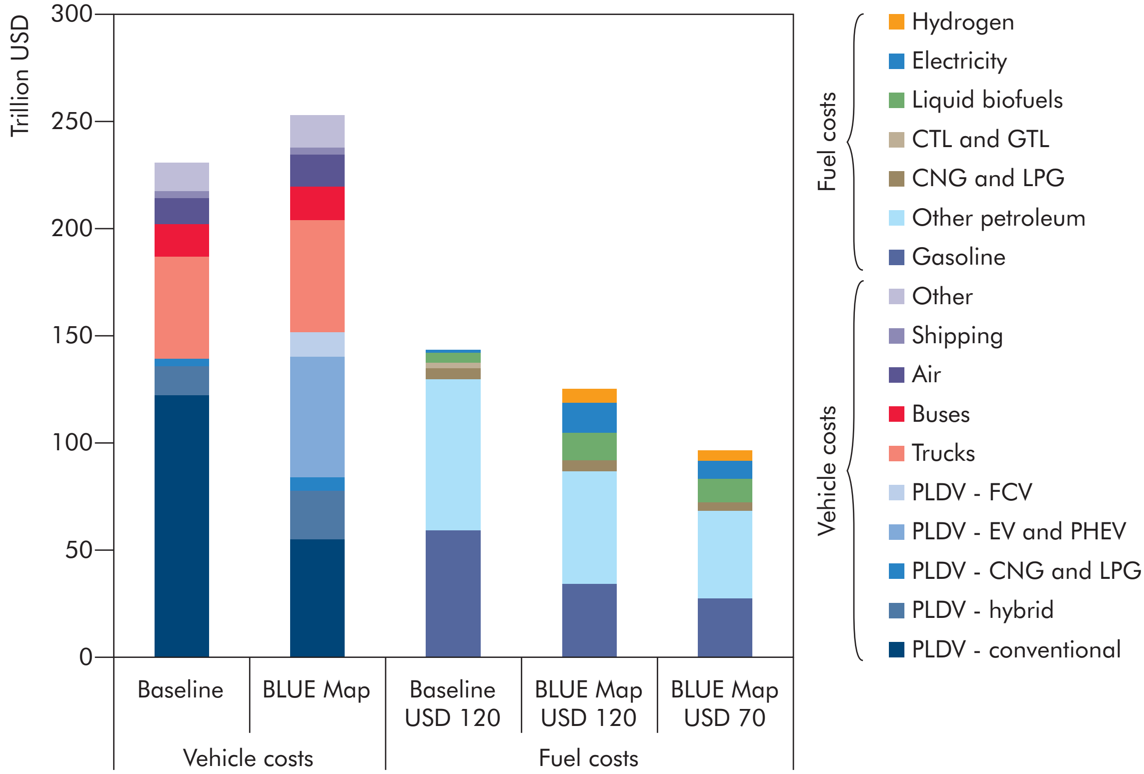
The Baseline and BLUE Map scenarios require different levels of investment in specific vehicle types and in the fuels they use (Figure 7.13). Taking into account the value of fuel savings, BLUE Map does not appear to be more expensive than the Baseline scenario, and may be significantly cheaper.

Today the world spends several trillion US dollars each year on vehicles and fuels. In the Baseline scenario, the total undiscounted cost of vehicles and fuel from 2010 to 2050 is about USD 374 trillion, comprising USD 231 trillion on vehicles and USD 144 trillion on fuels. This is equivalent to nearly USD 10 trillion per year on average, although it starts well below this level and rises over time. In the BLUE Map scenario, vehicle investment needs increase by about 10% to USD 253 trillion, about USD 22 trillion over the Baseline scenario in 2050. For fuel, the BLUE Map scenario costs about USD 96 trillion, USD 48 trillion less than in the Baseline scenario in the period 2010-2050. The investment needed in vehicles and fuel together is, therefore, around USD 25 trillion lower in the BLUE Map scenario than in the Baseline scenario. This reflects an assumed reduction in oil prices from USD 120/bbl in the Baseline to USD 70/bbl in the BLUE Map scenario in 2050. If fuel prices do not change, the fuel cost reduction is only USD 19 trillion and the net (vehicle plus fuel) cost difference in BLUE Map is about USD 2 trillion. If fuel prices do not change *and* if a 10% discount rate is assumed across the 40-year time period for all vehicle and fuel purchases (not shown in Figure 7.13), this results in vehicle and fuel costs dropping by more than half in both the Baseline and BLUE Map. In the Baseline these costs drop to USD 95 trillion over the time period. In BLUE Map they become about USD 96 trillion, for a net cost increase of about USD 1 trillion over the Baseline. Discounting slightly reduces the net cost difference.

All of these calculations only include costs through 2050, whereas the energy savings from vehicles bought through 2050 actually would extend well after. Including the fuel savings after 2050 would tend to increase the net savings in BLUE Map, which uses less fuel. It would also increase the difference between the undiscounted and 10% discount cases, since the fuel savings after 2050 would be heavily discounted to present value.

Although the analysis projects net vehicle and fuel costs in BLUE Map between 2010 and 2050 that are similar to or even lower than in the Baseline scenario, the range of results shows that the outcome is subject to quite significant uncertainties, such as future oil prices, and the extent of cost reductions that occur over time for advanced-technology vehicles. Even so, the analysis suggests that achieving the transport outcomes envisaged in the BLUE Map scenario may be of very low or negative net cost, particularly when considering societal cost (with low discount rates).

Figure 7.13 ▶ Transport vehicle investment costs and fuel costs, 2010-50



Key point

Vehicle cost increases in BLUE Map are mostly offset by oil savings if oil prices remain at USD 120/bbl, and more than fully offset if oil prices drop to USD 70/bbl.

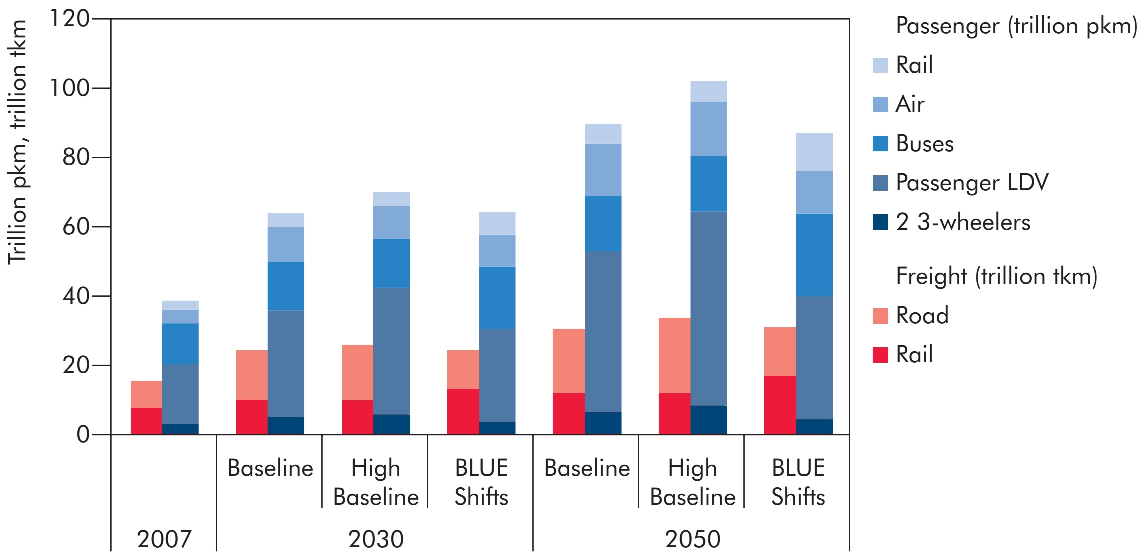
Travel activity

The overall picture that emerges from the *ETP* transport projections is that as of 2010, OECD countries are nearing or have reached saturation levels in many aspects of travel. Non-OECD countries, especially rapidly developing countries such as China and India, are likely to continue to experience strong growth rates into the future through at least 2050. In OECD countries, the biggest increases in travel appear likely to come from long-distance travel, mainly by air. In non-OECD countries, passenger LDV ownership and motorised two-wheeler travel are likely to grow rapidly, although growth in two-wheeler travel may eventually give way to passenger LDV travel as countries become richer. Freight movement, especially trucking, is also likely to grow rapidly in non-OECD regions. In all regions of the world, international shipping and aviation are likely to increase rapidly.

In the Baseline scenario, travel growth will be triggered by strong growth in the number of households that gain access to individual motorised transport modes such as cars and motorcycles. This will in turn lead to a rise in average travel speeds and increased travel distances, and reinforce land-use changes such as suburbanisation. Increasing wealth will also trigger more frequent and longer-distance leisure-related trips, in particular through increased tourism that generates considerable amounts of long-distance travel. Estimated motorised passenger travel worldwide was about 40 trillion kilometres in 2007. This is projected to more than double by 2050 in the Baseline scenario and to increase by 150% in the High Baseline scenario (Figure 7.14).

The BLUE Shifts scenario projects a different future for travel. Although it only reduces overall passenger travel slightly on a worldwide basis compared to the Baseline scenario, the composition of that travel changes significantly, with much greater travel shares being undertaken by buses and rail, the most efficient travel modes. For freight movement, the strong link between GDP and freight continues in the future in the Baseline scenario. As a result, non-OECD countries are expected to show the biggest growth in freight transport.

Figure 7.14 ▶ ***Passenger and freight mobility by mode, year and scenario***



Key point

The BLUE Shifts scenario explores a future with significantly different modal shares than the Baseline scenario, resulting in 25% less air and car travel and 20% less energy use in 2050.

The Baseline, High Baseline and BLUE Shifts scenarios result in different travel patterns by mode. In OECD countries:

- urban rail travel in 2050 is nearly 100% higher in the BLUE Shifts scenario than in 2005; urban bus travel in 2050 is 50% higher in the BLUE Shifts scenario than in the Baseline scenario;

- the higher use of LDVs in urban travel from 2007 to 2050 in both the Baseline and High Baseline scenarios is reversed in the BLUE Shifts scenario, with light truck travel slightly lower than in 2007 and car travel far lower than in 2007;
- for non-urban travel, in the BLUE Map/Shifts scenario in 2050 the growth in air travel is cut by half with the result that it doubles in the BLUE Shifts scenario rather than tripling in the Baseline scenario. Intercity rail travel triples compared to 2007 and doubles compared to the Baseline scenario in 2050.

In non-OECD countries:

- the very rapid growth in urban car use in the BLUE Map scenario is curtailed in the BLUE Shifts scenario. Instead, urban bus use and rail use increase by over 50%;
- for non-urban travel, rail travel increases to a share similar to that of air travel and LDVs in the BLUE Shifts scenario, as a result of rapid expansion of rail systems such as high-speed rail and regional rail; air travel growth is cut from about 600% in the Baseline scenario from 2007 to 2050 to about 400% in the BLUE Shifts scenario in 2050.

The BLUE Shifts scenario represents a significant departure from the Baseline scenario. At minimum it would require a major change in patterns of development and investment, away from road systems and private vehicles and towards collective modes of transport, particularly rail systems. This must be coupled with spatial development that helps make these collective modes of transport efficient and attractive to users. Intelligent transport systems such as real-time schedule information and traffic routing systems will also support a modal shift. In some countries, it may also require disincentives for car use, such as higher fuel taxes or the widespread implementation of road pricing. The changes in investment costs implicit in the BLUE Shifts scenario have not yet been evaluated. Such an analysis would help in the better understanding of the relative costs and benefits of the BLUE Shifts scenario.

Passenger LDV ownership

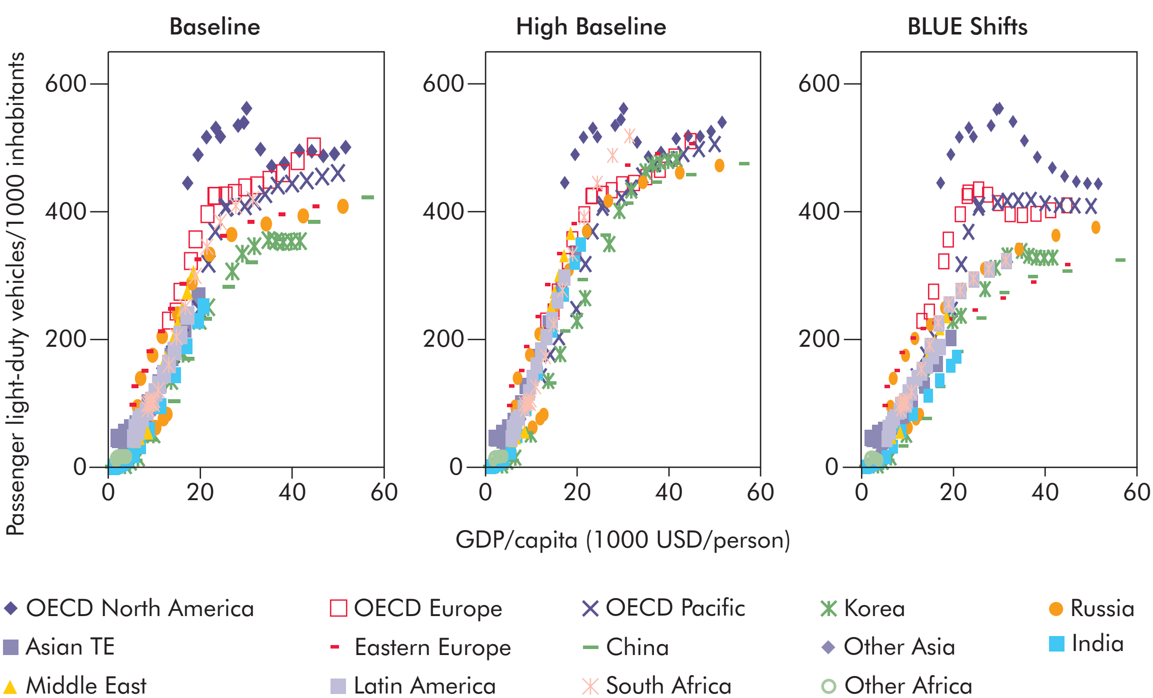
Passenger LDV ownership rates are likely to have a particularly significant impact on future travel patterns and energy use. Historically, there has been a strong correlation between income levels and the rate of passenger LDV ownership. This typically follows an S-shaped curve that becomes steep when per-capita income reaches about USD 5 000. LDV ownership rises rapidly with income above this level until income reaches a level at which LDV ownership saturates. Experts have used such a curve to model rates of LDV ownership against per-capita GDP, reflecting such factors as income distribution, road infrastructure development, the urbanisation of the population and the cost of LDV ownership relative to income (Dargay and Gately, 1999; IEEJ, 2010).

The Baseline and High Baseline scenarios reflect different assumptions as to the way in which the income/LDV ownership relationship may evolve. In the High Baseline scenario, growth in LDV ownership in non-OECD countries is assumed broadly to follow the pattern in which passenger LDV ownership has grown historically in OECD countries. In the Baseline scenario, LDV ownership in non-OECD countries is lower than it has historically been in the OECD for the same level of income, and levels of ownership saturate at a lower level.

There are a number of reasons why this might be the case. Income growth in some non-OECD countries such as China may reflect much greater income disparities than in most OECD countries in the past. Some regions are likely to reach higher levels of urbanisation with more wealth concentration in urban areas and hence less need for personalised travel. In South and East Asia, ownership of motorised two-wheelers is already very high. This may dampen growth in the ownership of LDVs. And a relatively slower rate of road infrastructure development could also inhibit the rate of increase in LDV ownership, for example if severe traffic congestion develops.

The impact of the different ownership assumptions in the two scenarios by region, together with the corresponding assumptions used for the BLUE Shifts scenario, is shown in Figure 7.15. By 2050, passenger LDV ownership levels in the Baseline scenario reach about 350 LDVs per 1 000 people in Korea, Russia, Eastern Europe, Latin America and South Africa, and about 250 LDVs per 1 000 people in China, India and South–East Asia. The overall difference in the total number of LDVs in the three scenarios is very significant: in the Baseline scenario, world LDV stock reaches about 2.2 billion vehicles in 2050, whereas in the High Baseline scenario it reaches 2.6 billion, and only 1.7 billion in the BLUE Shifts scenario.

Figure 7.15 ▶ Passenger LDV ownership rates versus GDP per capita in three scenarios



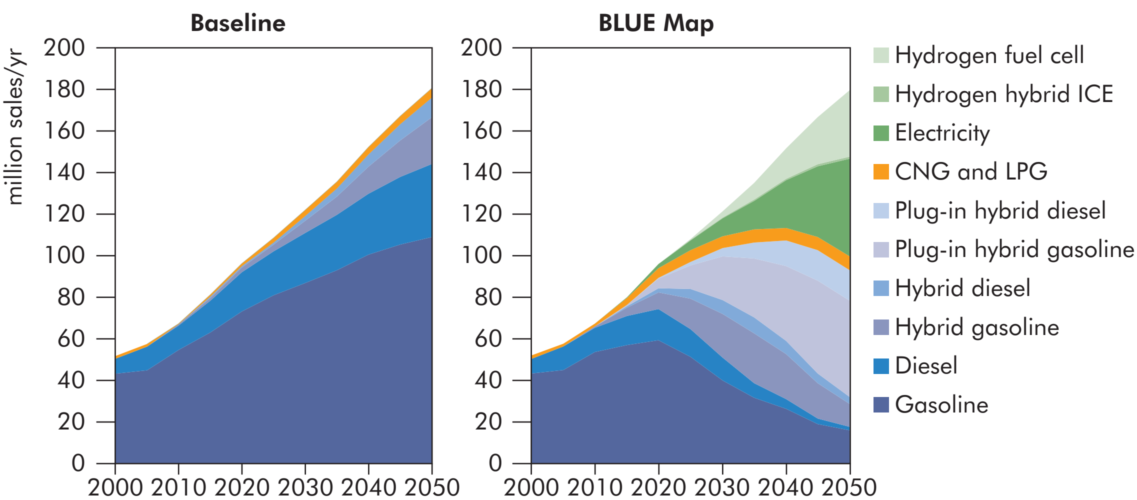
Key point

The Baseline, High Baseline and BLUE Shifts scenarios assume significantly different futures for car ownership.

The sales of different vehicle technologies varies considerably between the Baseline and BLUE Map scenarios (with BLUE Shifts the same as the Baseline). In the Baseline scenario, conventional gasoline and diesel vehicles continue to dominate to 2050 (Figure 7.16), with just a small increase in the sale of hybrid vehicles over time. Gaseous-fuelled vehicles (mainly running on CNG) hold a small share of the global market, though in a few countries with abundant natural gas, they achieve a significant share.

In the BLUE Map scenario, changes over time are based on the projected evolution of technologies and costs described later in this chapter, and assume that strong policies are enacted to encourage a shift away from conventional vehicles. After 2010, the rate of growth in conventional gasoline and diesel LDV sales begins to be trimmed by the sale of hybrids, with PHEV and EV sales increasing quickly after 2015 (Figure 7.16). By 2020, PHEV sales reach 5 million and EV sales 2 million worldwide. Around 2020, commercial hydrogen (H_2) FCVs sales begin. From 2030, EV and FCV sales increase significantly, taking a progressively higher proportion of the overall growth in LDV sales. From 2030 onwards, demand for non-PHEV ICEs declines rapidly in absolute terms. By 2040, more EVs and FCVs are sold than any ICE vehicles. By 2050, LDV sales are equally split between FCVs, EVs and PHEVs. As described below, strong policies will be needed to make these changes happen.

Figure 7.16 ▶ *Evolution of passenger LDV sales by technology type in the Baseline and BLUE Map scenarios*



Key point

In the BLUE Map scenario, advanced technology vehicles such as PHEVs, EVs and FCVs dominate sales after 2030.

Box 7.1 ▶ Advanced technology vehicles in the BLUE Map scenario

There are currently only four main LDV engine types: gasoline, diesel, gasoline hybrid and gaseous fuel (CNG/LPG). By 2050 in the BLUE Map scenario, many new types of LDV are being sold (Figure 7.16).

Diesel hybrids, plug-in gasoline hybrids, plug-in diesel hybrids and pure electric vehicles seem likely to start to enter the market in material numbers within the next few years. Hydrogen vehicles are likely to take longer to achieve a material market share. In the near term, current and alternative technologies may all play a part in the worldwide market for LDVs, although different types may dominate in different countries, just as diesel and gasoline vehicles currently dominate in different countries. The extent to which diesel hybrids and plug-ins sell will mainly depend on their cost and fuel savings relative to their gasoline counterparts. In the BLUE Map scenario, they are assumed to be important, especially in Europe.

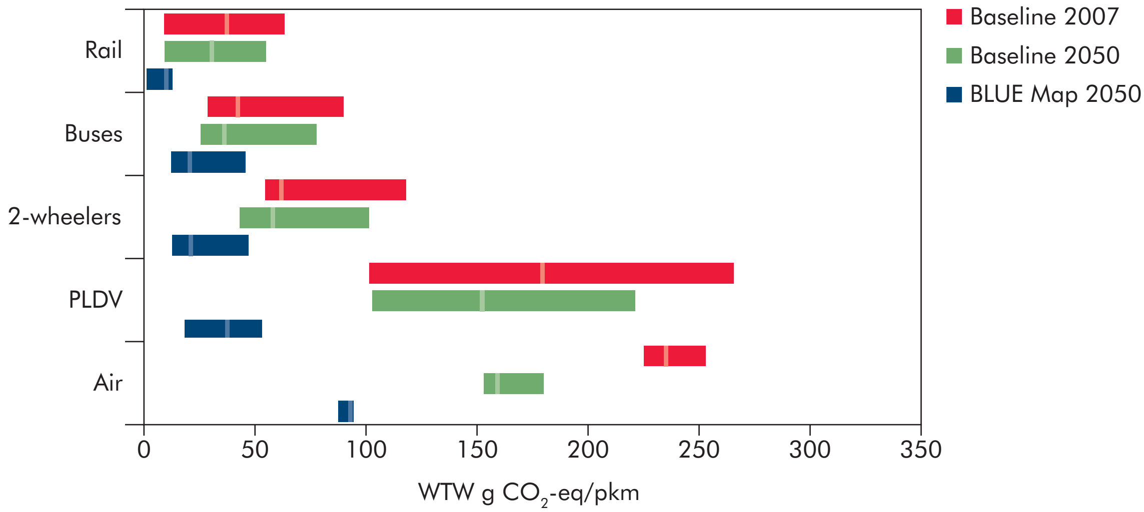
In the longer term, if PHEVs and EVs successfully secure a significant market share, the question is likely to be the extent to which FCVs can penetrate the market. In the BLUE Map scenario, it is assumed that FCV costs are low enough by 2025 that they can compete in some market segments, given some policy support e.g. to develop the necessary refuelling infrastructure. The BLUE Map scenario assumes that the potential of FCVs to provide long-range, zero-emission driving creates a niche for these vehicles, such that they take some market share from PHEVs and EVs, especially in Japan and the United States. In addition, fuel-cell vehicles provide a "portfolio" benefit. Given the uncertainty regarding whether EVs (and especially batteries) will achieve the improvements and cost-reductions assumed in BLUE Map, having both electric and fuel-cell vehicles in the mix acknowledges that broad mix of options should be pursued, given the underlying technology uncertainties.

Energy and greenhouse-gas intensity

In both the Baseline and BLUE Map scenarios, the energy intensity and associated greenhouse-gas intensity of all major passenger transport modes improves between 2007 and 2050 (Figure 7.17). In the Baseline scenario, higher oil prices and existing policies such as the fuel economy standards in many OECD countries result in a 30% reduction in the greenhouse-gas intensity of LDVs between 2007 and 2050. The greenhouse-gas intensity of all other modes except motorised two-wheelers also decreases, by about 15%. In the BLUE Map scenario, all modes reduce their greenhouse-gas intensity by at least 50% by 2050. The widespread availability of very low-carbon hydrogen and/or electricity by 2050 enables FCVs, EVs, two-wheelers and rail transport to cut their CO_2-eq emissions to very low levels by 2050.

In the BLUE Shifts scenario, some future travel growth shifts towards more efficient modes such as bus and rail for passenger transport and rail for freight transport help to reduce average energy and CO_2-eq intensities compared to the Baseline scenario. But as all modes become much less energy-intensive in the BLUE Map scenario, modal shift offers smaller emissions reductions in the BLUE Map/Shifts scenario than it does in the BLUE Shifts scenario. The BLUE Map/Shifts scenario achieves lower levels of CO_2-eq intensity than the BLUE Map scenario, but not significantly so, since in the BLUE Map scenario by 2050 LDVs have achieved almost the same average CO_2-eq intensity as mass transit modes. Shifting from air to rail travel still provides a strong efficiency and CO_2-eq intensity benefit.

Figure 7.17 ▶ Evolution of the greenhouse-gas intensity of passenger transport modes



Note: Covers the range of values for vehicle stocks by region. The clear line indicates world's average, the bar representing regional differences.

Key point

The CO_2-eq intensity of all modes improves significantly by 2050 in the BLUE Map scenario, with all but air travel emitting less than 50 g of CO_2-eq per passenger-kilometre.

Transport technologies and policies

Fuels

Petroleum fuels offer a number of benefits such as high energy density. These make it likely that, in the Baseline scenario, they will continue to dominate the overall fuel mix. But petroleum fuels also have at least two major drawbacks: potential supply limitations, including for many countries significant geopolitical risks, and high CO_2-eq emissions. For both of these reasons, there are strong incentives to develop and secure acceptable substitutes. A range of feedstocks and fuels is included in the *ETP* fuels analysis (Table 7.2). These fuels are described in IEA (2009a), where the IEA's recent cost analysis of these fuels is also available.

The cost of reducing greenhouse-gas emissions through the use of different fuels can be estimated by combining fuel costs with life-cycle greenhouse-gas emissions, compared to a common gasoline baseline. The same set of information can be used to evaluate the effect of carbon prices on the relative costs of different fuels.

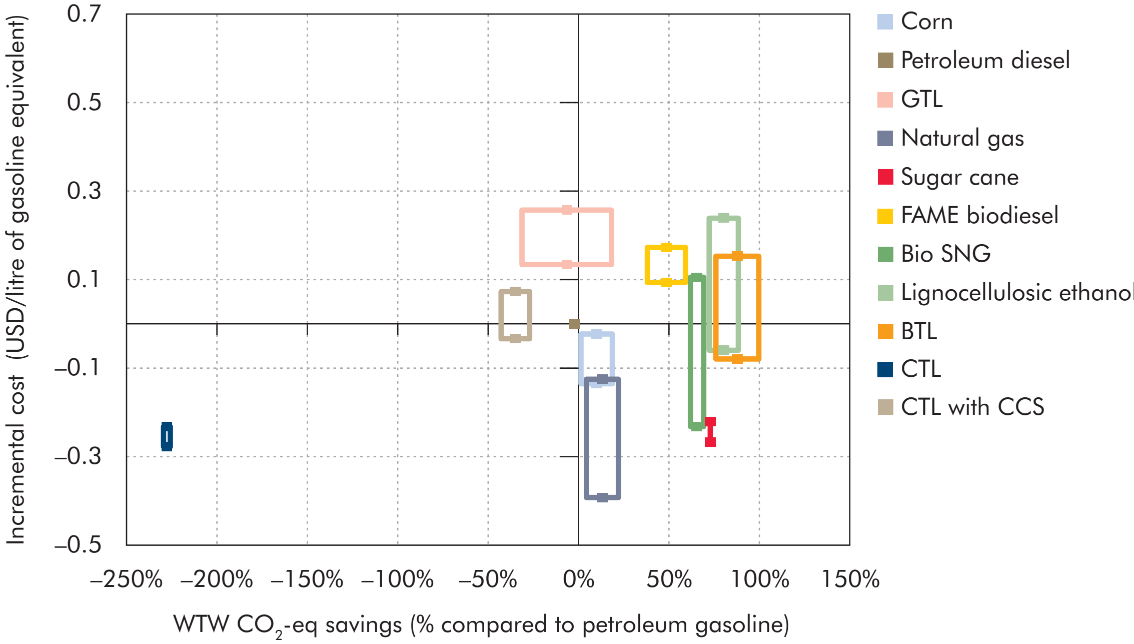
The incremental cost of a range of alternative fuels as a function of their CO_2-eq saving potentials varies widely (Figure 7.18). The rectangles in Figure 7.18 indicate typical ranges of variation for both CO_2-eq savings and cost.

Table 7.2 ▶ Fuels and their production process

Fuel	Feedstock	Process/notes
Liquid petroleum fuels: gasoline, diesel, kerosene, jet fuel	Oil from both conventional sources and non-conventional sources such as heavy crudes and tar sands	Refining
Liquid synthetic fuels	Natural gas, coal	Gasification/Fischer-Tropsch (FT) process (with or without CCS): GTL or CTL
Biodiesel	Oil-seed crops	Esterification, hydrogenation (resulting in fatty acid methyl esters [FAME]) or H_2-treated oils
Ethanol	Grain crops	Saccharification and distillation
Ethanol	Sugar crops (cane)	Distillation
Advanced biodiesel (and other distillate fuels)	Biomass from crops or waste products	Gasification/FT (with or without CCS): biomass-to-liquids (BTL)
Compressed natural gas	Natural gas	Compression to store on vehicle
	Biomass	Methane production from biomass via digestion (biogas) or via gasification and chemical conversion (bio-SG)
Electricity	Coal, gas, oil, nuclear, renewables	Different mixes in different regions, including with or without CCS
H_2	Natural gas	Reforming, compression, centralised with or without CCS, or at point of use
	Electricity	Electrolysis at point of use
	Direct production using e.g. solar, nuclear energy, biomass	High-temperature process or biomass gasification

Biofuels for LDVs as well as for other vehicle types and modes will play an increasing role over time. The use of ethanol and biodiesel is likely to require only minor modifications to new vehicles. But a transition is needed to achieve much more sustainable approaches to the production of feedstocks and fuels. As sustainability criteria and rating systems emerge, policies will need to shift towards promoting the most sustainable, lowest-CO_2-eq, and most cost-efficient biofuels while minimising impacts from land-use change. A transition to second-generation fuels from non-food feedstocks will play a key role. This is particularly true in OECD countries, since their current biofuels production is dominated by ethanol from grain crops and biodiesel from oil-seed crops. These compete with food/feed supplies and do not perform well in terms of costs per tonne of CO_2-eq saved or land-use efficiency. The long-run supply potential of sustainable biomass feedstocks is uncertain, but with careful management it should be large enough to support the levels of bioenergy and transport biofuels envisaged in the BLUE Map scenario. Agriculture and forestry residues alone could be sufficient to supply most of the feedstocks in this scenario, at least until 2030 (IEA, 2010).

Figure 7.18 ▸ Incremental cost of alternative fuels as a function of their CO_2-equivalent saving potentials (at USD 120/bbl)



Note 1: Negative CO_2-eq savings means the use of the fuel results in higher WTW CO_2-eq emissions than using gasoline
Note 2: Assumes oil priced at USD 120/bbl. Costs reflect a bottom-up technology cost analysis of making each fuel, including feedstock production, transport, conversion to fuel, fuel transport, storage and retail supply to vehicles.
Note 3: Natural gas and bio-SG are assumed to be widely used in different end uses, sharing the costs of the transmission and distribution infrastructure required.

Key point

At USD 120/bbl, first- and second-generation biofuels become a cost-effective solution in certain regions.

Box 7.2 ▸ Natural gas for transport: the role of biogas and bio-synthetic gas[2]

The transport scenarios include a significant uptake of CNG as a transport fuel in some regions. Some countries, such as India, have already taken steps in this direction. The inclusion of CNG recognises the energy security and air quality benefits that are associated with the use of natural gas as a transport fuel, as well as CNG's lower cost than oil for vehicle owners, notwithstanding the incremental costs associated with the need for refuelling infrastructure.

Natural gas emits typically about 25% less CO_2-eq per kilometre than gasoline in spark-ignition vehicles on a WTW basis. Emissions are similar to those of diesel vehicles. The use of CNG in diesel engines can bring greater emissions reductions.

2. Bio-synthetic gas (bio-SG) is sometimes termed bio-synthetic natural gas (bio-SNG). The word "natural" has been dropped here since the gas is synthetic, not natural.

If CNG vehicles are to play a more significant role in the long-term decarbonisation of transport, a substitute for fossil natural gas will need to be found. There are two main renewable alternatives for natural gas: biogas and bio-SG.

- ***Biogas*** *is obtained by the anaerobic digestion of biomass, and contains mainly methane and CO_2. Digestion requires specific wet feedstocks which are available in only limited amounts.*

- ***Bio-SG*** *is a methane-rich gas produced by the thermo-chemical conversion of biomass first into a combination of synthetic gas (H_2 and CO), methane and other gases and, later, by the cleaning and the transformation of the synthetic gas component (as well as other gases) into methane through a catalytic process. The bio-SG product also needs to be further upgraded to pipeline specification by removal of CO_2 and water. Nearly all biomass materials are suitable as feedstocks for the production of bio-SG.*

Both fuels can be produced with zero or possibly negative (if methane emissions are avoided) greenhouse-gas emissions. The energy efficiency of SG production from biomass typically is close to 65% and can exceed 70% in large-scale plants (Åhman, 2010). The heat generated during gas production can also serve as a useful energy source.

Since bio-SG can be derived from a wide range of biomass products, its potential availability is comparable with that of other biofuels. Its large-scale implementation would require an adequate transport and logistics system for biomass, as well as guaranteed supplies of sustainable biomass.

The production costs of bio-SG are estimated to be comparable to the cost of production of sugar-cane ethanol, at around USD 0.40/litre of gasoline-equivalent (lge) to USD 0.50/lge for large-scale plants after a wide technology deployment. This is at the low end of the cost range for advanced low greenhouse-gas biofuels.

More work is needed to better understand the regions and countries with the potential to produce sufficiently large quantities of biogas or bio-SG to support a significant transition to these fuels. The extent to which it would be advantageous to use biogas or bio-SG for transport rather than as a substitute for fossil natural gas in other sectors also needs to be assessed.

7

Light-duty vehicles

Passenger LDV ownership around the world is expected to rise broadly in parallel with incomes. In the Baseline scenario, the total stock increases from about 750 million in 2007 to more than 2.2 billion by 2050. In the High Baseline scenario, car ownership rates rise even faster, with ownership more closely tracking the historical rates observed in OECD Europe and Japan for a given income level, and reach 2.7 billion in 2050. This growth results in a less-than-proportionate increase in the rate of fuel use, given about a 25% improvement in vehicle fuel economy in the Baseline scenario over time. This improvement reaches 50% in the BLUE Map scenario, which along with a strong uptake of electric and fuel-cell vehicles, results in 2050 LDV fuel use about half that in the Baseline scenario. In the BLUE Shifts scenario, LDV fuel economy and technology shares closely mirror those in the Baseline scenario. But stocks grow more slowly, to about 1.8 billion by 2050, with less driving per vehicle. This results in nearly 25% less LDV energy use than in the Baseline scenario in 2050. In the BLUE Map/Shifts scenario, a combination of technology improvements and modal shifts results in a 60% reduction in 2050 LDV fuel use compared to the Baseline.

Improvements to ICE vehicles, including full hybridisation, can provide a 50% reduction in fuel use per kilometre for average new LDVs around the world by 2030 if average vehicle size and power do not significantly increase. These improvements are likely to be cost-effective at oil prices of USD 120/bbl or even well below this, using a societal discount rate. Many of these changes could be achieved at net negative CO_2-eq reduction costs, *i.e.* reducing emissions and saving costs at the same time. Policies will be needed both to ensure the maximum uptake of efficiency technologies and to ensure that their benefits are fully translated into fuel economy improvement. Fuel economy standards already play an important role in a number of OECD countries. If complemented by CO_2-based vehicle registration fees, these standards can help achieve the 50% target. It is important that non-OECD countries adopt similar policies, and that all countries continue to update these policies in the future, rather than letting policies expire or stagnate. The Global Fuel Economy Initiative, in which the IEA is a partner, is focused on helping achieve such outcomes (GFEI, 2010).

Advanced technology vehicles

Beyond incremental improvements to today's ICE vehicles, rapid growth in the number of advanced technology vehicles will also play an important role, especially after 2020. Initiatives to promote EVs and PHEVs, and the continuing development of FCVs, will be extremely important in order to achieve a very low-CO_2 stock of LDVs around the world by 2050. Achieving the co-development of vehicle and battery production, a recharging infrastructure, and incentives to ensure sufficient consumer demand to support market growth will be a significant near-term challenge for governments. Working initially with regions and metropolitan areas which are keen to be early adopters, and achieving early market success in these areas, may be an effective approach. As described in IEA (2009d), lessons learned and information sharing over the next three to five years will be critical in moving towards a global mass market for EVs between 2015 and 2020.

Plug-in hybrid electric vehicles (PHEVs)

PHEVs are essentially similar to conventional ICE-electric hybrids except that they also have the capacity to draw electricity from the grid to charge their batteries. They require electric motors with sufficient power to drive the vehicle on their own in a wide range of driving conditions. They also require more battery capacity than conventional hybrids to increase the vehicle range on battery power and to provide more motive power, since the vehicle is designed to run on its electric motor a significant percentage of the time.

PHEVs would rely mostly on their batteries in what is known as charge-depleting mode, *e.g.* for shopping trips or commuting between home and work after the batteries have been recharged at night or during working hours. PHEVs, however, can also function in the same way as conventional hybrids. When the battery charge is relatively low, for example on longer trips, the ICE can work with the electric motor in a charge-sustaining mode to make the most of the available battery power. This characteristic adds a significant degree of flexibility in the design of PHEVs, allowing manufacturers to choose among plug-in versions that have different degrees of reliance on the electric components for the delivery of power and energy. Different configurations can have very different electricity and system costs, especially for batteries.

The battery power in ICE-electric PHEVs may also be used when these are stationary either to offset electricity grid demands, for example in households, or to help stabilise the electricity grid. Such uses would need to be supported by appropriate battery management systems to avoid over-depletion of batteries or excessive cycling that could reduce battery life. Appropriate metering and billing systems will also be needed.

Electric vehicles

Electric vehicles are entirely powered by batteries and use a motor without the need for an ICE. They are charged solely by electricity from external sources (*e.g.* the grid). This is stored in batteries or other storage devices on board the vehicle. They offer the prospect of zero vehicle emissions, as well as very low noise. An important advantage of EVs is the very high efficiency and relatively low cost of the electric motor. The main drawback is the need to rely exclusively on batteries which are a costly, heavy and cumbersome means of storing energy.

Given the high cost of batteries, their high weight and limited storage capacity, if EVs are to be cost-competitive, they need to compromise on their range. They may be particularly useful in towns and cities, where ranges are inherently shorter and where it may be easier and more cost-effective to set up recharging infrastructures. Viewing urban mobility as a service would enable conventional charging, fast charging and battery replacement to be integrated in such as way that EVs might be sold at prices that would exclude the relatively high capital cost of the battery, that cost being recovered during the battery's life in the cost of the electricity needed to run the vehicle.

Electric vehicles are well suited to urban driving, given the short distances and the high value of eliminating vehicle pollutant emissions in the urban context. For EVs to play a bigger role, it will be necessary to develop a public-access recharging infrastructure and eventually either fast-charge facilities or battery-swap centres where drivers can quickly get a fresh set of batteries. Such infrastructure is likely to be expensive and finding a cost-effective balance between consumer demands and recharging options will be critical.

Batteries for PHEVs and EVs

A number of technical issues, especially related to batteries, still need to be resolved. Unless batteries continue to improve and become cheaper, they may form a major barrier to the rapid and widespread introduction of EVs. Achieving a target of USD 300/kWh for EV battery costs by 2015 would help ensure that EVs become affordable in the mass market.

Batteries for PHEVs and EVs need to be designed to optimise their energy storage capacity. The need for higher specific energy and energy densities, as well as to contain costs, will require a strong commitment to ongoing RD&D programmes. Although rapid improvements in the lithium-ion family of batteries have improved the near-term potential for EVs and PHEVs, specific energy and energy density must continue to improve if these vehicles are ever to fully replace ICE LDVs in all applications. Batteries for PHEVs and EVs also need to be able to cope with a range of different discharging cycles. They will be subjected both to deep discharging cycles, for example on commuting trips, and to more frequent shallower cycles such as those from regenerative braking while driving.

It seems likely that the first ICE-electric PHEVs will need to offer a range of 30 to 50 km of pure electric range. For this, they would need batteries with a storage capacity of roughly 6 to 10 kilowatt-hours (kWh) capable of delivering 50 kW of power, or more if the vehicle is to run on battery-only power for some of the time. PHEVs with a lower battery-based driving range, *e.g.* 10 to 20 km, would allow for much cheaper battery systems, and may still provide a significant share of daily driving on electricity. But whether this is sufficient battery range to be interesting to consumers is uncertain.

Fuel-cell vehicles

Fuel-cell vehicles use fuel cells to convert the chemical energy contained in hydrogen into electricity, which is then used to power an electric motor that propels the vehicle.

Although several types of fuel cells have been developed, the most suitable for vehicle applications is the proton exchange membrane (PEM) fuel cell. Proton exchange membrane are relatively efficient, especially under partial load,[3] and operate best at temperatures of around 80°C. PEM FCVs can start quickly, but they need to warm up to optimal operating temperatures and then need to be cooled to avoid overheating. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes with a platinum catalyst. The use of platinum makes PEM cells highly sensitive to carbon monoxide and sulphur pollutants. As a result, they need to be fuelled by very pure hydrogen. Hydrogen produced from natural gas, for instance, is likely to require purification before being used by PEM fuel cells.

Fuel-cell vehicles are well suited to recover the energy dissipated in braking, since their motors can be reversed to act as generators. This, together with the fact that fuel cells achieve their maximum efficiency at partial loads, suggests that they are particularly well adapted to use in hybridised EVs in which the batteries can be used both to store recovered braking energy and to help provide peak power. Hybridisation in this way can also help reduce costs if the battery has higher specific power and lower cost than the fuel-cell stack, as seems likely to be the

3. Fuel cells are significantly more efficient than ICEs when operated at partial load, in which circumstances they can achieve efficiencies of 50% to 60%. At high loads, the efficiency of the two systems is similar at around 35% to 40%.

case when comparing Li-ion battery costs to fuel-cell system costs. Given these considerations, it seems likely that most FCVs will be FCV-EV hybrids[4] (Ahluwalia *et al.*, 2005).

The refuelling of FCVs raises difficult issues. They either need on-board hydrogen reforming, which is expensive, or they need on-board hydrogen storage, which raises issues of cost, safety, driving range, and the need for an extensive hydrogen production and distribution infrastructure. As fuel-cell systems improve and FCVs are proven technically, the refuelling and fuel infrastructure issues are likely to become the main barriers to commercialisation. Vehicle fuel-cell stack and system costs have declined in recent years but are still very expensive compared to conventional ICE vehicles.

Carbon dioxide reduction and cost comparison

Different vehicle and fuel combinations result in different lifetime incremental costs and CO_2-eq savings (Figure 7.19). These variables also affect the resulting cost per tonne of CO_2-eq saved corresponding to different vehicle and fuel options (Figure 7.20).

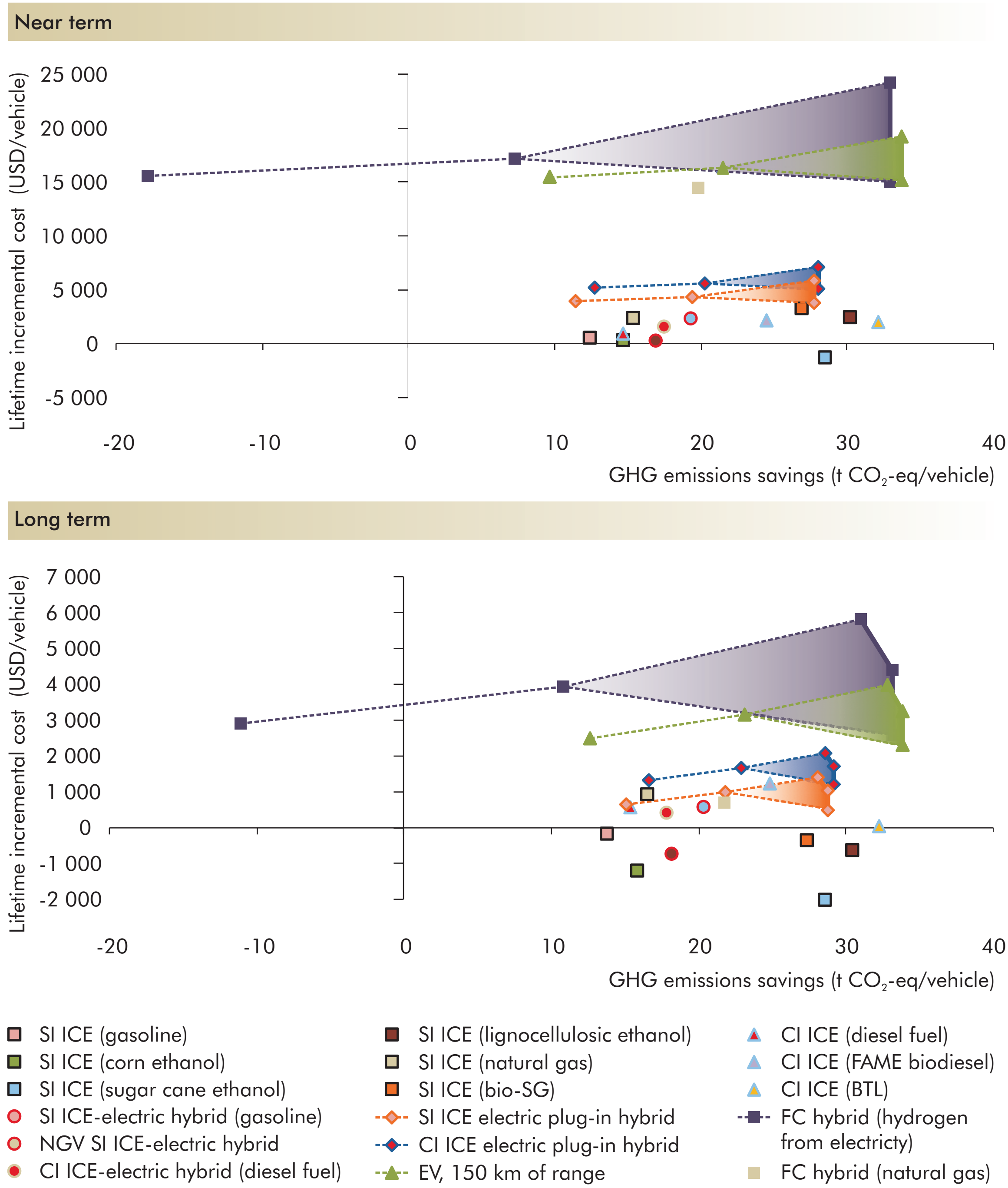
At USD 120/bbl of oil, some of the options are cost-competitive in the near term and virtually all are characterised by low incremental costs or negative costs in the longer term. In contrast, at oil prices around USD 70/bbl (not shown), none of the vehicle options considered achieves CO_2-eq savings at a net negative cost per tonne saved in the near term though several do in the longer term (IEA, 2009a).

The CO_2-eq reduction potential of EVs and FCVs is heavily dependent on the electricity generation mix. Depending on the mix, the use of PHEVs, EVs and FCVs can result in large CO_2-eq reductions or substantial CO_2-eq emission increases compared to a 2050 gasoline vehicle. The mix also has a significant impact on costs per tonne of CO_2-eq saved, with the least CO_2-intensive options also being among the most expensive. The generation mix also affects the emissions associated with hydrogen produced by electrolysis. FCVs using hydrogen from electrolysis in carbon-intensive power generation regions may increase CO_2-eq emissions compared to gasoline vehicles.

The net CO_{2-}eq mitigation costs for advanced ICEs and ICE-hybrids is very close to zero USD/tCO_2-eq in the near term, and negative in the case of spark-ignition ICE hybrids and advanced spark-ignition ICEs in the long term. PHEVs deliver CO_2-eq savings at a cost between USD 140/tCO_2-eq and USD 210 /tCO_{2-}eq in the short term, reducing to USD 20/tCO_2-eq in the best case (electricity from hydro), and up to USD 50/tCO_2-eq using more expensive electricity (e.g. from biomass) in the long term. This reflects a significant reduction in battery and other technology costs.

4. FCVs could even be conceived as plug-ins, if they have sufficient storage capacity and their batteries are optimised for such a configuration.

Figure 7.19 ▶ Lifetime incremental cost of vehicle and fuel pathways as a function of CO_2-equivalent savings



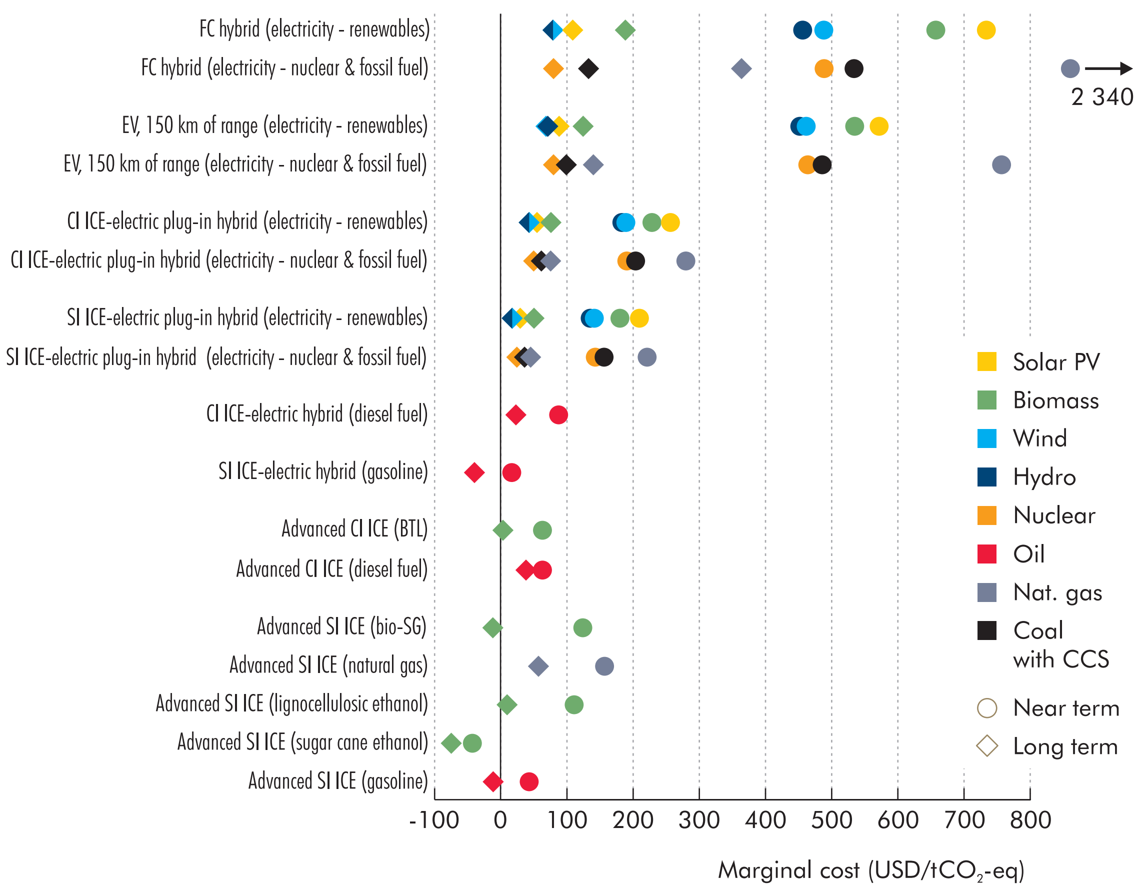
Notes: The points along the dotted lines represent typical electricity mixes, which determine the net CO_2-eq emissions for electricity. From the left, the first symbol is electricity from coal, then from natural gas and, clustered on the right side, a range of renewables. For visualisation purposes, the vertical axes in the near and long term do not have the same range. Costs and CO_2-eq savings based on 7.5 lge/100km for baseline vehicle, 200 000 km, 3% discount rate, 15 years, US 90 cents/lge for oil-based fuels (USD 120/bbl), US 13 to 26 cents/kWh for electricity, US 70 cents to USD 1.10/lge for biofuels

Key point

Most technologies and fuels lead to net greenhouse-gas savings over the vehicle lifetime, but at a wide range of costs.

In regions with low CO_2-eq power generation, in the long run EVs with 150 km range reach roughly USD 80/tCO_2-eq, rising to USD 120/tCO_2-eq for renewable electricity produced from biomass. In the same timeframe, FCV hybrids achieve values close to USD 100/tCO_2-eq if they use hydrogen produced from low-cost, low-carbon electricity, with a high cost of USD 190/tCO_2-eq for more expensive generation. Across the range of electricity generation mixes by region in the BLUE Map scenario, the marginal cost of EVs and FCVs does not exceed USD 175/tCO_2-eq in the long run. These values compare with near-term cost estimates of as much as USD 500/tCO_2-eq for both vehicle technologies. The difference reflects the expected cost reductions in advanced technologies over the coming 10-20 years.

Figure 7.20 ▶ Cost per tonne of CO_2-equivalent saved over the vehicle's life, oil price at USD 120/bbl



Key point

With oil at USD 120/bbl, long-term CO_2-eq mitigation costs range from negative to about USD 175 per tonne for FCVs using hydrogen from biomass (this excludes options that use H_2 or electricity from fossil sources, not included in BLUE Map).

Trucking and rail freight

Trucking has been one of the fastest growing modes in most countries over the past ten to twenty years. This growth is likely to continue in the future, although possibly with some decoupling from GDP growth as an increasing share of economic growth comes from information and other non-material sectors. Trucks have also become more efficient over time. But there remain major opportunities to improve efficiency further, through technical measures, operational measures such as driver training and logistical systems to improve the efficiency in the handling and routing of goods. Rail remains, on average, far more energy-efficient than trucking and shifting more future freight movement to rail systems, where possible and cost-effective, remains an important option.

Through better technologies such as improved engines, light-weighting, better aerodynamics and better tyres, new trucks can probably be made 30% to 40% more efficient by 2030. More information is needed on technology costs. But many of the improvements appear likely to be quite cost-effective. This suggests that truck operators are less responsive to market signals on the cost-effectiveness of truck technologies than is often believed. Logistic systems to ensure better use of trucks, and shifts to larger trucks in some cases, can provide additional system efficiency gains, and may also be cost-effective. But to maximise the gains, governments will need to work with trucking companies, for example through supporting driver training programmes, and to create incentives or requirements for improved efficiency. Japan's Top-Runner efficiency requirements for trucks are the first of their kind in the world.

Diesel-powered trucks can use biodiesel fuel very easily, especially the very high-quality biodiesel that comes from biomass gasification and Fischer-Tropsch liquefaction. Electricity will not be appropriate in most trucking contexts, given range requirements and energy storage limitations. Hydrogen may be a good long-term option for certain types of trucks, depending in part on the evolution of hydrogen storage technologies. Other gaseous fuels, such as CNG and liquefied natural gas (LNG), and eventually bio-SG, may also play a key role for trucks, especially if high-quality biodiesel does not become affordable over time.

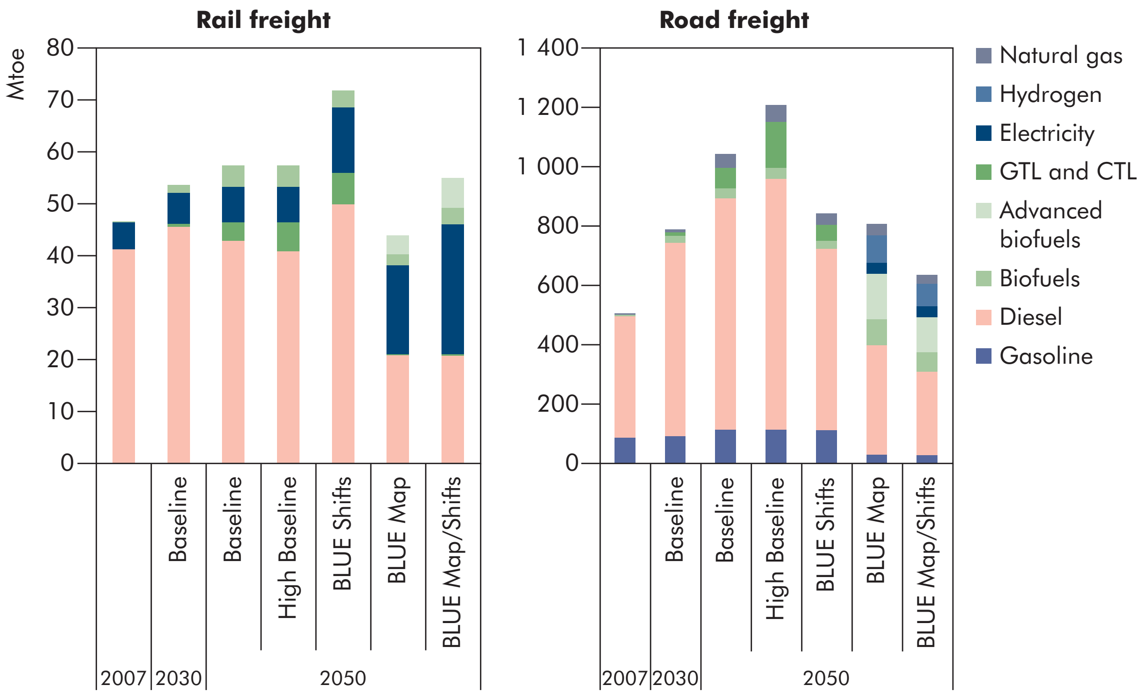
Modal shift to rail continues to be an attractive option to save energy and cut CO_2-eq emissions, given the inherently efficient nature of rail freight transport. Many countries move only a small share of goods by rail. But to achieve shifts, very large investments in rail and intermodal systems will be necessary in most countries.

As for passenger travel, the BLUE Map scenario takes into account the contributions of freight transport technology improvements, whereas BLUE Shifts focuses on opportunities to shift some of the road freight transport towards more efficient modes (Figure 7.21). The BLUE Map/Shifts scenario combines technology improvement and modal shifts. For trucks, both the BLUE Shifts and BLUE Map scenarios result in about a 20% reduction in fuel use in 2050 compared to the Baseline scenario. This increases to over a 30% reduction in the BLUE Map/Shifts scenario, somewhat less than the sum of the two individual cases since, as trucks improve their efficiency, the benefits of shifting to rail are reduced. The outcomes envisaged in the BLUE Map scenario are achieved by strong efficiency improvements reaching nearly 40%

by 2050 compared to 2007, against about a 20% improvement in the Baseline. Trucks also increase their use of alternative fuels, in particular of advanced biofuels. Second-generation biofuels are used as a blend in diesel fuel, reaching 30% by 2050. Some hydrogen fuel-cell trucks, plug-in hybrid trucks and pure electric trucks are also assumed in this scenario, mostly for light commercial and medium-duty freight movement.

The shift from road to rail freight in the BLUE Shifts scenario results in rail freight using more energy than in the Baseline scenario (Figure 7.21). In the BLUE Map/ Shifts scenario, a 25% improvement in rail efficiency led by a strong shift towards more efficient rail electrification results in rail energy use in 2050 being kept at the level of the Baseline scenario, while providing the higher level of transport activity in BLUE Shifts.

Figure 7.21 ▶ *Road and rail freight energy use by fuel, by scenario and by year*



Key point

Trucks increase fuel use in the Baseline and High Baseline scenarios far more than rail, owing to faster activity growth. Both shift away from conventional diesel in BLUE Map. Rail energy use increases in BLUE Shifts as freight is shifted over from trucking.

The available information permits only a very broad categorisation of fuel-savings potentials and costs across a range of fuel-saving policies and measures for freight transport (Table 7.3). The measures in blue text are those requiring direct public regulatory intervention, although most of the others can also be encouraged by government fiscal policy and advisory programmes.

Table 7.3 ▶ A rough guide to energy-saving measures for truck and rail freight transport

		Energy/CO_2-eq savings: Lower	Energy/CO_2-eq savings: Higher
Cost per unit fuel savings/CO_2-eq reduction	Lower	• Idling control devices • Lower rolling resistance tyres • Improved intermodal logistics through information and communication technology • Night-time delivery • Rail locomotive efficiency	• Improved diesel powertrains • Retrofit package including aerodynamics • Vehicle routing and scheduling systems • Lower speed limits • Increase truck size/weight limits • Driver training
	Higher	• Hybridisation of long-haul trucks • Reduce vehicle tare weight (truck or rail) • Scrappage incentives for older trucks	• Hybridisation of local delivery vehicles • Advanced powertrains (*e.g.* fuel cell) • Decentralisation of production/ warehousing • Relax just-in-time regimes • More localised sourcing • Improved rail infrastructure • Fiscal incentives for use of rail • Road user charging • Biofuels, LPG, CNG

Colour code: grey = technical efficiency measures, orange = system efficiency measures, green = measures directed towards rail, blue= fiscal incentive measures, magenta = alternative fuels.

Measures that appear to offer the greatest potential for fuel savings at minimal cost include improved diesel powertrains, retrofit truck efficiency packages, better routing systems, lower speed limits, increased truck size/weight limits and driver training programmes. A package of measures might be able to improve overall trucking efficiency by around 20% to 30%, at low or possibly even negative costs per tonne of CO_2-eq saved. Although uncertain, this is likely to be consistent with an estimate of a 33% efficiency improvement in the BLUE Map scenario at a marginal cost below USD 175 per tonne of CO_2-eq saved, possibly well below. Additional cost-effective CO_2-eq reductions can come from fuel switching, especially to advanced biofuels, and from modal shift.

Aviation

Air travel is expected to be the fastest growing transport mode in the future as it has tended to grow even faster than incomes during normal economic cycles. Air passenger-kilometres increase by a factor of four between 2005 and 2050 in the Baseline scenario, and by a factor of five in the High Baseline scenario. In the same period, aviation benefits from steady efficiency improvements in successive generations of aircraft.

The technical potential to reduce the energy intensity of new aircraft has been estimated to lie between 25% and 50% by 2050 (Lee *et al.*, 2001). This is equivalent to an improvement of about 0.5% to 1% a year on average.

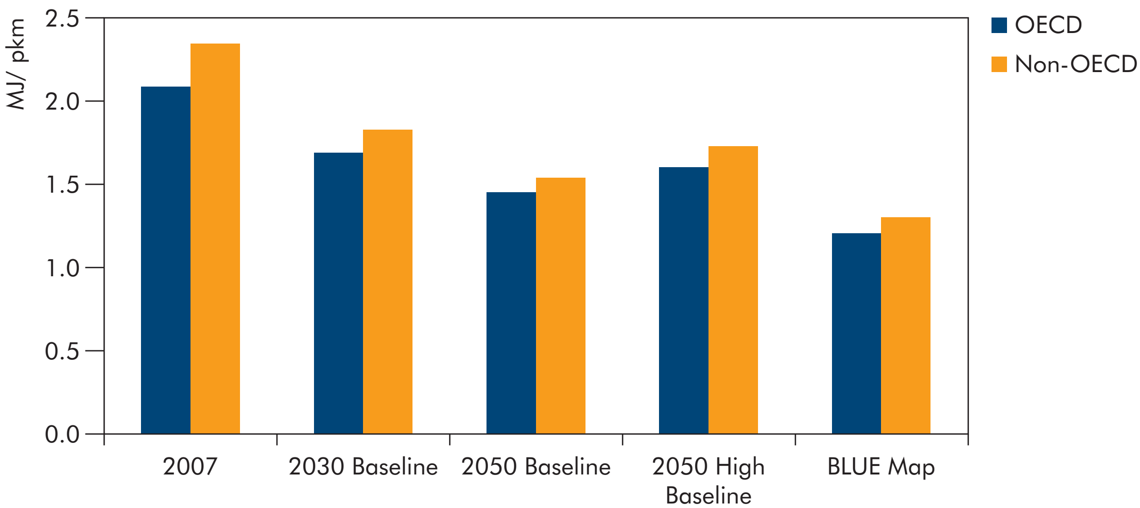
Given the length of time it takes for new aircraft fully to replace the existing stock, the average efficiency of the current stock may lag behind new aircraft efficiency by up to 20 years. But since new aircraft are more efficient than average aircraft, the overall stock of aircraft can also be expected to improve at a steady rate, with an average annual rate that is similar to or slightly faster than the improvement rate of new aircraft.

Steps to increase operational efficiencies and load factors on the existing stock of aircraft continue to offer an important opportunity for efficiency improvement. If the annual historical rate of improvement in load factors of around 0.2% a year continues, the worldwide average load factor could reach nearly 0.8 (*i.e.* 80% of available seats filled with passengers) by 2025. This may be close to an upper bound.

Improving logistical operations and air-traffic controls can also improve aircraft efficiency, for example by reducing delays in landing and by allowing aircraft to fly on more optimal routes. Such measures may also reduce environmental impacts by around 10% (Penner *et al.*, 1999). New practices such as continuous-descent landing patterns can lead to additional savings. Most of these changes will require regulations to be amended and air-traffic control technologies and procedures to be increasingly harmonised (RCEP, 2007).

As a result of some of these measures, aircraft efficiency is projected to improve by 30% between 2010 and 2050 in the Baseline scenario, an improvement of about 0.6% a year (Figure 7.22). Much higher efficiency improvements, of nearly 1% a year, are achieved in the BLUE Map scenario where an overall improvement of 43% is achieved by 2050.

Figure 7.22 ▶ *Average energy intensity of aircraft by region*



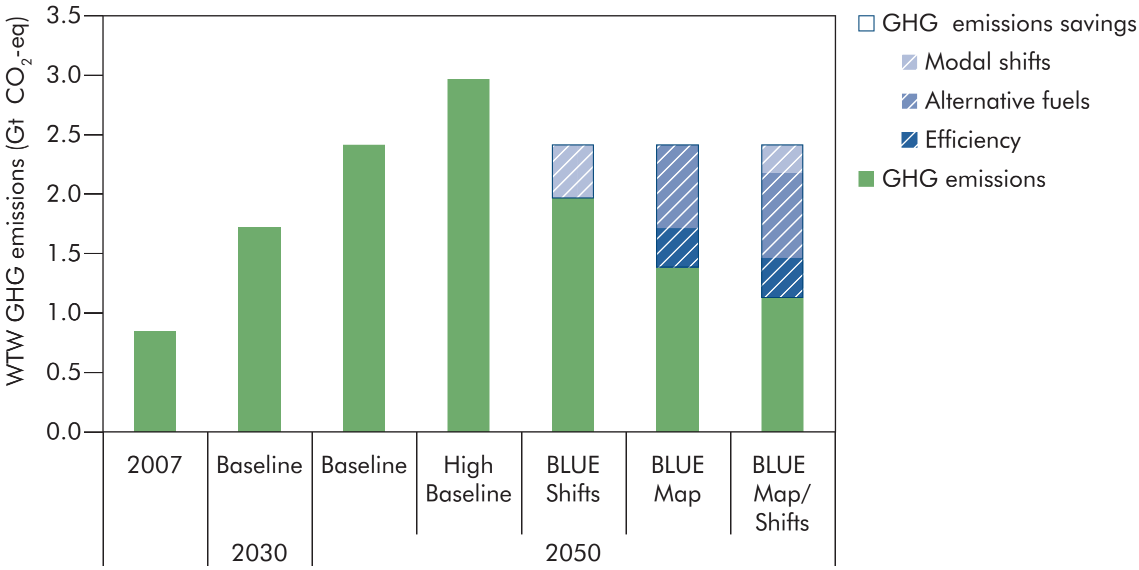
Key point

An efficiency gap between OECD and non-OECD countries is expected to remain as second-hand planes are sold mainly in non-OECD countries.

More work is needed better to understand the cost-effectiveness of different options for aviation. Recent estimates suggest that some available options may be quite cost-effective (IEA, 2009a). One significant factor in assessing technology costs and benefits for aircraft is that aircraft burn large quantities of fuel over their lifetimes. A very large aircraft may use up to a billion litres of jet fuel in a 30-year lifetime. So cutting fuel use can provide enormous long-run fuel cost savings. This suggests that even major investments to improve aircraft efficiency may be cost-effective, at least using a long-term, societal cost perspective.

Aircraft have very few alternatives to today's kerosene jet fuels. The energy density of jet fuel is critical for providing adequate aircraft flying range, so shifting to gaseous fuels or electricity appears impractical. Liquid hydrogen would require major compromises in other airplane design features, while other gaseous options are limited by the large storage volume they would require. This would be incompatible with the aerodynamic shape of airplanes. So high-quality, high energy-density biodiesel fuels are of great interest to airlines and aircraft manufacturers, as these may hold the best hope of providing low-CO_2-eq aircraft fuels in the future. But the concerns expressed above regarding biofuels and sustainable feedstock supplies apply to aircraft as they do for other modes. In the BLUE Map scenario, by 2050 30% of aircraft fuel is second-generation biofuel such as BTL fuel or other aircraft-compatible advanced biofuel.

Figure 7.23 ▶ *Aircraft greenhouse-gas emission projections by scenario*



Key point

Most of the reduction potential is expected to come from alternative fuels, mainly BTL.

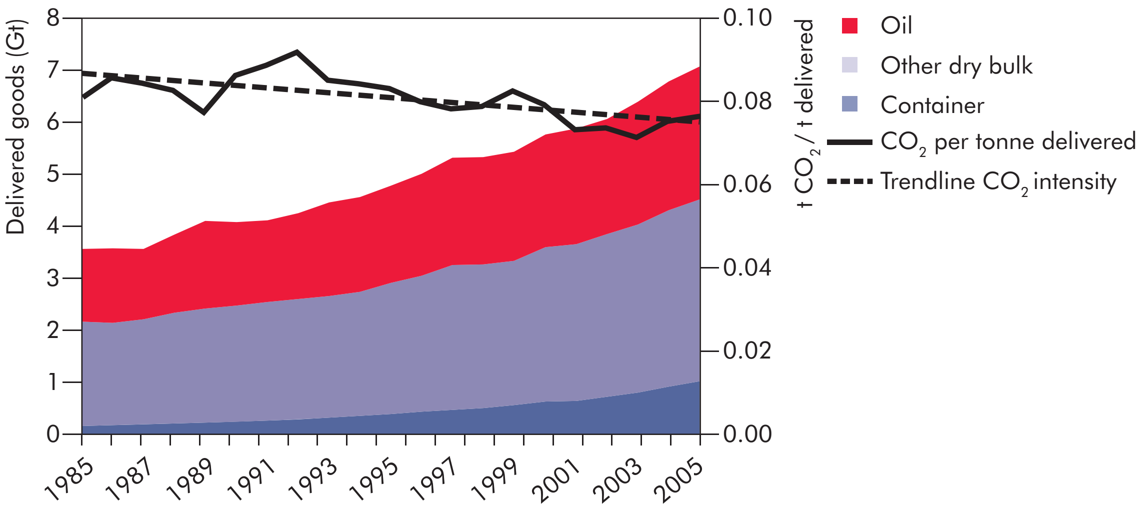
Modal shift and a general reduction in aviation travel growth can also help. In the BLUE Shifts scenario, air travel growth is cut by 25%, resulting in its tripling by 2050 rather than quadrupling. This will to some extent occur naturally if alternatives such as high-speed rail systems are available, but it must also be encouraged by policies that, for example, help ensure the availability and cost-competitiveness of rail travel. Substituting telematics such as teleconferencing for some long-distance trips could also play an important role, and could also be encouraged by governments as well as by businesses. Since the BLUE Shifts scenario focuses on travel shifting rather than efficiency gains, it makes the same assumptions about efficiency improvements as the Baseline scenario.

The different scenarios, taking into account efficiency improvements, modal shifts and biofuels, result in different net impacts on energy use and CO_2-eq emissions (Figure 7.23). The growth in CO_2-eq emissions in the Baseline scenario is very large, increasing nearly threefold between 2005 and 2050, even after efficiency improvements are taken into account. In the High Baseline scenario, the increase is almost fourfold. In the BLUE Map scenario, CO_2-eq emissions in 2050 are cut by 43% relative to the Baseline scenario. In the BLUE Map/Shifts scenario, the reduction reaches 55%, although emissions still remain above 2007 levels.

Shipping

International maritime activity has grown significantly in recent years, doubling between 1985 and 2007 (Figure 7.24). This growth has been driven in particular by the growth in Asian manufacturing and exports to other countries. International maritime activity now represents about 90% of all shipping energy use, the remainder being used in-country by river and coastal shipping. Container-shipping fuel use has risen the fastest, and may rise much more in the future; projections of up to an eightfold increase for container shipping to 2050 have been made (Buhaug et al, 2008). Shipping has become steadily more efficient per tonne-kilometre moved as the average size of ships has risen, although practical limits to ship size may be close to being reached.

Figure 7.24 ▶ Trends in maritime transport volumes and related CO_2-equivalent emissions



Source: Crist (2009).

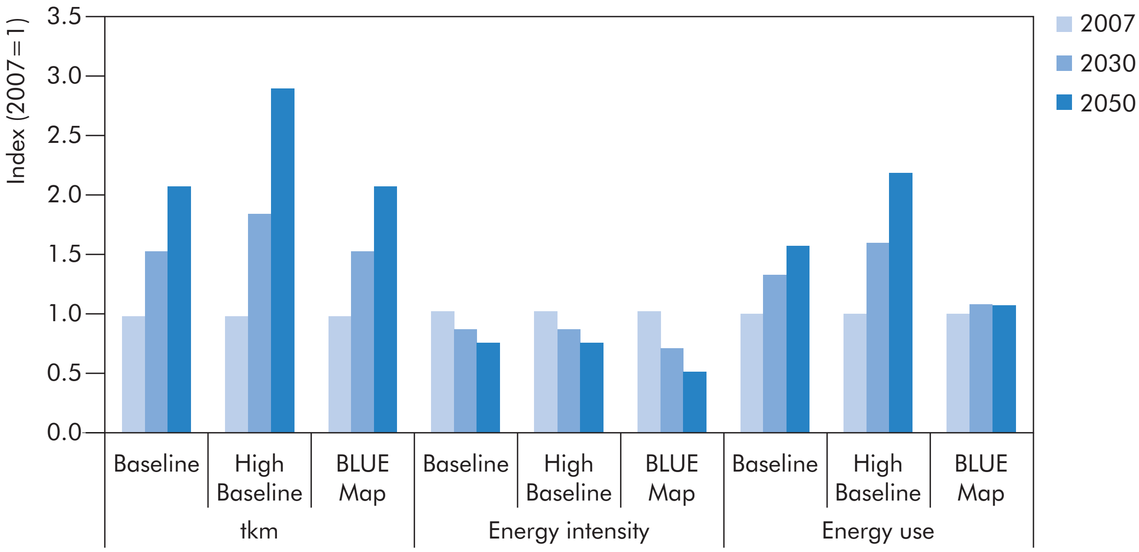
Key point

Transport volumes of major categories of shipped goods have doubled in the past 20 years, but CO_2-eq intensity has improved by only 15%.

Steady increases in average ship size in recent years have helped improve fuel efficiency. Apart from this, however, ship efficiency has not changed significantly in recent years. The fragmented structure of the shipping industry, with different systems of ownership, operation and registration, often all happening in different countries for a given ship, may serve to limit the market incentives to optimise ship efficiency.

The *ETP* Baseline projections of energy use and CO_2-eq emissions by international shipping are based on the growth projections of the International Maritime Organization (Buhaug *et al.*, 2008). The energy use projections reflect past relationships between GDP growth, shipping activity and fuel use (Figure 7.25). In the Baseline scenario, activity roughly doubles by 2050, energy intensity improves by 25% and, as a result, energy use increases by about 50%. In the High Baseline scenario, activity growth nearly triples. Therefore, with the same energy intensity improvement as in the Baseline scenario, energy use more than doubles. In the BLUE Map scenario, activity growth matches that in the Baseline scenario but energy intensity is cut by half, resulting in essentially unchanged energy use over time. Achieving a reduction in energy intensity that matches the rate of activity growth in the Baseline scenario will be very challenging. If activity growth is closer to that in the High Baseline scenario, it will be virtually impossible to achieve sufficient improvements in energy intensity to offset the volume growth.

Figure 7.25 ▶ *International shipping activity, energy intensity and energy use by scenario*



Source: IEA projections based in part on Buhaug *et al.* (2008).

Key point

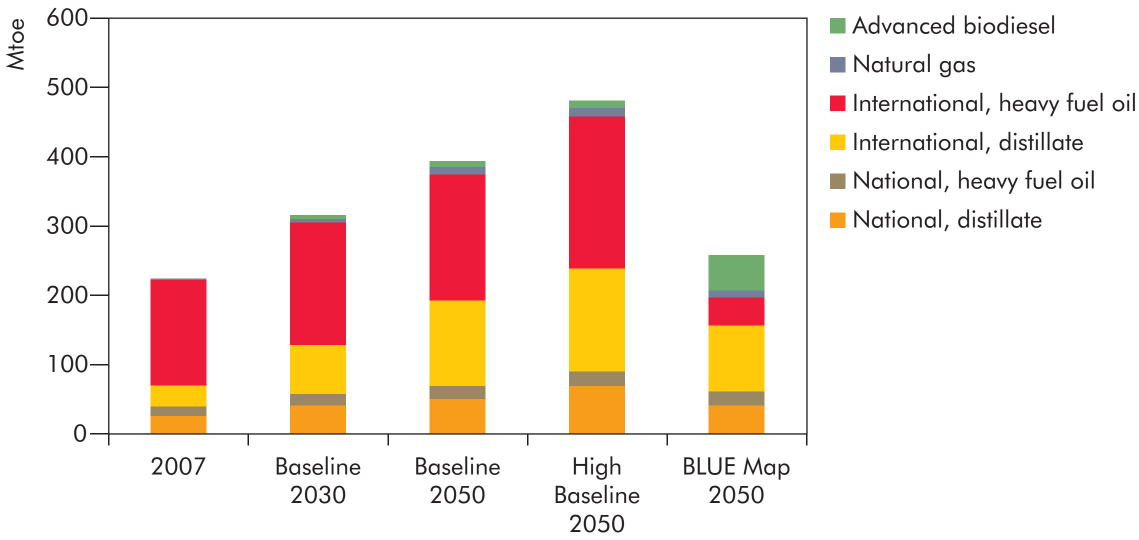
In the BLUE Map scenario, energy intensity is cut by half and energy use remains nearly flat through 2050.

The improvement in energy intensity assumed in the BLUE Map scenario is justified by the large number of efficiency improvement measures that have been identified for the shipping sector. About 50 energy efficiency options for shipping are outlined in IEA (2009a). If most of these options were adopted, it is estimated that a 50% or greater reduction in energy use per tonne-kilometre could be achieved, even taking into account various interactions between options. Recent research also suggests that many options for retrofitting existing ships could achieve substantial energy and CO_2-eq savings at very low or net negative cost.

The more conservative estimates on energy intensity used in the Baseline and High Baseline scenarios account on the one hand for the significant opportunities identified, and on the other for the relatively negative performance of the sector in achieving efficiency improvements to date.

The resulting demand for different fuels, using IEA data, for both national and international shipping is shown in Figure 7.26. In the Baseline scenario, fuel use grows from about 210 Mtoe in 2007 to about 306 Mtoe by 2030 and to 381 Mtoe by 2050, reflecting a decoupling of shipping growth from GDP growth as economies grow more in information sectors than material sectors. In the High Baseline scenario, past growth rates are assumed to decouple far less than in the Baseline scenario. Shipping energy use reaches 400 Mtoe by 2050. In both cases, most of the fuel used is HFO, although the share of diesel-type fuel (middle distillate) is assumed to increase.

Figure 7.26 ▶ Shipping energy use by scenario



Note: Figure based on IEA data for 2007.

Key point

With efficiency improvements and advanced biofuels, petroleum fuel use in BLUE Map in 2050 is slightly lower than in 2007.

Biofuels and some gaseous fuels may also have the potential to help decarbonise shipping. Ship engines are capable of using a wide range of fuels, and may be able to use relatively low-cost types of biofuels such as biodiesel or even "bio-crude" oils from pyrolysis or other processes. LNG already plays a role, particularly for powering LNG tankers; this fuel could be used more widely and eventually produced from biomass, such as bio-SG (see Box 7.2). In the BLUE Map scenario, 30% of ship fuel by 2050 is low greenhouse-gas biofuel.

Fuel use by shipping within national borders is much less than that used for international shipping, reaching about 70 Mtoe in 2050 in the Baseline scenario and about 90 Mtoe in the High Baseline scenario.

Growth in CO_2-eq emissions generally closely follows fuel use except in the BLUE Map scenario where the increased use of second-generation biofuels reduces the CO_2-eq emissions attributable to the petroleum fuels they displace by 80% to 90%. This is dependent on successful development of such fuels and on the production of enough sustainably produced feedstocks to meet the demand from a number of competing sectors. If achievable, a 30% biofuels share would provide about a 25% reduction in CO_2-eq emissions in the BLUE Map scenario on top of that already resulting from reductions in energy use.

Chapter 8 OECD EUROPE

Key findings

- *In the Baseline scenario, OECD Europe's primary energy demand grows by 5% between 2007 and 2050. The increased use of renewable energy and natural gas results in CO_2 emissions decreasing by 8% in the same period.*
- *Countries in OECD Europe need to cut their carbon dioxide (CO_2) emissions by about three-quarters of their 2007 levels by 2050 if they are to make their full contribution to the halving of global CO_2 emissions envisaged in the BLUE Map scenario. These developments also bring considerable energy security benefits. The share of fossil fuels in the primary energy mix in 2050 is halved compared to 2007 levels.*
- *To achieve the BLUE Map scenario, OECD Europe will need to invest an additional USD 7.1 trillion between 2010 and 2050 compared to the Baseline scenario. However, this will bring substantial fuel savings that will more than offset these investments on an undiscounted basis.*
- *End-use sectors contribute two-thirds of the CO_2 savings required from OECD Europe in the BLUE Map scenario. The transport sector, including fuel transformation, provides 50% of these end-use reductions. Buildings provide 35% and industry 15%. In industry, energy efficiency and the use of carbon capture and storage (CCS) offer the largest least-cost emissions reductions.*
- *Despite a large proportion of older housing in Europe and the expected growth in the number of households and in floor area in the service sector, buildings' energy consumption falls by 14% between 2007 and 2050 in the BLUE Map scenario. Efficiency improvements and better building insulation in space and water heating provide almost 40% of the emissions reduction in the buildings sector. Solar thermal heating, heat pumps, combined heat and power (CHP) and more efficient appliances also contribute.*
- *Transport volumes in OECD Europe are expected to remain relatively constant. Deep emissions reductions can be realised by more efficient vehicles as well as a shift to electricity and biofuels. The greater use of natural gas, followed by a transition to biogas and bio-synthetic gas, offers a further option for reducing emissions in the transport sector.*
- *Nuclear, CCS and renewable energy sources contribute with broadly equal shares to the CO_2 savings from the power sector in the BLUE Map scenario. Given very different local conditions, the energy mix varies widely between different countries in OECD Europe.*
- *Europe has a comprehensive and ambitious energy and climate change programme. Further actions are recommended to rapidly decarbonise power generation, improve the electricity infrastructure, strengthen energy efficiency targets and encourage modal shifts to public transport.*
- *Particular emphasis should be put on improving the efficiency of Europe's existing housing stock. Policies are needed to encourage improvements in building shells*

and the installation of energy-efficient heating and lighting. Gradual improvements in the buildings standards for residential and service sector buildings will also be important, coupled with improved compliance with these standards.

- *More funding will be required for energy technology research, development and demonstration (RD&D) if Europe is to maintain its strong position in renewable and other low-carbon technologies. Further co-ordination of European Union (EU) and member state level RD&D activities and additional funding is needed to deliver the priority actions identified in the EU Strategic Energy Technologies plan.*

Regional description

In 2007, the 23 European member countries[1] of the OECD represented a population of 543 million people or 8% of the global population. Geographically, OECD Europe stretches from Norway to Spain and from Portugal to Turkey. With the exception of Iceland, Norway, Switzerland and Turkey, all other countries within OECD Europe are also member states of the European Union. The energy and climate policies of the 19 EU states in OECD Europe are heavily influenced by decisions taken at EU level. Of the non-EU members, Iceland, Norway and Switzerland are members of the European Free Trade Association (EFTA). Norway and Iceland are part of the European Economic Area (EEA) which allows them to participate in the single European market with free movement of goods, capital, services and people.

OECD Europe's GDP in 2007 was USD 10 532 billion, roughly one-fifth of global GDP in that year. OECD Europe was responsible for 15% of global primary energy consumption in 2007, but accounted for only 9% of global primary energy production. OECD Europe's 4 gigatonnes (Gt) of energy-related CO_2 emissions in 2007 represented 14% of global CO_2 emissions.

Recent trends in energy and CO_2 emissions

OECD Europe was responsible for nearly one-sixth of global primary energy consumption in 2007. Of these energy needs, 58% were met by indigenous energy sources.

OECD Europe's hard coal deposits represent 3% of global hard coal reserves (Table 8.1). They are mainly located in Poland, the United Kingdom and Germany. Indigenous hard coal production has been declining since the beginning of the 1990s, mainly for economic reasons. OECD Europe has 20% of global lignite reserves, mainly in Germany, Greece and Poland. Nearly all lignite is used for power generation in plants located near mines, given the very large volumes of lignite that are needed per unit of electricity generated.

1. OECD Europe comprises Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

There are still significant oil and gas reserves in the North Sea, although these amount to only 1.3% of global oil reserves and 2.7% of global gas reserves. Oil production in the North Sea, mainly by the United Kingdom and Norway, has been in decline since 2000. Natural gas production from the United Kingdom's continental shelf is in decline, to the extent that the United Kingdom has become a net importer of natural gas in recent years. But Norway's production has almost doubled since 2000.

Table 8.1 ▶ **Proven energy reserves in OECD Europe and the world**

	Hard coal (billion tonnes)	**Lignite** (billion tonnes)	**Crude oil** (million toe)	**Natural gas** (billion cubic metres)
Proven reserves: OECD Europe	18.5	52.5	2 219	5 044
Proven reserves: World	558	268	170 800	185 020
Production in 2007: OECD Europe	0.16	0.45	230	290
Reserve-to-production ratio: OECD Europe	116	117	10	17

Note: Reserve-to-production ratio indicates the length of time that the proven reserves would last if production were to continue at current rates and if no additional reserves could be recovered.
Sources: BGR (2009); BP (2009); IEA (2009a).

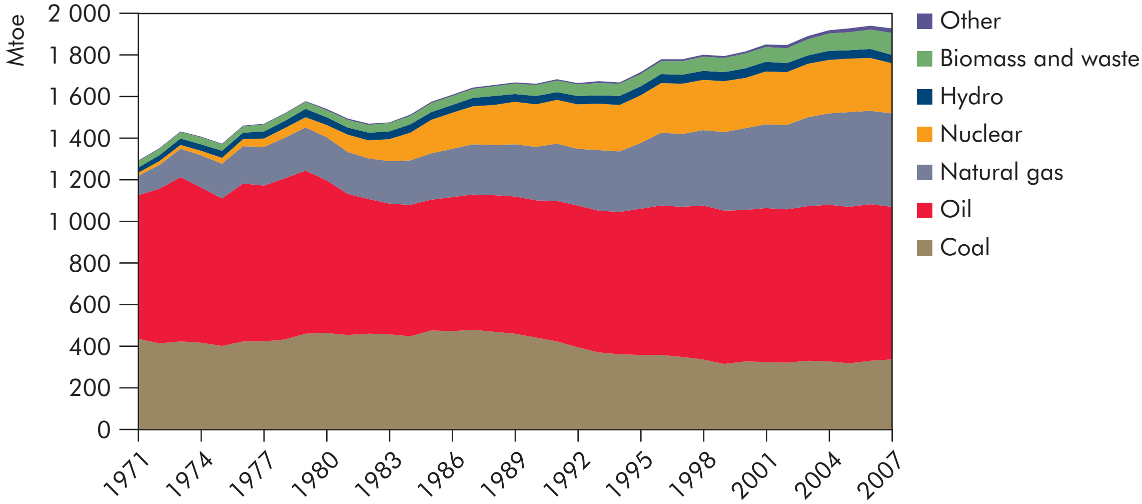
Energy production and supply

Total primary energy supply (TPES) in OECD Europe has increased only slightly since 2000 (Figure 8.1). Oil accounts for more than one-third of primary energy needs. Although the primary energy supply of coal, oil, hydro and nuclear levelled off or slightly declined between 2000 and 2007, natural gas and renewables grew at a rate of 2% a year and 4% a year respectively. Including hydro, renewable energy sources accounted for 9% of TPES in 2007.

Renewables have grown, albeit from a low base. But OECD Europe remains strongly dependent on the import of fossil fuels (Figure 8.2). OECD Europe imports 45% of its coal supplies, mainly from Russia, South Africa, Colombia and Australia. The increasing use of gas for power generation and increased gas use in industry and the residential sector have led to growth of almost three-quarters in natural gas consumption in OECD Europe between 1990 and 2007. The United Kingdom, Germany and Italy are the largest gas consumers, representing 51% of OECD Europe's consumption in 2007. Indigenous gas supplies met roughly half of all demand in 2007. Imports from Russia and Algeria accounted for more than 70% of OECD Europe's gas imports.

OECD Europe accounted for 17% of global oil demand in 2007. Nearly two-thirds of its petroleum demand was satisfied by imports, mainly from Russia, the Middle East and Africa.

Figure 8.1 ▶ Total primary energy supply in OECD Europe

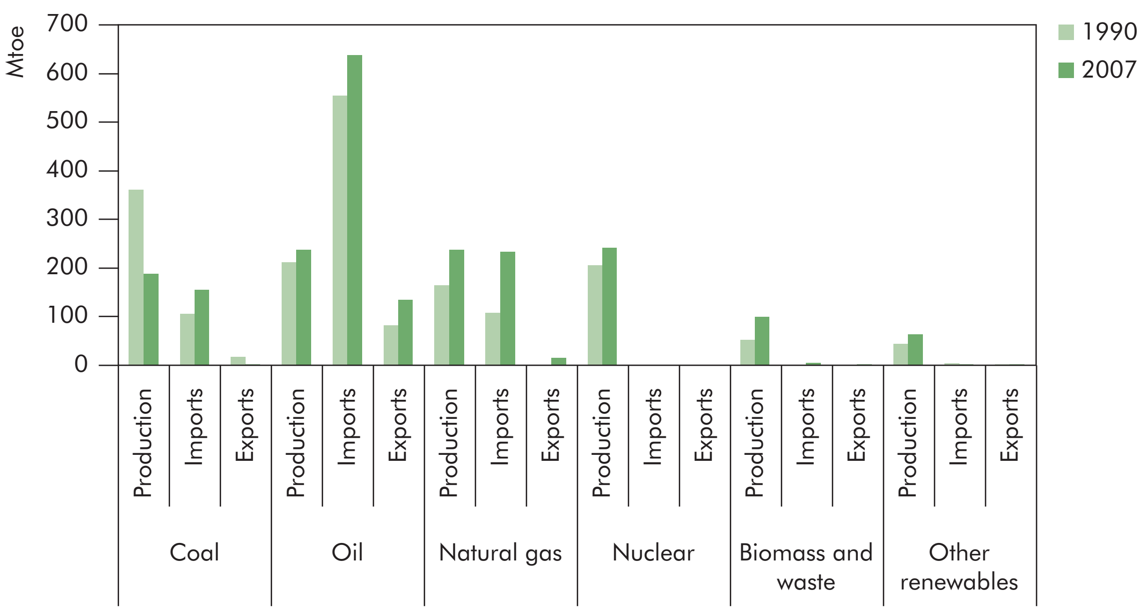


Note: Other includes renewables and heat.
Source: IEA (2009a).

Key point

Total primary energy supply has grown only slightly since 2000, with the growth coming mainly from increases in natural gas and renewables.

Figure 8.2 ▶ Energy production, imports and exports by fuel for OECD Europe



Note: Nuclear production refers to the heat produced in nuclear reactors, irrespectively of whether the nuclear fuel used is from domestic sources or imported.
Source: IEA (2009a).

Key point

More than half of OECD Europe's fossil fuel consumption relies on energy imports, with two-thirds of oil imported.

Energy consumption

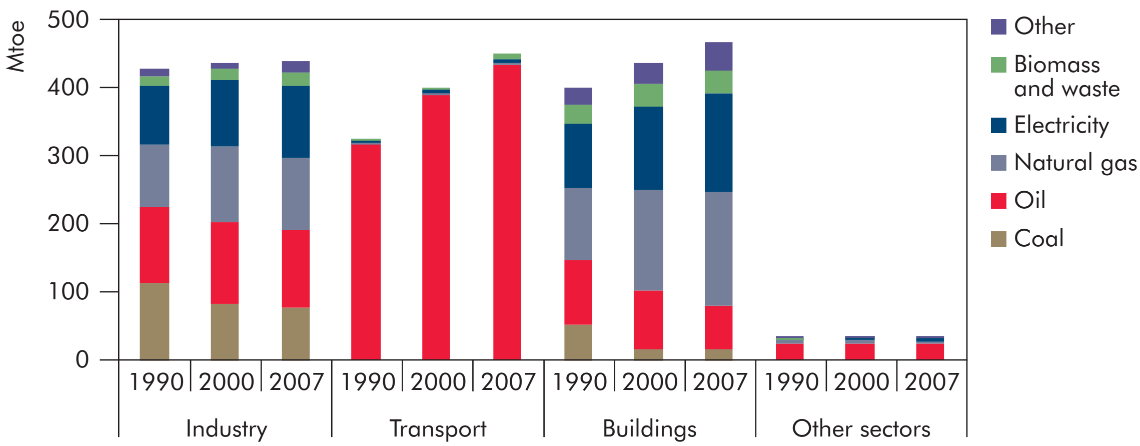
Final energy consumption in OECD Europe grew on average by less than 1% a year between 1990 and 2007, with wide differences in the levels of growth in different countries. Annual growth rates in final energy consumption in Ireland, Portugal, Spain and Greece were between 2% and 3%, but have slowed to 1% to 2% in recent years. The former Eastern Bloc countries of the Czech Republic, the Slovak Republic, Hungary and Poland experienced a decline in final energy demand by between 1% and 3% a year between 1990 and 2000, increasing modestly since then. From 1990 to 2007, Turkey has shown the highest rate of growth in final energy demand of between 3% and 4% a year, nearly doubling total demand from 40 million tonnes of oil equivalent (Mtoe) to 76 Mtoe.

The changes in the final energy mix between 1990 and 2007 in OECD Europe are characterised by a drop in coal consumption of 46% due to reduced demand in industry and the residential sector in the formerly centrally planned countries. In the same period, electricity demand and gas consumption grew by 38% each (Figure 8.3).

Overall, petroleum demand grew only slightly between 1990 and 2007 with an average annual growth of 0.8%, declining oil consumption in the buildings sectors being more than offset by growth of 1.8% a year for transportation. Nearly 70% of final petroleum consumption was used in the transport sector in 2007. Biomass and waste, mainly used in the residential and industry sectors, reached a share of 5% in total final energy consumption in 2007. Biofuels accounted for 8 Mtoe in 2007, only 2% of the transport sector's final energy consumption.

8

Figure 8.3 ▶ *Final energy consumption by fuel and by sector in OECD Europe*



Notes: Final transport consumption includes international aviation and marine bunkers; industry includes coke ovens, blast furnaces and petrochemical feedstocks; other sectors comprise agriculture, foresting and fishing.
Source: IEA (2009a).

Key point

Between 1990 and 2007 final consumption rose mainly for electricity and natural gas, but stagnated for other fuels. Growth in total final consumption is mainly caused by transport and to a lesser extent by the buildings sector.

End-use efficiency improvement

Final energy intensity in OECD Europe is currently 0.122 tonnes of oil equivalent (toe) per USD 1 000. Final energy intensity improved on average by 1.3% a year between 1990 and 2007, largely thanks to energy efficiency improvements in most countries (IEA, 2009f).

Analysis based on end-use data shows that the overall improvement in energy efficiency in the 12 European countries for which data are available was 0.6% per year between 1990 and 2006.[2] Without the energy savings resulting from these improvements, total final energy consumption would have been 11% higher in 2006.

Carbon dioxide emissions

Energy-related CO_2 emissions in OECD Europe were 4 374 million tonnes (Mt) in 2007. Emissions increased by 7% between 1990 and 2007 while primary energy supply increased by about 16% over the same period. This difference was due to fuel switching from coal to natural gas and an increase in the share of renewables.

Overall energy policy framework

European Union policy, which directly affects 19 of the 23 countries that constitute OECD Europe, plays a major part in determining the broad thrust of policy within the OECD European countries. Current EU energy policy focuses on "creating a competitive internal energy market offering quality service at low prices, developing renewable energy sources, reducing dependence on imported fuels, and doing more with a lower consumption of energy".[3] These priorities are reflected in the integrated energy and climate package adopted by the EU member states in 2008 (EC, 2008a). This package commits the European Union to achieve so-called "20/20/20 targets" of:

- reducing greenhouse-gas emissions by at least 20% compared to 1990 by 2020, or by 30% if a satisfactory international agreement is reached which commits other countries to higher than 20% cuts;
- meeting at least 20% of total EU gross final energy consumption, including electricity, heat and transport, from renewable sources by 2020;
- reducing total primary energy consumption by 20% by 2020 compared to a business-as-usual baseline.

2. The 12 countries are Austria, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom.
3. http://ec.europa.eu/energy.

Most EU energy policies are enacted through EU legislation in the form of EU directives. These directives are proposed by the European Commission (EC) following a period of stakeholder consultation, and then approved by the European Parliament and the European Council. In some areas in the energy field, EU member states have gone further than the requirements of EU directives or have adopted innovative national policies to achieve their contributions towards EU targets. Some of those OECD Europe countries that are outside the European Union have also implemented policies specifically designed to tackle climate change-related energy issues.

Current status of energy policies and climate change initiatives

Energy markets and security of supply

The process of liberalising the market for natural gas and electricity in the European Union started in the late 1990s with the first directives for electricity and gas (EU, 1996; EU, 1998). These directives required member states to allow large consumers to choose their supplier, to give third parties access to the grid, and to unbundle transmission system operations from vertically integrated utilities and gas companies. Different degrees of market opening among the member states and recognition that effective markets depended on non-discriminatory access to the electricity and gas networks led to a second set of directives for gas and electricity, which were adopted in 2003. These opened the market for small customers and required that transmission networks be operated independently of generation and supply (EU, 2003a; EU 2003b). A third package of directives was adopted in June 2009. This requires the full unbundling of transmission from generation and supply, strengthens the role of national regulators, foresees the creation of a new European agency with some regulatory power for cross-border trade and investment in interconnections, and requires the establishment of a European Network of Transmission System Operators to harmonise standards in pipeline and grid access and to co-ordinate investments in cross-border transmission capacities (EU, 2009a).

Security of supply

Traditionally the European Union has regarded a well-functioning internal market for energy as the best guarantee of security of supply. External aspects of energy policy have largely been left to member states. But electricity blackouts and disruptions in gas supply from Russia in recent years have led to greater focus on energy security at the EU level. The European Union's 2nd Strategic Energy Review proposed by the EC in November 2008 includes recommendations to strengthen infrastructure, to diversify energy supplies, more proactively to engage in external energy relations, to manage and report on oil and gas stocks, to improve energy efficiency and to make best use of the EU's indigenous energy resources (EC, 2008b). The EC's January 2009 proposal for a European Economic Recovery Plan includes approximately a EUR 4.85 billion component focused on investments in interconnections and infrastructures aimed at enhancing the EU's energy security (HSBC, 2010).

The European Union Emissions Trading Scheme (EU ETS)

The EU ETS is the European Union's main policy instrument for improving efficiency and reducing CO_2 emissions in the power and industry sectors. It is the world's largest greenhouse-gas emissions trading scheme. It covers around 12 000 installations and nearly 50% of all European Union CO_2 emissions. These installations include combustion plants, oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, brick, ceramics, pulp and paper. The EU ETS is currently in its second phase, which will limit emissions from these sectors to 2 080 Mt CO_2-equivalent for the period 2008-12, corresponding to a greenhouse-gas emissions reduction of 1.9% compared to 2005 levels. Currently, national allocation plans drawn up by member states create the basis for national emission caps. For the third phase of the EU ETS from 2013 to 2020, the European Union agreed on a system-wide cap in contrast to national ones in the first two phases. The gap corresponds to an emissions reduction of 21% by 2020 compared to 2005 levels for the sectors included in the ETS. The third phase will also introduce new sectors including aviation, will include provisions to increase the proportion of allowances that are auctioned and will take steps to support those EU industry sectors that are assessed to be most at threat from the potential movement of business to countries that are not subject to the ETS, an undesirable consequence of the application of a price to carbon emissions known as carbon leakage (EU, 2009b). Iceland, Liechtenstein and Norway joined the EU ETS in 2008. Switzerland has a national ETS and plans to link it to the EU system in due course (EC, 2009a).

Renewable energy

The Renewable Energy Directive of April 2009 sets out the EU's target to have renewable energies constitute 20% of gross final energy consumption by 2020 (EU, 2009c). This includes an obligation for at least 10% of transport fuel to be from renewable sources by 2020, provided that production is sustainable and that second-generation biofuels become commercially available. The directive sets mandatory national targets for member states that take account of their different starting points and potentials, including existing levels of energy from renewable sources and energy mixes. This has led to a wide range of targets, from 10% in Malta to 49% in Sweden.

Feed-in tariffs to support renewable energy are in place in many European countries, including Denmark, France, Germany, Spain and Switzerland. Under these policies, generators can sell renewable electricity at a fixed tariff, often significantly higher than market rates, for a specified time period under specific conditions depending on location and technology. The price remains constant for a defined period but may be reduced for new connections in subsequent years. National feed-in tariffs are often combined with priority grid access. The tariff costs are usually passed on to electricity consumers.

Italy, Belgium, the Netherlands and the United Kingdom have adopted forms of green certificate trading in which electricity generators are required to ensure that a certain quantity of electricity is based on renewables. Generators can buy renewable generation from other suppliers if they have a shortfall against their obligation, or sell it if they produce more than they are obliged to produce. Setting the obligation at a level higher than the expected total level of renewables creates a market advantage for renewable generation. The United Kingdom and Italy have recently revised their schemes to differentiate between different renewable technologies. Less mature technologies such as wave power and offshore wind now receive more support than established technologies such as onshore wind and biogas. Both countries are also introducing feed-in tariffs for smaller installations.

Carbon capture and storage

An EU directive on the geological storage of CO_2 entered into force on 25 June 2009 (EU, 2009d). The CCS Directive sets out a comprehensive regime to regulate exploration and storage, and applies to all projects which intend to store more than 100 kilotonnes (kt) of CO_2. It covers aspects such as the criteria for selection of storage sites, procedures for exploration and storage permits, operation, closure and post-closure obligations, and national reporting requirements. EU member states have until June 2011 to transpose the CCS irective into their respective national laws.

Allowances have been set aside within the EU ETS to support up to twelve CCS demonstration projects and a range of innovative renewable projects. At a carbon price of USD 30/tCO_2, these allowances would be worth up to some USD 8.8 billion. Further funding has since been pledged from the EU's Economic Recovery Plan for six CCS demonstration projects in Germany, Spain, the Netherlands, the United Kingdom, Poland and Italy. The European Union is also working with China on CCS, through the Near Zero Emissions Coal (NZEC) initiative (EC, 2009b).

Outside the European Union, Norway is developing a CCS policy framework and a series of projects focused on CCS from gas-fired power plant, drawing on its extensive experience of geological storage. Over one million tonnes of CO_2 a year have been separated from gas production in the Sleipner field and stored under the North Sea since 1996 (Ministry of Petroleum and Energy of Norway, 2010).

Energy efficiency

The European Union has initiated a range of policies and measures to improve energy efficiency in the industry, services and residential sectors. An overarching Directive on Energy End-Use Efficiency and Energy Services (ESD; EU, 2006b) covers all sectors except those included in the EU ETS. The ESD requires member states to put in place National Energy Efficiency Action Plans which set out policies that will contribute to the achievement of an energy saving of at least 9% from energy efficiency measures between 2008 and 2016.

Other EU directives associated with energy efficiency include the Ecodesign of Energy Using Products (EUP) Directive (EU, 2009e), the CHP Directive (EU, 2004) and the Energy Performance of Buildings Directive (EPBD; EU, 2002). Many of these directives are currently being revised and strengthened in light of the targets in the energy and climate package. For example, proposed revisions to the EPBD would expand the scope of the existing directive to more buildings, require new houses being built after 2020 to be nearly zero-carbon buildings and make the installation of smart meters mandatory in new or renovated buildings.

The EUP Directive establishes a framework for setting eco-design requirements, including energy efficiency requirements, for all energy-using products in the residential, services and industrial sectors. It will be followed by implementing measures which will establish specific eco-design requirements for products such as household appliances, electric motors, air-conditioning units and refrigeration systems.

A number of countries in Europe have agreements with industry sectors or organisations to improve energy efficiency and reduce CO_2 emissions. Most of these agreements are voluntary, although they often include incentives for participation such as tax reductions. A scheme of negotiated voluntary agreements in the Netherlands has been running since 1999 and currently involves about 900 companies (Janssen, 2009). These agreements are supplemented by sector roadmaps to encourage innovation and are expected to lead to a 30% energy efficiency improvement between 2005 and 2020. Turkey has recently set up similar voluntary agreements with industrial organisations that pledge to reduce their energy intensity by 10% on average over a three-year period in return for financial support equivalent to up to 20% of their energy costs in the first year (IEA, 2010).

In the residential sector, the United Kingdom, France and Italy have established innovative white certificate schemes that encourage energy suppliers to install insulation and more energy-efficient appliances including boilers in the homes of their customers. Latvia, Finland and Denmark have had long-standing and successful schemes to promote CHP in the residential and commercial sectors.

Energy use in transport

In December 2009, the European Union adopted a new regulation which sets emissions performance standards for new passenger cars. These require that by 2015 all car manufacturers achieve a maximum fleet average level of emissions of 130 grammes (g) of CO_2/kilometre (km) for all their cars that are registered in the European Union, with a phased introduction from 2012 (EC, 2009c). A so-called limit-value curve has also been set which allows heavier cars to have higher emissions than lighter cars while preserving the overall fleet average. A longer-term target of 95 gCO_2/km by 2020 has been set. This regulatory approach replaces previous voluntary agreements with the European, Japanese and Korean automotive trade associations. A similar regulation is currently being prepared on CO_2 emissions from vans.

Other relevant EU transport policies include a requirement for the fuel economy labelling of all new cars, although the impact of this is reduced by the lack of any standardised labelling scale across European countries. The provision of data on

CO_2 emissions is also mandatory on new passenger cars. The requirement that 10% of transport fuel must be renewable by 2020 and the introduction of high-speed rail networks and the proposed inclusion of aviation within the EU ETS by 2012 will also all contribute to reductions in greenhouse-gas emissions.

Individual OECD European countries also have a wide range of national policies in place to reduce CO_2 emissions. These include regulations on the adoption of alternative fuels, incentives for motorists to purchase more fuel-efficient vehicles, measures to increase vehicle occupancy through car sharing and policies to encourage modal shifts to public or non-motorised transport. Alternative fuels policies are generally tailored to local circumstances and fuels. For example, Germany has a major programme to support the use of biodiesel, Sweden's policies promote the use of bioethanol, and Iceland is seeking to promote the use of hydrogen. Many countries have introduced incentives to purchase more efficient cars through differential purchase taxes or graduated annual registration taxes. For example, United Kingdom motorists currently pay an annual car tax ranging from about USD 20 for the lowest emitting to USD 220 for the highest emitting cars. Cars that emit less than 100 gCO_2/km pay no annual road tax (Directgov, 2010).

Energy research and development

The multi-annual Framework Programmes for Research and Technology Development (FP) are the main instrument for the implementation of European energy research policy, and for the provision of EU R&D funding. The Seventh FP, which runs from 2007 to 2013, allocates 7% of its overall budget to energy-related R&D. To amplify this, the Commission has recently implemented a Strategic Energy Technology Plan that aims to accelerate the development and implementation of low-carbon technologies in the priority areas of wind, solar, bioenergy, CCS, the European electricity grid and sustainable nuclear fission (EC, 2009d).

Overview of scenarios and CO_2 abatement options

A number of significant energy indicators for OECD Europe in the Baseline and BLUE Map scenarios are set out in Table 8.2. Population and GDP growth assumptions are the same in both scenarios.

In the Baseline scenario, TPES grows only slightly between 2007 and 2050 at an annual rate of 0.1%. Historic rates of decoupling between GDP and energy use are assumed to continue, with the result that 35% less energy is needed per unit of GDP in 2050 than in 2007. In the BLUE Map scenario, per-capita CO_2 emissions are reduced from 8.0 t in 2007 to 1.9 t in 2050, 72% lower than in the Baseline scenario. Total primary energy supply in 2050 is 20% lower than in the Baseline scenario, with the result that primary energy consumption per unit of GDP in the BLUE Map scenario is almost halved in 2050 relative to 2007.

Table 8.2 ▶ **High-level indicators for OECD Europe**

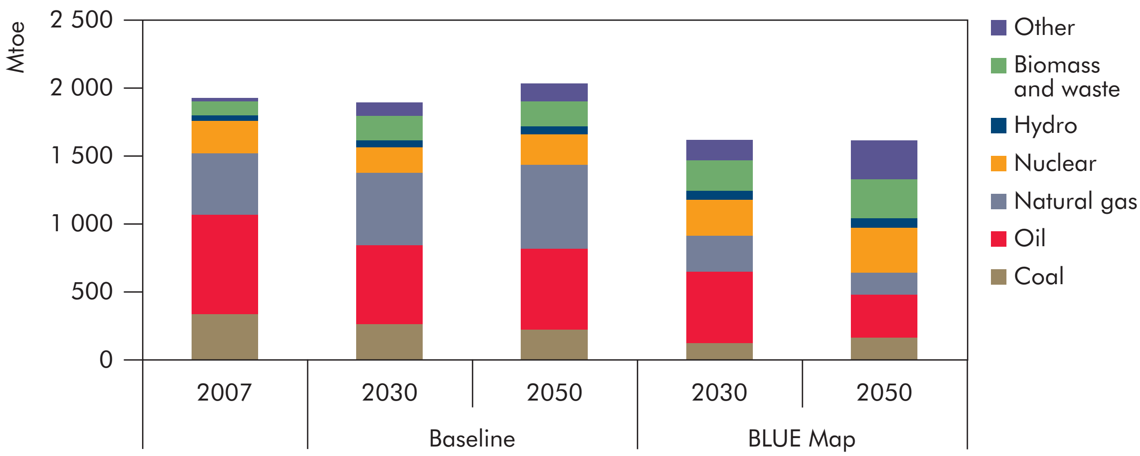
			Baseline		BLUE Map	
	2000	2007	2030	2050	2030	2050
TPES (Mtoe)	1 818	1 926	1 924	2 031	1 619	1 615
Electricity consumption (TWh)	3 000	3 387	4 200	5 168	3 612	4 306
CO_2 emissions (Gt)	4.22	4.37	4.14	4.01	2.24	1.11
GDP (billion USD using exch. rates)	9 066	10 532	14 904	17 136	14 904	17 136
GDP (billion USD using PPP)	11 258	13 223	18 712	21 513	18 712	21 513
Population (millions)	522	543	575	575	575	575
TPES/GDP (toe per thousand USD 2 000 PPP)	0.161	0.146	0.103	0.094	0.087	0.075
TPES/population (toe per capita)	3.48	3.55	3.35	3.53	2.82	2.81
Electricity consumption /population (kWh per capita)	5 753	6 239	7 304	8 988	6 282	7 489

Note: International aviation and shipping are included in TPES and CO_2 emissions; GDP is expressed in 2000 USD.
Sources: IEA (2009a); IEA analysis.

Energy and CO_2 emission scenarios

In the Baseline scenario for OECD Europe, fossil fuels account for 75% of TPES in 2050, lower than the 79% they accounted for in 2007 (Figure 8.4). Oil consumption decreases by 19%. Natural gas use increases by 38%, mainly driven by power generation. The share of renewables more than doubles, from 9% in 2007 to 18% in 2050, with increased wind and solar generation.

Figure 8.4 ▶ **Total primary energy supply by fuel for OECD Europe, Baseline and BLUE Map scenarios**



Note: International aviation and shipping are included in TPES.
Sources: IEA (2009a); IEA analysis.

Key point

The share of fossil fuels in TPES is halved in BLUE Map in 2050 compared to 2007, while the share of renewable energy grows more than fourfold.

In the BLUE Map scenario, TPES in 2050 is 16% lower than in 2007 and 20% lower than in the Baseline scenario in 2050. Fossil fuels account for 40% of TPES in the BLUE Map scenario in 2050, while renewables and nuclear cover 40% and 21%, respectively.

OECD Europe emissions reductions by sector in the BLUE Map scenario are shown in Table 8.3. Absolute CO_2 emissions of OECD Europe fall in this scenario from 4 374 Mt CO_2 in 2007 to 1 122 Mt CO_2 in 2050, *i.e.* by 3 252 Mt CO_2 or 74%. To achieve a 50% reduction in global emissions by 2050, the BLUE Map scenario projects that OECD Europe has to cut its emissions by almost three-quarters. To realise this ambitious reduction, electricity generation is nearly decarbonised by cutting its CO_2 emissions by 95%. Other sectors show a reduction of between 66% for buildings and 42% for transformation other than power generation compared to 2007. Transport becomes the largest emitting sector in 2050, accounting for 46% of CO_2 emissions, despite achieving the second-largest absolute reductions. After 2050, it is likely that the transport sector will need to make the largest contribution to any further efforts to reduce CO_2 emissions.

Table 8.3 ▶ ***OECD Europe's absolute and relative CO_2 emissions reductions by sector in the BLUE Map scenario***

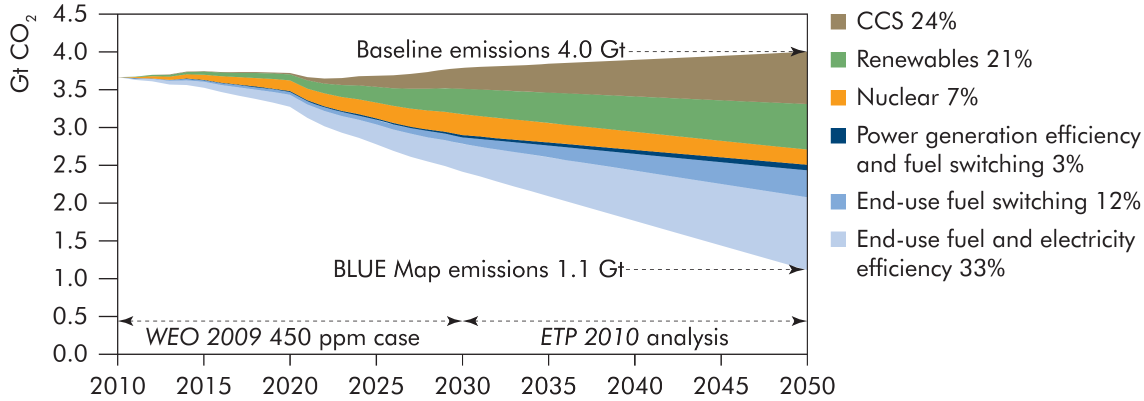
	Absolute reductions in the BLUE Map scenario 2050 (Mt CO_2) relative to		Relative reductions in the BLUE Map scenario 2050 (%) relative to	
Reference	**2007**	**Baseline 2050**	**2007**	**Baseline 2050**
Power sector	1 409	1 160	–95%	–94%
Other transformation	31	225	–35%	–80%
Industry	545	277	–70%	–54%
Transport	798	694	–61%	–57%
Buildings	469	533	–66%	–68%
Total	**3 252**	**2 889**	**–74%**	**–72%**

Notes: Industry includes blast furnaces, coke ovens and emissions from non-energy use of feedstocks; industrial process emissions are excluded.

Carbon dioxide abatement options

OECD Europe's CO_2 emissions to 2050 in the Baseline and BLUE Map scenarios are shown in Figure 8.5. CO_2 emissions reduce by 2.9 Gt or 72% in 2050 in the BLUE Map scenario as compared with the Baseline scenario. Measures in the end-use sectors contribute 66% of the CO_2 savings. On the end-use side, efficiency improvements deliver 33% of the overall CO_2 savings followed by fuel switching to electricity and natural gas (12%), CCS in industry and fuel transformation (12%) and the increased use of biofuels (9%). The power sector contributes 34% of the overall emissions reduction between the Baseline and BLUE Map scenarios in 2050, with around 12% each from renewables and CCS and a further 7% from nuclear.

Figure 8.5 ▶ Contributions to emissions reductions in OECD Europe



Note: Unlike otherwise indicated, all material derives from IEA data and analysis.

Key point

End-use sector measures contribute nearly two-thirds of the emissions reductions between the Baseline and BLUE scenarios in 2050.

Sectoral results

Power sector

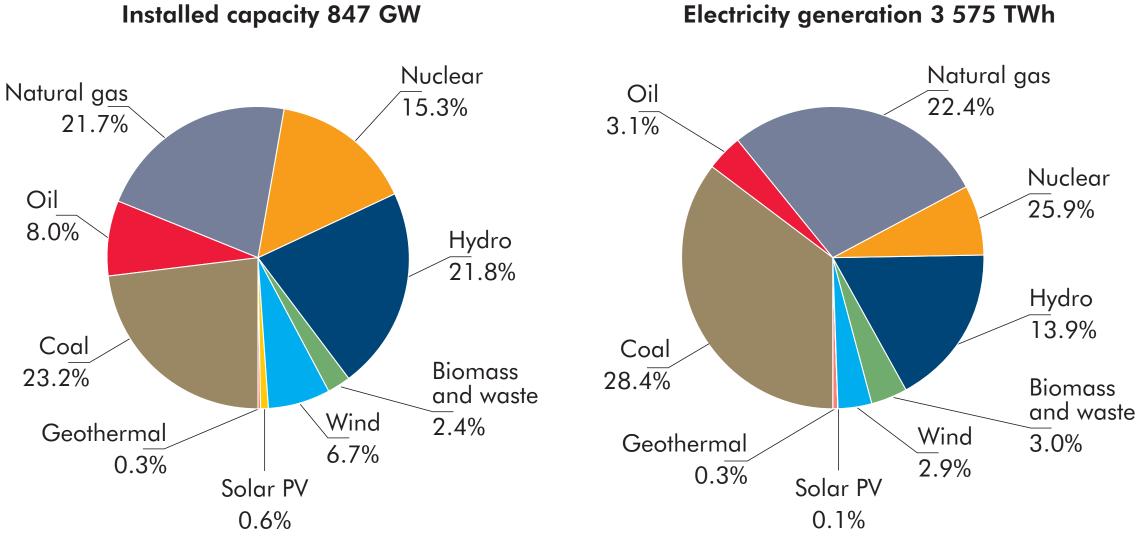
Europe's electricity system today

In 2007, OECD Europe had a total installed generating capacity of 847 gigawatts (GW), of which 196 GW were based on coal, 185 GW on hydro (including 40 GW of pumped storage), 184 GW on gas, 130 GW on nuclear, 68 GW on oil, 57 GW on wind, 20 GW on biomass and 7 GW on other renewable sources (Figure 8.6). Utilities owned 93% of the total capacity, with the remainder being owned by industrial producers. Germany, France, Italy, Spain and the United Kingdom have the largest installed capacities, together accounting for 62% of the capacity in OECD Europe in 2007. The capacity of CHP stood at 89 GW in 2007 (Eurostat, 2009; Eurelectric, 2009). This was 11% of the total installed capacity in OECD Europe in that year.

OECD Europe generated 3 575 terawatt-hours (TWh) of electricity in 2007. Of this, 54% was based on fossil fuels, 26% on nuclear and 20% on renewables.

Generation from coal and oil declined between 1990 and 2007 while generation from hydro and nuclear grew modestly by 12% and 18%, respectively. Gas-fired power generation grew almost fivefold between 1990 and 2007, accounting for 800 TWh in 2007. The growth in gas-fired generation was driven by the favourable economics of new highly efficient natural gas combined-cycle (NGCC) power plants which have lower emissions than coal and oil plants and higher operational flexibilities.

Figure 8.6 ▶ Electricity generating capacity and generation for OECD Europe, 2007



Sources: Platts (2010); IEA (2009a).

Key point

More than half of all power generation in 2007 was based on fossil fuels, with the remainder split between nuclear and renewable energies.

8

Developments in renewable power generation

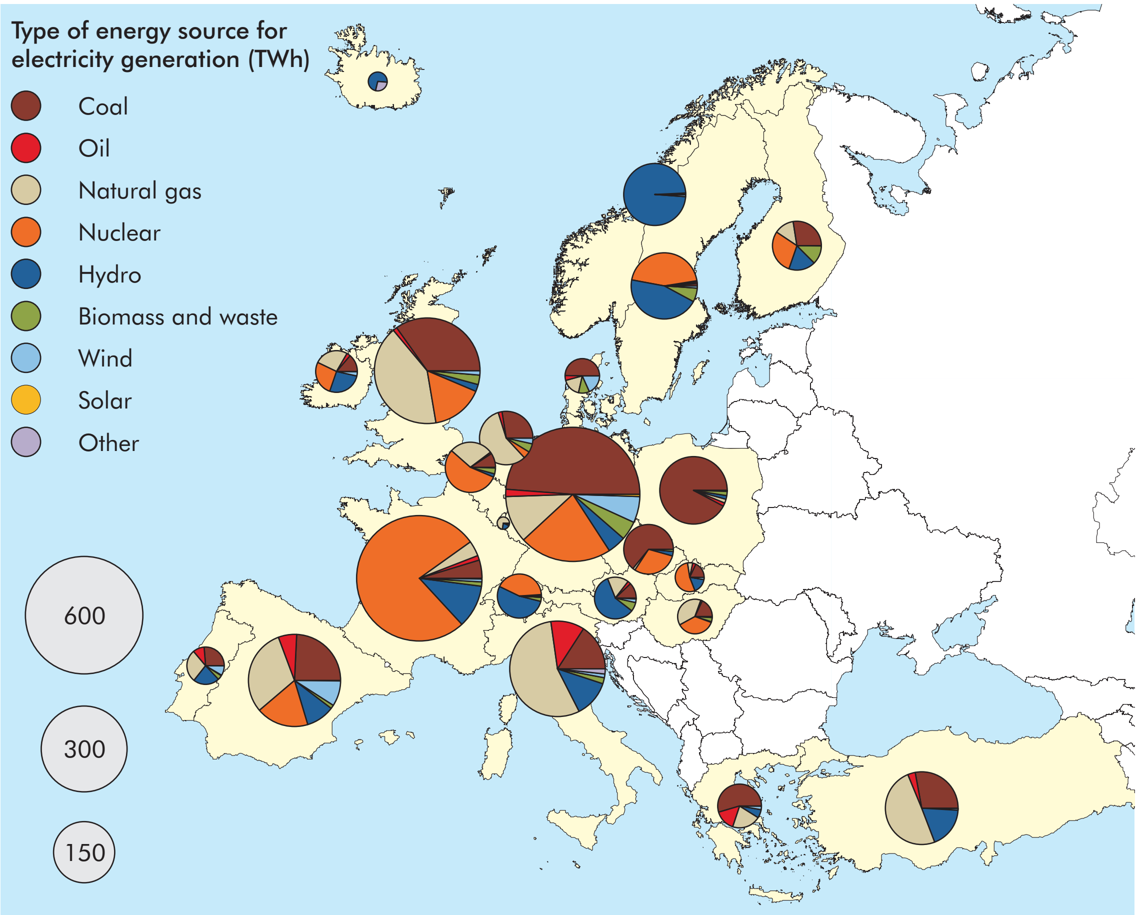
Renewable electricity generation has grown rapidly over the last 20 years as a result of government support in many OECD European countries. In 1990, renewables excluding hydro generated 20 TWh. This grew by a factor of 10, to 209 TWh in 2007, mainly owing to support policies such as renewable feed-in tariffs or green certificate schemes in many European countries. Most of the growth is from wind (+104 TWh) and biomass (+75 TWh). Germany and Spain are responsible for much of the wind deployment, while the uptake of biomass focused on Germany, Finland, Sweden and the United Kingdom. Including hydro, which grew by only 12% between 1990 and 2007, renewable power generation comprised 707 TWh, one-fifth of total generation, in 2007.

The share of renewable power generation varies among OECD member states. Abundant hydro and geothermal resources allow Norway and Iceland to cover nearly their entire electricity generation from renewable sources. Low renewable shares of 4% to 5% are found in many of the new EU member states such as Poland, Hungary and the Czech Republic, but also in the United Kingdom with a share of just 6%.

Regional electricity supply in 2007

The generation mix varies widely between countries in OECD Europe (Figure 8.7). Germany and Poland rely predominantly on coal-fired generation which accounts for 49% and 96% of their total generation respectively. Italy (55%) and the Netherlands (57%) rely to a high degree on natural gas. France generates a high proportion of its electricity from nuclear power stations. Norway, Iceland and Switzerland also have very high percentages of non-fossil power, mostly from hydro.

Figure 8.7 ▶ Electricity generation mix, OECD Europe, 2007



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Key point

Fuel mix in the power sector varies widely between countries in OECD Europe.

Electricity transmission and distribution

The trading of electricity between countries in Europe has increased steadily, from 171 TWh in 1990 to 309 TWh in 2007. Investment in transmission capacities has not kept pace with this growth. As a result, cross-border capacities at a number of places within the European electricity system have become increasingly congested.

Price differences between countries are helping to drive increased trading. This has led to congestion from Northern and Central Europe to Germany and, to a lesser extent, for electricity imports to Italy. The interconnection between the United Kingdom and France is always at its capacity limit.

The integration of larger amounts of wind energy in Northern Europe and Germany has also required a reinforcement of the North-South grid. Other interconnection capacity shortfalls are a result of geographical constraints, for example across the Pyrenees and the Alps.

The EC has developed a set of energy priority projects within its Trans-European Networks programme to address bottlenecks in the European gas and electricity transmission infrastructure. These projects seek to increase competition in the internal energy markets, to strengthen security of supply, and to support the increased use of renewables. In 2002, the EC set a goal to increase the interconnection capacity between member states to a minimum of 10% of their electricity demand. In 2006, in a new regulation for guidelines to list and rank electricity and gas infrastructure projects, nine priority axes for electricity have been identified (EU, 2006a). Within the European Energy Programme for Recovery the EC has granted EUR 910 million to 12 electricity interconnection projects (EC, 2010).

Electricity demand projections

Total final electricity demand in OECD Europe increases by 19% between 2007 and 2050 in the BLUE Map scenario (Table 8.4). At the same time, overall final energy demand decreases owing to reduced demand for fossil fuels by 13%, so that the share of electricity in final energy consumption grows from 19% in 2007 to 27% in 2050. The main drivers for the growth in electricity demand are the buildings and transport sectors, in which the increased use of electricity, for example by heat pumps or electric vehicles (EVs), is essential to the overall BLUE Map reduction in CO_2 emissions.

Table 8.4 ▶ Current and projected final electricity demand for OECD Europe by end-use sector

(TWh/yr)		Baseline		BLUE Map	
	2007	2030	2050	2030	2050
Industry	1 250	1 414	1 575	1 112	1 252
Transport	76	109	113	126	360
Residential	853	1 084	1 326	835	1 017
Commercial	756	1 142	1 668	1 052	924
Other	127	107	137	77	83
Total	**3 062**	**3 856**	**4 819**	**3 202**	**3 636**

Sources: IEA (2009a); IEA analysis.

Power capacity and generation projections

In the Baseline scenario, power capacity in OECD Europe grows by 77% between 2007 and 2050 to 1 495 GW. The share of fossil fuels in power generation declines between 2007 and 2050 from 54% to 44% (Table 8.5). Compared to other countries and regions, where the share of fossil fuels increases in the Baseline scenario, in OECD Europe the continuation of the EU ETS beyond 2012 is assumed to continue to constrain fossil fuel use. The Baseline scenario assumes that carbon prices in the ETS sectors increase from USD 43/tCO_2 in 2020 to USD 83/tCO_2 in 2050.[4] Nuclear power's generation share falls in the Baseline scenario from 26% in 2007 to 17% in 2050 as a result of policies in several European countries to phase out nuclear power and of the retirement of old reactors. Renewables constitute 40% of electricity generation in 2050 compared to 20% in 2007.

In the BLUE Map scenario, the power sector is nearly decarbonised in OECD Europe, emitting 15 gCO_2/kWh in 2050. The power generation mix changes significantly compared to the Baseline scenario. Power plants with carbon capture from coal, gas or biomass comprise 19% of the power generating capacity in 2050. Generation from fossil fuel plants without CCS is nearly completely abandoned by 2050. Coal capacity of 25 GW is scrapped before the end of its technical lifetime. The remaining 211 GW of gas capacity without CCS runs partly as reserve capacity and partly to support 50 GW of pumped storage, to balance the fluctuating generation from wind and photovoltaics (PV). Renewables further increase their share in power generation compared to the Baseline scenario, reaching 55% in 2050. Combined heat and power generation increases from 10% in 2007 to nearly 20% by 2050, mainly with biomass-fired CHP plants. Increases in nuclear power in the BLUE Map scenario result in nuclear generating 29% of electricity in 2050.

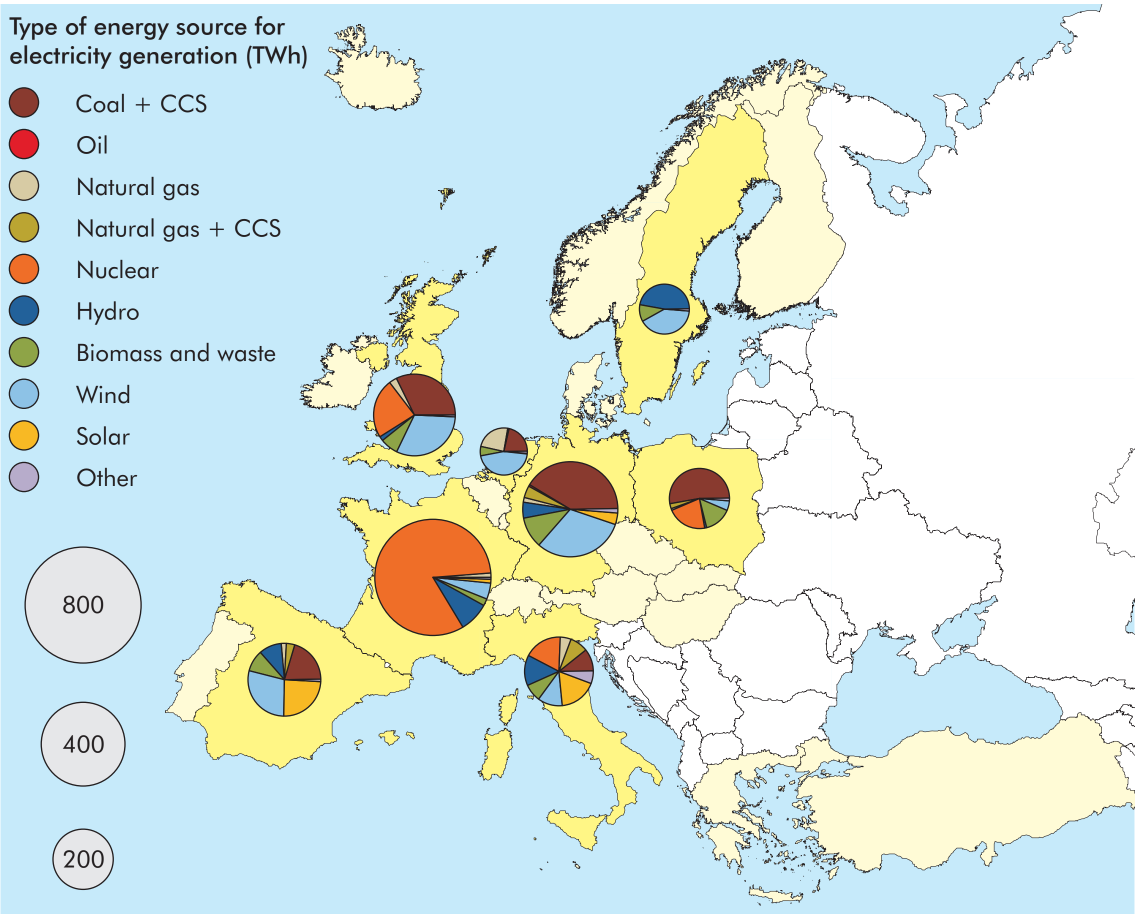
Table 8.5 ▶ *OECD Europe's power generation mix and capacity, Baseline and BLUE Map scenarios, 2050*

	Power generation share		Capacity	
	Baseline (%)	**BLUE Map** (%)	**Baseline** (GW)	**BLUE Map** (GW)
Coal	13.3	0.0	115	0
Coal + CCS	0.0	11.0	0	97
Gas	30.4	1.5	556	211
Gas + CCS	0.0	3.0	0	23
Biomass	5.6	7.1	36	56
Biomass + CCS	0.0	0.4	0	3
Oil	0.1	0.0	1	2
Nuclear	16.7	29.3	117	162
Hydro	13.9	17.1	257	268
Tidal	0.2	0.7	5	12
Geothermal	0.5	1.7	4	10
Solar PV	2.5	3.9	93	125
Solar CSP	1.2	2.2	20	22
Wind onshore	11.8	14.2	236	259
Wind offshore	3.9	7.9	55	99
Hydrogen	0.0	0.0	0	0
Total	**100.0**	**100.0**	**1 495**	**1 350**

4. This assumption is consistent with the *World Energy Outlook 2009* (IEA, 2009e). There, a carbon price of USD 43/tCO_2 is reached for the EU ETS sectors (industry and power generation) in 2020, increasing by 2.2% until 2030. In the *ETP* baseline scenario, this trend is assumed to continue resulting in a price of USD 83/tCO_2 by 2050.

The power generation fuel mix of the largest electricity producing countries in OECD Europe in 2050 varies widely in the BLUE Map scenario (Figure 8.8). Unlike in 2007, power generation is dominated in all countries by low-carbon technologies. France relies on nuclear power and increases its nuclear share from 77% in 2007 to 83% in 2050 in the BLUE Map scenario.

Figure 8.8 ▶ Power generation mix in major European electricity producing countries in BLUE Map scenario, 2050



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Key point

Technology choices to decarbonise the power sector in BLUE Map differ largely between countries in OECD Europe depending on national conditions.

Countries such as Italy and Spain generate 60% and 73% of their total electricity needs from renewable sources, primarily through the increased utilisation of solar, biomass and wind. Wind power generation, especially offshore wind, is also expanded in countries in Northern Europe, such as the United Kingdom and Germany. The countries bordering the North Sea also have access to offshore CO_2 storage sites at comparably low costs. This makes power generation at coal plants equipped with carbon capture a further important option for cutting emissions in the power sector in the BLUE Map scenario.

Decarbonising the power sector

In OECD Europe, electricity demand only grows moderately in the BLUE Map scenario between 2007 and 2050 at an average annual rate of 0.6%. As a result, unlike many non-OECD countries, total installed capacity in OECD Europe increases at moderate rates in this timeframe (1.1% per year in BLUE Map). But OECD Europe will need to reduce its CO_2 emissions by nearly 75% if it is to play its full part in achieving the overall 50% reduction in emissions needed by 2050.

A large proportion of the existing capacity is expected to reach the end of its lifetime over the next 20 years. Decisions on the replacement of this capacity, given the long life of a power plant, will have a major impact on Europe's ability to decarbonise the power sector and the speed at which it can do so. Renewables, CCS and nuclear offer the principal options for reducing CO_2 emissions in the power sector. Different European countries are likely to adopt each in different measures. In the BLUE Map scenario, nuclear contributes 20% of the reductions needed to decarbonise power generation from an additional capacity of 55 GW in 2050. CCS enables 36% of the total reduction achieved in power generation, saving a further 347 Mt CO_2 in 2050. Fuel switching from coal to gas and efficiency improvements in fossil power generation are responsible for 8% of the reductions in the power sector. The balance comes from the wider deployment of renewable energy sources, particularly biomass, wind and solar energy, which deliver 36% of the reduction needed in the power sector.

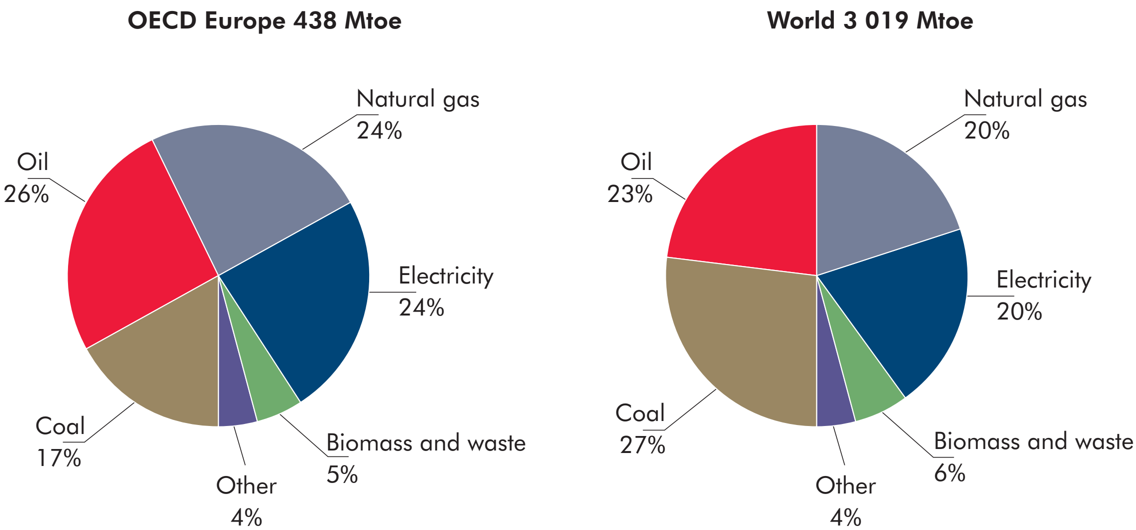
The import of low-carbon electricity from outside Europe is also an option. Plans to import electricity produced from solar thermal plants in Northern Africa are being pursued within the DESERTEC project (DESERTEC, 2009). In the BLUE Map high renewable scenario described in Chapter 3, these imports of solar electricity meet around 550 TWh of OECD Europe's electricity needs in 2050.

Industry sector

In OECD Europe, industry used 438 Mtoe in 2007. This accounted for a third of total energy used. Europe's industries account for 15% of global industrial energy use. The final energy mix of industry is dominated by oil and natural gas (Figure 8.9). Industry accounts for 41% of all electricity consumption in OECD Europe.

The chemicals and iron and steel sectors in OECD Europe account for almost half of all industrial energy use and CO_2 emissions (Table 8.6). Measures taken to improve energy use and reduce emissions in these two sectors will have an important impact on the overall energy use and emissions of European industry.

Figure 8.9 ▶ **Industrial final energy mix in OECD Europe and the world, 2007**



Note: Includes coke ovens, blast furnaces and petrochemical feedstocks.
Sources: IEA (2009a and 2009b).

Key point

Oil and gas represent half of all energy use by industry in OECD Europe.

8

Table 8.6 ▶ **Industrial production, energy use and CO_2 emissions in OECD Europe, 2007**

	Production (Mt)	Reported energy use (Mtoe)	CO_2 emissions (Mt CO_2)
Industry sector		438	932
Iron and steel	228	71	258
Chemicals and petrochemicals	84	137	187
Aluminium	14	11	12
Cement	307	24	200
Pulp, paper and printing		40	34
Paper and paperboard	105		
Pulp	43		
Recovered paper	58		
Other		155	241

Note: Iron and steel includes energy use for coke-making and the energy data for chemicals and petrochemicals include feedstocks. The table has been compiled from a mixture of top-down and bottom-up sources and so the totals may not match.
Sources: IEA (2009a and 2009c); IEA analysis.

Energy and CO_2 savings potential with best available technologies

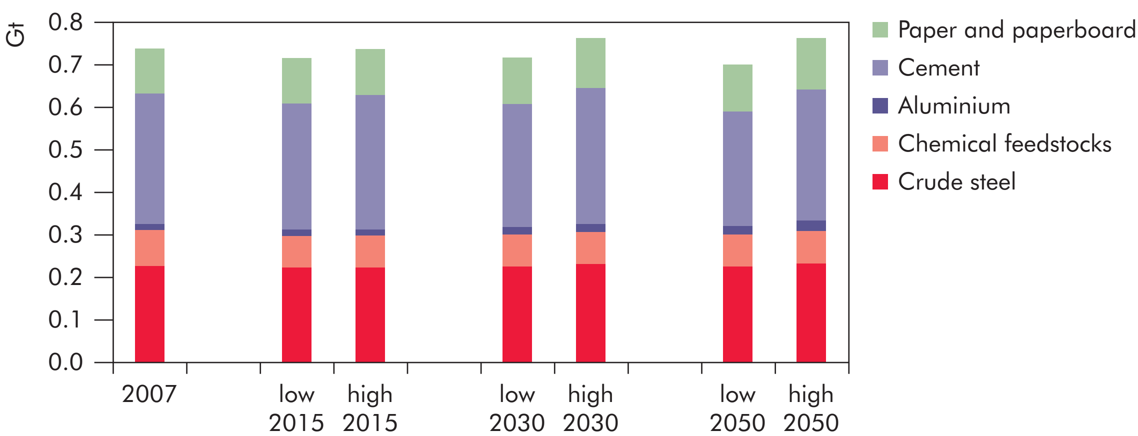
Significant energy and CO_2 savings in European industry are possible through the implementation of currently available best available technologies (BATs). It is estimated that the application of BATs could reduce final energy use by between 9% and 28% in the five most energy-intensive sectors. Total estimated savings for the five sectors is 45 Mtoe per year, equivalent to 10% of energy use in industry and 3% of total energy consumption in OECD Europe in 2007.

OECD Europe has on average one of the most energy-efficient industry sectors. The energy savings potential from the implementation of BATs is, therefore, below global levels at around 10% to 20%. Some of this will be realised as old capacity is scrapped and replaced by BATs.

Scenarios for industrial energy use and CO_2 emissions

Two variants of the Baseline and BLUE scenarios are considered for the industry sector: a low-demand variant assuming a modest decline in material production in OECD Europe, and a high-demand variant stipulating a moderate demand growth in materials (Figure 8.10). Industrial energy use in OECD Europe in 2050 in the Baseline scenarios is lower than 2007 levels, thanks to increased energy efficiency measures and some reduction in cement and crude steel industrial production. Higher levels of energy efficiency in the BLUE scenarios lead to significant reductions in industrial energy use in 2050, 32% lower than in 2007 and about 25% lower than in the Baseline scenarios in 2050 for both the low- and high-demand cases. The largest reductions are achieved in the iron and steel sector (66%) as well as in the chemical industry (41% to 53%).

Figure 8.10 ▶ Materials production in OECD Europe in the low-demand and high-demand scenarios



Note: Production of materials is the same for both the Baseline and BLUE scenarios.
Source: IEA data and estimates.

Key point

The production of materials in OECD Europe declines or grows only moderately between 2007 and 2050.

In the Baseline scenarios, industry emissions in OECD Europe decline by about 30% between 2007 and 2050. In the BLUE low- and high-demand scenarios, direct industrial CO_2 emissions fall by 66% and 71% compared to 2007 levels (Table 8.7).

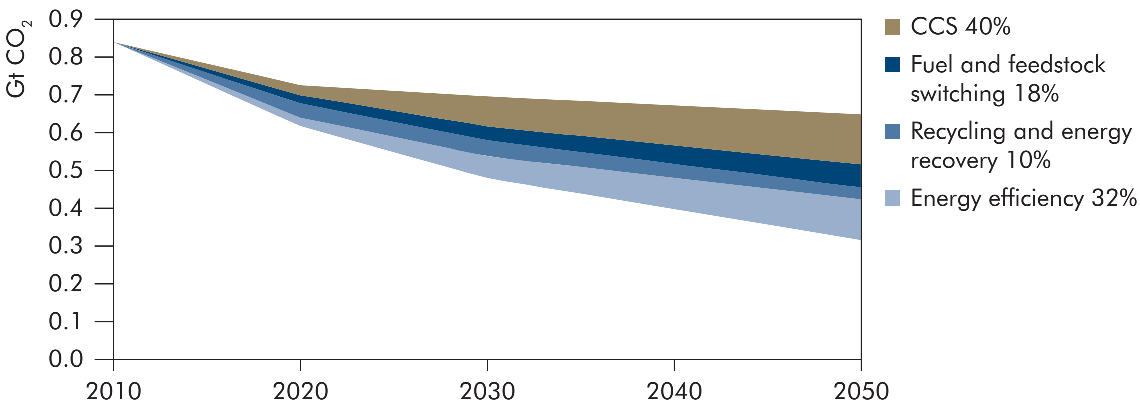
Table 8.7 ▶ **Direct energy and process CO_2 emissions by industry sector in OECD Europe**

Mt CO_2	2007	Baseline low 2050	Baseline high 2050	BLUE low 2050	BLUE high 2050
Aluminium	12	21	27	19	20
Iron and steel	258	157	152	53	51
Chemicals	187	177	176	83	68
Cement	200	167	190	108	77
Pulp and paper	34	30	33	9	4
Other	241	95	95	44	46
Total	**932**	**648**	**673**	**316**	**267**

Note: Emissions from blast furnaces, coke ovens and feedstock are included.
Sources: IEA (2009a and 2009c); IEA analysis.

Carbon capture and storage offers the largest potential to reduce industrial CO_2 emissions in OECD Europe, representing 40% of all industry emissions reductions in the BLUE scenarios (Figure 8.11). Energy efficiency represents another third and the remaining 28% is attributed to fuel and feedstock switching and higher recycling and energy recovery.

Figure 8.11 ▶ **Options for reducing direct CO_2 emissions from European industry**



Source: IEA (2009c).

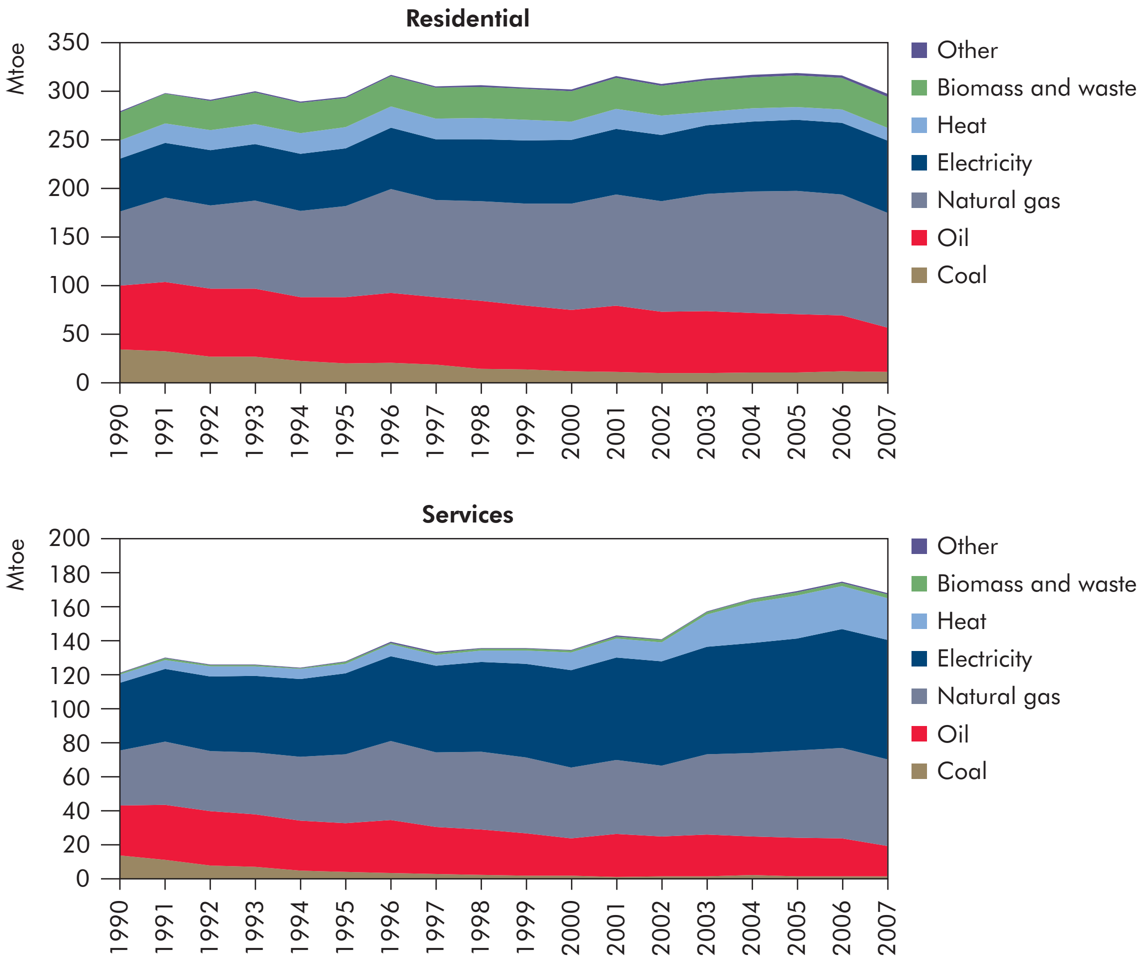
Key point

Energy efficiency and CCS offer the best important opportunities to decrease OECD Europe's industrial CO_2 emissions.

Buildings sector

The buildings sector (including the residential, commercial and public service sectors) accounts for about 26% of TPES in OECD Europe. Although energy consumption by the sector has grown by 11% since 1990, the consumption of coal and oil has declined by 7.3% and 1.9% a year respectively. Energy consumption in the commercial and public service sectors grew by 1.3% a year between 1990 and 2007, and by 0.4% in the residential sector (Figure 8.12).

Figure 8.12 ▶ *Residential and service sectors' energy consumption by fuel in OECD Europe*



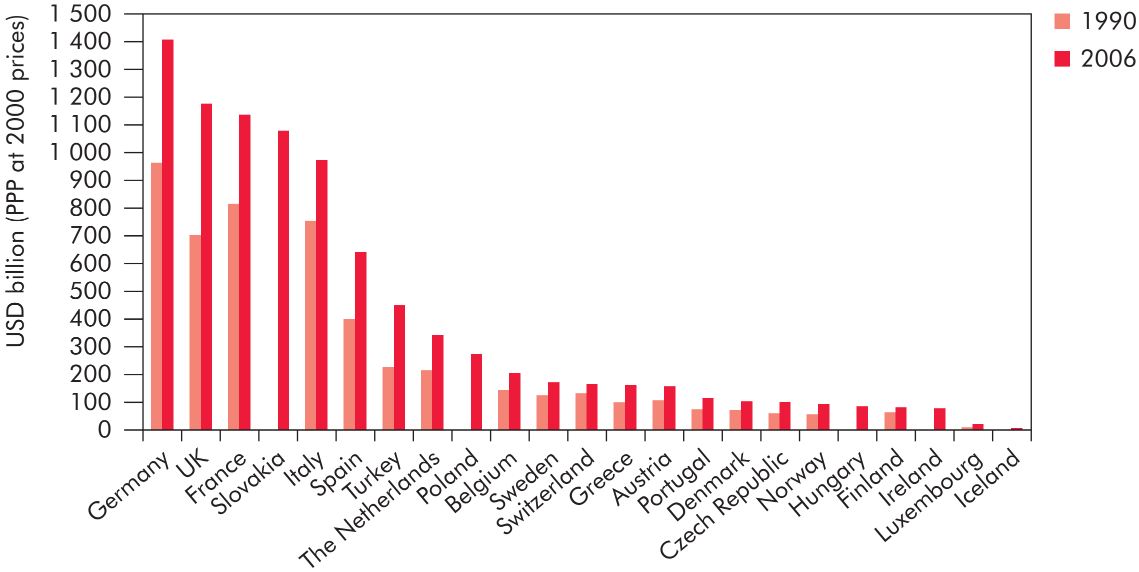
Sources: IEA (2009a).

Key point

Energy demand in the service sector has grown faster than in the residential sector since 1990.

Part of the reason for stronger growth in the commercial and service sectors has been the faster growth in service sector activity compared to the growth in the number of households. Between 1990 and 2006, value added in the service sector grew by an estimated 2.8% a year (Figure 8.13) while household numbers grew by an estimated 1.2% per year in the same period.[5]

Figure 8.13 ▶ Commercial and services value added for OECD Europe



Sources: IEA indicators database (IEA, 2009f); IEA estimates.

Key point

Significant growth of the commercial and service sector in many countries is one of the main drivers for the sector's energy demand.

Energy consumption by end use

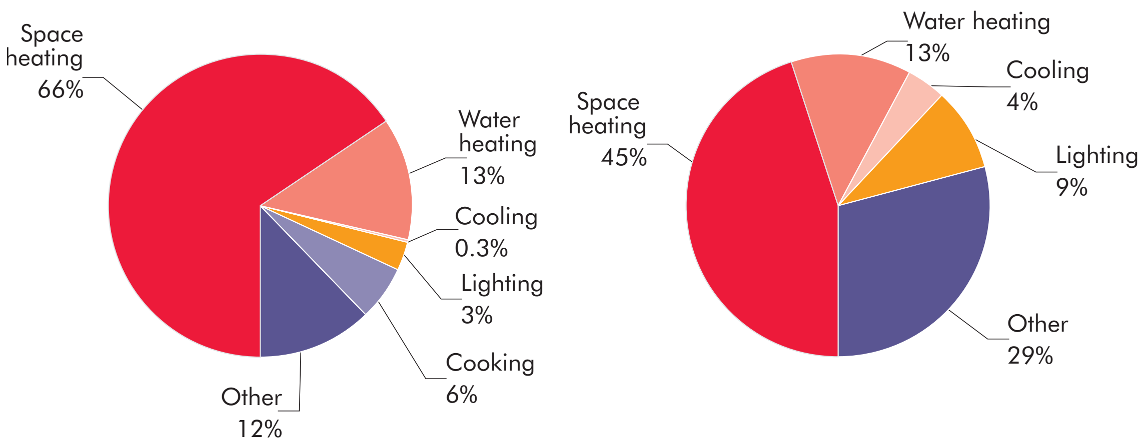
Europe covers a number of very diverse climate regions. The Scandinavian countries have very significant heating loads for most of the year. Countries in Central Europe have cold winters and warm summers. In Southern Europe, heating needs are much lower, but cooling needs can be significant. This diversity has a significant impact on individual countries' energy consumption levels and patterns.

The estimated breakdown of energy consumption by end use is shown in Figure 8.14.[6] In the residential sector, space and water heating dominates. In the service sector electrical end uses are much more important, although space heating still has the largest share. The rapid growth in electrical end uses in the residential and service sectors means that electricity consumption and the electrical end uses share of the total are both growing quickly.

5. Data for service sector value added and household numbers come from the IEA's Energy Indicators database. Household numbers for Turkey were estimated from population data.

6. The estimate for the residential sector is based on 18 European countries that have data from which estimates can be derived. The service sector end-use shares are based on IEA energy consumption statistics, with an allocation to end-uses made using data available for four OECD countries. In the service sector, energy consumption for space cooling and ventilation is likely to be underestimated.

Figure 8.14 ▶ Residential and service sectors' energy consumption by end use in OECD Europe, 2006/07



Sources: IEA indicators database; IEA estimates.

Key point

Energy demand for space and water heating currently represents the majority of energy consumption in the buildings sector.

Scenarios for buildings energy use and CO_2 emissions

The population of OECD Europe is projected to grow by 0.1% a year between 2007 and 2050, to reach around 577 million in 2050. The growth in households will be much higher than this as the trend towards fewer persons per household continues. Total households will grow from an estimated 209 million in 2005 to 287 million in 2050, growing by 0.7% a year. In the service sector, floor area is projected to grow to more than twice the 2007 level by 2050.

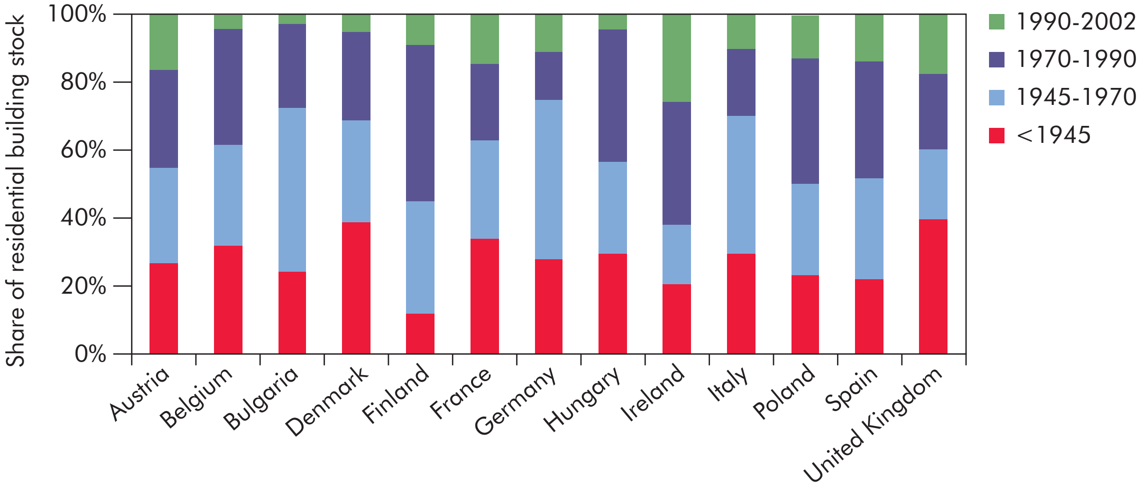
The Baseline scenario

In Europe, the vast bulk of the building stock was built before the first oil crisis (Figure 8.15). The biggest challenge for the buildings sector in Europe, if CO_2 emissions are to be significantly reduced, is to address the existing building stock.

Energy efficiency policies have been successful in restricting the growth in energy consumption, particularly in the residential sector for space heating. Building codes for new construction have been progressively tightened in many countries, and significant programmes to improve the thermal envelope of existing buildings have also helped reduce energy consumption growth.

The average consumption of large appliances has declined steadily over time as a result of energy efficiency labelling and minimum energy performance standards. But the growing use of an ever increasing range of smaller electrical appliances has seen the overall energy consumption of appliances grow strongly and the share of small appliances increase significantly.

Figure 8.15 ▶ Residential building stock in selected countries by vintage



Source: IEA (2008).

Key point

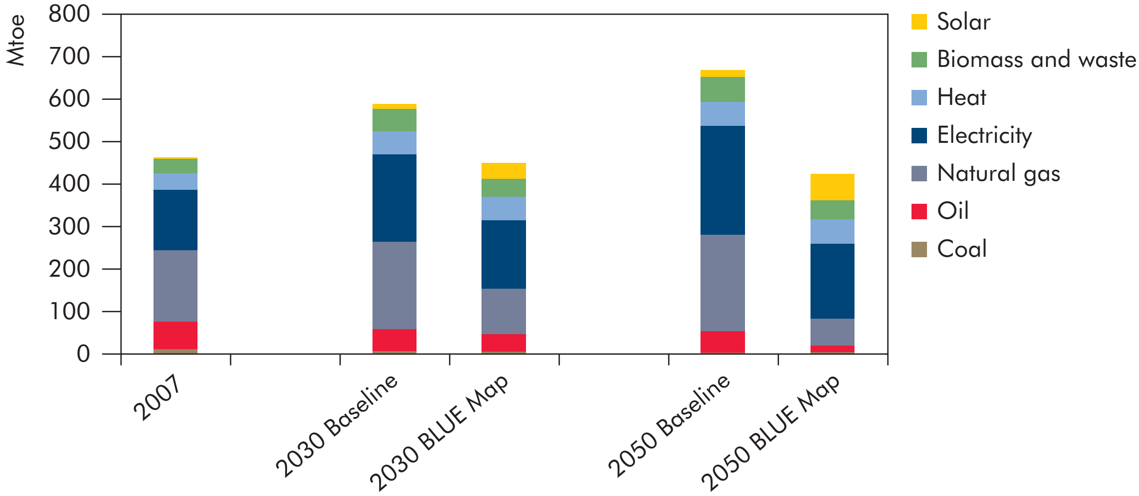
The vast majority of Europe's building stock was built before 1970.

Energy consumption increases by 0.9% a year between 2007 and 2050 in the Baseline scenario, from around 463 Mtoe to 668 Mtoe in 2050, an increase of 44%. The consumption of gas grows at 0.7% a year, electricity at 1.4% a year, solar at 3.9% a year, and purchased heat at 0.9% a year. The consumption of coal declines by 3.5% a year and that of oil by 0.5% a year (Figure 8.16). The continued rapid growth of the service sector sees its share of energy consumption in the buildings sector increase from 36% in 2007 to 42% in 2050. Energy consumption in the service sector grows at 1.2% a year between 2007 and 2050, while the residential sector sees growth of 0.6% a year.

The BLUE Map scenario

In the BLUE Map scenario, energy consumption in the residential and service sectors reduces by 40% below the Baseline level in 2050, equivalent to a saving of 265 Mtoe (Figure 8.16). This represents a decline in energy consumption in 2050 of 14% compared to 2007 levels in the BLUE Map scenario, despite the 0.7% a year growth in household numbers and the doubling of service sector floor area. Gas consumption is reduced by the most in percentage (77%) and absolute terms (173 Mtoe) as heat demand is reduced both by tighter building codes for new buildings and by the refurbishment in cold climates of around three-quarters of the existing building stock to low-energy standards. The increased use of CO_2-free fuel sources, such as solar thermal and decarbonised electricity for space and water heating, also reduces emissions.

Figure 8.16 ▶ **Energy use in the buildings sector in the Baseline and BLUE Map scenarios for OECD Europe**



Sources: IEA (2009a); IEA analysis.

Key point

In the BLUE Map scenario, energy consumption in buildings is 9% lower than today's level in 2050.

In the BLUE Map scenario, electricity demand is reduced by 91 Mtoe, being equivalent to 35% of the Baseline scenario level in 2050. Oil consumption is also significantly reduced. Solar thermal space and water heating increases significantly and solar use increases to 62 Mtoe in 2050, a level almost four times larger than in the Baseline scenario in 2050 and 20 times larger than in 2007. Heat consumption increases slightly over the Baseline scenario level in 2050, despite the decline in underlying demand for space heating, as building-scale CHP using hydrogen starts to penetrate from 2030.

Energy consumption in the BLUE Map scenario is 150 Mtoe (39%) lower in the residential sector in 2050 than the Baseline scenario level, and 98 Mtoe (35%) lower in the service sector. In the residential sector, around four-fifths of the savings come from space heating, as a very large-scale refurbishment programme on the existing building stock halves space heating demand by 2050 compared to the Baseline level. Important contributions come from electrical end uses, notably lighting and appliances.

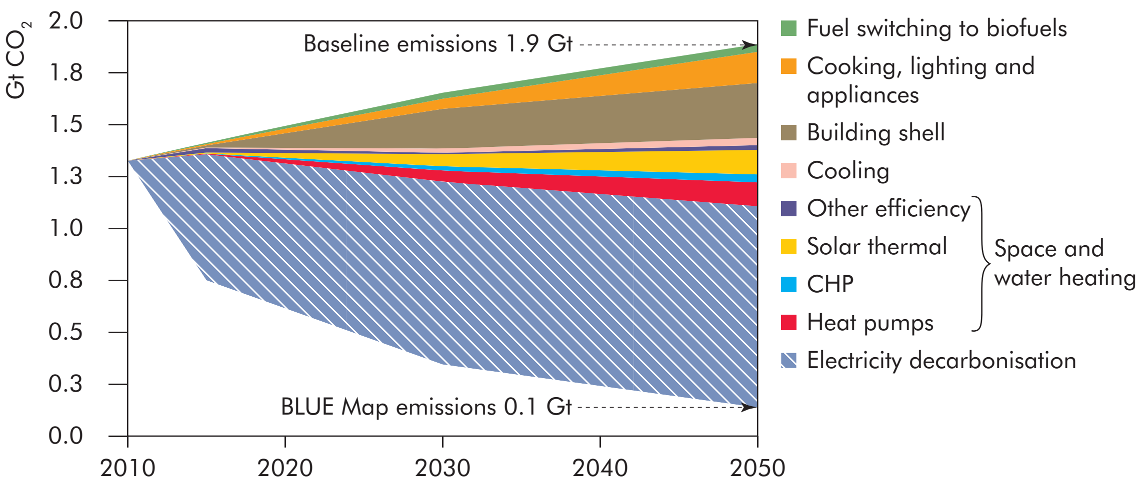
In the service sector, water and space heating accounts for around half of the savings. Very significant savings from the electricity-intensive end uses of cooling, lighting and other miscellaneous loads make a significant contribution to the CO_2 savings in the BLUE Map scenario.

CO_2 emissions attributable to the residential and service sector in the BLUE Map scenario are 42% or 785 Mt CO_2 lower than in the Baseline scenario in 2050. Taking into account that the residential and service sectors, because of their electricity and district heat demand, cause indirect CO_2 emissions in the power sector, the buildings sector is responsible for 1.9 Gt of CO_2 emissions in 2050 in the

Baseline scenario. Thanks to the decarbonisation of power generation in the BLUE Map scenario by 2050, these indirect emissions are reduced by 1.1 Gt in the BLUE Map scenario compared to the Baseline development.

The savings attributed to electricity production are offset to some extent by the switching from fossil fuels to electricity for space and water heating and for cooking. In the BLUE Map scenario, the substantial decarbonisation of the electricity sector allows electrification to be an attractive abatement option. Space and water heating account as well as improvements in the building shell for 72% of the reduction in direct CO_2 emissions below the Baseline scenario in 2050 (Figure 8.17). The assumed continuous tightening of building codes and standards results in accelerated savings after 2030. Important contributions are also made by solar thermal, heat pumps and CHP/district heating. Fuel switching to biofuels and energy efficiency improvements in cooling, lighting appliances and miscellaneous end uses account for 28% of the reduction below the Baseline level.

Figure 8.17 ▶ Contribution to reductions in CO_2 emissions in the buildings sector in OECD Europe under the BLUE Map scenario



Key point

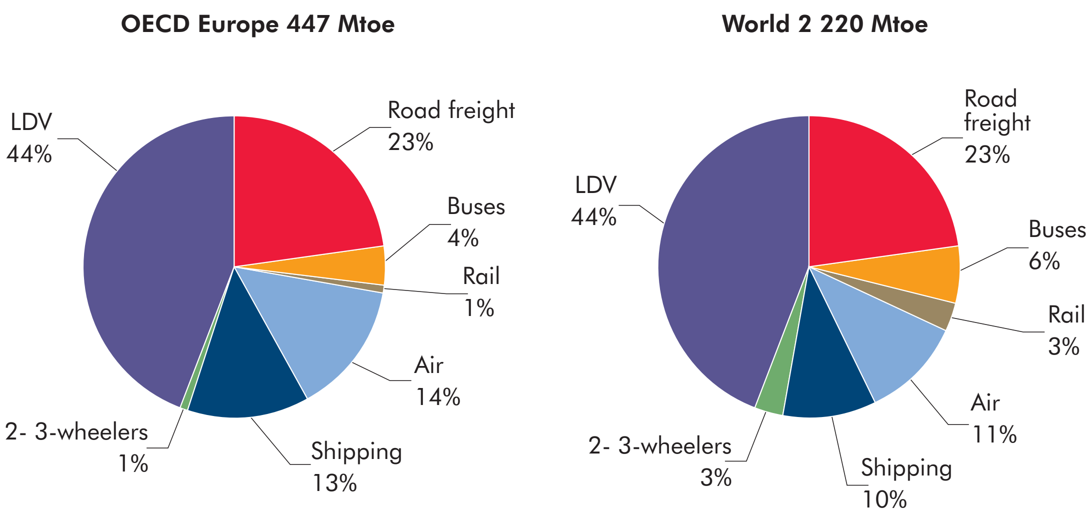
A wide range of options are needed to limit growth in CO_2 emissions in the buildings sector.

The CO_2 emissions reductions from cooling are achieved predominantly by cooling system improvements but also by improvements in building shells through, for example, the increased use of shading and active shutters, reflective coatings and insulation. Lighting systems become significantly more efficient in the Baseline scenario. Extensive further improvements are still possible, particularly in the service sector, and the emergence of solid state lighting will help expand the savings potential.

Transport sector

The transport sector in OECD Europe, including international aviation and shipping, used 447 Mtoe in 2007. This accounted for 31% of total final energy use in OECD Europe and about 20% of worldwide transport energy use. OECD Europe's energy shares are similar to world averages, but with a higher share of energy-intensive modes, such as light-duty vehicles (LDVs) and aviation (Figure 8.18).

Figure 8.18 ▶ Transport sector final energy use by mode in OECD Europe and the world, 2007



Sources: IEA (2009a and 2009b).

Notes: Air and shipping include an estimate of international trips starting from OECD Europe; energy use for pipeline transportation are excluded.

Key point

The energy mix in the transport sector in OECD Europe is similar to the global mix.

A range of transport indicators by mode, including activity, intensity and fuel use variables, is outlined in Table 8.8. The energy use data reported in the IEA statistics do not specify road fuel use in terms of vehicle type. This is estimated by the IEA using data and assumptions on vehicle stocks, efficiency, and average travel. Both the energy use as reported in IEA statistics as well as estimates for energy use that have been used in the present analysis are shown in Table 8 8. These estimates are based on current production levels and energy intensities from a range of sources. These data need further validation.

Table 8.8 ▶ **Transport energy indicators in OECD Europe, 2007**

	Passenger travel (bn pkm)	Freight travel (bn tkm)	Stock average energy intensity (MJ/pkm)	Stock average energy intensity (MJ/tkm)	Fuel use (Mtoe)
LDVs	4 366		1.9		193
2- 3-wheelers	205		1.1		5
Buses	917		0.8		17
Freight trucks		1 682		2.6	105
Rail	334	266	0.3	0.4	5
Air	1 089		2.4		62
Water		n.a.	n.a.	n.a.	60
Total/Average	**6 911**	**1 948**	**1.7**	**2.3**	**447**

Notes: In totals row, averages are provided for intensity figures and are weighted across modes. bn pkm = billion passenger-kilometres, bn tkm = billion tonne-kilometres.

Sources: IEA (2009d); IEA analysis.

Europe has an extensive public transit infrastructure. Even though, cars and other passenger LDVs carry nearly two-thirds of total passenger-kilometres of travel. Rail accounts for about 5%, although perhaps twice as large a share in urban areas. Buses account for about three times as much passenger travel as rail.

Trucks carry about five times as much freight (in tonne-kilometres) as rail. Buses carry passengers at about half the energy intensity per passenger-kilometre of cars, and rail at less than a quarter. Rail is less than one-tenth as energy-intensive as trucking, on average. The net effect of these factors in OECD Europe is that LDVs dominate fuel use, followed by trucks and air travel. In terms of CO_2 emissions (Table 8.9), a similar pattern emerges.

8

Table 8.9 ▶ **Transport CO_2 indicators in OECD Europe, 2007**

	Passenger (Mt CO_2-eq)	Passenger (kg CO_2-eq/pkm)	Freight (Mt CO_2-eq)	Freight (kg CO_2-eq/tkm)
LDVs	665	0.15		
2- 3-wheelers	18	0.09		
Buses	60	0.07		
Freight trucks			374	0.22
Rail	11	0.03	11	0.04
Air	218	0.20		
Water			219	n.a.
Total/average	**967**	**0.14**	**610**	**0.31**

Note: In totals row, averages are provided for intensity figures and are weighted across modes.

Sources: IEA (2009d); IEA analysis.

Scenarios for transport energy use and CO_2 emissions

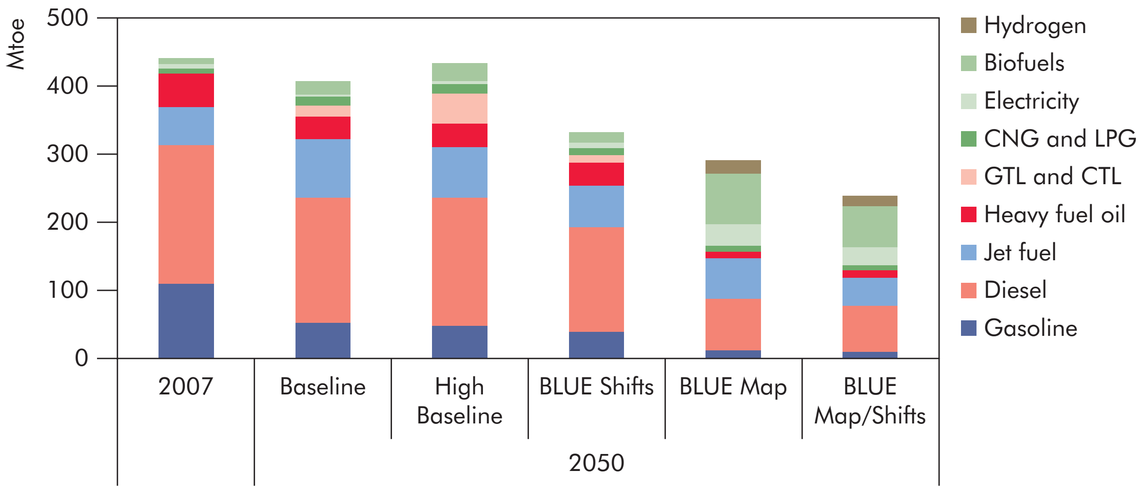
OECD Europe has a high average travel per capita. With little expected population growth over the next 40 years, total transport activity is unlikely to grow significantly in Europe. It is also unlikely that energy use per passenger-kilometre and per tonne-kilometre for freight will improve significantly without strong policy interventions.

In the Baseline scenario, transport energy use in OECD Europe remains fairly flat, reflecting the impact of a wide range of initiatives around Europe which are expected to help cut energy intensity over the next 5 to 10 years. Without further significant expansion of these initiatives, energy intensity is projected to improve little if at all after 2020, especially in LDVs.

Energy efficiency gains affect the consumption of different fuels in different ways (Figure 8.19). Gasoline demand is likely to decrease, thanks to improvements in the fuel efficiency of passenger LDVs and the partial or total electrification of smaller vehicles. Larger diesel vehicles, including trucks, are much less likely to be shifted to electricity, so the consumption of diesel fuel becomes relatively more significant. The refining implications of this scenario have not been explored in detail. Growing demand for aviation is likely to overshadow efficiency gains in planes, creating a need for more jet fuel in Europe. Synfuels also rapidly increase their share after 2030, as conventional oil supplies decline.

In 2007, the transport sector in OECD Europe used about 447 Mtoe, or around 20% of global transport energy use. By 2050 this share is likely to drop to about 10%, as the transport sector energy use of developing economies grows very quickly over the next 40 years (IEA, 2009d).

Figure 8.19 ▶ Transport energy use by fuel in the Baseline and BLUE scenarios* in OECD Europe



* The Baseline and BLUE Map variant scenarios for transport are described in detail in Chapter 7.

Sources: IEA (2009a); IEA analysis.

Key point

Energy use in 2050 is very similar to today in the Baseline scenario but there are major changes in the fuel mix in the BLUE scenarios.

The BLUE Map scenarios: technological pathways for transport in OECD Europe

Different European countries, with cultural differences, transport system differences, climate differences and a range of different commitments on CO_2, will adopt different approaches to ensuring that their transport sectors make the contributions they need to make to attain the outcomes implicit in the BLUE Map scenario. Some countries will rely heavily on biofuels, others more on electrification. Some countries may have particular opportunities to deploy EVs, for example because they have a proportion of LDVs used exclusively within large cities. Cold and biomass-rich Scandinavian countries may be more likely to go towards compressed (and eventually bio-synthetic) natural gas or biomass-to-liquids fuel options. In most of the big passenger LDV markets such as the United Kingdom, France, Germany, Spain and Italy, the electrification of vehicles is now high on the agenda.

The projected OECD Europe greenhouse-gas emissions in each of the transport scenarios explored in Chapter 7 are set out in Figure 8.20. The emissions for individual modes depend on a combination of efficiency improvements and the use of low-carbon fuels. Modal shifts to the most efficient modes account for the remaining reductions.

In particular, reductions depend on:

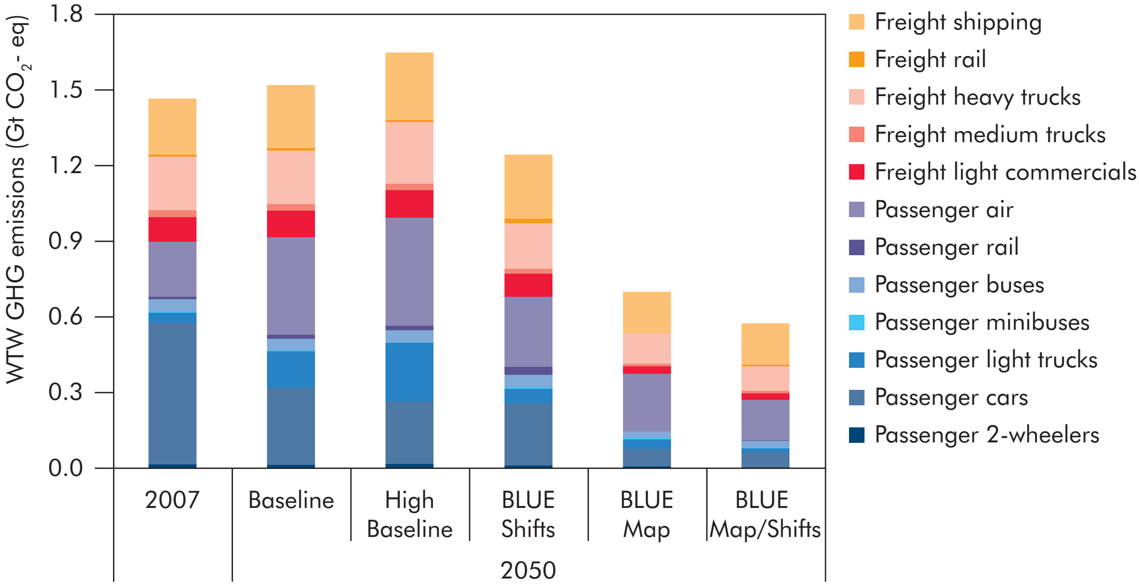
- Achieving a 50% improvement in new LDV fuel efficiency by 2030 compared to 2005.
- Achieving efficiency improvements in the stock of trucks, ships, trains and aircraft of the order of 40% to 50% by 2050.
- Reaching substantial sales of EVs and plug-in hybrid electric vehicles (PHEVs) by 2030 (9 million) and 2050 (12 million).
- Biofuel being about 12% of transport fuel by 2030 and 25% by 2050. This assumes that most of the biofuel is imported into OECD Europe.

In the BLUE Shifts scenario, travel by rail and bus in 2050 increases by 50% to 100% compared to the Baseline scenario in that year. This, together with other changes such as improvements in land-use planning and investment in non-motorised transport infrastructure, results in a 25% cut in the growth of car and air travel in OECD Europe.

Decarbonisation of power generation will also play an important part in reducing greenhouse-gas emissions in the transport sector as EVs start to play a larger role. Europe starts from a relatively good position, producing on average 345 gCO_2/kWh of generation in 2007. This is expected to reduce to 208 gCO_2/kWh in 2050 in the Baseline scenario and to 15 gCO_2/kWh in the BLUE Map scenario. In the BLUE Map scenario, CO_2 emissions reductions benefit not only from there being many more EVs than in the Baseline scenario, but also from the much lower carbon footprint of the electricity that runs them.

In the BLUE Map scenario, transport greenhouse-gas emissions are reduced by around 60% in OECD Europe, with the aggressive promotion of low-greenhouse-gas technologies into the market. The cost of such greenhouse-gas emissions reductions over the lifetime of a vehicle depends on energy prices. But it will often be negative as energy savings exceed the extra investment cost in new technologies.

Figure 8.20 ▶ OECD Europe's greenhouse-gas emissions evolution by transport mode



Note: WTW (well-to-wheel) greenhouse-gas emissions comprise the emissions of the vehicle (tank-to-wheel) and the upstream emissions along the fuel production pathway (well-to-tank).

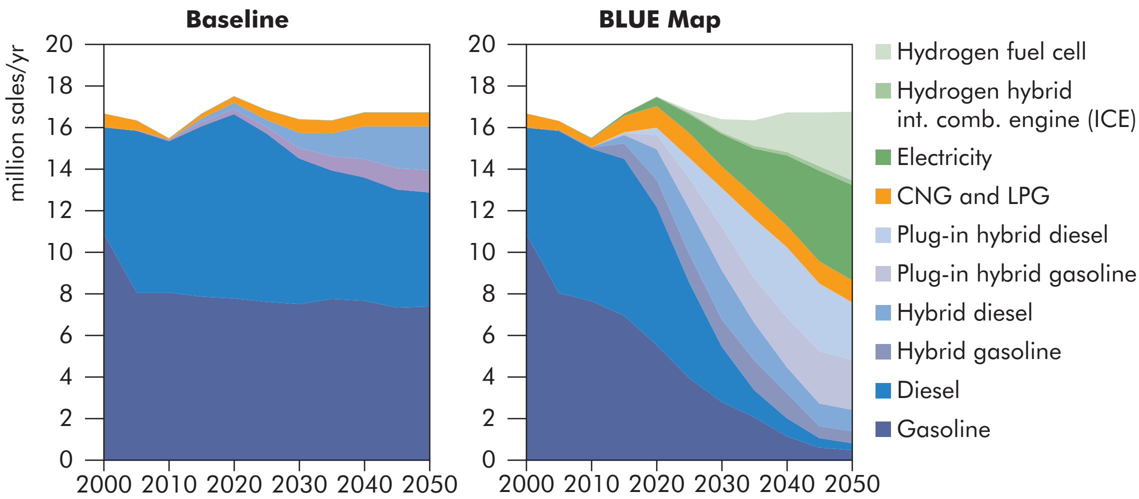
Key point

Major reductions in greenhouse-gas emissions are achieved in the BLUE Map scenario by efficiency improvements, the substitution of low-carbon fuels and modal shifts.

In the BLUE Map scenario, PHEV and EV technologies dominate new LDV sales after 2030 (Figure 8.21). Sales of EVs and PHEVs begin in earnest in 2015; by 2030 they reach more than 50% of sales; and by 2050 70% of all new vehicles are electric.

Transport volumes in OECD Europe are relatively stable. They may also decline during periods of slow economic growth or when energy prices increase, as in 2008. Deep cuts in greenhouse-gas emissions can be achieved by adopting an aggressive strategy towards efficiency. This has already begun for passenger LDVs. Further big reductions will come from shifting towards electricity and advanced biofuels. Natural gas can also play a significant role in European transport for cars and perhaps especially for trucks. Over time there must be a transition to biogas and bio-synthesised gas in order to reach very low CO_2 intensities by 2050. Pursuing a growth strategy for the most efficient transit and non-motorised modes, and dampening demand growth for the least efficient single-occupant passenger LDVs can also contribute to substantial energy savings and greenhouse-gas reductions by 2050 or even earlier.

Figure 8.21 ▶ Passenger light-duty vehicles sales by technology in OECD Europe in the Baseline and BLUE Map scenarios



Sources: IEA (2009a); IEA analysis.

Key point

A wide range of new LDV technologies contribute to emissions reductions under the BLUE scenario.

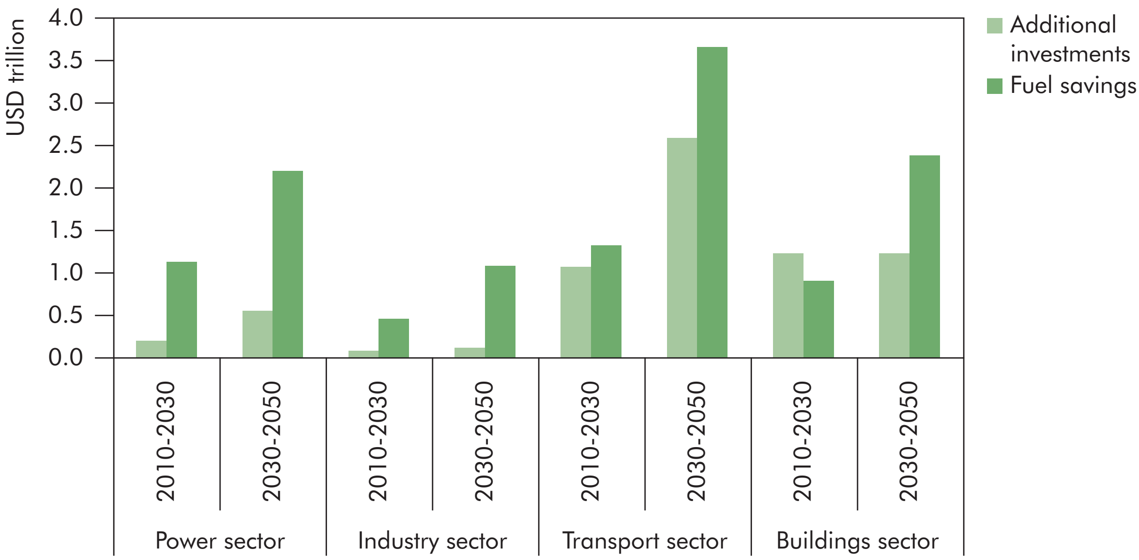
8

Investment needs in the BLUE Map scenario

To achieve an almost 75% reduction in CO_2 emissions between 2007 and 2050 in OECD Europe will require investment of around USD 7.1 trillion. Most of this (52%) will need to be made in the transport sector, with less in power generation (11%) and the buildings sector (35%) (Figure 8.22). Investment needs increase over time, as the least-cost emissions reduction options are taken first. Achieving around 50% reductions in CO_2 emissions in OECD Europe by 2030 requires the investment of USD 2.6 trillion. Moving from a 50% reduction in 2030 to a 75% reduction by 2050 in OECD Europe requires approximately twice as much investment, of the order of USD 4.5 trillion.

Almost all of this additional investment should be offset by fuel savings due to the more efficient use of energy, especially in the transport sector. Additional vehicle costs are estimated to be offset by undiscounted fuel savings of around USD 5.0 trillion. So, changes in the BLUE Map scenario may result in net savings of USD 1.3 trillion in the OECD Europe an transport sector. Similarly, in the buildings sector fuel cost savings result in net savings of USD 0.8 trillion. Overall, the additional investment needs of USD 7.1 trillion are more than compensated by total fuel savings of USD 13.1 trillion. Although these estimates are inevitably uncertain, it seems at least possible that the additional investment needed in vehicles and the fuel infrastructure in OECD Europe will be largely compensated for by reduced fuel costs.

Figure 8.22 ▶ Additional investment needs and fuel cost savings for OECD Europe



Note: Fuel savings are calculated on the basis of BLUE Map fuel prices. They refer to final energy use for the transport and industry sectors and to primary energy consumption for the power and transport sectors. Savings drop significantly, if Baseline energy prices are assumed, as fossil fuel prices in BLUE Map are significantly lower than in the Baseline scenario, reflecting the impact of lower fossil energy use on prices.

Key point

Large investment needs in transport and the building sectors may be compensated by fuel savings.

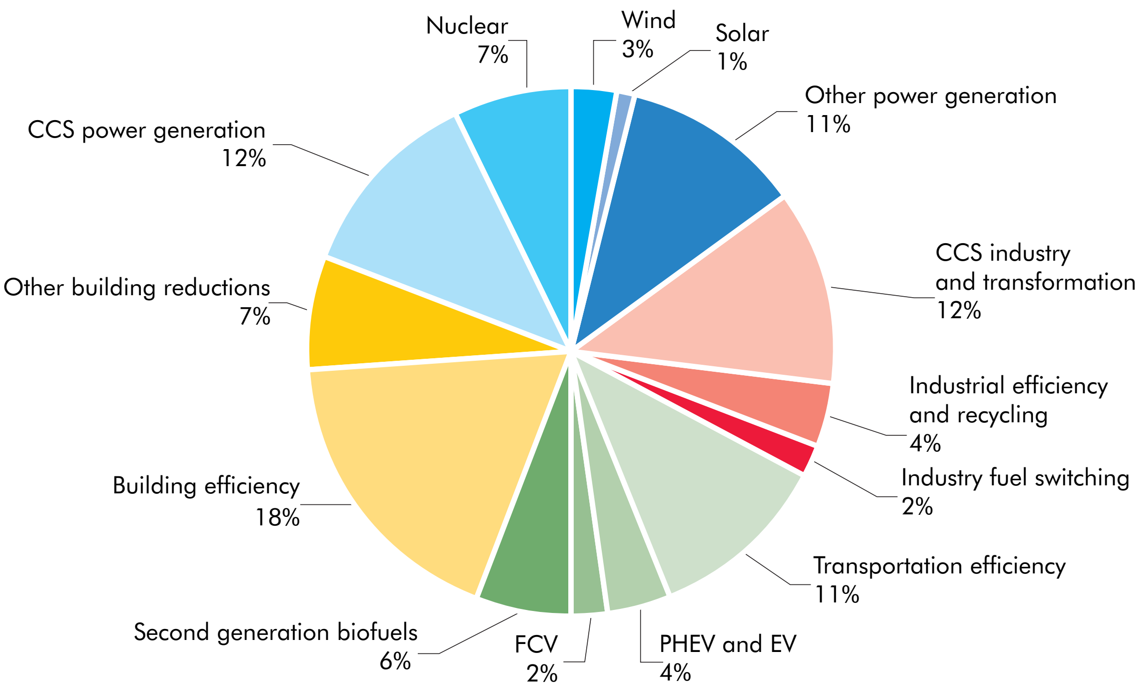
Transition to a low-carbon energy future

In the BLUE Map scenario, OECD Europe's CO_2 emissions in 2050 are cut by roughly three-quarters compared to 2007 levels. Achieving the deep emission cuts required in the BLUE Map scenario will require a significant intensification of current efforts to develop and deploy low-carbon technologies through the expansion and further radical development of existing policy measures in OECD Europe.

Future technology priorities

Different sectors and technology options make different levels of contribution to the achievement of the reduction of CO_2 emissions in the BLUE Map scenario in 2050 compared to the Baseline scenario (Figure 8.23). End-use sectors contribute 66% of the reduction; the transport sector is responsible for 23%, buildings for 25% and industry together with CCS in fuel transformation for 18%. The power sector contributes the remaining 34% of the total emissions reductions.

Figure 8.23 ▶ **CO_2 emissions reductions by technology area in the BLUE Map scenario in OECD Europe, 2050**



Key point

Technology changes in all sectors are required to achieve deep emissions reductions of nearly three-quarters in OECD Europe by 2050.

Decarbonising power generation is crucial to the achievement of deep CO_2 emission cuts, since it reduces emissions not only in power generation, but also in those end-use sectors which have the potential for greater electrification.

A large proportion of the existing generating capacity in OECD Europe will reach the end of its planned lifetime over the next 20 years. This presents an opportunity to invest in low-carbon generation technologies. To prepare for this, RD&D efforts in power generation should focus on:

- Improving efficiency in conventional fossil power generation, which will subsequently also improve the overall performance of CCS.
- The implementation of CCS demonstration projects which can prove the viability of the capture, transport and storage technologies that are needed.
- Continuing R&D on immature or not yet cost-competitive renewable energy technologies.

- Continuing research on the impacts of the increased penetration of variable renewables such as wind and solar on system stability and the grid and storage options for ensuring stable operation of the electricity system.

- More R&D on the components needed for smart grids and their operation.

The import of solar electricity produced in the Middle East and North Africa may also help to decarbonise the power sector in Europe. High-voltage direct current (HVDC) transmission technology will be fundamental to the success of this strategy. Bi-directional HVDC lines are already operating today, but further developments are needed in the operation of meshed HVDC network structures.

In the transport sector, a transition to biofuels, biogas and EVs may offer a route to significantly reduce CO_2 emissions from Europe's transport sector. Further research and deployment in the production of second-generation biofuels is needed. Strategies for the provision of industrial-scale plants with biomass resources have to be developed. This is being analysed in an EU-funded OPTFUEL project (OPTFUEL, 2009). Further research in the areas of battery technology, biogas combustion technologies and the impacts of transport electricity demand on the electricity infrastructure is also needed. These are being addressed in the European Green Car Initiative project (EC, n.d.) which is part of the European recovery package.

In the industry sector, major reductions are expected in the BLUE Map scenario through efficiency improvements and the use of CCS in the cement, chemicals and iron and steel sectors. To fully exploit efficiency improvement potentials, all industry sectors have to be brought up to BAT standards. For example, older cement kilns should be replaced with six-stage pre-heating and pre-calciners. The benefits of using the coke dry quenching process in iron and steel production should also be investigated. Areas for further RD&D include the use of carbon-free energy and alternative feedstocks such as hydrogen in the iron and steel sector, bio-based feedstocks in the chemicals industry, and the demonstration of CCS.

In the buildings sector, new and improved technologies will be required to achieve deep greenhouse-gas reductions in the second quarter of this century. For example, more efficient and lower-cost heat pumps will make a major contribution. R&D efforts are also required on fuel cells and advanced lighting technologies.

Future policy priorities

To achieve these technology changes, OECD Europe should also:

- Continue to develop ambitious climate change policies at EU level and through national programmes both within and outside the EU.

- Strengthen the EU ETS such that it sets a carbon price over the next decade that is high enough to drive the necessary investment in energy efficiency in the traded sector. Allocation rules should be designed to prevent carbon leakage.

- Consider developing a harmonised trading system for renewables in the EU that is consistent with the internal energy market and the EU ETS.

- Clarify national policies on new nuclear power plants.
- Develop a roadmap for improving gas and electricity interconnections in Europe consistent with the requirements of a low-carbon economy. This will require closer transnational co-operation within OECD Europe and with neighbouring countries.
- Consider the introduction of mandatory national energy efficiency targets for EU member states to replace the indicative targets in the Energy Services Directive.
- Strengthen the Energy Performance of Buildings Directive and ensure compliance with building standards in all countries.
- Introduce additional national policies on white certificates, efficiency obligations and whole-building retrofits to ensure many more residential buildings are retrofitted to low-energy standards.
- Strive to achieve agreed vehicle standards for new passenger cars of 130 gCO_2/km in 2015 and 95 gCO_2/km in 2020. Tighten fuel efficiency standards for vans and trucks.
- Consider further policies to reduce greenhouse-gas emissions from ships, trains and aircraft.
- Fully implement the Strategic Energy Technology (SET) plan and associated roadmaps. This will require additional funding of about USD 5 billion per year, better alignment of this funding with the priorities in the SET plan and more co-ordination of RD&D activities between the EU and its member states.

Chapter 9 UNITED STATES

Key findings

- *In the Baseline scenario, primary energy supply in the United States (US) increases by more than 5% between 2007 and 2050. Carbon dioxide (CO_2) emissions increase by only 1%. In the BLUE Map scenario, primary energy supply decreases by 17% and CO_2 emissions by 81% by 2050 from 2007 levels.*

- *The BLUE Map scenario brings energy security benefits as well as climate benefits. Oil and gas demand in 2050 is reduced to around 40% of 2007 levels. As a result, the United States is much less dependent on imported oil and gas in the BLUE Map scenario than in the Baseline scenario.*

- *The investments between 2010 and 2050 needed to achieve the BLUE Map scenario are USD 5.8 trillion higher than for the Baseline scenario. However, fuel savings from these investments are projected to be even higher on an undiscounted basis.*

- *The US outcomes in the BLUE Map scenario are largely achieved through increased energy efficiency in all end-use sectors and by essentially decarbonising the power and transport sectors. Measures to improve energy efficiency and fuel switching in the end-use sectors together provide more than half of all emissions reductions. Other major contributors include carbon capture and storage (CCS), biofuels and other renewables.*

- *Energy efficiency measures should be given high priority. Efficiency improvements represent some of the lowest-cost means of achieving a low-carbon energy future. While the United States has made important progress in this area, all levels of government (federal, state and local) need to accelerate their efforts.*

- *In the BLUE Map scenario, the generation mix in 2050 is dominated by low-carbon technologies such as wind, solar, biomass, nuclear and fossil fuels with CCS. The installed capacity of nuclear generation doubles and there is a 24-fold increase in wind power generation. Gas- and coal-fired generation with CCS accounts for about 16% of generation in 2050.*

- *To realise a more diversified and low-carbon power sector, policy actions are required to reduce subsidies for fossil fuels, harmonise national policies on renewables and remove uncertainties affecting the development of new capacity. Measures are also required to increase the efficiency of power generation through regulation, incentives and cost-reflective prices.*

- *Improvements in energy efficiency and the transition to decarbonised power and transport sectors will require major investment in the electricity transmission grid, including the strengthening of interstate connections and the development of smart grid technologies.*

- *Other policy priorities include strengthening policies and standards for new and refurbished buildings, introducing additional measures to improve energy efficiency in industry, further strengthening the Corporate Average Fuel Economy (CAFE) standards for light-duty vehicles (LDVs) beyond 2016 and promoting modal shift from LDVs through land-use changes and an expansion of high-speed and conventional rail.*

- *To enable these transitions, the United States should pass comprehensive energy and climate legislation to encourage investment in clean energy technologies and put a price on carbon emissions. Additional funding is required for both basic and applied research and development (R&D) on a wide range of energy technologies.*

Regional description

The United States covers a land area of 9 570 million square kilometres (km^2). It had a population of 302 million in 2007. It is the largest economy in the world. The major population centres are New York City and northern New Jersey with 20 million inhabitants on the east coast; Los Angeles, Long Beach and Santa Ana with 15 million on the west coast; and the Chicago area with 10 million in the eastern-central part of the country. The civilian labour force stood at 154 million in 2008. The population density of the United States is relatively low, with 30.4 inhabitants per km^2. The country is a union of 50 states and the District of Columbia.

The US gross domestic product (GDP) per capita was USD 46 673 in 2007. From 2000 to 2007, GDP per capita grew by an average of approximately 3.2% a year (World Bank, 2009). Like all major economies, the economic performance of the United States has weakened since the start of the financial crisis at the end of 2008.

Recent trends in energy and CO_2 emissions

Today, most of the energy consumed in the United States comes from fossil fuels, particularly oil. The United States is self-sufficient in coal. It is largely self-sufficient in natural gas, with about 16% of gas supplied by imports from North American neighbours. Renewable energy resources supply 7% of the country's energy needs. In the late 1950s, nuclear power generation began to be used to generate electricity. It currently supplies 20% of electricity output and 9% of all energy used in the United States (EIA, 2008).

The United States has substantial proven reserves of fossil fuels (Table 9.1). About 29% of the world's proven coal reserves are located in the United States and about 4% of the natural gas reserves.

Table 9.1 ▶ **Proven energy reserves in the United States and in the world, 2008**

	Coal (Mt)	Crude oil (Mt)	Natural gas (bcm)
Proven reserves: US	238 308	3 700	6 730
Proven reserves: World	826 000	170 800	185 020
Production in 2008: US	1 063	305.1	582.2
Reserve-to-production ratio: US	224	12.4	11.6

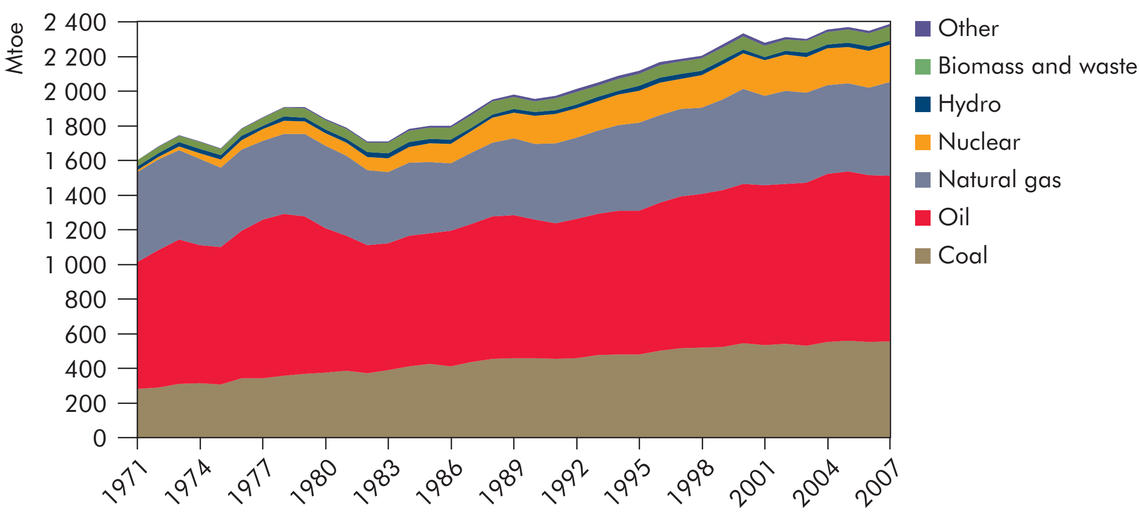
Note: Reserve-to-production ratio indicates the length of time that recoverable reserves would last if production were to continue at current rates and if no additional reserves could be recovered.
Source: BP (2009).

Energy production and supply

Total primary energy supply (TPES) in the United States has steadily increased since 1971 across all energy sources (Figure 9.1). Between 1971 and 2007, energy supplied from coal almost doubled to 554 million tonnes of oil equivalent (Mtoe); oil rose by 30% to 957 Mtoe; natural gas rose by 4% to 538 Mtoe; nuclear increased from 11 Mtoe to 218 Mtoe; and renewables increased by almost 150% to 85 Mtoe. Energy supplied from hydropower declined by around 7% to 22 Mtoe in 2007.

9

Figure 9.1 ▶ **Total primary energy supply in the United States**



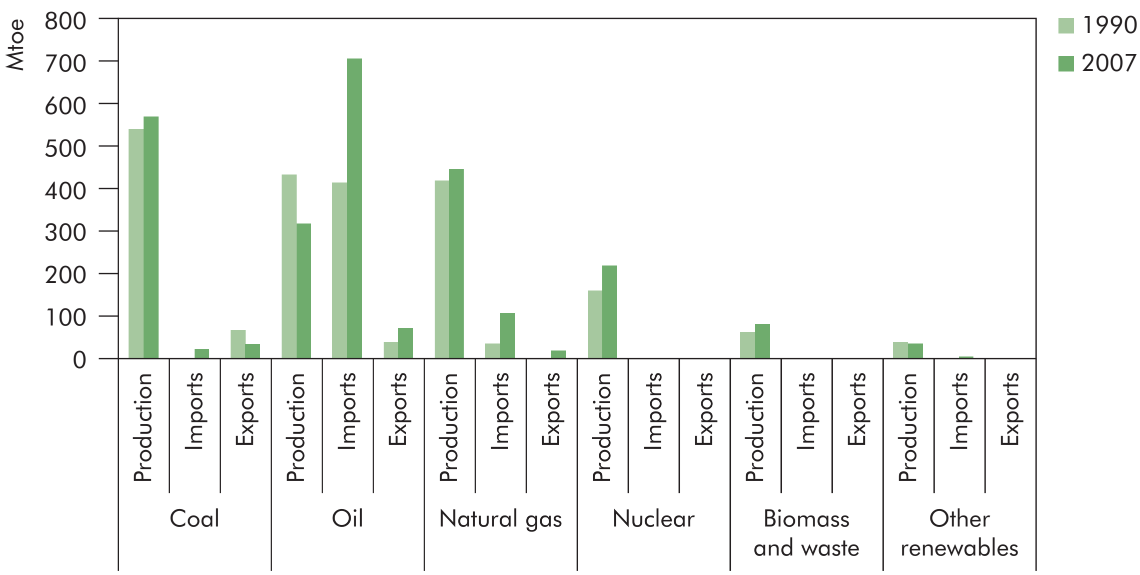
Source: IEA (2009a).

Key point

The United States continues to rely heavily on fossil fuels.

In 2007, the United States imported 840 Mtoe of energy and exported 127 Mtoe. It was self-sufficient in energy until the late 1950s when energy consumption began to outpace domestic production. In 2007, net energy imports accounted for 25% of all energy consumed (Figure 9.2). Historically, most of the exported energy from the United States was in the form of coal although in recent years oil exports have exceeded coal exports. In 2007 most (84%) of the imported energy was in the form of oil. In the last 20 years, natural gas imports, particularly from Canada, have grown rapidly, rising from 35 Mtoe in 1990 to 107 Mtoe in 2007. The United States now imports more oil and natural gas than any other country.

Figure 9.2 ▶ **United States energy production, imports and exports**



Note: Nuclear production refers to the heat produced in nuclear reactors, irrespective of whether the nuclear fuel used is from domestic sources or imported.

Source: IEA (2009a).

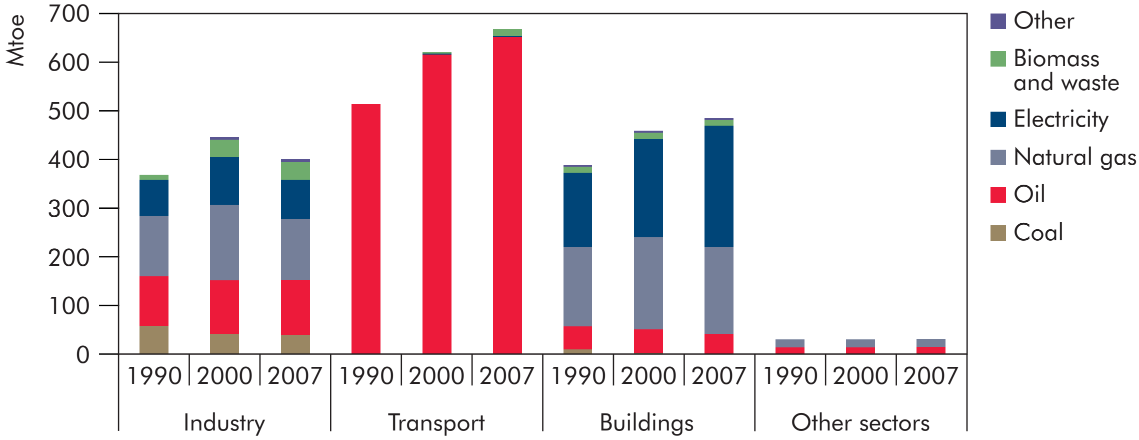
Key point

The United States is a significant net importer of energy, primarily oil.

Energy consumption

In 2007, oil consumption was 52% of total energy consumption, natural gas 20%, renewables 5% and electricity 21%. The pattern of energy use varies by sector. For example, oil provides 96% of the energy used for transportation but only 1% of the energy used to generate electric power (Figure 9.3). The transport sector was the largest consumer of energy (43%), followed by buildings (31%) and industry (25%) in 2007.

Figure 9.3 ▶ ***Final energy consumption by fuel and by sector in the United States***



Notes: Industry includes coke ovens, blast furnaces and feedstocks. Transport includes international aviation and marine bunkers. Other sectors include agriculture, fishing and forestry as well as energy use for pipeline transport.
Source: IEA (2009a).

Key point

The transport sector continues to be the largest consumer of oil.

End-use efficiency improvement

9

The final energy intensity of the United States is currently 0.20 tonnes of oil equivalent (toe)/USD 1 000. The final energy intensity in 2000 was 0.23 toe/USD 1 000. This improvement can partly be explained by strong efficiency improvements resulting from the introduction of modern technologies and processes.

Analysis based on end-use data shows that the overall improvement in energy efficiency in the United States was 1.5% per year between 1990 and 2006. Without the energy savings resulting from these improvements, total final energy consumption would have been 25% higher in 2006.

Carbon dioxide emissions

Energy-related CO_2 emissions in the United States were 5 915 Mt in 2007. Emissions increased by 18% between 1990 and 2007 while primary energy supply increased by about 22% over the same period. This difference was due to some fuel switching from coal in the industry sector and increases in the share of nuclear power and renewables.

Overall energy policy framework

Energy policy in the United States is developed through a series of co-ordinated efforts by several agencies and among the executive and legislative branches of government. Primary responsibility for federal energy policies and programmes is vested in the United States Department of Energy (DOE). Data collection and analysis is headed by the Energy Information Agency (EIA), an independent administration within DOE.

The DOE's mission is to advance the national, economic and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental clean-up of the national nuclear weapons complex.

The federal government has a strong preference for market-based policies and regulations in the energy and environment policy area. Consistent with this, the current Administration has established a set of principles to guide its energy policy. These principles include:

- *Investing in the clean energy jobs of the future* by creating new clean energy jobs, and investing USD 150 billion over ten years in energy R&D in next-generation clean energy technologies.
- *Securing the nation's energy future* through investments in clean energy sources to curb dependence on fossil fuels and make the country energy-independent. Efforts will focus on:
    - promoting the next generation of cars and trucks and the fuels they run on,
    - enhancing US energy supplies through the responsible development of domestic renewable energy, fossil fuels, advanced biofuels and nuclear energy, and
    - promoting investments in the transport, electricity, industrial, building and agricultural sectors that reduce energy bills.
- *Creating a fair but effective market framework to drive down emissions* by applying a market-based cap on emissions, eliminating carbon leakage,[1] and ensuring a level playing field for domestic manufacturing by securing significant actions to combat climate change on the part of the United States' trading partners.

In addition to the DOE, a number of other federal agencies and executive branch offices are actively engaged in energy policy. These include the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), the Department of Transportation (DOT), the Department of the Interior (DOI), the Environmental Protection Agency (EPA), the Council on Environmental Quality (CEQ) and the Office of Science and Technology Policy (OSTP).

The 50 federal states, the District of Columbia and US Territories are responsible for many environmental and energy-related issues within their borders. They have regulatory commissions, usually elected or appointed by state governors or state legislatures, which are responsible for regulating energy undertakings with the state. States regulate all retail electricity rates and services as well as the siting and construction of electricity generation and transmission infrastructures.

1. Carbon leakage refers to the movement of economic capacity from areas that are subject to emission controls to areas that are not, simply to avoid the cost of reducing emissions.

Current status of energy policies and climate change initiatives

Since January 2009, the United States government has taken a number of initiatives on energy and climate change. These include:

Domestic actions

- Through the 2009 American Recovery and Reinvestment Act (the Recovery Act), more than USD 90 billion will be invested in clean energy, including programmes intended to double the generation of clean renewable energies such as wind and solar in three years. Specific funding includes commitments for smarter grids and for 40 million smart meters to be deployed in American homes, home weatherisation projects, the greening of federal buildings, and a range of state and local renewable energy and energy efficiency efforts. The package also includes USD 600 million for green job training programmes.
- USD 2.0 billion in competitive grants to develop the next generation of batteries.
- A new Efficiency Standard for Automobiles. This sets for the first time joint fuel economy and greenhouse-gas emission standards for 2011 model cars and trucks to increase fuel economy to 6.7 litres per 100 kilometres or 35 miles per gallon by 2020.
- Steps to advance far-reaching energy and climate change legislation. The United States House of Representatives passed the American Clean Energy and Security Act in June 2009. This aims to promote clean energy investments and to lower US greenhouse-gas emissions by more than 80% by 2050. This legislation is currently held up in the US Senate.
- Implementing more aggressive efficiency standards for residential appliances, including microwaves, cookers, dishwashers, light bulbs and other common appliances.
- A new regulatory framework has been established to facilitate the development of alternative energy projects. This will enable the United States to tap into the vast energy potential of its Outer Continental Shelf.
- Steps to catalogue greenhouse-gas emissions from large emission sources. This will for the first time enable transparent measurement, on the basis of which greenhouse-gas emissions reductions can be quantified.

International actions

- Initiating the Major Economies Forum on Energy and Climate (MEF) to create a new dialogue among developed and emerging economies to combat climate change and promote clean energy. This group has 17 member countries.[2] In December 2009, it published a suite of ten Technology Action Plans based on an IEA analysis of global gaps in research, development and demonstration (RD&D) funding.

2. www.majoreconomiesforum.org

- Leading an initiative for all G20 nations to phase out their fossil fuel subsidies over the medium term and to work with other countries to do the same. Asia-Pacific Economic Co-operation (APEC) nations have since adopted a similar approach, expanding the number of countries committing to abolishing these subsidies.

- Plans for accelerating collaboration with China, India, Mexico, Canada and other international partners to combat climate change, co-ordinate clean energy R&D, and support the international climate talks.

- Partnering with neighbours in the western hemisphere to advance energy security and combat climate change. An early product of this co-operation is Chile's Renewable Energy Centre, which receives technical support from the US DOE.

Box 9.1 ▶ Clean energy investment under the 2009 Recovery Act

Under the 2009 Recovery Act, more than USD 90 billion was earmarked for government investment and tax incentives to lay the foundation for a clean energy economy of the future. Over USD 30 billion had been committed and over USD 5 billion had been spent by December 2009 (Table 9.2). Because most of the clean energy investments occur through grants and contracts that require that proposals be reviewed before funds can be expended, only a portion of the appropriation has been spent to date.

The largest investments are in renewable energy generation, energy efficiency, transit, and grid modernisation.

Table 9.2 ▶ United States clean energy spending by category

(USD millions)	Appropriations	Commitments	Spent
		to December 2009	
Energy efficiency	19 935	11 913	1 162
Renewable generation	26 598	1 513	1 479
Grid modernisation	10 453	2 666	72
Advanced vehicles and fuel technologies	6 142	3 149	450
Traditional transit and high-speed rail	18 113	8 834	1 805
Carbon capture and storage	3 400	425	4
Green innovation and job training	3 549	2 197	123
Clean energy equipment manufacturing	1 624	14	14
Other	408	148	12
Total	**90 222**	**30 859**	**5 121**

Note: Other contains programmes that do not fit in elsewhere.
Source: US CEA (2010).

In terms of jobs saved or created by clean energy investments, the US Council of Economic Advisers (US CEA) estimates that the clean energy segments of the Recovery Act saved or created about 52 000 clean energy jobs and supported another 11 000 jobs throughout the United States.

Overview of scenarios and CO_2 abatement options

Significant energy indicators for the United States in the Baseline and BLUE Map scenarios are set out in Table 9.3. In both the Baseline and the BLUE Map scenarios, GDP and population projections are the same. Carbon dioxide emissions reduction potentials are based on an assumed marginal cost of up to USD 175/tonne (t) of CO_2 in 2050.

Table 9.3 ▶ High-level indicators for the United States

			Baseline scenario		BLUE Map scenario	
	2000	2007	2030	2050	2030	2050
TPES (Mtoe)	2 350	2 387	2 396	2 508	1 816	1 979
Electricity consumption (TWh)	3 857	4 113	4 895	5 610	3 936	4 667
CO_2 emissions (Gt)	5.84	5.92	5.54	5.99	2.44	1.14
GDP (USD billion 2000)	9 765	11 468	18 333	23 775	18 333	23 775
Population (millions)	282	302	370	404	370	404
TPES/GDP (toe per thousand USD/2000)	0.241	0.208	0.131	0.105	0.099	0.083
TPES/population (toe per capita)	8.5	7.9	6.5	6.2	4.9	4.9
Electricity consumption /population (kWh per capita)	13 657	13 616	13 230	13 886	10 638	11 552

Notes: TWh = terawatt-hours; international aviation and shipping are included in TPES and CO_2 emissions.
Source: IEA (2009a).

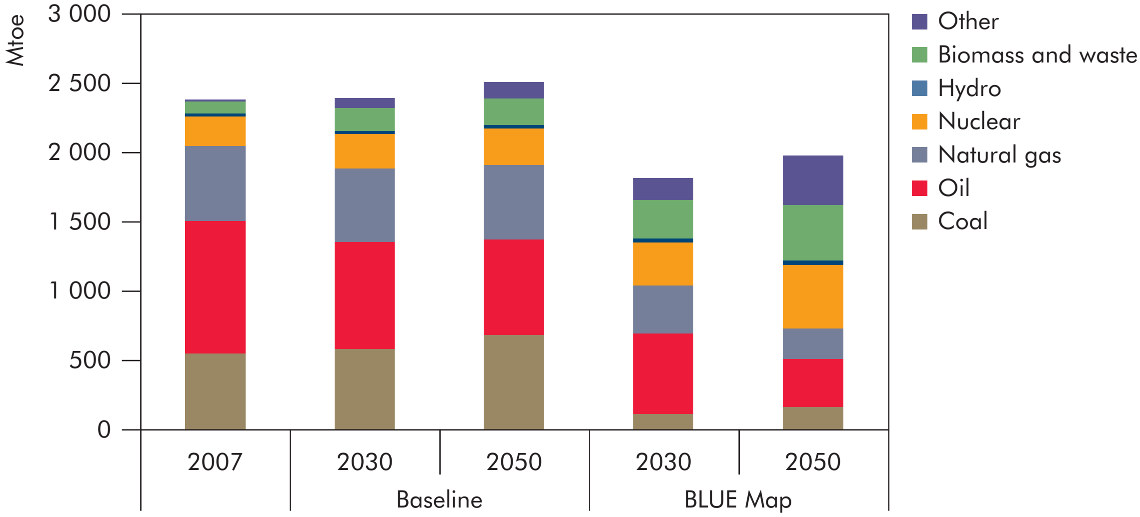
9

Energy and CO_2 emission scenarios

Total primary energy supply increases by more than 5% between 2007 and 2050 in the Baseline scenario (Figure 9.4). Nuclear and hydro remain fairly constant over the period. Coal use grows from 554 Mtoe to 686 Mtoe a year and biomass including waste grows from 82 Mtoe to 188 Mtoe a year. Oil use declines during the same period from 957 Mtoe to 686 Mtoe a year. The decrease in oil is driven mainly by increased fuel efficiency in the transport sector. Coal remains the primary energy supply source in the Baseline scenario.

In the BLUE Map scenario, TPES reduces by 17% from 2 387 Mtoe to 1 979 Mtoe between 2007 and 2050. The energy mix changes significantly, with nuclear, biomass and waste and renewables playing an increasing role. Coal, oil and natural gas all decline between 2007 and 2050.

Figure 9.4 ▶ **Total primary energy supply by fuel for the United States, Baseline and BLUE Map scenarios**



Note: Other includes non-combustible renewables and heat. Oil includes international bunkers.
Source: IEA (2009a).

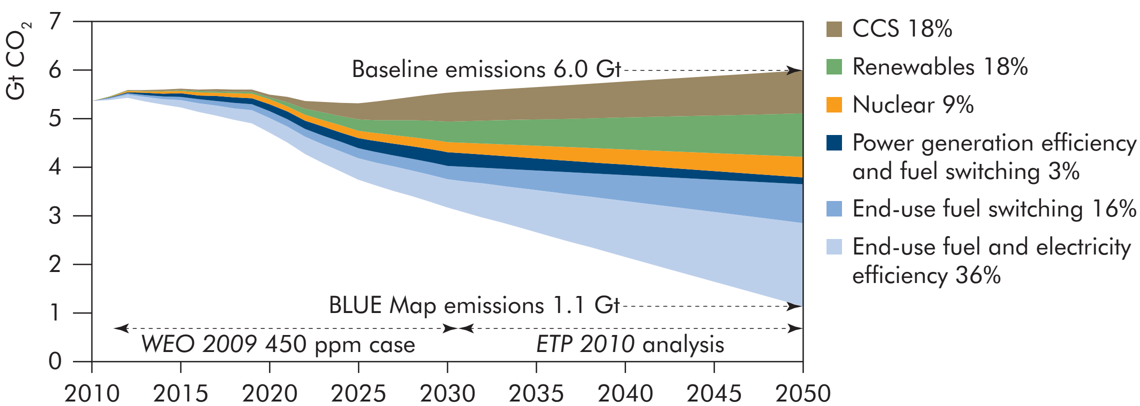
Key point

Fossil fuels decline in the BLUE Map scenario both in absolute terms and relative to growth in renewables, nuclear and biomass and waste.

Carbon dioxide abatement options

In the Baseline scenario, CO_2 emissions in the United States are estimated to grow from 5.9 gigatonnes (Gt) in 2007 to 6.0 Gt in 2050 (Figure 9.5).

Figure 9.5 ▶ **Contribution to emissions reductions in the United States**



Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

Efficiency improvements, fuel switching and CCS make the largest contributions to CO_2 reductions by 2050.

In the BLUE Map scenario, energy efficiency improvements, fuel switching and CCS enable the United States to reduce its CO_2 emissions from 5.9 Gt in 2007 to approximately 1.1 Gt by 2050. This is 81% lower than in the Baseline scenario in 2050. The largest savings come from end-use fuel and electricity efficiency (36%), end-use fuel switching (16%), CCS in power generation, industry and other transformation (18%), renewables (18%) and nuclear power (9%). All of these technologies would need to be implemented to achieve the contribution the United States needs to make to play its part in achieving a 50% reduction in global emissions by 2050.

Sectoral results

Power sector

The US electricity system today

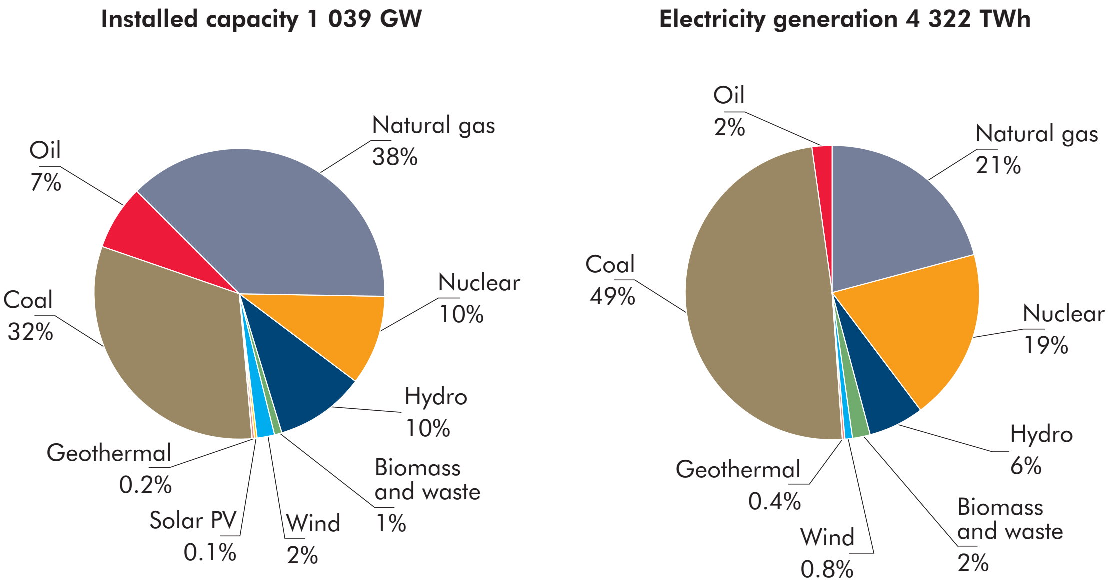
The continental United States comprises a vast area, diverse in geography, climatic conditions and energy resources. As a consequence, the availability and price of access to energy sources vary across the country. Coal is abundant and widely available across much of the country. The most prolific mining areas are the Powder River basin in Wyoming and the Appalachian range, which stretches from Alabama to Pennsylvania. An extensive infrastructure of railways, barges and trucks transports the coal from the mines to end users, making coal available in most parts of the country. Because of the high availability and relatively low cost of coal, coal-fired thermal power plants form the backbone of the United States power system, currently supplying almost half (49%) of the nation's electricity.

Natural gas is also widely available throughout the country. The main production areas are the Gulf Coast, the Mexico Gulf outer continental shelf, West Texas, Oklahoma, the Rocky Mountain region, the Appalachian basin, the Sacramento and Los Angeles basins in California and Alaska. A vast pipeline network covers most of the country and makes natural gas available to customers in virtually all parts of the country. The last few years have seen a marked increase in natural gas production as new drilling and fracturing techniques have made it possible economically to produce shale gas. Natural gas generation often serves as mid-merit or peaking generation and is often the marginal production technology, setting electricity prices. Natural gas generation comprises roughly 21% of total generation with annual totals being highly dependent on natural gas prices.

There are over 100 nuclear power stations in operation in the United States today, most of them located in the eastern parts of the country. They supply roughly 20% of the nation's electricity. Although no new nuclear power project has been undertaken since the 1979 Three-Mile Island incident, there is growing interest in constructing new nuclear plants. Currently, more than 30 new nuclear units are under consideration, with licence applications having been submitted for 22 of these by the end of 2009 to the United States Nuclear Regulatory Commission.

United States electricity utilities generated 4 322 terawatt-hours (TWh) of electricity in 2007. Of this, 21.2% was from natural gas plants, 48.9% from coal, 19.4% from nuclear, 5.8% from hydro, 1.8% from oil and 3% from renewables (Figure 9.6).

Figure 9.6 ▶ ***Electricity generating capacity and generation in the United States, 2007***



Source: IEA (2009a).

Key point

Fossil fuels continue to be the primary source of electricity generation today.

Growth in electricity consumption has been led by the commercial and residential sectors, in which electricity consumption accounts for almost three-quarters of the energy used. The industrial sector accounted for 25% of electricity use in 2007 and the transport sector a negligible amount of less than 1%.

Strong growth in the commercial buildings sector is predicated on a continued rise in service industries. Growth in the residential sector is driven by a growing population, which needs more cooling as it continues to shift to warmer regions, and by per-capita floor space increases. The EIA estimates that approximately 300 GW of new generating capacity will be needed to service this increased demand by 2030. In addition, a large part of the current installed capacity will have to be replaced and modernised over the next ten years, at the same time as significant new investment in electricity networks will be required.

In terms of capacity utilisation, in 2007 nuclear plants operated at about 90% capacity and coal plants at around 73%, indicating high levels of baseload demand. Gas has a very low capacity factor of around 22%, indicating that the role of gas in the system is to act primarily to supply medium- and peak-power demand, especially in summer. Hydro availability has been constrained in recent years by dry conditions in several regions.

Natural gas continues to be viewed as the most promising and economically feasible energy source to meet future power demand. Natural gas prices are relatively low and capital costs are lower than for other plant types. Gas-fired power plants represent about half of new capacity currently under construction, and most capacity additions over the next decade are expected to be gas-fired.

There are 12.5 GW of coal-fired plants currently under construction for entry into service between 2009 and 2011. New coal-fired plants are expected to make up more than half of all capacity additions between 2006 and 2030. The EIA's *Annual Energy Outlook 2007* estimates that demand will grow by 400 TWh between 2006 and 2012 and that 250 TWh of this demand will be met by new combined-cycle gasification turbine (CCGT) plant.

Developments in renewable power generation

Renewable electricity generation accounted in 2008 for around 9% of total electricity production, with the bulk of this (6%) coming from hydroelectric power plants. Wind generation has expanded rapidly over the past few years and accounted in 2008 for 1.3% of total electricity generation. Biomass generation, including co-firing at coal power stations, accounts for around 1% of the total. Geothermal, municipal solid waste and solar make up the balance.

Wind power is available throughout most of the country, but suitable areas with high average wind speeds are concentrated predominantly in the northern and western parts of the United States. The Pacific north-west and mid-west in particular have considerable potential for the development of wind power. The south-eastern United States, on the other hand, has relatively poor wind resources. Offshore wind resource potential is high along the coastlines and on the Great Lakes, but some areas are protected and off-limits to developers.

Insolation is stronger in the south than in the north and also generally higher in the west than in the east. The deserts of California, Arizona, New Mexico and Nevada are prime locations for solar power. Areas suitable for concentrating solar power (CSP) are mainly found in the south-west where large undeveloped land areas are available. Investments in, and installations of, photovoltaic (PV) panels are heavily influenced by the incentives offered by state governments and a significant share of PV installations are in states that are not typically considered to be sun-rich, such as New Jersey.

Sites suited for geothermal power generation are exclusively located in the western United States. Many identified sites have not yet been developed. The resource potential could be greatly expanded through enhanced geothermal systems and engineered reservoirs if this technology proves to be viable and cost-effective.

Biomass in some form is available in most of the country, but more in the east than in the west and least in the arid south-west. The availability of woody biomass is highest in the south and south-east. The power sector is in direct competition with the forestry industries for this resource and may also see competition for biomass resources from the cellulosic biofuel industry in the future.

Regional electricity supply in 2007

Because of the vast size of the continental United States, power is delivered through a series of systems, rather than through a single unified grid. Most of these systems have strong interconnections with neighbouring systems, although some are relatively isolated. The ability to transport power between and across systems is limited by infrastructure constraints. As a result there may be instances of stranded resources where a cheap and abundant resource cannot be fully used because the local demand is not large enough and the infrastructure to transport it to other markets is not in place. Tackling such infrastructure constraints has been identified as a priority by the federal government. Federal agencies have been given the additional responsibility to increase transmission infrastructures in congested corridors. But local opposition to new transmission capacity may remain an impediment to renewable power capacity expansion.

Regional differences are not merely physical but also regulatory. Electricity utilities are regulated by state utility commissions (or by local governments in the case of municipal utilities) and regulatory and market structures differ between states. Some states have been slow to deregulate their power markets and still rely on vertically integrated monopoly utilities. Others have introduced some level of competition in generation and power marketing. Wholesale markets for electricity are regulated by the FERC.

Differences in resource availability and costs, existing infrastructures, market structures and regulation mean that climate policies will vary in their regional impact. Resource availability, existing infrastructure and regulation will influence the regional cost of the power sector mitigation options. Market structures will affect the way in which policy interventions promote greenhouse gas mitigation by power producers and the regional effectiveness of individual policy measures.

Electricity transmission and distribution

The US electricity transmission grid consists of more than 200 000 miles of high-voltage (230 kilovolt [kV] and higher) transmission lines. The national average price of electricity increased by 19.7% from US 7.6 cents per kilowatt hour (kWh) in 2004 to US 9.1 cents per kWh in 2007. Much of this increase is attributable to increases in fuel costs as well as the expiration of transitional rate caps in a number of states that had introduced retail competition into their elecricity markets.

The US bulk power system is based on three major interconnected power grids within which regional transmission organisations and independent system operators operate transmission systems. Virtually all utilities are interconnected to at least one other utility by these three major grids. The exceptions are in Alaska and Hawaii. Two of these major grids are linked to Mexico and two are completely integrated with the Canadian grid or have links to the Québec Province power grid.

The bulk power system makes it possible for utilities to engage in wholesale electric power trades. These enable utilities to reduce power costs, to increase power supply options and to improve reliability. With open access and the deregulation of wholesale markets, cross-border trade has become more significant in meeting domestic electricity requirements. United States international trades are mostly imports, predominantly from Canada.

The management of the interconnected power systems is the responsibility of the NERC. The NERC has eight regional entities which are responsible for overall co-ordination of bulk power policies that affect the reliability and adequacy of electricity service in their areas. They also regularly exchange operating and planning information among their member utilities.

In 2008, 14 states[3] operated retail markets in which customers could choose alternative power suppliers. Eight other states have suspended deregulation or amended laws and regulations governing competition and energy procurements by regulated utilities because of the lack of competition for residential customers and the substantial rate increases that have occurred or were anticipated to occur as a result of the introduction of retail competition. Other states have retained retail competition while relaxing their controls on vertical integration between generation and supply, or created new government-owned energy suppliers.

The Energy Independence and Security Act of 2007 provided a legislative framework for transmission system modernisation, including smart grid expansion, tax incentives for investment, and federal funding for R&D.

Renewable energy sources other than conventional hydro accounted for the largest proportion of capacity additions for the first time in 2007. Wind, solar and geothermal power capacity is constrained to specific and often remote parts of the country. As a result, these capacity additions have created a need for new high-voltage transmission lines to transport their output to markets. In response, merchant transmission companies are being formed to serve renewable energy suppliers and their wholesale customers.

Electricity demand scenarios

Electricity consumption in the United States has increased by 7% between 2000 and 2007, driven by strong residential and commercial demand. The final electricity demand projections by end-use sectors in the Baseline and BLUE Map scenarios are shown in Table 9.4.

In both scenarios, electricity consumption is expected to continue to rise as the US economy recovers from the current recession and as consumer demand and industrial productivity recover. In the Baseline scenario in 2050, final electricity consumption is 34% higher than in 2007. In the BLUE Map scenario, it increases by 7% compared to 2007. This is 20% lower than the Baseline scenario level of consumption. The reduction is achieved by higher levels of industrial energy efficiency and more efficient lighting and air conditioners in the building sector, and by the deployment and commercialisation of electric vehicles (EVs). Electric vehicles represent a 33% share of the sale of new vehicles in 2050. As a result of the demand from EVs offsetting reductions in electricity consumption in other sectors, electricity consumption in 2050 is higher in the BLUE Map scenario than in 2007.

3. Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Ohio, Michigan, Illinois, Texas and the District of Columbia.

Table 9.4 ▶ Current and projected final electricity demand in the United States by end-use sector

		Baseline		BLUE Map	
(TWh/yr)	**2007**	**2030**	**2050**	**2030**	**2050**
Industry	929	865	812	656	611
Transport	8	19	26	162	665
Residential	1 392	1 722	1 956	1 190	1 285
Commercial	1 337	2 047	2 319	1 559	1 530
Agriculture and other	160	23	30	17	18
Total	**3 826**	**4 676**	**5 143**	**3 584**	**4 109**

Sources: IEA (2008a); IEA analysis.

Electricity generation scenarios

Installed capacity in the United States in 2007 amounted to 1 039 GW. Total capacity in 2050 is projected to be broadly similar in both the Baseline and BLUE Map scenarios with capacities of 1 548 GW and 1 477 GW, respectively (Table 9.5). In the Baseline scenario, fossil fuels represent 72% of total generation in 2050. In the BLUE Map scenario this is 22%. Additionally, in the BLUE Map scenario, 68 GW of coal capacity and 95 GW of gas capacity are fitted with CCS, 225 GW is from nuclear, and 409 GW is from renewables in 2050.

Table 9.5 ▶ United States power generation mix and capacity in the Baseline and BLUE Map scenarios, 2050

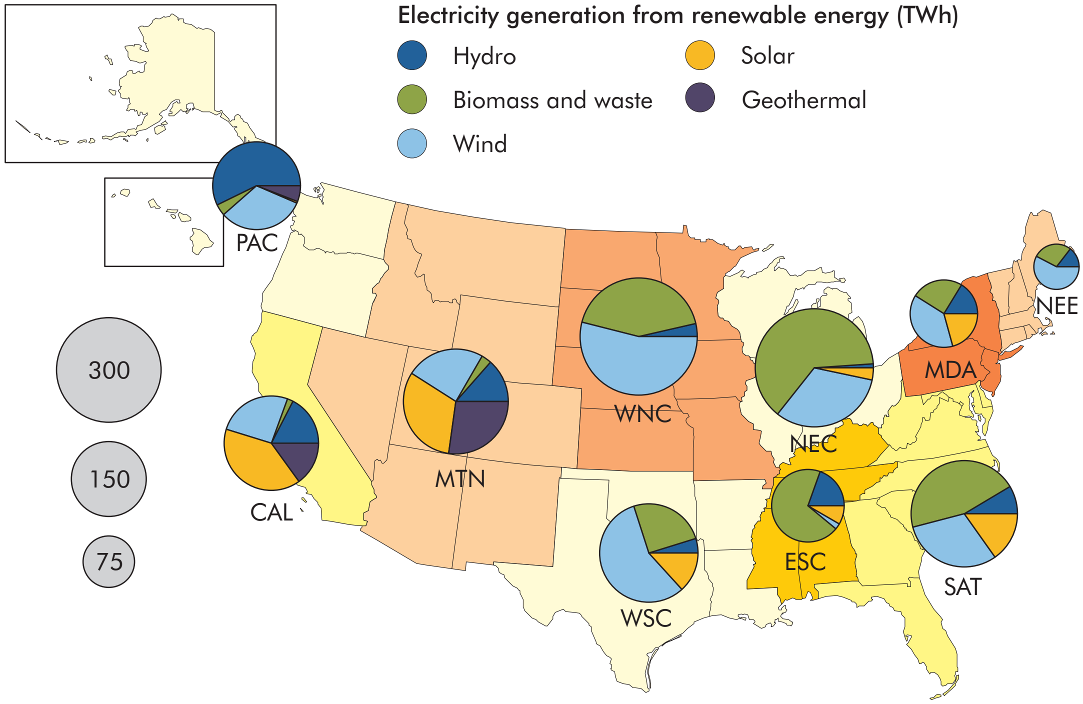
	Power generation share		Capacity	
	Baseline (%)	**BLUE Map** (%)	**Baseline** (GW)	**BLUE Map** (GW)
Coal	57	0	497	0
Coal with CCS	0	10	0	68
Gas	14	5	582	432
Gas with CCS	0	6	0	95
Biomass	2	12	14	84
Oil	1	1	87	86
Nuclear	12	35	93	225
Hydro	5	6	78	78
Geothermal	0	2	4	16
Solar	3	7	85	132
Wind	6	16	108	261
Total	**100**	**100**	**1 548**	**1 477**

Decarbonising the power sector in the United States

Decarbonising the US power system will require higher levels of renewable and nuclear power generation capacity and CCS for coal, gas and bio-fired plants. It will take time to build up the country's nuclear and renewable power capacity. As a result, coal will likely continue to account for a large share of the US electricity mix for the next several decades.

In the BLUE Map scenario, a more radical rebuilding of the capital stock results in power sector carbon emissions declining by over 90% compared to 2010 levels. Virtually all existing generation assets are replaced by 2050. The generation mix is dominated by low-carbon technologies such as wind, solar, biomass and nuclear (Figure 9.7). By 2050, 43% of total generation is renewable and 35% nuclear. Steam coal generation is phased out by 2050. This leaves a demand for new baseload generation, which in the BLUE Map scenario is largely met by a doubling of the installed capacity of nuclear generation. Some integrated gasification combined cycle (IGCC) plants with CCS are also built. Gas- and coal-fired generation with CCS accounts for about 16% of total generation.

Figure 9.7 ▶ *Renewable power generation mix by region in the United States, 2007*



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

US 10-Region MARKAL description: PAC (Pacific); CAL (California); MTN (Mountain); WNC (West North Central); WSC (West South Central); NEC (North East Central); ESC (East South Central); NEE (New England); MDA (Mid Atlantic); SAT (South Atlantic).

Key point

The US power sector will change significantly by 2050.

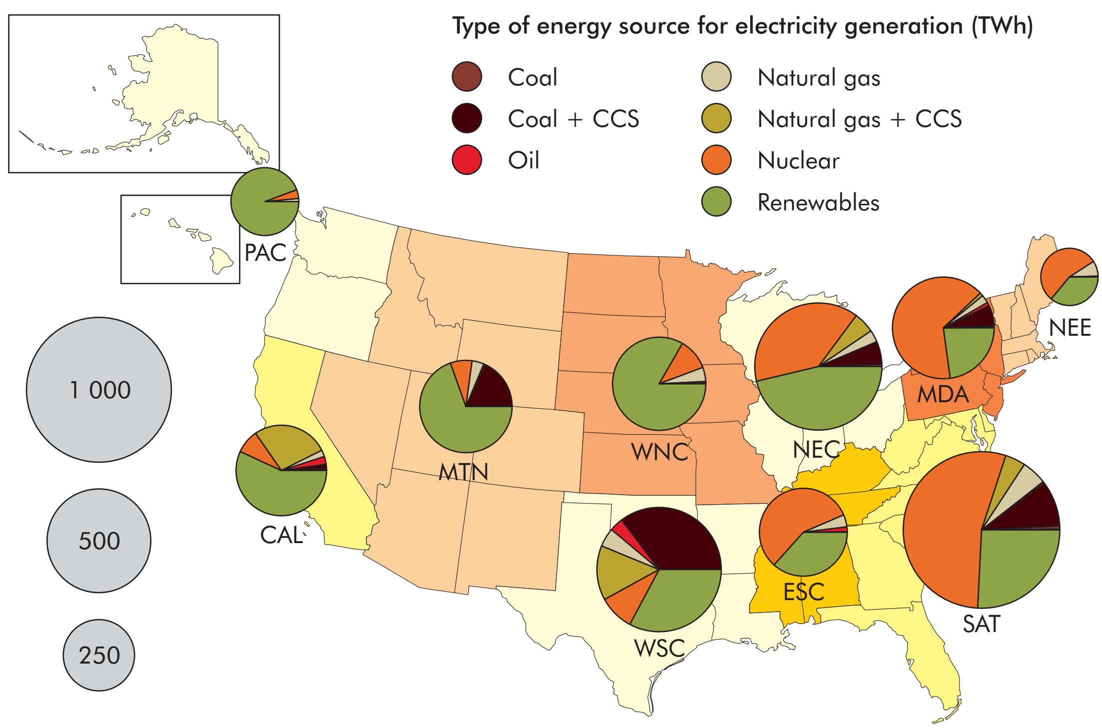
Wind power capacity increases by a factor of six between 2007 and 2050 in BLUE Map scenario. Solar generation also expands rapidly from a virtually negligible contribution today to 7% in 2050. In the BLUE Map scenario, large-scale central solar plants tend to be concentrated in the south-west. Distributed rooftop PV installations are more widely dispersed across the United States, but also particularly strongly represented in the western and south-western parts of the country (Figure 9.8).

The geothermal resource base remains relatively underdeveloped in all scenarios. Conventional resources are developed in the BLUE Map scenario, but there is little or no development of enhanced geothermal systems.

The high share of non-dispatchable renewable generation will require a significant amount of electricity storage both to cover for a shortfall in generation when variable resources are unavailable and to ensure that electricity generated during times of high production does not go to waste. In the BLUE Map scenario, 150 GW of storage is installed by 2050 in addition to the 22 GW of pumped storage plants that are currently in service.

The large increase in more dispersed renewable generation will also require significant upgrade and extension of the transmission network. As solar and wind expand, additional natural gas-fired generating capacity will be required to firm up capacity and provide enough flexibility to ensure system stability. The concentration of renewable capacity in areas which may have relatively low levels of local demand is likely to lead to additional stranded resources that will need new transmission capacity to get to market.

Figure 9.8 ▶ Power generation mix by region in the United States in the BLUE Map scenario, 2050



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

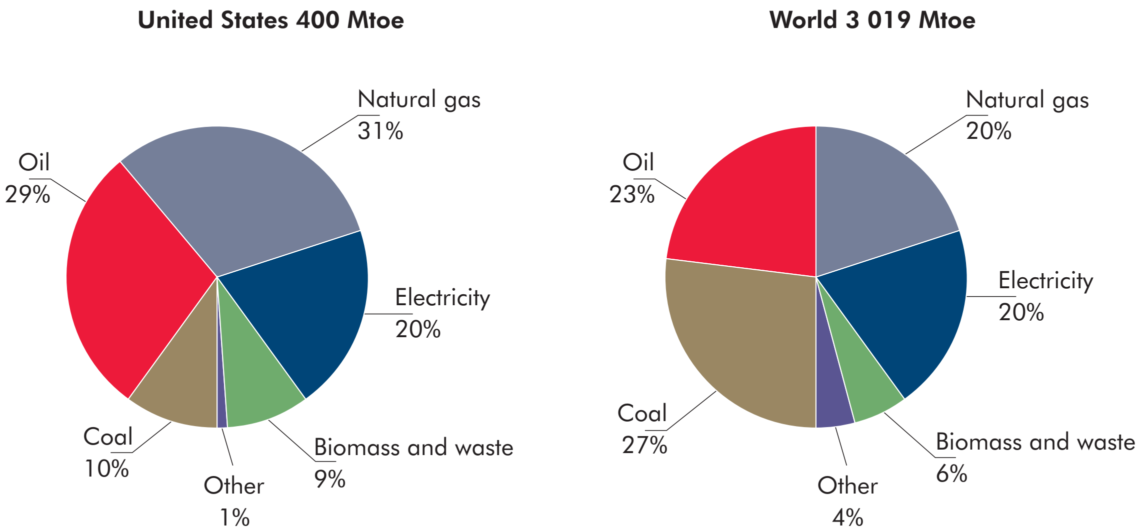
Key point

Different regions will produce markedly different amounts of renewable generation from very different mixes of inputs by 2050.

Industry sector

Industry accounted for the use of 400 Mtoe in 2007, 25% of total US final energy use. The United States is the third-largest industrial energy consumer, accounting for 13% of global industrial energy use. The final energy mix of industry is dominated by oil and natural gas (Figure 9.9). Industry accounts for 24% of total final electricity consumption. Electricity represents 20% of industrial final energy use.

Figure 9.9 ▶ Industrial final energy mix in the United States and in the world, 2007



Note: Includes coke ovens, blast furnaces and petrochemical feedstocks.
Sources: IEA (2009a and 2009b).

Key point

The United States continues to rely on fossil fuels in the industrial sector.

Table 9.6 ▶ Industrial production, energy use and CO_2 emissions in the United States, 2007

	Production (Mt)	Reported energy use (Mtoe)	CO_2 emissions (Mt CO_2)
Industry sector		400	690
Iron and steel	98	31	91
Chemicals and petrochemicals	97	178	250
Aluminium	10	6	3
Cement	97	11	87
Pulp, paper and printing		57	62
Paper and paperboard	*84*		
Pulp	*52*		
Recovered paper	*46*		
Other		117	197

Notes: Iron and steel includes energy use for coke-making. The energy data for chemicals and petrochemicals include feedstocks. The table has been compiled from a mixture of top-down and bottom-up sources and so the totals may not match.
Sources: IEA (2009a and 2009c), IEA analysis.

The United States is the largest producer of chemicals and pulp and paper in the world, and the third-largest producer of steel and cement (Table 9.6) With over half of industrial energy use and approximately 45% of industrial direct emissions attributed to the chemicals and pulp and paper sectors, reducing industrial energy use and CO_2 emissions in the United States will depend significantly on action in these sectors. Realising the potential offered from energy efficiency will require the diffusion of current best available technology (BAT) in both sectors.

Energy and CO_2 savings potential with best available technologies

Significant energy and CO_2 savings in US industry are possible through the implementation of currently available BATs. It is estimated that the application of BATs could reduce final energy use by between 18% and 36% in different sectors. Total estimated savings for the five sectors analysed is 92 Mtoe per year, equivalent to 23% of energy use in industry in 2007 and 6% of final energy consumption in the United States.

For chemicals, cement and pulp and paper, the United States has a higher-than-average potential to achieve savings, while for aluminium and iron and steel the potential is less than the global average. Typically 10% to 30% efficiency gains seem feasible, on account of the gap between United States average energy use and BATs. Part of this gap will be closed by investment in new capital stock as old capacity is scrapped and replaced by current BATs.

It will not be possible to achieve these savings immediately. The rate of implementation of BATs in practice depends on a number of factors, including capital stock turnover, relative energy costs, raw material availability, rates of return on investment and regulation.

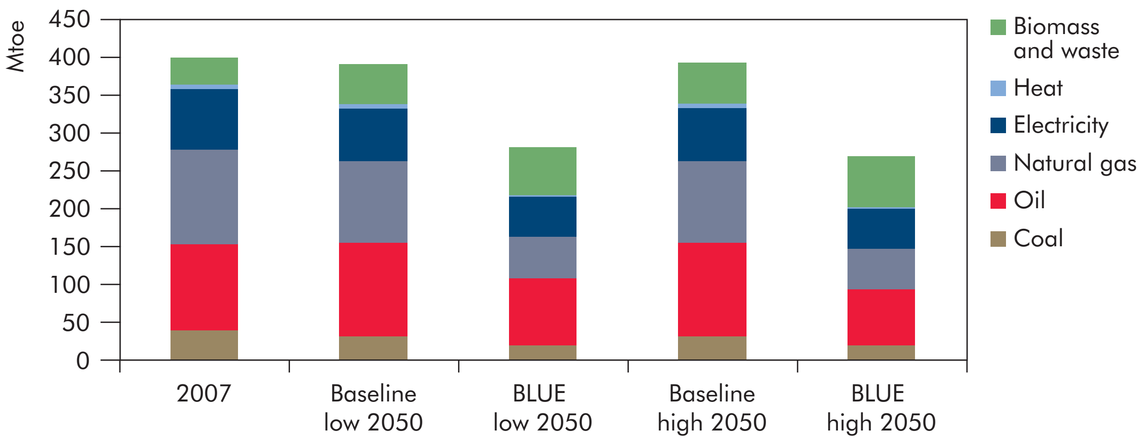
Scenarios for industrial energy use and CO_2 emissions

As a result of increased energy efficiency measures and some reductions in industrial production, energy use in US industry declines slightly from current levels in the Baseline scenarios. In the BLUE scenarios, even greater levels of energy efficiency are assumed. These enable a larger reduction in industrial energy use, resulting in a decrease of 30% to 33% in the BLUE low- and high-demand scenarios compared to 2007 levels and of 28% to 31% compared to the Baseline scenario (Figure 9.10).

In the Baseline low- and high-demand scenarios, US industry emissions are 5% lower in 2050 than in 2007. Total industrial CO_2 emissions fall from 690 Mt CO_2 in 2007 to approximately 658 Mt CO_2 in Baseline 2050 (Table 9.7). In the BLUE scenarios, total industrial CO_2 emissions fall even further to 242 Mt CO_2 to 283 Mt CO_2 in 2050, a reduction of 63% to 67% as against the comparable Baseline scenario levels.

Energy efficiency offers the largest potential to reduce industrial CO_2 emissions (Figure 9.11), representing almost half (48%) of all emissions reductions in the BLUE scenarios. Fuel and feedstock switching, together with higher levels of recycling and energy recovery, contribute another 23%. The remaining 28% is accounted for by CCS.

Figure 9.10 ▶ **Industrial energy use in the United States, Baseline and BLUE scenarios**



Sources: IEA (2009a); IEA analysis.

Key point

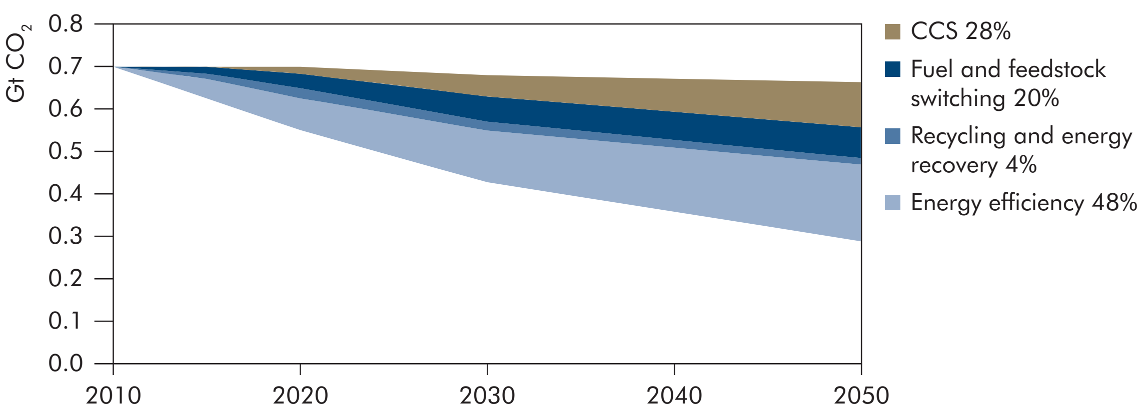
Energy use in US industry declines significantly in the BLUE scenarios.

Table 9.7 ▶ **Direct energy and process CO_2 emissions by industry in the United States**

Mt CO_2	2007	Baseline low 2050	Baseline high 2050	BLUE low 2050	BLUE high 2050
Aluminium	3	6	7	5	5
Iron and Steel	91	95	97	26	22
Chemicals	250	335	329	155	134
Cement	87	101	104	58	43
Pulp and paper	62	47	48	5	2
Other	197	74	74	34	36
Total	**690**	**657**	**658**	**283**	**242**

Sources: IEA (2009a and 2009c); IEA analysis.

Figure 9.11 ▶ **Options for reducing direct CO_2 emissions from United States industry**



Key point

Energy efficiency offers the most important opportunity to limit growth in industrial CO_2 emissions.

9

Best available technologies offer significant opportunities for improvement in industrial energy efficiency in the United States. Further reductions in greenhouse-gas emissions from industry can be realised through reductions in process-related emissions, fuel switching to lower-carbon fuels, and integrated pollution prevention and material efficiency improvements (Price and Worrell, 2004).

Many energy-intensive industries in the United States are relatively inefficient when compared to their counterparts in Europe, Japan, Canada, or to rapidly industrialising countries such as South Korea and China. The US DOE's Industrial Technologies Program has established a goal to reduce industry energy intensity by 25% in ten years and to contribute to an 18% reduction in carbon intensity by 2012.

The DOE provides national leadership through collaborative technology R&D and the development of best energy management practices, promotes better energy management in industry, and encourages investment in energy efficiency through strategic partnerships with states, utilities, businesses and the financial community. The DOE's Industries of the Future (IOF) programme has worked with ten industrial sectors to identify the most promising technologies and practices to receive further R&D funding. Each sector has identified around 100 to 150 technologies or processes to be funded. The DOE expects to save 50 Mtoe of energy and avoid 135 Mt CO_2-eq by 2020.

Buildings sector

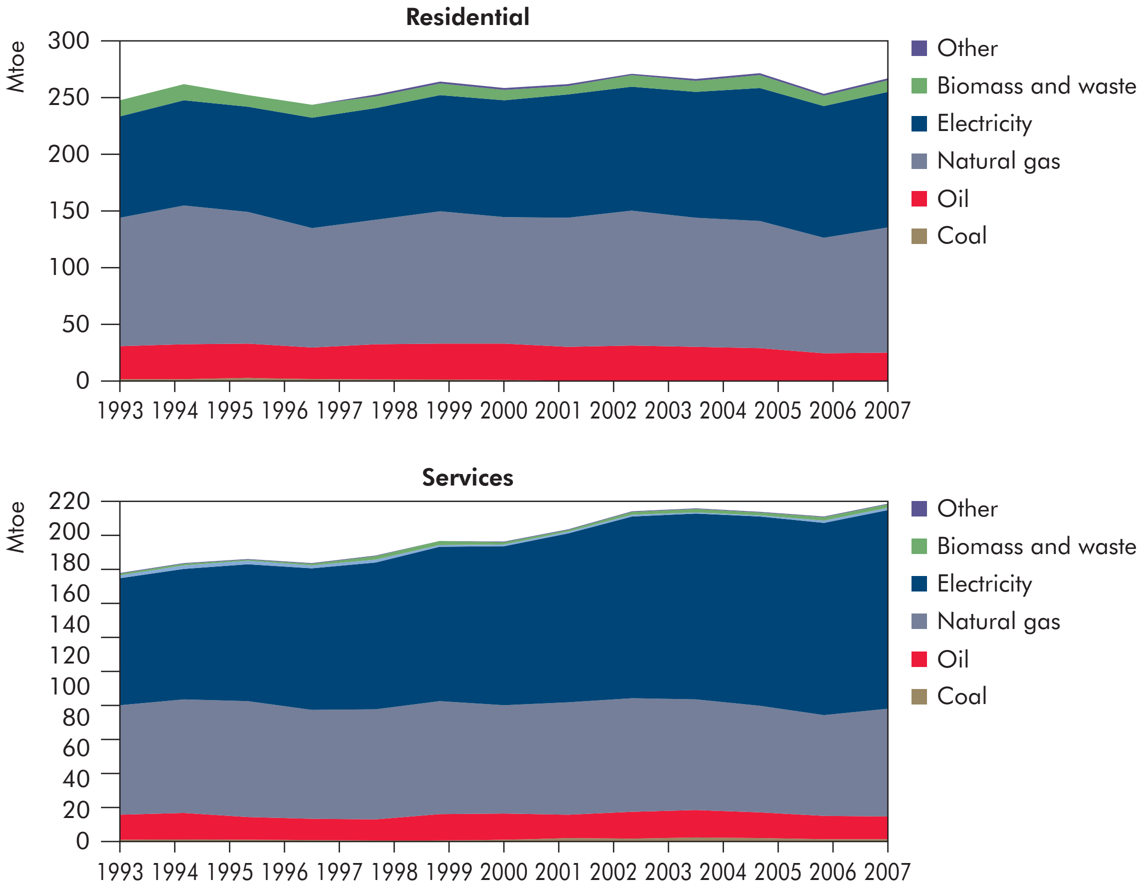
The residential and service sectors account for about 30% of total final energy consumption in the United States, somewhat less than the global average. Including energy consumption from agriculture, fishing, forestry and other non-specified uses raises this to 32%.[4]

Since 1995, the consumption of the residential sector has grown at 0.6% a year from 248 Mtoe to 267 Mtoe in 2007. Consumption in the service sector has grown by 1.9% a year to 218 Mtoe in 2007 (Figure 9.12). The growing importance of electrical end uses is underlined by the growth in consumption of electricity at 3.1% a year between 1995 and 2007, with electricity accounting for 49% of energy consumption in 2007, up from 41% in 1990.

The consumption of energy for space heating has remained relatively stable over time owing to increased demand being offset by improved building shells and heating system efficiencies. The share of energy consumption taken by appliances and lighting (excluding air-conditioning) has increased from 17% in 1978 to 26% in 2006 (US DOE, 2009). In the service sector, electrical end uses, excluding air-conditioning, account for around 32% of the sector's energy use. Including air-conditioning raises this to 41%. Electrical end uses are projected to continue to grow in the future and remain the main driver of energy consumption growth in the buildings sector as a whole.

4. In this section, the buildings sector is defined as including the residential, service and other non-specified sectors. "Other non-specified" activities are included in the service sector, which is consistent with the treatment in the *World Energy Outlook*. In 2007, "other non-specified" accounted for 14 Mtoe.

Figure 9.12 ▶ *Residential and service sectors energy consumption by fuel in the United States*



Source: IEA (2009a).

Key point

Electricity accounts for almost half of residential and services energy consumption and is the only energy commodity to have shown significant growth since 2000.

The United States has a very diverse building stock, with a significant proportion of older homes. The number of households has grown from 94 million to 113 million between 1990 and 2006, and the average number of persons per household has declined from 2.9 to 2.7 in that time. Single-family dwellings make up 69% of households, multi-family dwellings 25% and mobile homes 6%.

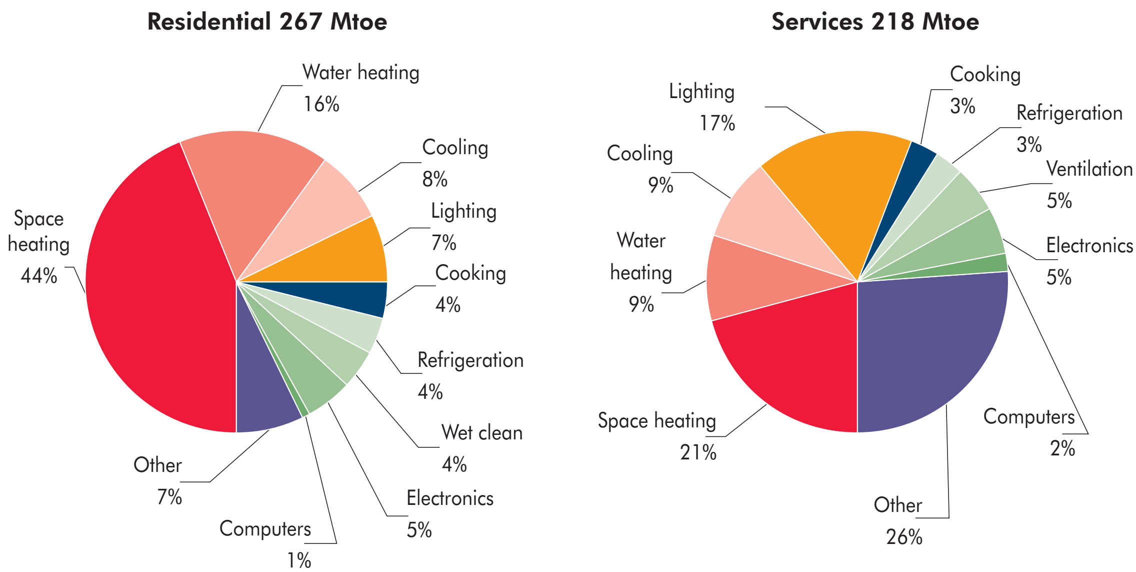
Energy consumption by end use

The estimated breakdown of energy consumption by end use is presented in Figure 9.13. In the residential sector, space heating dominates, accounting for 44% of energy consumed. The high growth in electricity consumption means that the electrical end-use share of the total is growing.

9

In the service sector, space heating represents around one-fifth of consumption, while electrical end uses represent a higher proportion of energy consumption. Lighting is particularly important, consuming almost as much energy as space heating.

Figure 9.13 ▶ Residential and service sectors energy consumption by end use in the United States, 2007



Source: US DOE (2009).

Key point

Space heating and cooling consume over half of all energy consumption in the residential sector, and lighting and space cooling and heating consume nearly half the energy consumed in the service sector.

Scenarios for buildings energy use and CO_2 emissions

The US population is projected to grow from around 306 million in 2007 to around 404 million in 2050. The number of households will grow even faster, as the trend towards fewer persons per household continues. Total households will grow to 141 million in 2030 and to 161 million in 2050. In the service sector, floor area is assumed to grow by 1.1% a year from around 6 950 million square metres (m^2) in 2006 to 11 330 million m^2 in 2050.

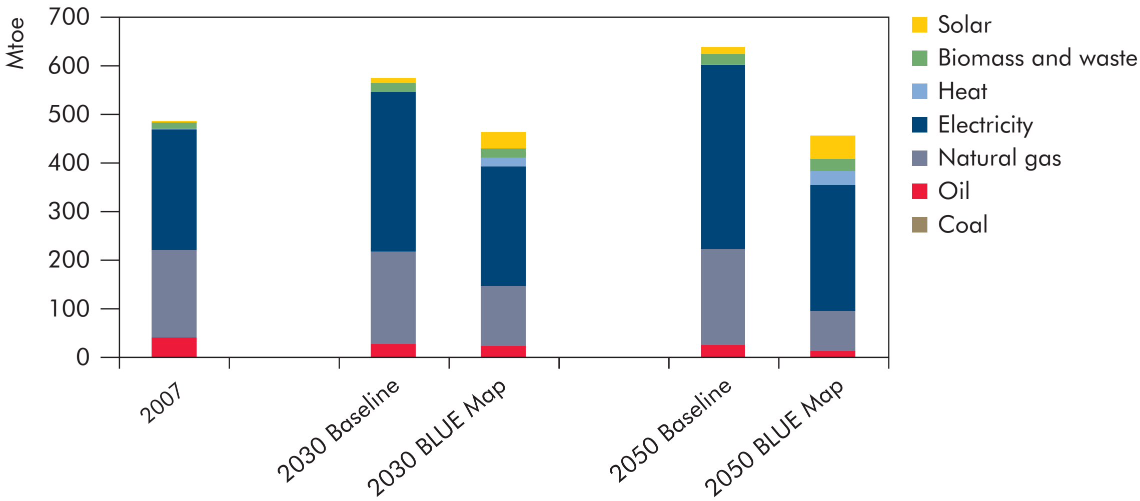
The Baseline scenario

The US buildings sector is one of the most energy-intensive of the 19 IEA countries for which good data are available. However, energy consumption is on a downward trend, with consumption declining from 45 gigajoules (GJ) per household in 1990 to 42 GJ per household in 2006.

The United States has a range of policies and programmes in place to address energy consumption in the residential and service sectors. These include the Energy Star labelling programme, the DOE Appliance Standards Program and the Buildings Technologies Program (IEA, 2008). The Recovery Act included USD 16.8 billion for the Office of Energy Efficiency and Renewable Energy (Pew Center, 2009). This included a USD 5 billion allocation for the DOE's weatherisation programme over two years to help low-income households improve the energy efficiency of their homes. These programmes have been taken into account in the Baseline scenario.

Energy consumption in the residential and service sectors increases by 32% between 2007 and 2050 in the Baseline scenario (Figure 9.14). The use of solar energy grows the most rapidly at 4.4% a year, followed by electricity at 1.0% a year, heat at 0.6% a year and gas at 0.2% a year. Coal consumption declines by 2.7% per year and oil by 1.0% per year.

Figure 9.14 ▶ ***Energy use in the buildings sector in the Baseline and BLUE Map scenarios in the United States***



Key point

Energy efficiency and fuel switching reduce energy demand in buildings in the BLUE Map scenario.

The BLUE Map scenario

In the BLUE Map scenario, energy consumption in the residential and service sectors is 29% below the Baseline level in 2050. Energy consumption reduces to slightly below 2007 levels in 2015 and continues to decline slightly between 2030 and 2050. Despite growing energy service demand, energy efficiency measures and fuel switching achieve most of these savings. Gas consumption reduces by the most in percentage terms (58%) and absolute terms (115 Mtoe) as the result of improved building shell performance for new and renovated dwellings and improved heating system efficiency, and as the use of CO_2-free fuel sources such as hydrogen combined heat and power (CHP), solar thermal and heat pumps increases for heating. Electricity demand reduces by slightly less in absolute terms (126 Mtoe), representing a 34% reduction below the Baseline scenario level in 2050. Oil consumption is also significantly reduced in percentage terms in the BLUE Map scenario. The use of solar thermal energy for space and water heating increases significantly to 47 Mtoe in 2050, a level more than three times higher than in the Baseline scenario in 2050.

Residential energy consumption accounts for slightly more than half of the total savings below the Baseline, as the larger share of space heating in the residential sector allows slightly larger cost-effective savings than in the service sector.

In the residential sector, 45% of the savings come from space and water heating. For space heating, the savings stem from improvements in the performance of the building shell, including a gradual tightening of the building codes for new buildings towards very low space heating requirements in cold climate states as well as the renovation of around 60% of the existing dwelling stock by 2050 to a low-energy standard. The use of solar water heating and heat pumps for both space and water heating also contribute significant savings. Electrical end uses account for around half of the savings. The reduction in cooling demand is achieved through a mixture of building shell improvements and cooling system improvements. The coefficient of performance (COP) of room air conditioners, for instance, approximately doubles to reach seven by 2050.[5]

In the service sector, water and space heating account for less than one-fifth of the savings. Very significant savings are achieved in the electricity-intensive end uses of cooling, lighting and other miscellaneous loads.

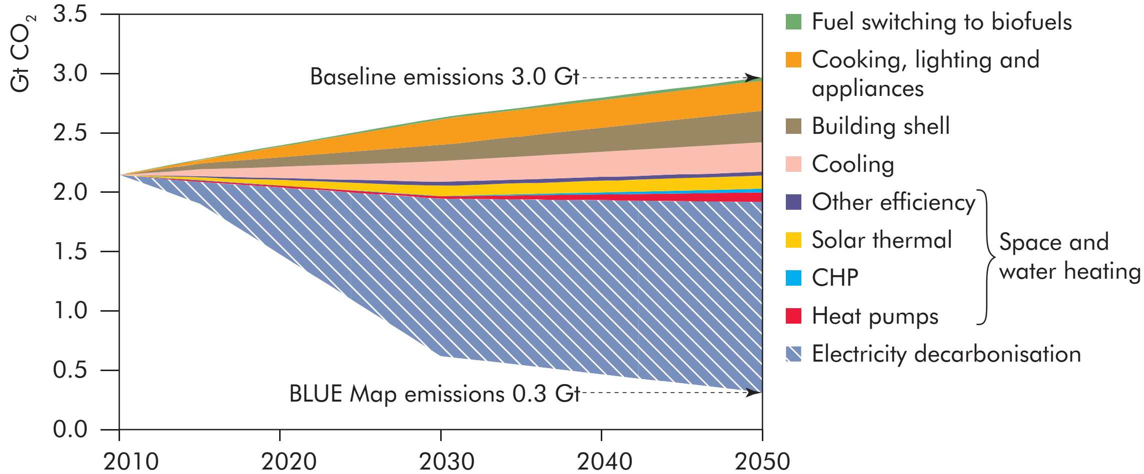
Buildings-sector CO_2 emissions are 35% lower in the BLUE Map scenario in 2050 than in the Baseline scenario. CO_2 emissions from oil are reduced by 50%, those from gas by 59% and those from electricity by 31%. Overall CO_2 emissions are reduced by 1 061 Mt CO_2 below the Baseline level in 2050, with 748 Mt CO_2 of this reduction attributable to reduced consumption of electricity. Electricity use is marginally increased from what it otherwise would be by the switching from fossil fuels to electricity for cooking and water and space heating in the BLUE Map scenario, as the substantial decarbonisation of the electricity sector allows electrification to become an increasingly effective abatement option.

Space and water heating accounts for around 24% of the reduction in CO_2 emissions below the Baseline scenario in 2050 (Figure 9.15). The assumed continuous tightening of building codes and standards results in accelerated savings after 2030. Important contributions are also achieved by solar thermal, heat pumps and CHP district heating. Energy efficiency improvements in lighting, appliances and miscellaneous end uses account for 24% of the reduction below the Baseline level.

5. The COP of a heat pump is the ratio of useful energy output (heat or cold) to energy input (typically electricity).

The CO_2 emissions reductions from cooling are around 31% of the total, with around two-thirds coming from improvements in the efficiency of heating, ventilation and air-conditioning (HVAC) systems, and the balance from improvements in building shells and design, including the increased use of shading and active shutters, reflective coatings and insulation.

Figure 9.15 ▶ Contributions to reductions in CO_2 emissions in the buildings sector in the United States in the BLUE Map scenario



Key point

Carbon dioxide savings accelerate from 2015 onwards.

9

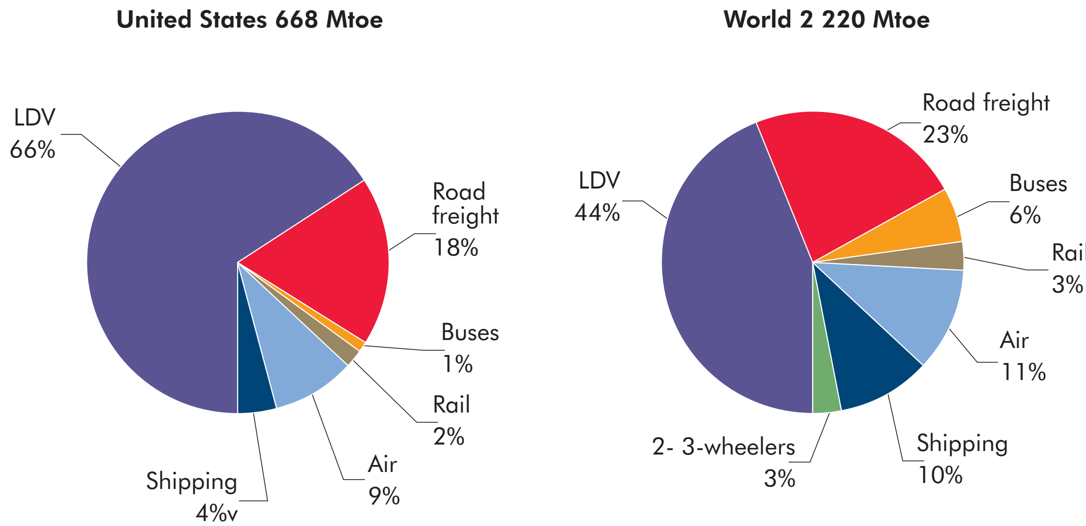
Transport sector

In the United States, the transport sector used 668 Mtoe in 2007,[6] accounting for 40% of total final energy used in the country. This share is large compared to other OECD countries. Light-duty vehicles account for nearly two-thirds of transport energy use, with freight trucks and air travel accounting for most of the rest (Figure 9.16).

A breakdown of transport indicators by mode, including activity, intensity and fuel use variables is shown in Table 9.8. The United States has a higher share of passenger travel by LDVs (82%) than any other country or region, with air travel accounting for most of the rest (14%). For freight, the United States has an almost equal split between trucks and rail in terms of tonne-kilometres (tkm). Most other countries, except Russia and China, have much greater tkm shares for trucks than rail. This suggests that rail freight has particular benefits over long distances.

6. Includes pipelines and international bunkers.

Figure 9.16 ▶ Transport sector final energy use by mode in the United States and in the world, 2007



Notes: Freight shipped by air rail, road and water includes an estimate of international trips starting from the United States. Energy use for pipeline transport is excluded.

Sources: IEA (2009a and 2009b); IEA analysis.

Key point

Light-duty vehicles in the United States use a far higher share of transport energy than the world average.

The average energy intensity per passenger-kilometre (pkm) for LDVs is similar to that for air, and much larger than that for buses and rail. For freight, trucks are much more energy-intensive than rail. Although long-haul trucks are much more efficient than other types of trucks, a shift even from long-haul trucks to rail would achieve significant energy efficiencies.

Table 9.8 ▶ Transport energy and CO_2 indicators in the United States, 2007

	Passenger travel	Freight travel	Stock average energy intensity		Fuel use	Passenger	Freight
	(billion pkm)	(billion tkm)	(MJ/pkm)	(MJ/tkm)	(Mtoe)	(Mt CO_2)	(Mt CO_2)
LDVs	5 879		3.1		442	1 484	
2- 3-wheelers	19		1.6		1	3	
Buses	234		1.2		7	24	
Freight trucks		1 426		3.6	122		429
Rail	36	1 848	0.6	0.2	10	2	36
Air	1 001		2.4		57	200	
Water		n.a.		n.a.	29		108
Total/average	**7 169**	**3 274**	**3.0**	**1.7**	**668**	**1 709**	**578**

Note: In the totals row, averages are provided for intensity figures and are weighted across modes.
Sources: IEA (2009d); IEA analysis.

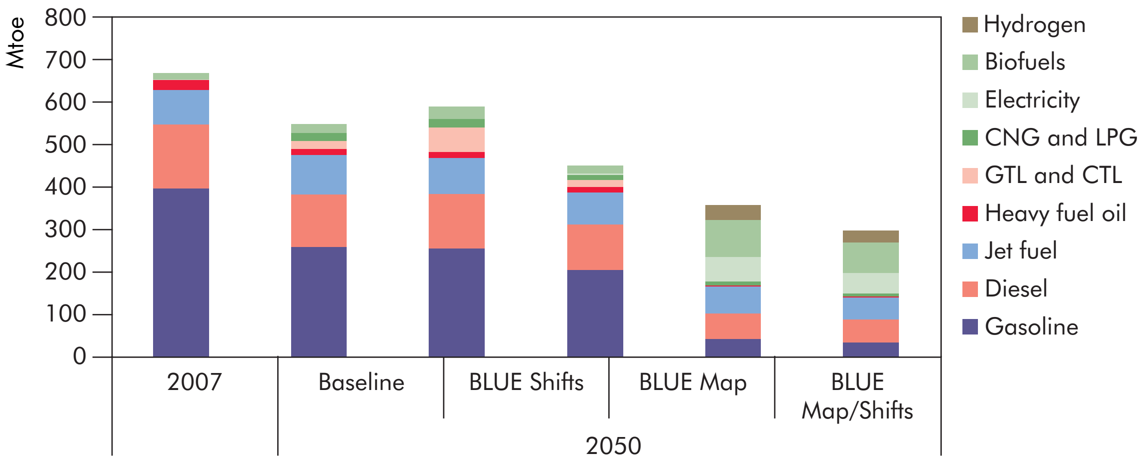
Scenarios for transport energy use and CO_2 emissions

Baseline scenario

Given current high levels of travel per capita and relatively energy-intensive vehicle stocks in the United States, there is considerable scope to save fuel in transport. In the Baseline scenario, transport energy use is roughly flat between 2010 and 2050, with a slight decrease to 2030 as a result of a planned tightening of CAFE standards and a slight increase thereafter (Figure 9.17).

By mode, the biggest growth in the Baseline scenario is in air travel. Light-duty vehicle energy use declines slightly over time. As in other regions, the availability of conventional oil declines after 2030, and increasing amounts of unconventional oil, synthetic fuels such as gas-to-liquids (GTL), coal-to-liquids (CTL) and biofuels are used.

Figure 9.17 ▶ United States transport energy use by fuel in the Baseline and BLUE scenarios



Source: IEA Mobility Model.

Key point

United States energy use is expected to remain roughly flat in the Baseline scenario.

The BLUE Map scenario: technological pathways for the United States

The BLUE Map scenario for US transport includes strong efficiency improvements for all types of internal combustion engine (ICE) vehicles and the aggressive adoption of low-CO_2 alternative fuels. The current average on-road fuel economy of US LDVs at about 11 l/100 km (or 21 mpg) is among the most energy-intensive in the world. New cars and light trucks currently average about 8.4 l/100 km (or 28 mpg).

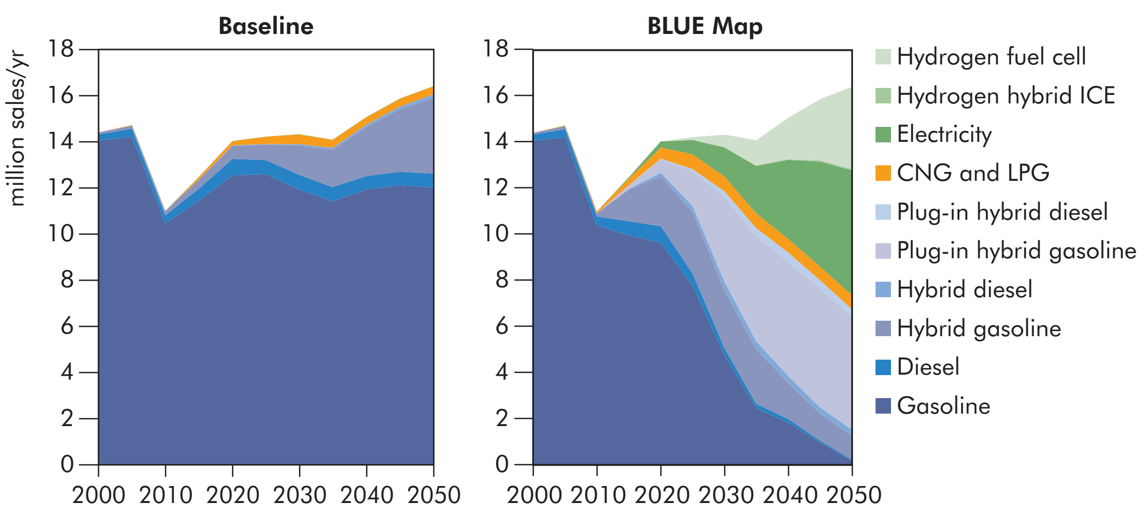
The target improvement under the new CAFE rules is 6.6 l/100 km (35.5 mpg) by 2016 (US EPA, 2009). This is about the level achieved today in some of the most efficient countries in the world such as France and India. This improvement is included in the Baseline scenario, with fuel economy then remaining fairly flat from 2016 onwards. The BLUE Map scenario assumes that this CAFE standard is further tightened after 2016 so that by 2030 the average efficiency of the LDV stock reaches 4.2 l/100 km (56 mpg).

Few advanced-technology vehicles penetrate the market in the Baseline scenario. In the BLUE Map scenario, EVs and plug-in hybrid electric vehicles (PHEVs) begin to be sold in the United States around 2010 and reach significant volumes by 2015. By 2020, hybrid vehicles reach a quarter of sales and PHEVs also reach sales of over one million by that year. Electric vehicles reach sales of one million a year by 2025 and are widespread among the LDV fleet by 2030. Electric vehicles penetrate the market mainly in the small- and medium-car segments and PHEVs penetrate mainly in the larger-car segments (Figure 9.18).

By 2030, significant numbers of fuel-cell vehicles (FCVs) also begin to penetrate the market, and by 2050 nearly all new LDV sales are PHEVs, EVs and FCVs. In that year, very low-CO_2 electricity and hydrogen account for over 80% of the fuel used by LDVs.

Similar patterns of development occur in trucks. Electrification is limited largely to urban delivery vehicles. Long-haul vehicles remain predominantly diesel with a small penetration of natural gas fuel in the near term and fuel cells in the longer term. Biofuels become increasingly important in achieving CO_2 reductions for diesel trucks. Advanced, low-greenhouse gas biodiesel accounts for about 30% of truck fuel by 2050. By 2050, similar middle-distillate advanced biofuels also account for around 30% of fuel for rail, ships and aircraft, as in other countries and regions. These shares could be higher worldwide if sustainable biomass was avvailable.

Figure 9.18 ▶ ***Passenger light-duty vehicles sales by technology in the United States in the Baseline and BLUE Map scenarios***



Source: IEA Mobility Model database.

Key point

In the BLUE Map scenario, US LDV sales become dominated by EVs, PHEVs and FCVs by 2050.

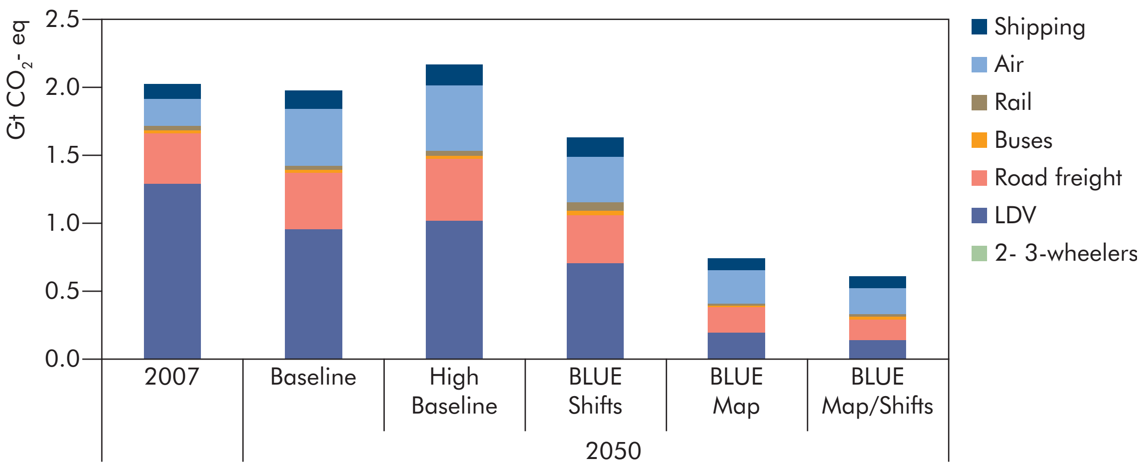
The BLUE Shifts scenario

The transport scenarios include a variant, called the BLUE Shifts scenario, which is focused on the potential to save energy and CO_2 through different patterns of travel. Since the vast majority of trips in the United States are taken by private car, there appear to be good opportunities to shift some of this travel to more efficient modes such as bus and rail. But US transport infrastructure and land-use patterns are fully developed and it will take considerable time and effort to change the underlying spatial structure to encourage more travel by transit and non-motorised modes.

In much of the United States, buses are currently more energy-intensive than cars on a pkm basis. To obtain the potential benefits of bus travel, efficiency first needs to improve by achieving higher passenger occupancies. This, in turn, will probably require significant changes in land use and policies to encourage higher levels of ridership on existing systems.

The US government has initiated a high-speed rail (HSR) development programme which would add ten new rail corridors around the country to the existing north-east corridor. Conventional rail systems would also be expanded and enhanced to carry passengers at higher speeds in areas without HSR. High-speed rail would be targeted principally for trips of distances of 160 to 1 000 km (100 to 600 miles) between and across areas with moderate to high population densities. This initiative may initially only shift a few per cent of intercity trips from air and car to rail, but it will also encourage other areas to work towards being linked into an expanding network. This will provide a basis for the network to attract an increasing share of intercity travel over time, especially if supported by policies that ensure that rail travel is competitively priced.

Figure 9.19 ▶ United States greenhouse-gas emissions evolution by mode for passenger travel in the Baseline and BLUE scenarios



Source: IEA Mobility Model database.

Key point

In the BLUE Map scenario, greenhouse-gas emissions (on a well-to-wheel basis) are cut by over half in 2050 compared to the Baseline scenario in that year.

The BLUE Shifts scenario for the United States assumes a 17% reduction in car and air travel by 2050 relative to the Baseline scenario, with about 10% coming from shifts to bus and rail travel, and 7% coming from land-use practices that result in fewer and shorter trips and travel avoidance, *e.g.* through substituting telecommunications for travel. These steps reduce energy use and CO_2 emissions by about 18%.

Projected US greenhouse-gas emissions in the Baseline and BLUE Map scenarios are shown in Figure 9.19. Light-duty vehicles account for the biggest increase in CO_2 emissions in the Baseline scenario, reaching more than 1 Gt CO_2 in 2050. But aviation emissions also increase significantly as US air travel grows rapidly.

The difference between the Baseline and BLUE scenarios is very significant for the United States. This highlights the enormous potential for cutting CO_2 by introducing new technologies and fuels into US transport. A 1.4 Gt reduction in CO_2 emissions is achieved by 2050 in the BLUE Map scenario.

Investment needs in the BLUE Map scenario

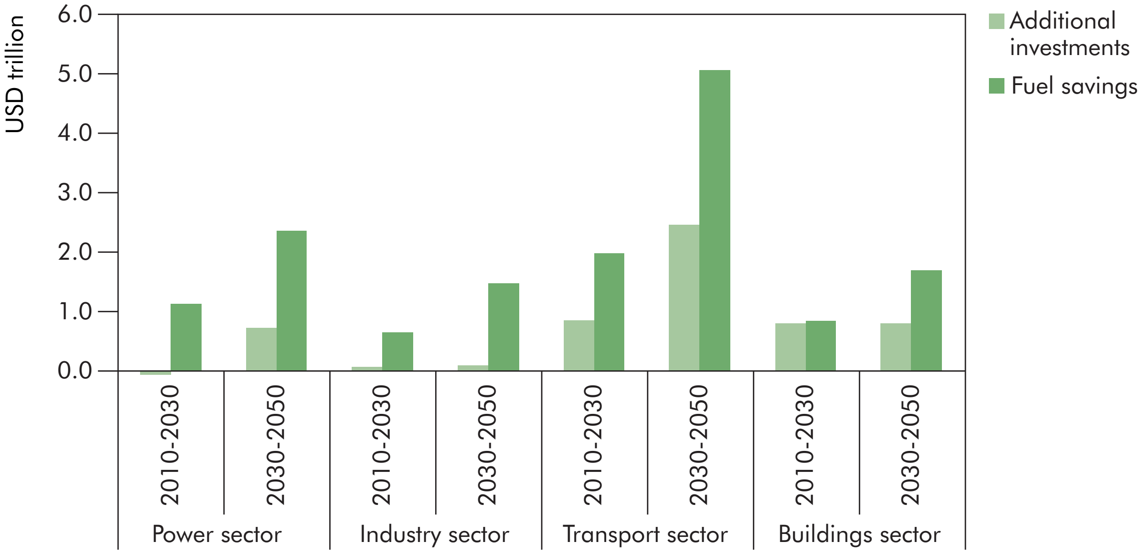
US GDP is assumed to increase by 1.7% a year over the 2007 to 2050 period. This growth will be driven by increasing demand for goods, services and leisure activities that use energy. Given this expected growth in energy demand, reducing CO_2 emissions in the United States will continue to be a challenge, although the rapid deployment of low-carbon technologies will help limit the growth in emissions.

For the United States to make its contribution to the global 50% emissions reduction envisaged in the BLUE Map scenario in 2050 compared to 2007, significant investments will need to be made in energy-efficient equipment, appliances, vehicles and buildings. The power sector will need to be significantly decarbonised, requiring large investments in nuclear, renewables and CCS. In the medium and long term, additional technologies will also be needed to reduce the CO_2 intensity of transport and industry. Taken together, these changes will require additional investments of USD 5.8 trillion over Baseline scenario levels between 2010 and 2050.

Of this total, USD 3.3 trillion will be required in the transport sector, almost all of it after 2030 for low-carbon vehicles (Figure 9.20). From 2010 to 2030, energy efficiency improvements in the BLUE Map scenario reduce the need for investment in both power plants and the distribution network. But the next step, the decarbonisation of the power sector, will require an additional USD 0.7 trillion in investment, all of which will be required between 2030 and 2050. Additional investment needs between 2010 and 2050 in the buildings sector are estimated at USD 1.6 trillion. Industry represents the smallest share of additional investment needs at USD 0.2 trillion.

Additional investment in efficient and low-carbon technologies will also enable a reduction in fuel requirements. Fuel savings are projected to outweigh investment costs across all end-use sectors, with the transport sector estimated to have the largest share.

Figure 9.20 ▶ Additional investment needs and fuel cost savings for the United States



Note: Fuel savings are calculated on the basis of BLUE Map fuel prices. Savings drop if Baseline energy prices are used as the fuel price assumptions in the BLUE scenario are lower than in the Baseline scenario, reflecting the impact of lower energy use on fuel prices.

Key point

Most additional investments will be needed in the transport and buildings sectors.

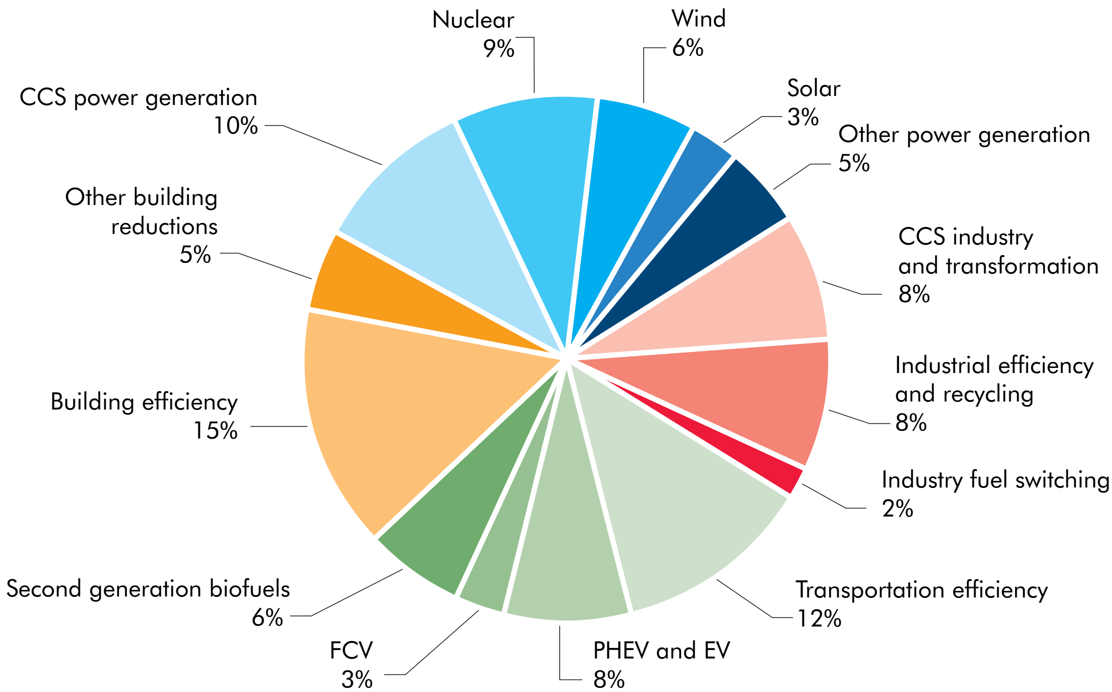
Transition to a low-carbon energy future

Future technology priorities

Deep reductions in US greenhouse-gas emissions are achievable through the application of a mix of energy technologies which are already available today and the introduction of new technologies currently being developed. Contributions will be needed from a range of technologies to achieve a 4.9 Gt CO_2 reduction in energy-related emissions by 2050 compared to 2007 levels (Figure 9.21). Compared to the Baseline scenario in 2050, this represents a reduction of 81%. Measures to improve end-use energy efficiency and fuel switching together provide about one-third of all emissions reductions. Other major contributors include CCS (18%), renewables (15%), nuclear power (9%) and FCV and PHEVs/EVs (11%).

There is still considerable scope for improving the efficiency of industry, buildings and transport. In industry, particular priority should be given to the chemicals and pulp and paper sectors, which together account for 50% of industrial energy. Improvements in building shells can reduce heating and cooling loads in both residential and commercial buildings. Energy use for cooling could then be further reduced by improving the efficiency of room air-conditioning. Research and development is also necessary to increase the efficiencies and reduce the costs of advanced space-heating technologies for buildings such as fuel cells and heat pumps. In transport, it will be important to continue to improve the efficiency of LDV technologies beyond 2015. There is also a need to demonstrate and eventually deploy advanced EVs and to develop second-generation biofuels suitable for heavy-duty vehicles.

Figure 9.21 ▶ ***CO_2 emissions reductions by technology area in the BLUE Map scenario in the United States, 2050***



Key point

A wide range of technologies will be needed to achieve a low-carbon energy future for the United States.

In the power sector, the introduction of advanced, more efficient coal-fired power generation could help reduce CO_2 emissions from fossil fuel use in the short-term. These plants should also incorporate CCS or at least be suitable for later retrofitting with CCS (*e.g.* IGCC) so that emissions can be reduced further in the longer term. This will require additional funding to ensure that CCS is technically and economically proven in a selection of applications by 2020. Equally important, a range of renewable technologies and nuclear power can also play an important role in decarbonising the power sector. The United States has significant potential for solar power. A priority should be to demonstrate large-scale centralised solar plants, particularly in the south-west. There also needs to be increased investment in the electricity transmission grid, particularly in interstate connections, and to demonstrate smart grid applications.

Future policy priorities

These technology changes will require particular attention in the following policy areas:

- Establish a cap-and-trade scheme that promotes domestic reductions and allows the purchase of credits to support emissions reductions in other countries and sectors.
- Continue to liberalise electricity markets by:
  - pursuing the effective separation of network management and power marketing to ensure non-discriminatory network access;
  - ensuring that independent regulation focuses on the creation of low-carbon incentives and cost-reflective prices;
  - increasing the capacity for interconnection between states to enable competitive wholesale markets to work effectively.
- Stimulate a diverse and adequate generation mix by removing subsidies for fossil fuels, reducing uncertainty on national climate change policy, harmonising national renewable energy policies and removing uncertainties affecting the development of new capacity.
- Take measures to increase the efficiency of power generation through regulation, incentives and cost-reflective prices.
- Further strengthen policies and standards for new and refurbished buildings.
- Consider additional measures to improve energy efficiency in industry, such as minimum energy performance standards or incentives to accelerate the capital stock turnover and the penetration of best-in-class technologies.
- Further strengthen the CAFE standards for LDVs beyond 2016.
- Promote modal shift from LDVs through land-use changes and the expansion of high-speed and conventional rail.
- Continue to expand the Emissions Inventory Rule initiative to catalogue greenhouse-gas emissions from large emission sources.
- Strengthen commitment to invest in energy technology RD&D and increase public funding levels in line with the 2009 American Recovery and Reinvestment Act.
- Set priorities within a coherent long-term strategy for public investment in RD&D based on a process involving academia, national laboratories and industry.
- Continue to support basic energy science research and strengthen current efforts to improve linkages between the basic science and the applied energy technology components of the DOE.

Chapter 10 CHINA

Key findings

- *Since 1990, China's economy has grown fourfold, resulting in more than a doubling of energy use. Strong energy efficiency improvements have helped to limit growth in energy use. But the rising dominance of coal in the country's energy mix has meant that energy-related carbon dioxide (CO_2) emissions have grown faster than energy consumption.*
- *In the Baseline scenario, CO_2 emissions rise to 15.9 Gt by 2050, a 158% increase compared to 2007 levels. In the BLUE Map scenario, the widespread deployment of low-carbon energy technologies results in emissions of 4.3 Gt, 30% less than in 2007.*
- *The deployment of low-carbon energy technologies will help to improve China's energy security as it reduces the need for imported fossil fuels. Oil demand in 2050 in the BLUE scenario is less than half the level in the Baseline scenario. Coal demand drops by 70%.*
- *Achieving the BLUE Map scenario results will require additional investments of USD 10.2 trillion between 2010 and 2050. Many of the investments made will yield reductions in fuel consumption and total fuel savings are estimated at USD 19 trillion.*
- *Measures to increase energy efficiency further could save an additional 3.9 Gt CO_2 in 2050 compared to the Baseline scenario. Stronger policy incentives and regulation will be needed to realise this savings potential.*
- *China's transition to a low-carbon energy system will require significant decarbonisation of the power sector. A mix of nuclear, more efficient coal technologies, carbon capture and storage (CCS), wind, solar and other renewable generation technologies will be needed.*
- *With coal currently accounting for around 65% of total primary energy supply (TPES) today, special attention should be given to the more efficient use of coal in power generation and industry as well as CCS.*
- *Industry accounts for the largest share of China's energy use and CO_2 emissions. Measures to improve energy efficiency and reduce CO_2 emissions in key energy-intensive sectors such as iron and steel, cement and chemicals should be a priority.*
- *The transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure and the introduction of new technologies. The eventual shift to electric vehicles (EVs) and the electrification of other transport modes will play an important role. Channelling more of the travel growth into the most efficient modes (i.e. bus and rail systems) can also help.*
- *In the buildings sector rapid growth in energy use is expected and priority attention should be given to improving the energy efficiency of building shells, the use of more efficient heating and cooling systems, the use of solar thermal for space and water heating, and the use of more efficient lighting systems and appliances.*

- *China has set ambitious energy technology targets in a number of different areas, including energy efficiency, renewables and nuclear power. Actions in these areas will help to reduce the country's CO_2 intensity, but additional and sustained efforts will be needed to reach the emissions reductions identified in the BLUE Map scenario.*
- *With extensive manufacturing capabilities, China's industry is well positioned to benefit from a global transition in the energy system. China has already established itself as a leader in the manufacture of a number of low-carbon energy technologies and is the world's largest producer of photovoltaic (PV) modules and wind turbines.*

Regional description

China is the most populous country in the world. With 1 327 million people in 2007, it represents about 14% of the world's population. An estimated 45% of the population lives in urban areas. Latest estimates suggest that China's urbanisation rate will increase by nearly 1% annually in the next 15 to 20 years, as a result of which around 300 million people will move from rural areas into cities (*China Daily*, 2009). Of the total working population, 41% is involved in agriculture, 27% in industry and 32% in services (NBS and NDRC, 2008).

China covers a land area of 9.6 million square kilometres (km^2), making it the fourth-largest country. It is characterised by three climatic zones, tropical, subtropical and temperate.

In 2007, China's GDP reached USD 2 400 billion, twice as large as it was in 2000. With China's rapid economic development, the income of Chinese residents has risen steadily. In 2007, the GDP per capita reached USD 1 809, equivalent to USD 7 509 in purchasing power parity terms.

Recent trends in energy and CO_2 emissions

Over the last two decades, China has moved from being a minor and largely self-sufficient energy consumer to become the world's fastest-growing energy consumer and a major player on the global energy market. Soaring energy use is both a driver and a consequence of the remarkable growth of the country's economy.

China's energy system is predominantly based on indigenous coal supplies. Oil and natural gas supplies are partly dependent on foreign imports. Proven coal reserves in China are 114.5 billion tonnes (t), 14% of the world total. At current production levels, they would last 46 years. Oil reserves in China are less than 2% of the total world's reserves and at current production rates would last just over 17 years. China's imports of oil will continue to grow in importance as demand from the transport sector rises sharply with higher income levels. China holds a relatively small share of the world's proven natural gas reserves (Table 10.1).

Regionally, the country's main coal reserves are concentrated in the north, while water or hydro resources are concentrated in the east and most of the country's oil reserves are located in the west. The distribution of energy resources makes energy transportation a particular issue for the Chinese energy supply system.

Table 10.1 ▶ **Proven energy reserves in China and in the world**

	Coal (bt)	Crude oil (bt)	Natural gas (bcm)
Proven reserves: China	114.5	3.3	2 455
Proven reserves: World	826	171	185 020
Production 2007: China	2.5	0.19	69.2
Reserve-to-production ratio: China	45.8	17.4	35.5

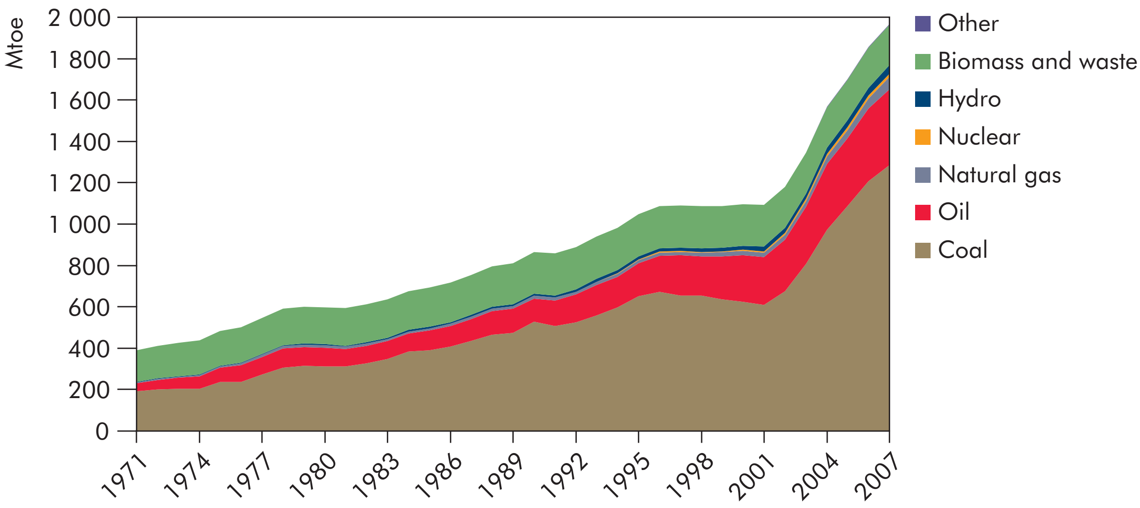
Note: Reserve-to-production ratio indicates the length of time that the proven reserves would last if production were to continue at current rates and if no additional reserves could be recovered.

Sources: BP (2009); NBS and NDRC (2008).

Energy production and supply

Energy production in China has increased rapidly in recent years, with TPES reaching 1 994 million tonnes of oil equivalent (Mtoe) in 2007, a 79% increase over production in 2000 of 1 116 Mtoe. Figure 10.1 shows the growth of primary energy production since 1971. This shows a sharp acceleration from 2000 owing to rapid growth in demand for industrial materials production. Since 2000, primary energy production has risen by an average of 8.7% a year, compared to just 2.2% a year in the 1990s and 5.3% a year in the 1980s. The majority of the growth in energy supply since 2000 has come from coal, which has led to significant increases in overall CO_2 emissions.

Figure 10.1 ▶ **Total primary energy supply in China**



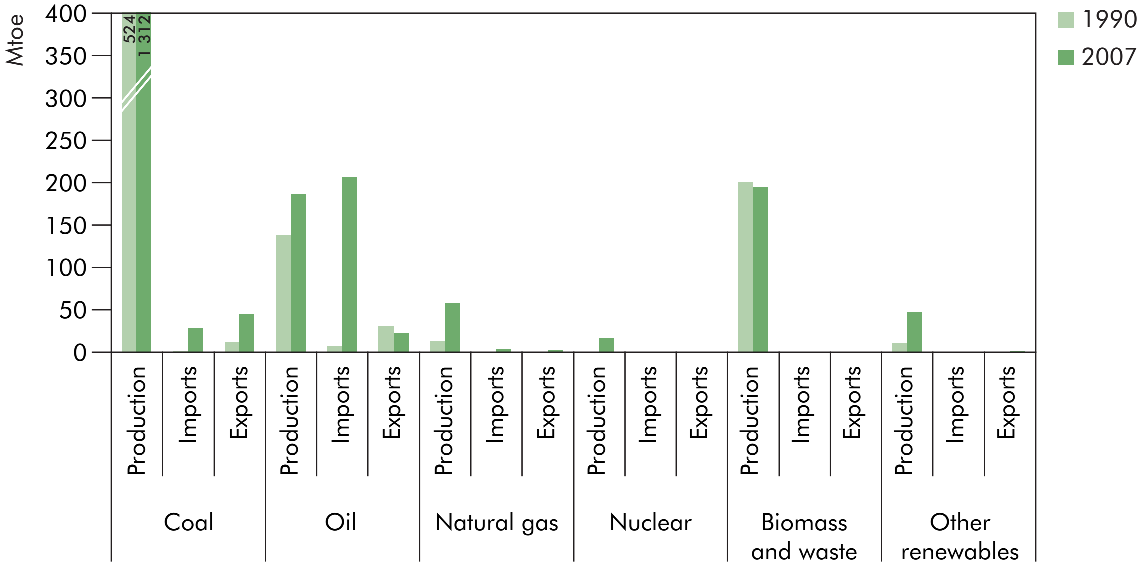
Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

Total primary energy supply has risen fivefold since 1971 and almost all of the growth since 2001 has been from coal even though other fuels, notably natural gas, have risen rapidly.

Coal is the most widely used energy source in China. Its share in TPES has decreased since the 1970s, but is still relatively high at 65% with more than half used for power generation.[1] Levels of oil production have been relatively steady, so that the overall share of crude oil has declined in the energy production mix. In 2007, oil represented 18% of TPES, up from 10% in 1971. Natural gas production has been rising steadily over the last decade and in 2007 reached 59 Mtoe, representing almost 3% of TPES, up from less than 1% in 1971.

Figure 10.2 ▶ Energy production, imports and exports for China



Note: Nuclear production refers to the heat produced in nuclear reactors, irrespectively of whether the nuclear fuel used is from domestic sources or imported.

Key point

China's energy production is dominated by coal, and rapidly increasing demand for oil has turned the country from a net exporter to a net importer of oil.

Box 10.1 ▶ Unconventional gas in China

Demand for natural gas in China has been growing sharply over the past years and current domestic production is roughly in line with consumption. Natural gas represents a small share of total energy supply today, the majority of which is used in the residential sector. Because of strong increases in demand for natural gas, China started to import liquefied natural gas (LNG) in 2006. A natural gas pipeline from Turkmenistan is expected to bring in 40 billion cubic metres (m³) per year by 2015 and a number of LNG terminals are also being built. Attention has also recently been focused on the development of unconventional gases such as coal-bed methane and shale gas.

1. China's own energy statistics, which exclude traditional biofuels that are included in IEA energy statistics, put coal's share at nearly 70% (NBS, 2008).

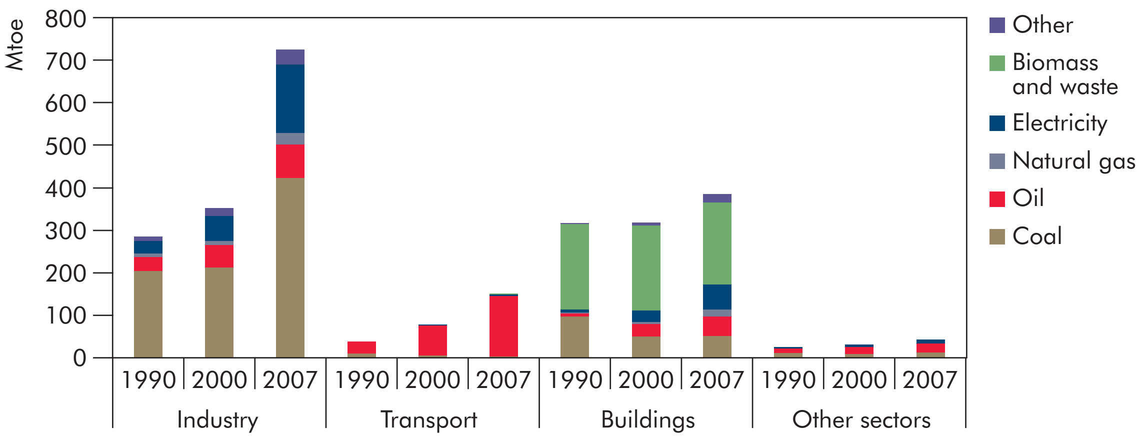
China's coal-bed methane potential is estimated at 37 trillion m³ of geological resources and 134.3 trillion m³ of proven resource, the third-largest in the world. Most of the resources are found in Shanxi province and Xingjiang autonomous region. The government plans initially to increase the extraction of coal-bed methane to 40 billion m³ a year by 2020. Estimates for shale gas resources are 26 trillion m³ which is more or less equivalent to those of the United States. The Chinese Ministry of Land and Resources has announced a strategic goal of reaching a production target of 15 billion m³ to 30 billion m³ a year by 2020.

The development of domestic unconventional gas reserves and greater imports of natural gas could help to reduce energy use and CO_2 emissions in sectors such as ammonia production as gas-based ammonia production is less energy-intensive than coal-based production. Even with these large supply additions, gas will remain a small part of China's energy supply.

Energy consumption

Energy consumption in China has increased rapidly in the last decade as a result of tremendous economic growth fuelled by the export of manufactured goods and high rates of domestic investment (Figure 10.3). Since 2000, total final energy consumption has nearly doubled from 776 Mtoe in 2000 to 1 297 Mtoe in 2007, an average annual increase of 8%. Over the same period, electricity consumption rose by a factor of 2.8 from 1 116 terawatt-hours (TWh) in 2000 to 3 114 TWh in 2007. Rapid industrial growth over the last decade has transformed the country's energy security situation, making it one of the world's largest importers of energy. As recently as 1992, China was a net exporter of energy. In 2007, imports represented 10% of China's primary energy supply. Oil accounts for the largest share of imports, as domestic reserves are relatively low, but large amounts of natural gas and even coal are also imported to meet energy demand.

Figure 10.3 ▶ Final energy consumption by fuel and by sector for China



Note: Industry includes coke ovens, blast furnaces and feedstocks. Transport includes international aviation and marine bunkers. Other sectors include agriculture, fishing, and forestry as well energy use for pipeline transport.

Key point

Industry represents the largest share of total energy use today and has experienced rapid demand growth since 2000 with a doubling in energy consumption.

End-use efficiency improvement

In 2007, China's energy intensity was 0.2 tonnes of oil equivalent (toe) per USD 1 000 of GDP, 50% less than the world average of 0.30 toe/USD 1 000 of GDP. Chinese per-capita consumption of electricity and energy is lower than in the OECD regions, but significantly higher than in most developing countries. During the 11th Five-Year-Plan (2006-2010) the Chinese government plans to reduce energy use per unit of GDP by 20%. A total cumulative reduction of 12.5% has been achieved from 2006 to 2008 (NBS, 2009).

Analysis based on end-use data shows that the overall improvement in energy intensity in China was 5.8% a year between 1990 and 2007. Without energy savings resulting from these improvements, total final energy consumption would have been 30% higher in 2007. The largest contribution to the energy savings from efficiency was from the manufacturing sector which improved by 3% a year over this period.

Carbon dioxide emissions

The near-doubling in energy consumption since 2000, fuelled primarily by additional coal use, has resulted in a doubling of China's energy-related CO_2 emissions. In 2007, with CO_2 emissions of 6.2 Gt, China became the world's largest CO_2 emitter, for the first time overtaking the United States which reported 5.9 Gt of emissions. Although China's CO_2 intensity per capita is still relatively low (4.6 t per capita) compared to the United States (18.9 t per capita) and OECD Europe (7.5 t per capita), China's CO_2 intensity per unit of GDP is one of the world's highest at 0.62 gCO_2/USD 1 000 GDP on a purchasing power parity basis.

China's economy is dominated by the manufacturing sector with two-thirds of emissions attributed to industry. A significant share of industrial production can be related to final products which are exported and highlight the importance of China's export- and investment-driven economy and the impact it has had on energy use and emissions. The buildings sector, which accounts for the largest share of emissions in the United States, represents only 23% of total emissions in China. Emissions from transport represent 8% of China's emissions, but this share is expected to rise quickly in the future as the country's economic growth spurs the demand for vehicles.

Overall energy policy framework

Many government agencies have a hand in shaping China's energy and climate change policies. In this they are supported by many research organisations and private firms. The government bodies charged with overseeing energy and energy policy are comparatively small.

The highest policy-making body is the 23-member National Energy Commission (NEC), chaired by the Premier and including heads of all the main agencies concerned with energy supply, transport, end-use, safety, security, sustainability, trade and finance. The distribution of energy sector responsibilities over numerous agencies has impeded co-ordination, formulation, implementation, and the enforcement of energy strategy, policies and regulations. The announcement in January 2010 of the membership and duties of the NEC is seen by many as the latest attempt to create an effective national-level energy authority that can co-ordinate across agencies and offer a counterweight to the considerable power of the large, state-invested energy companies.

The National Energy Administration (NEA), associated with the National Development and Reform Commission (NDRC), also plays a particularly important role. The NEA's responsibilities mainly relate to the energy supply sectors, and include the drafting of near- to long-range plans, developing and setting policy, and policy implementation through setting regulations, reviewing and approving investment projects, and issuing guidance. Nine separate departments look after the NEA's various portfolios (Table 10.2). In the discharge of its responsibility for energy security, NEA oversees the construction and operation of the nation's strategic oil reserves. Some NEA staff are concurrently assigned to the office of the NEC. This office is chaired by the NDRC Chair, with the NEA Administrator serving as deputy.

The NDRC has significant responsibilities, including overall authority for energy efficiency and leadership on climate change through a dedicated department. The NDRC is also home to China's Price Bureau, which has authority over electricity tariffs and oil prices, with major changes subject to approval of the State Council, the government's highest executive body. The NEA and other agencies provide input to the Price Bureau but do not have decision-making powers. The NDRC and NEA departments are replicated in provincial, municipal and many country administrations, and responsibility for implementation rests with these local branches except where issues concern centrally administered state-invested enterprises.

A range of other agencies have important roles in energy supply and demand. The Ministry of Finance and the State Bureau of Taxation are involved in directing investment and designing and implementing incentive policies. The Ministry of Land and Resources has control over mineral rights and is, thus, a key player for all fossil fuels. The State Administration for Work Safety oversees the critical issue of mine safety. The State Electricity Regulatory Commission provides guidance on power sector rate setting, grid operation, the development of power markets and other areas of utility policy.

Responsibility for energy technology research and development (R&D) is shared between the Ministry of Science and Technology and the Chinese Academy of Sciences. The NDRC leads on climate change. The Ministry of Environmental Protection is responsible for regional and local pollution stemming from energy use, including particulates, sulphur dioxide (SO_2) and acid rain. The NDRC takes the overall lead for energy efficiency, although sectorally focused agencies play an important part in setting regulations for buildings, industry and transport. Energy issues in rural areas, where the majority of the population still live, are overseen by the Ministry of Agriculture.

Table 10.2 ▶ *Responsibilities of China's National Energy Administration departments*

General administration Manages the Administration's daily operations, including personnel, Chinese Communist Party, financial management, asset management and press affairs.	**Policy and legislation** Studies important energy problems, organises the drafting of energy legislation, and conducts administrative auditing and review.	**Development and planning** Studies and provides suggestions on energy development strategy; organises the drafting of macro-level energy development programmes, yearly plans and industrial policy; and undertakes energy industry reform work.
Energy conservation and scientific equipment Directs energy conservation and comprehensive resource use, promotes energy-saving technologies and equipment, and prepares standards.	**Power** Plans thermal and nuclear power development, manages the national power network, and handles nuclear power station crisis management.	**Coal** Manages the coal industry, drafts plans for coal mining, undertakes system reform, and develops advanced technology for reducing pollution caused by coal burning.
Oil and natural gas Manages the oil and gas industry, plans oil and natural gas development, promotes industry reform, and manages national and commercial oil reserves.	**New and renewable energy** Directs and co-ordinates rural energy development and plans the use of new and renewable energy.	**International co-operation** Undertakes international energy co-operation, drafts strategies, laws and policies for opening up China's energy sector and co-ordinates the development and use of overseas energy.

Source: Downs (2008).

Current status of energy policies and climate change initiatives

Energy targets have long figured in China's national plans. In the 1980s, goals for energy production were joined by goals for efficiency and environmental improvements. Each successive Five-Year Plan (FYP) has seen more ambitious targets. The current 11th FYP (2006 to 2010) required that the energy intensity (primary energy demand per unit of GDP) of the national economy in 2010 be 20% below the level in 2005, and mandated a 10% absolute reduction in SO_2 emissions to the air and chemical oxygen demand (COD) emissions to surface waters. A variety of then-current and newly formulated policies and regulations were harnessed to achieve these targets, and, according to Chinese sources and analysis by outside observers, the country is largely on track to meet them (Levine *et al.*, forthcoming 2010).

China's energy efficiency policies for over two decades have leaned heavily on measures to increase overall plant efficiency through the building of new plants and the closure of older, less efficient plants. These measures have to some extent been undermined by economic stimulus measures that have financed continued high levels of investment in infrastructure. Some targeted measures seem to have been successful. Programmes to shut down the smallest, often most inefficient and polluting industrial facilities and power plants have achieved their targets ahead of time. This, combined with investment in larger new facilities, has resulted in average process efficiencies rising very quickly, in many cases approaching levels typical in OECD countries and even surpassing the performance of some developed nations.

The Top-1 000 Programme, under which the country's largest energy-consuming power plants and factories signed agreements to improve energy performance and gained access to supporting measures, has provided a large proportion of the energy savings achieved in recent years. A cluster of efficiency initiatives, termed the Ten Key Projects, has achieved nearly as much in energy savings as the Top-1000 Programme. Implementation was spurred by the incorporation of energy intensity goals into the performance criteria for local officials from provincial governors downwards. Programmes and standards to improve the efficiency of appliances, lighting, buildings, vehicles and industrial equipment have had a great impact. At the same time, China has invested in the capacity needed to track the progress of these initiatives, appointing more than 2 000 additional government energy statisticians since 2005.

The 12th FYP (2011 to 2015) promises to be even more challenging. It will need to put China on a path to comply with the target announced in November 2010, just prior to the 15th Conference of the Parties (COP-15) to the United Nations Framework Convention on Climate Change (UNFCCC), to reduce its CO_2 emissions intensity by 40% to 45% in 2020 compared to 2005. The Plan must also make progress towards targets for the deployment of non-fossil energy sources, which are to supply 20% of China's primary energy by 2020.

Several targets for generating capacity have been announced by officials. Current official targets for installed capacity in 2020 call for 70 GW of nuclear power, 100 GW of wind and 1.8 GW of solar. Most of the renewable energy generating capacity would be hydropower, as is the case now. It is targeted to exceed 300 GW by 2020. A new Renewable Energy Law and a series of regulations designed to support nascent renewable energy industries have had significant impact, but important challenges remain in deploying these technologies on the scale contemplated for the next decade. In terms of energy efficiency, some senior Chinese analysts feel that most of the easy gains in efficiency have already been exploited and that, even with the stronger deployment of renewables, CO_2 intensity reduction targets will not be easy to achieve.

Overview of scenarios and CO_2 abatement options[2]

GDP and population projections are the same in both the Baseline and BLUE scenarios. The different levels of energy supply and consumption in the two scenarios indicate different levels of decoupling of energy and economic activity over time (Table 10.3).

2. Chapter 2 provides a full description of the different scenarios.

Table 10.3 ▶ High-level indicators for China

			Baseline		BLUE Map	
	2000	2007	2030	2050	2030	2050
Total primary energy supply (Mtoe)	1 116	1 994	3 827	5176	3 181	3 759
Electricity consumption (TWh)	1 290	3 114	5 556	10 630	5 872	8 632
CO_2 emissions (Gt)	3.05	6.15	11.62	15.87	7.85	4.31
GDP (2000 USD billion using exch. rates)	1 368	2 623	8 944	18 857	8 944	18 857
GDP (2000 USD billion using PPP)	5 150	10 156	37 127	78 278	37 127	78 278
Population (millions)	1 269	1 327	1 471	1 426	1 471	1 426
TPES/GDP (toe per thousand 2000 USD using PPP)	0.22	0.20	0.10	0.07	0.09	0.05
TPES/population (toe per capita)	0.88	1.50	2.60	3.63	2.16	2.67
Electricity consumption/population (kWh per capita)	1 017	2 347	3 777	8 795	4 816	7 173

Sources: IEA (2009b and 2009d); IEA analysis.

Energy and CO_2 emission scenarios

In the Baseline scenario, TPES supply in China is expected to nearly double from 2007 to 2030 and rise by 165% by 2050. Oil, gas, nuclear and other renewables all grow strongly but coal remains the dominant fuel. Current policies aimed at increasing energy security in China will result in significant growth in nuclear, wind and solar energy. As China's average GDP per capita more than doubles over this period, strong growth in car ownership boots demand for oil, which more than triples from 2007 to 2050. In the Baseline scenario, most of the demand for light-duty vehicles (LDVs) will be based on conventional internal combustion engine (ICE) technology.

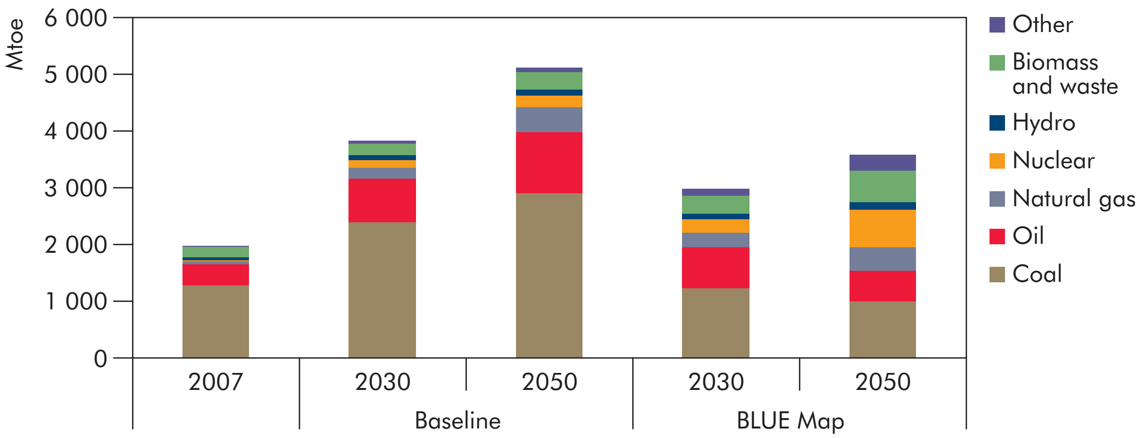
Baseline CO_2 emissions double by 2030 as coal continues to dominate in the industry and power sectors. Growth in emissions will slow as the economy matures and in 2050 reaches 15.9 Gt, a 158% increase compared to current levels. The largest absolute increase in emissions will come from the power sector which rises from 3.1 Gt in 2007 to 8.5 Gt in 2050. Transport will see the highest rates of growth in emissions rising from 0.5 Gt in 2007 to 2.7 Gt in 2050, an increase of more than fivefold.

In the BLUE Map scenario, higher rates of energy efficiency result in a 27% reduction in TPES in 2050 compared to Baseline levels. Total primary energy supply in China nearly doubles compared to current levels reaching 3 814 Mtoe in 2050. The demand for coal declines significantly by 2050, falling by 36% compared to current levels and by 70% compared to the Baseline scenario. Oil demand rises significantly less than in the Baseline scenario, but is still 60% above current levels owing to strong growth in car ownership. In the BLUE Map scenario, the demand for vehicles is met by a combination of conventional ICE technology and low-carbon vehicle technologies, including EVs, biofuels and fuel-cell vehicles (FCVs).

The share of non-fossil energy supply rises significantly in the BLUE Map scenario, reaching 48% in 2050 compared to 16% in 2007 and 15% in the Baseline scenario. Coal accounts for the largest share of the primary energy supply mix. Biomass and waste more than triples compared to current levels reaching 707 Mtoe, representing the second-largest share, followed closely by nuclear at 683 Mtoe. Energy supply from wind, solar and geothermal reaches 274 Mtoe, up from 5 Mtoe in 2007. A mix of increased energy efficiency and fuel switching helps to improve the country's energy security as lower energy demand and a switch to more renewables and nuclear power helps to reduce imports of oil.

High growth in non-fossil energy supply, coupled with a sharp decrease in coal use, leads in the BLUE Map scenario to significant reductions of CO_2 emissions in China. They fall from 6.2 Gt CO_2 in 2007 to 4.3 Gt CO_2 in 2050. Emissions in the BLUE Map scenario show a peak by 2020 as the wider deployment of low-carbon technologies allows China to reduce future emissions. China's recent announcement to reduce CO_2 intensity by 40% to 45% by 2020 would put the country on an emissions path between the trends in emissions intensity in the Baseline and BLUE scenarios.

Figure 10.4 ▶ Total primary energy supply, Baseline and BLUE Map scenarios by fuel for China



Note: Other includes non-combustible renewables and heat. Oil includes international marine bunkers.
Sources: IEA (2009a and 2009b); IEA analysis.

Key point

While coal and oil dominate in the Baseline scenario, nuclear and renewables play an important role in the BLUE Map scenario.

Carbon dioxide abatement options

Emissions in China need to peak by 2020 if significant reductions in CO_2 emissions are to be achieved by 2050. Investments made in infrastructure and equipment over the next two decades will determine the carbon footprint of the Chinese economy.

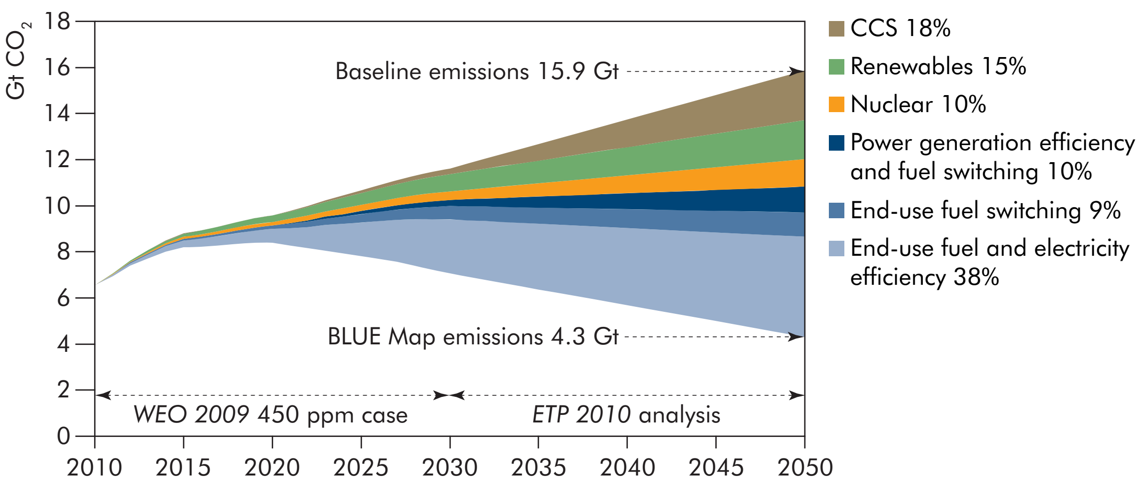
China is already taking important steps, but as in other countries further urgent action is needed to transform the way energy is used and produced.

10

In the BLUE Map scenario energy-related CO_2 emissions are very much lower between 2007 and 2050 than in the Baseline scenario (Figure 10.5). Energy efficiency and measures to reduce the carbon intensity of electricity production dominate the short- and medium-term options. A strategy for reaching a nearly decarbonised power sector by 2050 will be critical. This could be achieved through a combination of renewables, nuclear and CCS.

To achieve even deeper emission cuts by 2050 will require the deployment of CCS in the fuel transformation and industry sectors from 2030 to 2050. Additional technologies to reduce the CO_2 intensity in industry and transport will also be needed. These will have to include greater levels of electrification and other end-use fuel switching options.

Figure 10.5 ▶ Contributions to emissions reduction in China



Key point

End-use efficiency savings and CCS are the largest contributors to emissions reduction in China; nuclear and renewables are also important.

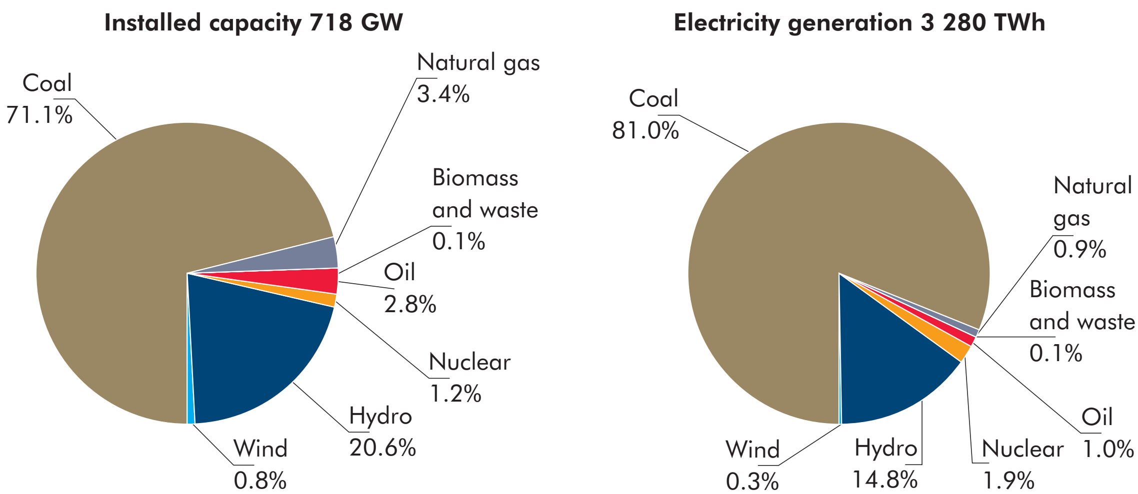
Sectoral results

Power sector

The Chinese electricity system today

In 2007, total installed power capacity in China reached 718 GW, with 556 GW of almost entirely coal-based thermal power, 148 GW of hydro-power, 8.8 GW of nuclear power, 4.2 GW of wind power and 0.86 GW of other renewable power generation. The country's reliance on coal for its electricity production, which accounted for 81% of total electricity generation in 2007, means that the average CO_2 intensity of its power generation is among the highest in the world at 777 g/kWh compared to a world average of 507 g/kWh (Figure 10.6).

Figure 10.6 ▶ Electricity generating capacity and generation for China, 2007



Source: NBS and NDRC (2008).

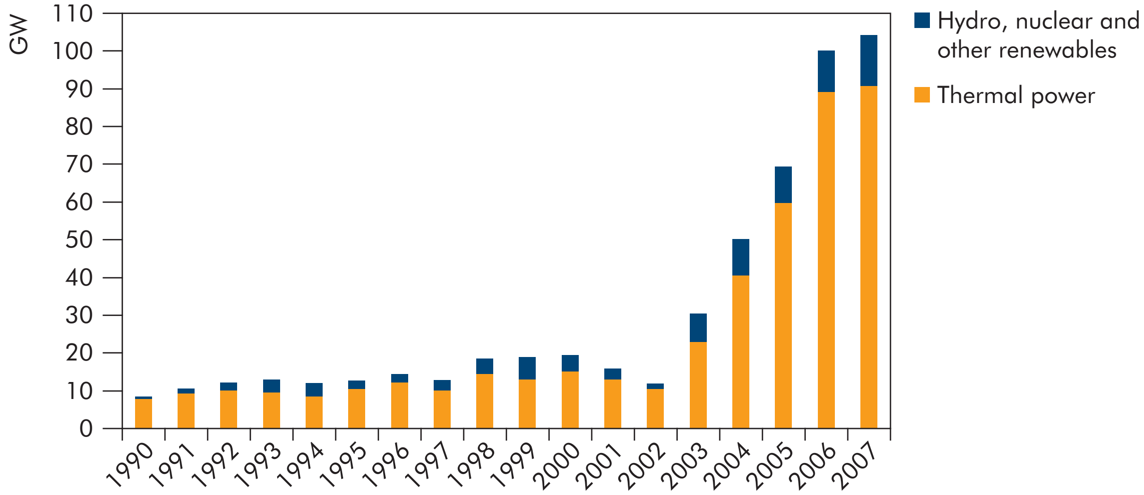
Key point

Electricity generation is dominated by coal.

Since 2000, because of strong growth in electricity demand from the manufacturing sector, China has been adding new, predominantly coal-fired, power generation capacity at an unprecedented rate (Figure 10.7). In 2007 alone, 104 GW of new capacity was added although since then the pace of construction has slowed. Much of the growth in new coal-fired capacity has been based on the deployment of larger, more efficient technologies. As a result, the average coal consumption per kWh produced has fallen approximately by 13% from 390 grams of coal equivalent (gce)/kWh in 2000 to just over 340 gce/kWh in 2009. The more efficient, newer plants consume less than 290 gce/kWh.

In 2006, China introduced a policy to promote the early closure of smaller, less efficient facilities. As a result, 60 GW of capacity was closed from 2006 to 2009. This has avoided the release of nearly 139 Mt CO_2 from inefficient coal-fired plants over that period (CEC, 2010). The approval for investments in new coal-fired plant is conditional on the early closure of smaller facilities with capacity under 200 megawatts (MW). China now has a policy of building no new plant of less than 300 MW, with much of its new capacity based on supercritical (SC) and ultra-supercritical (USC) units of 600 MW or 1 000 MW capacity.

Figure 10.7 ▶ **Commissioning of new generation capacity for China**



Source: NBS and NDRC (2008).

Key point

The addition of new generation plants has risen rapidly over the last five years, with 104 GW added in 2007 alone.

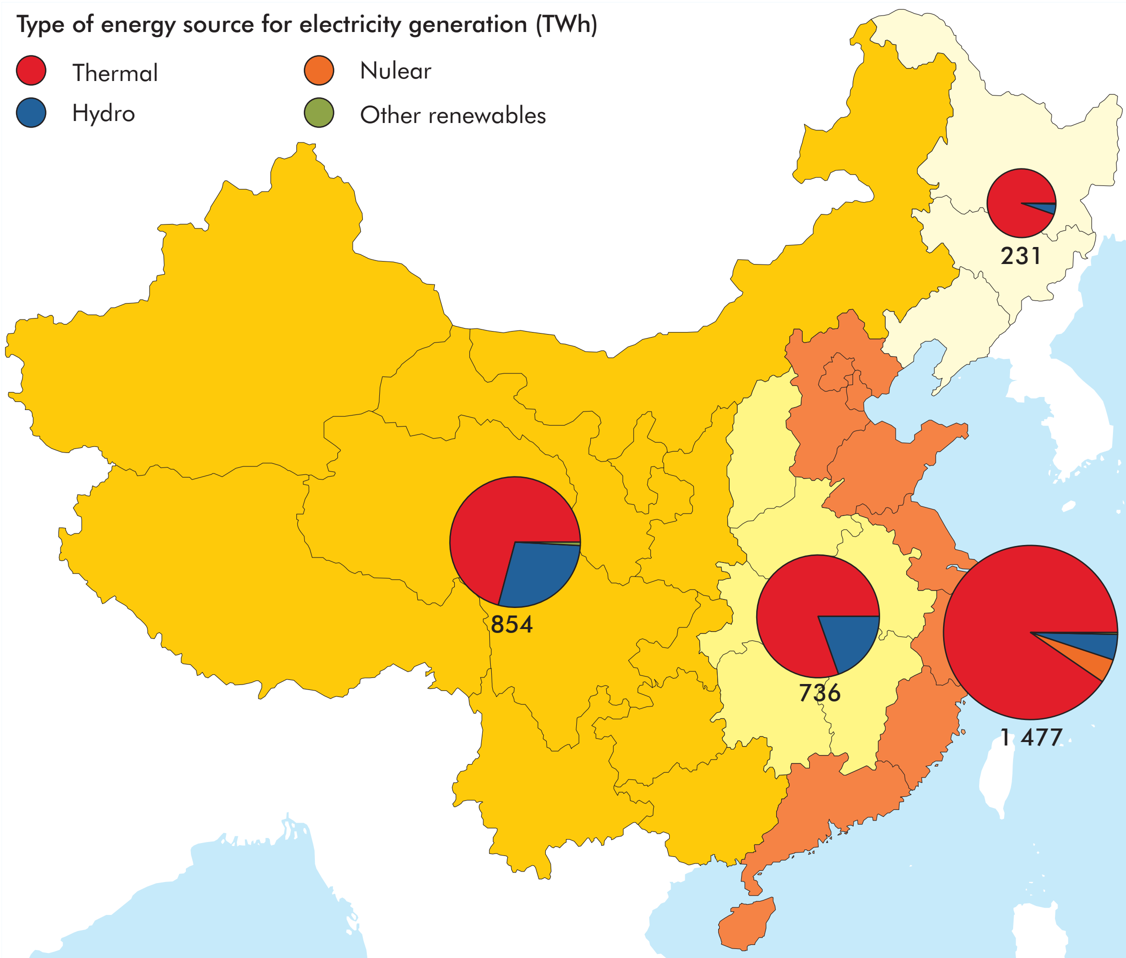
Developments in renewable power generation

Over the past decade, wind and solar power generation have developed rapidly in China. The installed wind capacity has risen from 28 MW in 1996 to over 25 GW in 2009. As a result of policies promoting the rapid uptake of renewables, China has seen wind capacity rise tenfold since 2005. China's total onshore wind resources are estimated to be in excess of 3 000 GW, concentrated in the provinces of Hebei and Inner Mongolia (UNEP, 2005). In addition, significant potential for offshore wind also exists in the Eastern coastal provinces. The growth in solar PV has been less significant than in wind, with installed capacity rising fivefold from 19 MW in 2000 to 145 MW in 2008.

Regional electricity supply in 2007

In 2007, total electricity generation in China amounted to 3 300 TWh having shown an annual average growth rate of 14% since 2000. Thermal power supply accounts for 83% of the total, hydro for 14.8%, nuclear for 1.9% and other renewables for just 0.3%. Guangdong, Shandong and Jiangsu provinces are the three largest electricity suppliers (Figure 10.8). Power generating capacity is most developed in the eastern coastal areas and middle-eastern provinces of China. Thermal generating capacity is mainly concentrated in the central-northern and south-eastern provinces of China. Hydropower is mainly located in the central and south-western provinces. Nuclear power is concentrated in the southern coastal area. Wind power has also been developed both in the inland part of China, such as Inner Mongolia and Xinjiang, and the coastal provinces of Shandong and Guangdong.

Figure 10.8 ▶ **Electricity generation by region in China, 2007 (TWh)**



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Source: NBS and NDRC (2008).

Key point

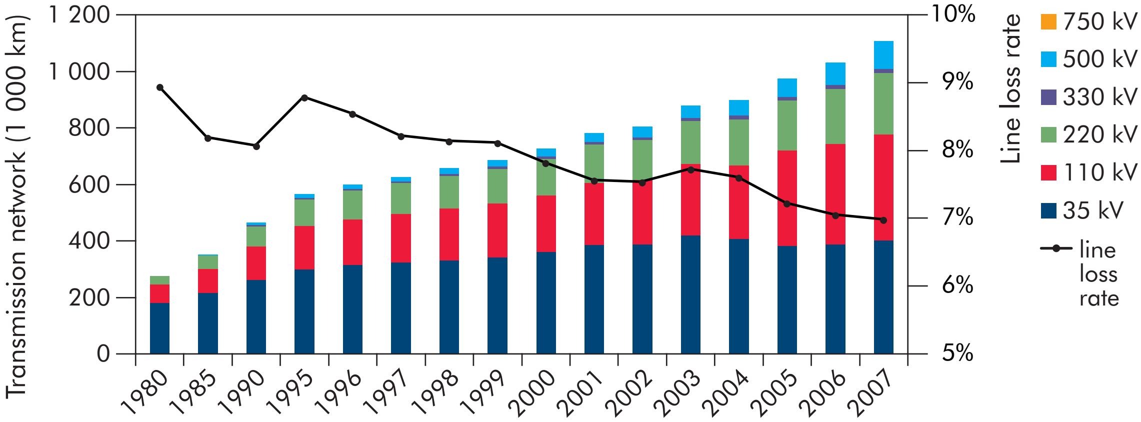
Electricity production in China is heavily located in the coastal provinces which are also the main centres of electricity consumption.

Electricity transmission and distribution

Since 2000, China has invested heavily in expanding its electricity transmission network, particularly in its high-voltage network, which has grown by more than 50% from 2000 to 2007 (Figure 10.9). The high-voltage (≥110 kilovolt (kV)) grid now spans over 500 000 km. Transmission and distribution losses have continued to fall over the last two decades, from 8.9% in 1980 to just under 7% in 2007 (NBS, 2008).

China's national grid is divided into two parts. The State Grid Corporation of China (SGCC) comprising five sub-grids in the north connected to a sixth Central Grid supplies a population of about 1.1 billion people. The China Southern Power Grid (CSPG) supplies a population of 230 million.

Figure 10.9 ▶ **Development of transmission network, and transmission and distribution losses for China**



Source: NBS and NDRC (2008).

Key point

China's electricity distribution losses have fallen significantly over the last three decades to less than 7% in 2007.

In 1996, with the introduction of the Electric Power Law, the State began to implement preferential policies for rural electrification, giving major support for the rural electrification of ethnic minority, remote and poverty stricken areas. The State encouraged and supported the use of solar energy, wind energy, geothermal energy, biomass and other energy sources so as to increase the power supply in rural areas. As a consequence of these efforts, China's electrification rate in 2009 reached 99.4%, with urban areas fully electrified and rural areas reaching 99% electrification (IEA, 2009b).

Electricity demand scenarios

Electricity consumption in China has increased by 144% between 2000 and 2007, fuelled by strong industrial demand. Industry's share of total electricity demand has risen from 48% in 2000 to 70% in 2007. As higher electricity demand is expected from other sectors, by 2050 the share of industrial electricity consumption declines to 65% in the Baseline scenario and 62% in the BLUE Map scenario (Table 10.4).

In both scenarios, electricity consumption continues to rise rapidly as China's economy continues to develop. In the Baseline scenario in 2050, final electricity consumption is about four times higher than in 2007. In the BLUE Map scenario, consumption grows to 8 632 TWh in 2050, more than three times higher than in 2007. This is 19% lower than in the Baseline scenario as the growth rate of electricity consumption is slowed by higher levels of industrial energy efficiency and more efficient lighting and air conditioners in the buildings sector. Electricity consumption for transport in the BLUE Map scenario is higher than in the Baseline scenario as a result of the deployment and commercialisation of plug-in hybrid electric vehicles (PHEVs) and EVs, which represent a 12% share of the sale of new vehicles in 2050.

Table 10.4 ▶ **Current and projected final electricity demand for China by end-use sector**

(TWh/yr)	2007	Baseline 2030	Baseline 2050	BLUE Map 2030	BLUE Map 2050
Residential	372	1 337	2 440	978	1 582
Commercial	348	805	1 300	541	864
Industry	1 872	5 117	6 720	4 024	5 211
Transport	28	33	53	228	875
Other	98	221	117	100	101
Total	**2 717**	**7 513**	**10 630**	**5 872**	**8 632**

Sources: IEA (2009b, 2008 and 2009c); NBS and NDRC (2008).

Electricity generation scenarios

China's installed capacity in the Baseline scenario grows to 2 084 GW in 2050 and in the BLUE Map scenario it grows to 2 307 GW in 2050 (Table 10.5). In the BLUE Map scenario, the share of electricity produced from fossil fuels falls from 83% today to 40% in 2050. Of the share generated by fossil-fuelled plants, almost half of all plants, and almost all of the coal plants, are equipped with CCS in the BLUE Map scenario in 2050.

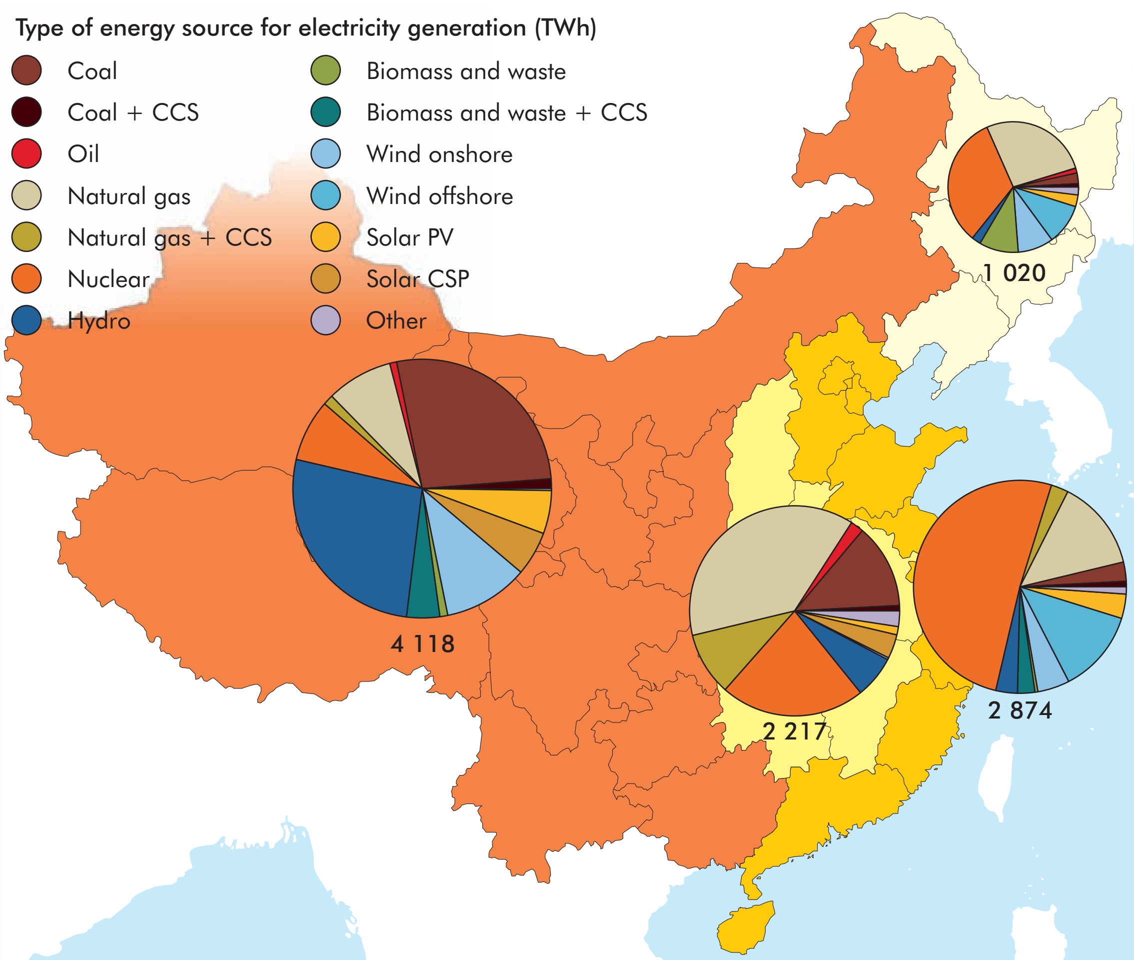
10

Table 10.5 ▶ **China's power generation capacity in the Baseline and BLUE Map scenarios, 2050**

	Power generation share Baseline (%)	Power generation share BLUE Map (%)	Capacity Baseline (GW)	Capacity BLUE Map (GW)
Coal	69.1	1.0	1 136	77
Coal + CCS	0.0	14.8	0	199
Gas	8.4	19.1	208	464
Gas + CCS	0.0	3.7	0	51
Biomass	1.3	3.4	26	58
Biomass + CCS	0.0	0.5	0	10
Oil	0.1	0.9	6	22
Nuclear	7.3	25.6	110	318
Hydro	9.2	12.5	365	370
Solar photovoltaic	0.8	4.4	62	270
Concentrating solar power	0.3	2.4	10	53
Wind onshore	3.1	5.8	150	263
Wind offshore	0.3	5.0	11	133
Other	0.1	0.8	2	19
Total	**100**	**100**	**2 084**	**2 307**

China plans to develop ultra high-voltage transmission systems and is investing heavily in R&D for 1 000 kV AC and 800 kV DC lines. These lines will be developed to transmit electricity, particularly hydropower, from the west to the east. Approval has already been granted for a 5 GW 800 kV DC demonstration project to be developed by the CSPG Company.

Figure 10.10 ▶ *Regional electricity generation in the BLUE Map scenario for China, 2050*



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Key point

The western provinces will represent the largest share of electricity generation in 2050 BLUE Map.

Different regions in China have varying electricity generation profiles in the BLUE Map scenario in 2050 (Figure 10.10). The largest share of electricity production (40%) in 2050 comes from the western provinces with abundant hydro, coal with CCS, wind and solar electricity generation. The coastal provinces in the east will see electricity production based largely on nuclear, offshore wind and gas. This area which today represents the largest share of electricity production will import a growing share of its electricity from other regions. Gas, nuclear and coal with CCS represent the largest share of electricity production in the central provinces, while in the north-east the largest shares come from nuclear and gas.

Decarbonising the power sector in China

China's current energy policy envisages a rapid expansion of nuclear, wind and solar capacity with targets of 70 GW of nuclear by 2020, 10 GW of wind by 2020 and 1.8 GW of solar by 2020. The rapid expansion of non-fossil electricity capacity will help to reduce the CO_2 intensity of the country's power sector. To reach levels of near-decarbonisation will require even higher levels of nuclear and renewable power generation and the development of CCS for coal-, gas- and biomass-fired plants.

It will take time to build up the country's nuclear and renewable power capacity. As a result, coal will continue to dominate China's electricity mix for the next 20 years. Investments in new coal-fired capacity and in non-fossil capacity will be needed to keep up with higher electricity demand. Replacing old subcritical plants with the latest state of the art SC, USC and integrated gasification combined cycle (IGCC) coal-fired plants will contribute significantly to reducing the CO_2 intensity of coal-fired generation. This transition to highly efficient coal-fired generation will in principle also allow the retrofitting of plants with carbon capture when the technology becomes available.

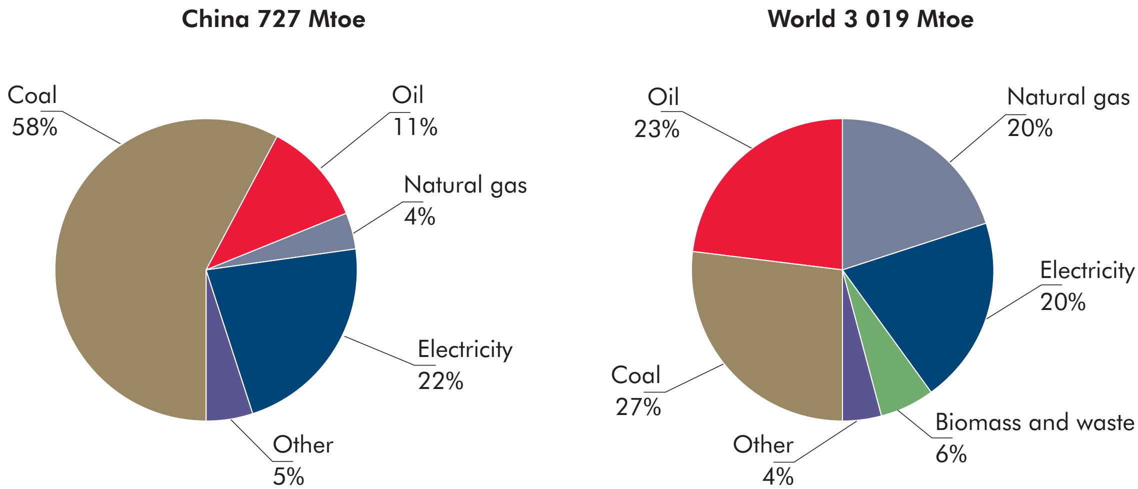
In the BLUE Map scenario, non-fossil capacity reaches 46% of all generation capacity by 2030 at 10 GW. Hydropower represents the largest share at 300 GW, while wind rises to 270 GW, solar to 71 GW and nuclear to 120 GW. From 2030 to 2050, the rapid growth of solar, nuclear, hydro and offshore wind will help boost non-fossil capacity to over 1 600 GW, representing 66% of total capacity in 2050. In addition to the rapid growth of non-fossil energy, carbon capture for fossil-fuelled plants will also need to be deployed from 2030 to reach levels of 250 GW by 2050. In the BLUE Map scenario, the CO_2 intensity of China's electricity sector falls to just 121 gCO_2/kWh from almost 777 gCO_2/kWh in 2007. These developments could be seen to set out a pathway towards the decarbonisation of China's power sector some time after 2050.

Industry sector

Industrial energy use in China reached 727 Mtoe in 2007, accounting for 60% of total energy used (Table 10.6). Dynamic growth in the country's manufacturing sector has led to a doubling in industrial energy consumption since 2000. China is the world's largest industrial energy user, accounting for 24% of global industrial energy consumption. This is 80% more than the United States, the second-largest industrial energy user. The final energy mix of industry is dominated by coal (Figure 10.11). Industry accounts for 74% of total electricity consumption, which is also a high share compared to other countries. Electricity accounts for 22% of industrial final energy use.

China dominates global industrial production and is the largest producer of cement, iron and steel, and aluminium. These three sectors represent 80% of direct emissions in industry which totalled 2.65 Gt in 2007. Total energy consumption for these sectors is equal to 59% of total energy use in Chinese industry.

Figure 10.11 ▶ Industrial final energy mix in China and in the world, 2007



Note: Includes coke ovens, blast furnaces and feedstocks.

Sources: IEA (2009a and 2009b).

Key point

Coal dominates industrial energy use in China where it accounts for more than twice the world average share.

Table 10.6 ▶ Industrial production, energy use and CO_2 emissions for China, 2007

	Production (Mt)	Reported energy use (Mtoe)	CO_2 emissions* ($MtCO_2$)
Industry sector		727	2 649
Iron and steel	495	276	1 095
Chemicals and petrochemicals	46	139	214
Aluminium	16	35	61
Non-metallic minerals		116	1 099
Cement	*1 354*	*112*	*953*
Pulp, paper and printing		17	40
Paper and paperboard	*78*		
Pulp	20		
Recovered paper	*31*		
Other		145	141

Note: Iron and steel includes energy use for coke-making. Chemicals and petrochemicals include feedstocks.
* CO_2 emissions are direct energy and process emissions only and do not include indirect electricity emissions.

Sources: IEA (2009a and 2009b); FAO stats (2010); World Steel Association (2009); IAI (2009); USGS (2009); IEA analysis.

Energy and CO_2 savings potential with best available technologies

Significant energy savings in Chinese industry are possible through the implementation of current best available technologies (BATs). The energy efficiency potential for China is similar to that of most industrialised countries. Typically an efficiency gain of 10% to 25% seems feasible, considering the gap between Chinese average energy use and BAT today.[3] Total estimated potential savings for the five sectors analysed is 118 Mtoe per year, equivalent to 16% of energy use in industry in 2007 and 10% of total energy consumption in China.

Part of this gap will be closed as old capacity is scrapped and replaced by current BATs. The country's capital stock is a mix of large state-of-the-art facilities and small outdated plants. Policies have been implemented in a number of sectors which require the mandatory closure of the smallest most energy-intensive facilities and much progress has been made since 2005, but additional potential still remains. Enforcing and monitoring the closure of some of these facilities has proven difficult in some cases as many of these facilities represent an important source of income for local communities.

China's high share of primary production makes it one of the most CO_2-intensive industries. As more scrap becomes available, its share of recycling will rise, which will help to reduce the country's industrial energy use and CO_2 emissions.

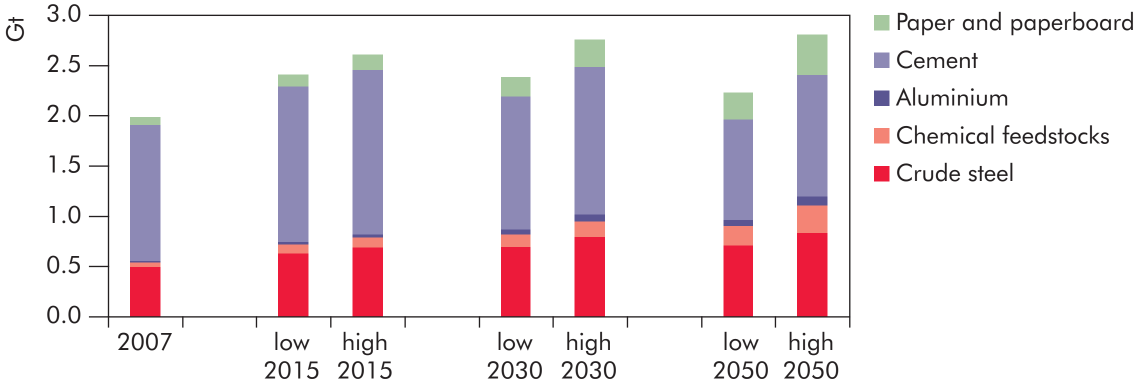
The 11th Five-Year Plan, announced in 2005, established an ambitious goal of reducing energy intensity by 20% between 2005 and 2010. One of the key initiatives for realising this goal is the Top-1 000 programme. The energy consumption of these 1 000 enterprises accounted for 33% of national and 47% of industrial energy use in 2004. A number of initiatives have been undertaken as part of this programme, including benchmarking, energy audits, the development of energy-saving action plans, information and training workshops, and annual reports of energy consumption.

Scenarios for industrial energy use and CO_2 emissions

Global industrial production growth over the last decade has been dominated by China and strong growth in many sectors is expected to continue over the next decades. As the economy matures, the consumption and production of energy-intensive materials such as cement and iron and steel are expected to peak over the next decade with a decline in cement production after 2030 as construction levels begin to slow.

3. The IEA's industry indicators analysis has highlighted some inconsistencies between reporting of energy use across countries. Energy data on Chinese industry are collected for all enterprises with sales above CNY 5 million and estimated for smaller enterprises which fall below this threshold, which could lead to under-allocation in different sub-sectors. Following extensive consultation with Chinese experts over the past several years on a variety of industrial sectors, the IEA has calculated energy savings potentials based on adjusted energy use data for Chinese industry.

Figure 10.12 ▶ Materials production in China in the low-demand and high-demand scenarios



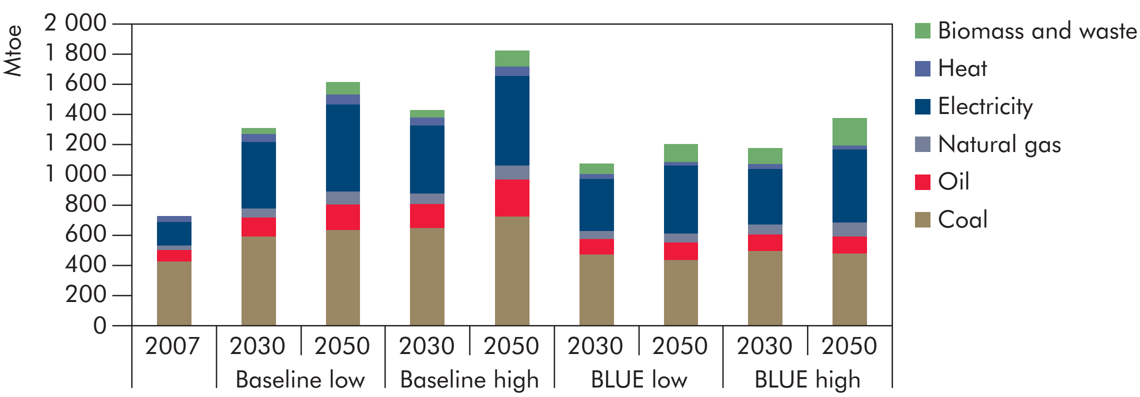
Note: Production of materials is the same for both the Baseline and BLUE scenarios.

Key point

Cement and iron and steel dominate materials production.

In the Baseline scenario, energy use is expected to increase to more than double current levels, reaching 1 610 Mtoe (low-demand case) to 1 820 Mtoe (high demand case) in 2050. Higher levels of energy efficiency in the BLUE scenarios will reduce the growth in industrial energy use to between 1 200 Mtoe and 1 380 Mtoe in 2050, 25% below the level of energy use in the Baseline scenario and 65% to 90% higher than in 2007. Coal currently represents 58% of total fuel use in industry. This will decline significantly in the BLUE scenario falling to approximately 35% in 2050. In both the Baseline and BLUE scenarios, electricity consumption rises sharply by 2050 as higher levels of recycling are achieved in many sectors. Measures to reduce the CO_2 intensity of industry in the BLUE scenarios will also result in higher shares of natural gas use, particularly in the chemical sector for the production of ammonia.

Figure 10.13 ▶ Energy use in industry by fuel type in the Baseline and BLUE scenarios for China



Key point

Energy use in the BLUE scenarios is 20% to 25% below Baseline scenario levels.

In the Baseline scenario, China's emissions continue to rise rapidly over the next 20 years, but then rise only moderately as the country's consumption of the most CO_2-intensive products, such as cement and iron and steel, begins to level off after 2030. Total direct and indirect industrial CO_2 emissions in the Baseline scenario are projected to rise from 4 Gt CO_2 in 2007 to between 8 Gt CO_2 and 8.7 Gt CO_2 in 2050. In the BLUE scenario, total industrial CO_2 emissions fall to just over 2.6 Gt in 2050 as the electricity sector reaches near-decarbonisation levels and indirect emissions from electricity fall to 0.2 Gt CO_2 in the BLUE scenarios in 2050.

Indirect emissions associated with industry in 2007 were 1.4 Gt CO_2. They are projected to reach 4.5 Gt CO_2 to 4.6 Gt CO_2 in the Baseline scenario in 2050. This highlights the benefits of decarbonising the power sector. Direct energy and process CO_2 emissions in China will continue rising in the Baseline scenarios, but at a slower rate than total direct and indirect CO_2 emissions, rising from 2.6 Gt CO_2 in 2007 to 3.5 Gt CO_2 to 4.0 Gt CO_2 in 2050 (Table 10.7). In the BLUE scenarios, direct emissions are 25% lower in 2050 than current levels. The largest reductions in direct emissions will come from the iron and steel and cement sectors.

Table 10.7 ► ***Direct energy and process CO_2 emissions by industry sector, China***

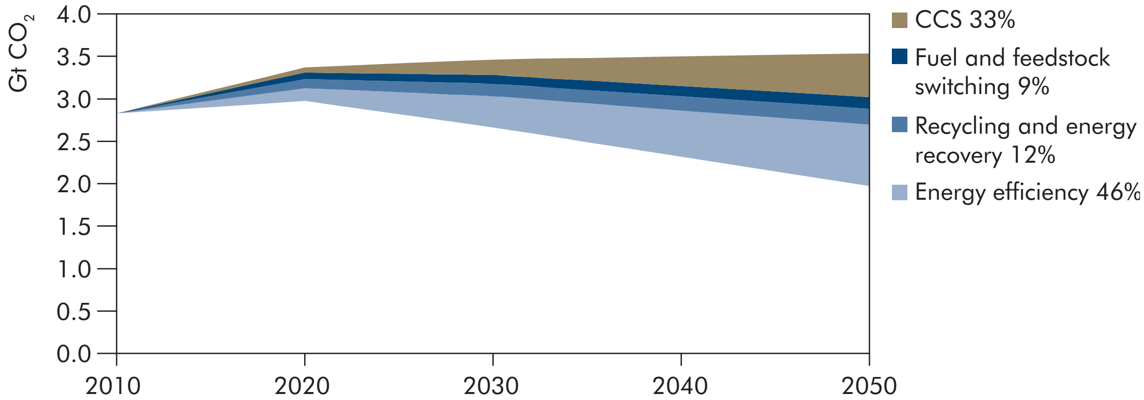
Mt CO_2	2007	Baseline low 2050	Baseline high 2050	BLUE low 2050	BLUE high 2050
Aluminium	63	148	194	131	98
Iron and steel	1 095	1 197	1 326	645	568
Chemicals	212	557	680	267	296
Cement	953	640	785	480	427
Pulp and paper	40	141	203	76	104
Other	286	863	863	382	405
Total	**2 650**	**3 545**	**4 051**	**1 981**	**1 898**

Sources: IEA (2009a and 2009b); IEA analysis.

10

A range of measures including energy efficiency, fuel and feedstock switching, higher levels of recycling and energy recovery, and CCS will be needed to reduce China's industrial emissions (Figure 10.14). Emissions will need to peak by around 2015 and then begin to decline as the benefits of greater energy efficiency and fuel and feedstock switching start to take effect. As the production of many materials will continue to grow strongly, efficiency, fuel and feedstock switching and greater levels of recycling will not be sufficient to offset strong production growth. Other more advanced technologies will be needed further to reduce energy intensity. To achieve a significant reduction in current industrial emissions will require the introduction of CCS technologies. The first carbon capture demonstration plants in industry will be needed from 2015 with wider deployment from 2025. In the BLUE scenarios, CCS alone reduces emissions by 0.5 Gt CO_2 to 0.8 Gt CO_2.

Figure 10.14 ▶ **Options for reducing direct CO_2 emissions from Chinese industry**



Key point

Energy efficiency and CCS represent the most important opportunities to limit growth in industrial CO_2 emissions.

In the BLUE scenario, China is the largest contributor to world industrial emissions reductions with direct industrial CO_2 emissions falling by approximately 0.7 Gt by 2050 compared to current levels. All industry sectors will need to reduce their CO_2 intensity if the industry sector as a whole is to reduce its emissions, but measures taken in the cement and iron and steel sectors will be particularly important as they represent over three-quarters of all emissions today. In both sectors, CCS will be needed to achieve significant reductions in emissions. Realising the potential offered by energy efficiency will require the diffusion of current BAT in both the cement and iron and steel sectors and the closure of small, inefficient, older facilities.

The closure and replacement of wet kilns and vertical shaft kilns in China with 5- and 6-stage preheater/precalciner kilns will reduce both the energy and CO_2 intensity of cement production. In addition, higher levels of alternative fuel use and lower cement-to-clinker ratios could further reduce emissions in the cement sector. In the BLUE scenario, alternative fuel use rises from 2% in 2007 to 31% in 2050, and the cement-to-clinker ratio falls from 0.77 to 0.68.

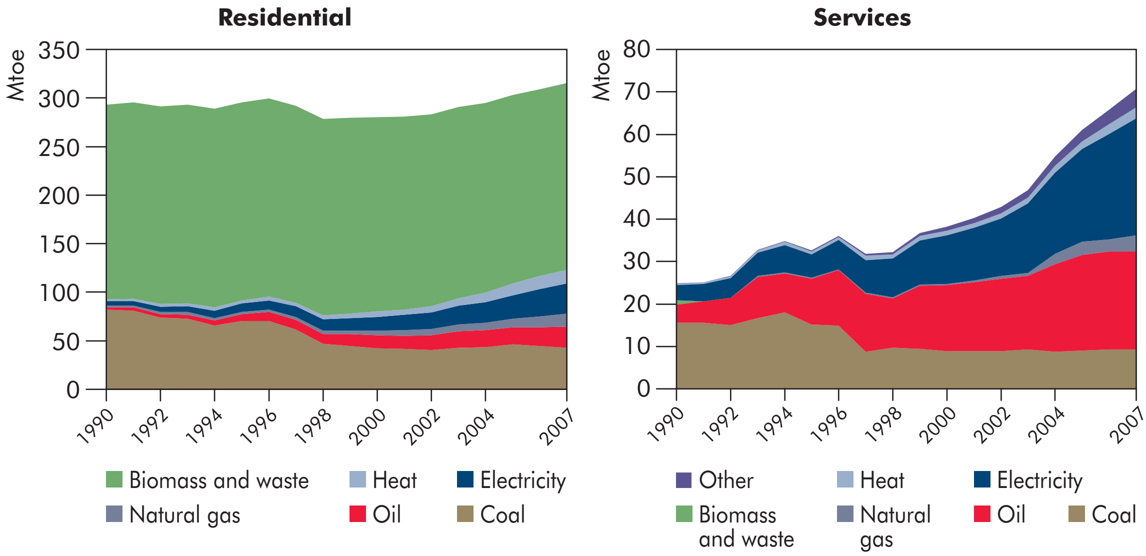
In the iron and steel sector, as more scrap becomes available, higher levels of recycling will become possible and a larger share of steel production can be based on electric arc furnace technologies which are significantly less energy-intensive than basic oxygen furnaces. As China's power sector progressively decarbonises, electrification options in steel production will help the sector to reduce its CO_2 intensity. Smelt reduction also offers an attractive opportunity to reduce the energy and CO_2 intensity of primary steel production and is assumed to be widely deployed in China in the BLUE scenario.

China's chemical sector is unlike that in many other countries because of its heavy reliance on coal for the production of ammonia. In most countries natural gas and to a lesser degree oil is used. An increase in the amount of ammonia production based on natural gas could significantly reduce emissions in the chemical sector, but this will depend on the development of unconventional gas sources as natural gas production in China is currently relatively low. In the BLUE scenario, high carbon prices lead to a shifting of ammonia production from coal to natural gas.

Buildings sector

The buildings sector, including the residential, commercial and public service sectors, accounts for about 18 % of TPES in China. Since 1990, the consumption of coal and biomass has been decreasing in Chinese households while the consumption of electricity, district heating, natural gas and petroleum products has been growing rapidly (Figure 10.15). With the boom in the commercial and service sectors in China since the early nineties, the demand for energy in this sector has also grown very rapidly (Figure 10.15).

Figure 10.15 ▶ ***Residential and service sectors energy consumption by fuel for China***



Key point

Biomass and waste are the dominant sources of energy in the residential sector. Energy demand in the commercial sector has shown much more rapid growth over the last two decades than demand in the residential sector.

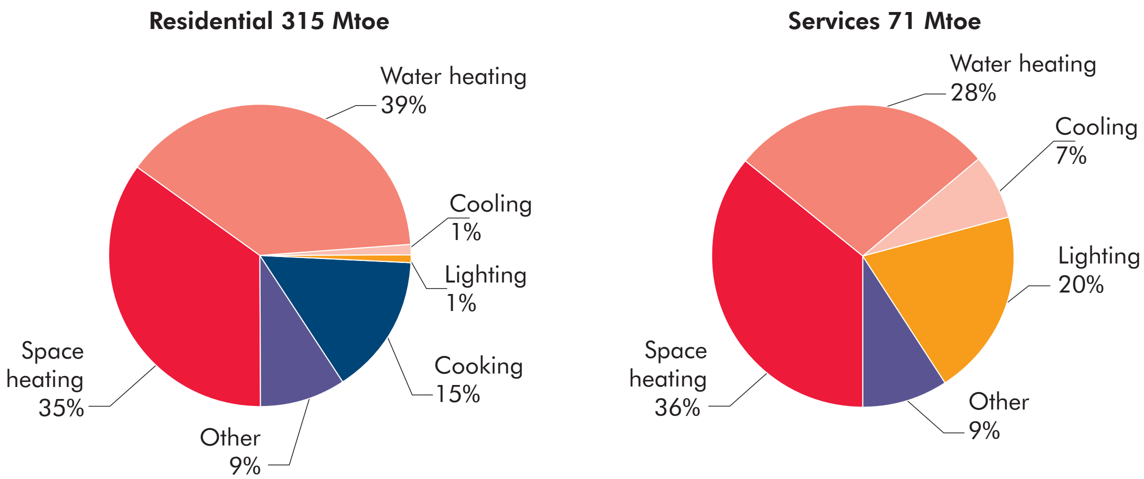
Part of the growth in electricity, gas, heat and oil products is due to the increasing urban population and the improved standards of living that are being driven by rapid economic growth. Between 1990 and 2006, the urban population increased from 302 million to 577 million (91%), and its share of all energy use increased from 26% to 45%.

Energy consumption by end-use

China covers a number of very diverse climate regions. As a result, energy consumption levels and patterns vary widely across the country. Regions in the north-east have significant heating loads, those in the centre have cold winters and warm summers, and those in the south-east have only very modest heating requirements.

Energy consumption by end-use is shown in Figure 10.16. In the residential sector, space and water heating and cooking dominate, while in the service sector space and water heating and lighting dominate. The rapid growth in electric appliances and applications means that the electrical end-uses share of the total is growing quickly, albeit from a low base. The potential growth in demand for cooling and appliances is particularly high.

Figure 10.16 ▶ ***Residential and service sectors energy consumption by end-use for China, 2007***



Sources: LBNL and IEA estimates.

Key point

Energy demand for space and water heating currently represent the majority of energy consumption in the buildings sector.

Scenarios for buildings energy use and CO_2 emissions

China's population is projected to grow from around 1.3 billion in 2007 to around 1.4 billion in 2050. At the same time, the growth in the number of households will be even higher as the trend towards fewer people per household accelerates. Total households are assumed to grow from 373 million in 2007 to just over 500 million in 2050, with the proportion of urban households rising from 45% to 78% over that period. The floor area of the service sector is expected to grow rapidly as economic growth expands, and is assumed to grow by an average of just over 4.4% a year between 2007 and 2050.

The Baseline scenario

China has experienced rapid growth in energy demand in the buildings sector in recent years, particularly for higher-quality fuels. This rapid growth is driven by increased incomes and urbanisation. The challenge this poses for energy and environmental systems is an area of increasing policy activity in China.

Energy efficiency in the buildings sector has been an emerging priority since the 1980s when China embarked on its large-scale urban construction effort (Huang and Deringer, 2008). Most recently, a revised Energy Conservation Law, released in 2007, has sought to address the issue of energy efficiency in buildings.

China has addressed the energy consumption of appliances by introducing labelling schemes and minimum energy performance standards (MEPs) for a wide range of appliances. The MEP for appliances continues to be tightened over time.

The result of these policy efforts has been to improve energy efficiency and generally to lower life-cycle costs for consumers. Increasing policy efforts have had a significant impact on the outlook for energy consumption in the buildings sector.

Energy demand growth in the Baseline scenario

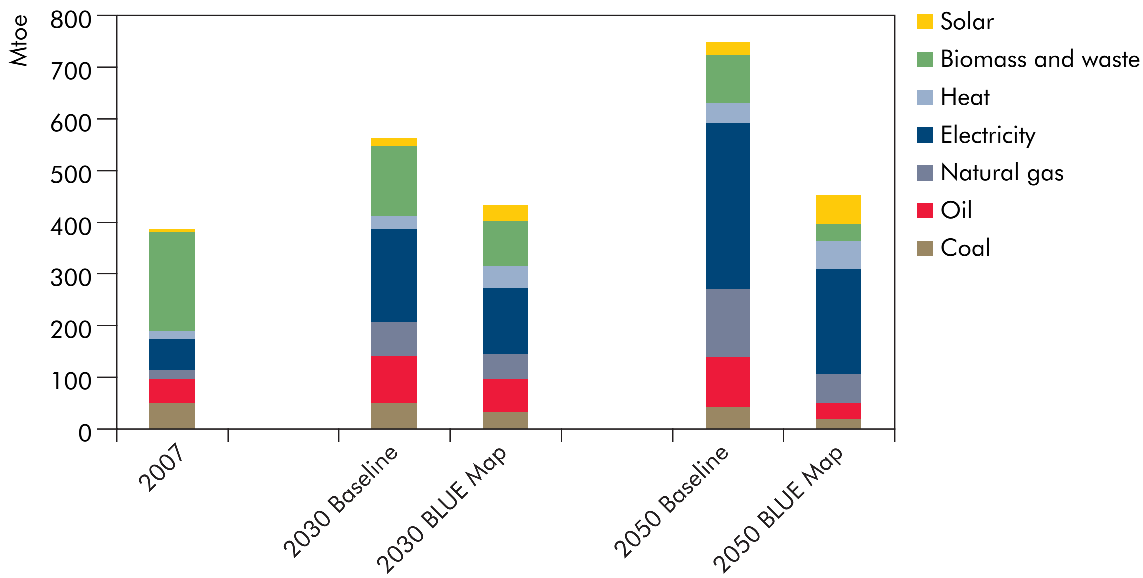
Energy consumption in the buildings sector increases by 94% between 2007 and 2050 in the Baseline scenario (*i.e.* by 1.6% per year), from around 386 Mtoe to 749 Mtoe. The consumption of gas is projected to grow at 4.8% a year, electricity at 4% a year, solar at 4.3% a year, purchased heat at 2% a year and oil at 1.8% a year. Coal consumption is projected to decline by 0.5% per year and biomass consumption by 1.7% per year.

The continued rapid growth in the importance of the service sector sees its share of energy consumption in the buildings sector increase from 18% in 2007 to 30% in 2050. The residential sector's share declines from 82% to 70%, in part owing to slower growth than the service sector, but also in part owing to improved efficiency in the use of biomass through improved stoves, biogas and bio-dimethyl ether.

The BLUE Map scenario

In the BLUE Map scenario, energy consumption in the residential and service sectors is reduced by 38% below the Baseline level in 2050, equivalent to a saving of 286 Mtoe (Figure 10.17). Energy consumption in these sectors is only 20% higher in 2050 than in 2007, despite growing energy service demand, as a result of efficiency measures and fuel switching. Biomass and petroleum products are reduced by the most in percentage terms (64% and 66% respectively) as improved efficiencies, and the increased use of solar water heating and other fuel switching, reduces demand. Electricity demand is reduced by 111 Mtoe, the largest amount in absolute terms, equivalent to a 35% reduction below the Baseline scenario level in 2050. Oil and gas consumption are also significantly reduced in the BLUE Map scenario. Solar thermal water heating increases significantly and solar use increases by 27 Mtoe to a level more than twice as large as in the Baseline scenario in 2050.

Figure 10.17 ▶ Energy use in the buildings sector in the Baseline and BLUE Map scenarios for China



Key point

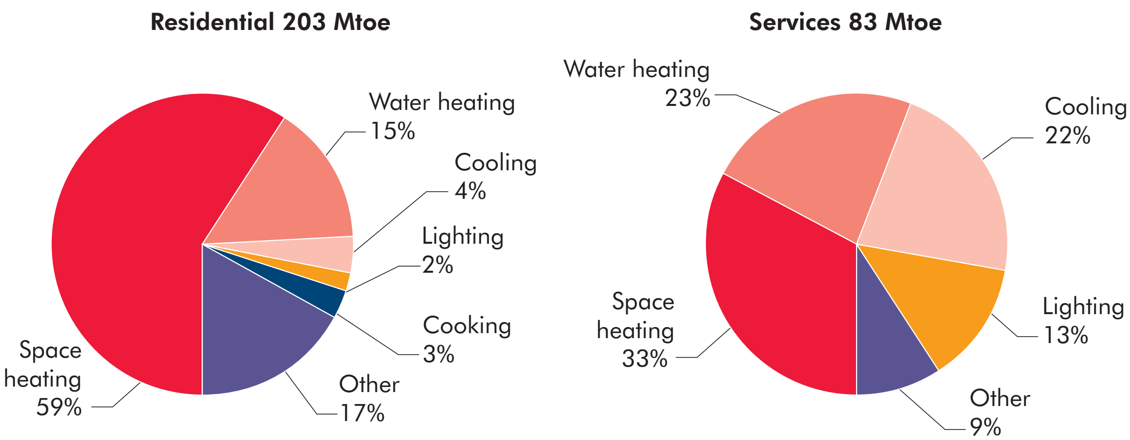
In the Baseline and BLUE Map scenarios, biomass use falls sharply while electricity consumption rises between three- and fourfold.

Residential energy consumption is reduced by around 203 Mtoe below the Baseline level in 2050 in the BLUE Map scenario (Figure 10.18). Service sector energy consumption falls by 83 Mtoe. In the residential sector, 77% of the savings come from space heating, cooking and water heating, as the very large-scale deployment of efficient cooking stoves and solar thermal water heating systems offers significant energy savings potential. The use of biomass derived DME and liquid biofuels also helps to improve efficiency. The reduction in space heating demand is achieved through a mixture of building shell improvements and heating system improvements. In zones with warm summers and relatively cold winters, highly efficient reversible air conditioners help reduce the energy demand for space heating significantly, while in colder regions ground source heat pumps are also projected to play an important, although not quite so significant, role.

In the service sector, water and space heating account for just under half of the savings. There are very significant savings from the electricity-intensive end-uses of cooling, lighting and other miscellaneous loads.

Residential and service sector CO_2 emissions are reduced by 36% below the Baseline scenario in 2050 in the BLUE Map scenario. Overall CO_2 emissions are reduced by 1 195 Mt CO_2 (excludes the impact of the decarbonisation of the electricity sector) below the Baseline level in 2050, with almost three-quarters of this reduction attributable to the reduced consumption of electricity. The savings from electricity are reduced to some extent by the switching from fossil fuels to electricity for cooking and water heating in the BLUE Map scenario, as a result of the substantial decarbonisation of the electricity sector, making electrification an attractive abatement option.

Figure 10.18 ▶ Contribution to reductions in energy use in the BLUE Map scenario for China, 2050



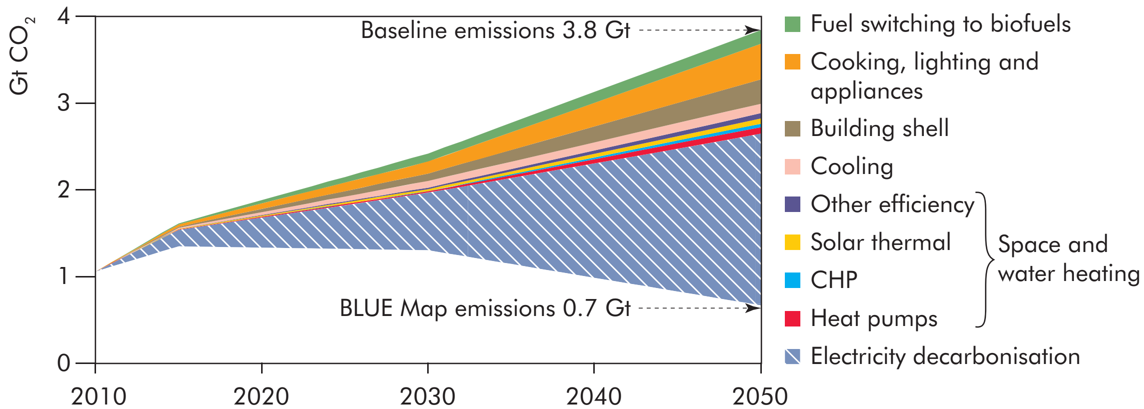
Key point

The largest potential for energy savings in the buildings sector comes from energy efficiency measures to reduce energy demand for space heating.

Space and water heating excluding building shell measures accounts for 20% of the reduction in CO_2 emissions below the Baseline scenario in 2050 (Figure 10.19). The assumed continuous tightening of building codes and standards to a low-energy standard of around 50 kWh/m^2/year for space heating results in accelerated savings in cold climate regions after 2030. Important contributions are also made from solar thermal, heat pumps and CHP/district heating. Energy efficiency improvements in appliances, lighting and cooking account for 34% of the reduction below the Baseline level.

The CO_2 emissions reductions from cooling are around 9% of the total, with slightly more than two-thirds coming from improvements in the efficiency of ventilation and air-conditioning systems. The balance comes from improvements in building shell and design, including the increased use of shading and active shutters, reflective coatings and insulation. Lighting systems are already estimated to be more efficient today in the residential sector than in many OECD countries thanks to the high use of fluorescent lights, but significant further improvements are possible, particularly in the service sector.

Figure 10.19 ▶ **Contribution to reductions in CO_2 emissions in the building sector in the BLUE Map scenario, China**



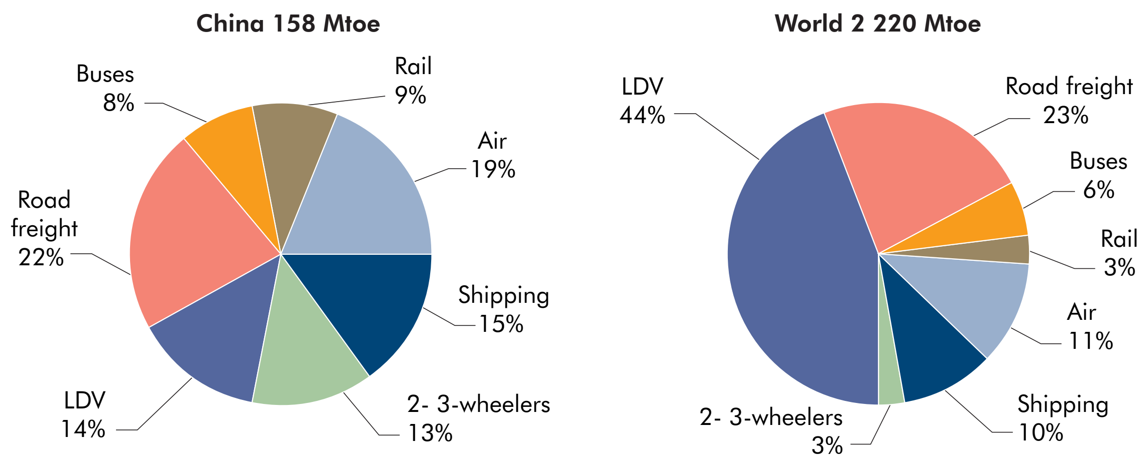
Key point

A wide range of options are needed to limit growth in CO_2 emissions in the buildings sector.

Transport sector

Transport sector energy use in China was 158 Mtoe in 2007 and accounted for 11% of total final energy use. This share is low compared to OECD countries, but the rapid increase of car ownership levels in China will undoubtedly change this picture in the near term. Passenger transport still accounts for a relatively small share of transport energy use especially for individual vehicles, with two- and three-wheelers, which far outnumber cars, using as much energy as passenger LDVs (Figure 10.20).

Figure 10.20 ▶ **Transport sector final energy mix in China and in the world, 2007**



Note: Air and shipping includes an estimate of international trips starting from China.
Sources: IEA (2009a and 2009b).

Key point

Transport energy demand from LDVs in China is currently well below global levels.

Modal transport indicators are broken down by activity, intensity and fuel use variables in Table 10.8. An important shortcoming of the Chinese energy use data as reported in the IEA statistics is that road fuel use is not specified in terms of vehicle type. This is estimated by the IEA using data and assumptions on vehicle stocks, efficiency and average travel. These estimates are based on current production levels and energy intensities from a range of sources. There is a need to validate these estimates.

Table 10.8 ▶ ***Transport energy and CO_2 indicators in China, 2007***

	Passenger travel	Freight travel	Stock average energy intensity		Fuel use	Passenger	Freight
	(bn pkm)	(bn tkm)	(MJ/pkm)	(MJ/tkm)	(Mtoe)	(Mt CO_2)	(Mt CO_2)
LDVs	621		1.5		22	73	
2- 3-wheelers	1 144	69	0.8	5.5	21	48	
Buses	1 725		0.3		13	45	
Freight trucks		755		1.7	34		144
Rail	639	1 814	0.2	0.3	14	19	39
Air	385		3.2		30	104	
Water		n.a.	n.a.	n.a.	24		90
Total / average	**4 514**	**2 638**	**0.8**	**0.7**	**158**	**291**	**271**

Notes: In totals row, averages are provided for intensity figures and are weighted across modes. pkm: passenger-kilometres; tkm: tonne-kilometres.
Sources: IEA (2009d); IEA analysis.

Scenarios for transport energy use and CO_2 emissions

Although China currently accounts for only a small share of the world's transport energy use and CO_2 emissions, Chinese travel growth is expected to change this picture rapidly over the next decade and beyond. The Baseline scenario to 2050 envisages almost an order of magnitude increase in passenger travel and goods transport, with accompanying large increases in energy use and CO_2 emissions. Large cuts in the growth of energy use and CO_2 emissions appear possible through efficiency measures, the adoption of new fuels, and directing travel growth towards the most efficient modes.

It will not be possible to achieve these savings immediately. The introduction of efficient technologies will take time, and will be dependent both on reductions in technology cost and on an increase in the capacity of Chinese businesses and consumers to afford these technologies. As new technologies are adopted in new vehicles, it will take many years for these vehicles to account for most of the stock and travel, since car stocks turn over completely only every 15 to 20 years and turnover in truck stocks is even slower.

Investments in sustainable transport, such as building high-quality rapid bus systems for cities and rail transit systems where travel densities are high, along with much better infrastructure for cycling and walking, can begin immediately. Investments in rapid public transit systems can provide important alternatives to private vehicles where motorised travel is needed. Despite rapid motorisation in China, it will be decades before car ownership levels are likely to reach those of Europe or the United States, and in the meantime most people will be dependent on mass transit and non-motorised modes for their mobility. The building of appropriate systems and infrastructure now may result in slower growth in cars, and in particular fewer cars in urban areas, relative to the Baseline scenario. This will result in long-term energy and CO_2 benefits along with lower pollutant emissions and important benefits both for mobility and for the quality of urban life. But even with such modal shifts, car ownership in China is likely to rise by a factor of five to ten in the coming decades.

Baseline scenario

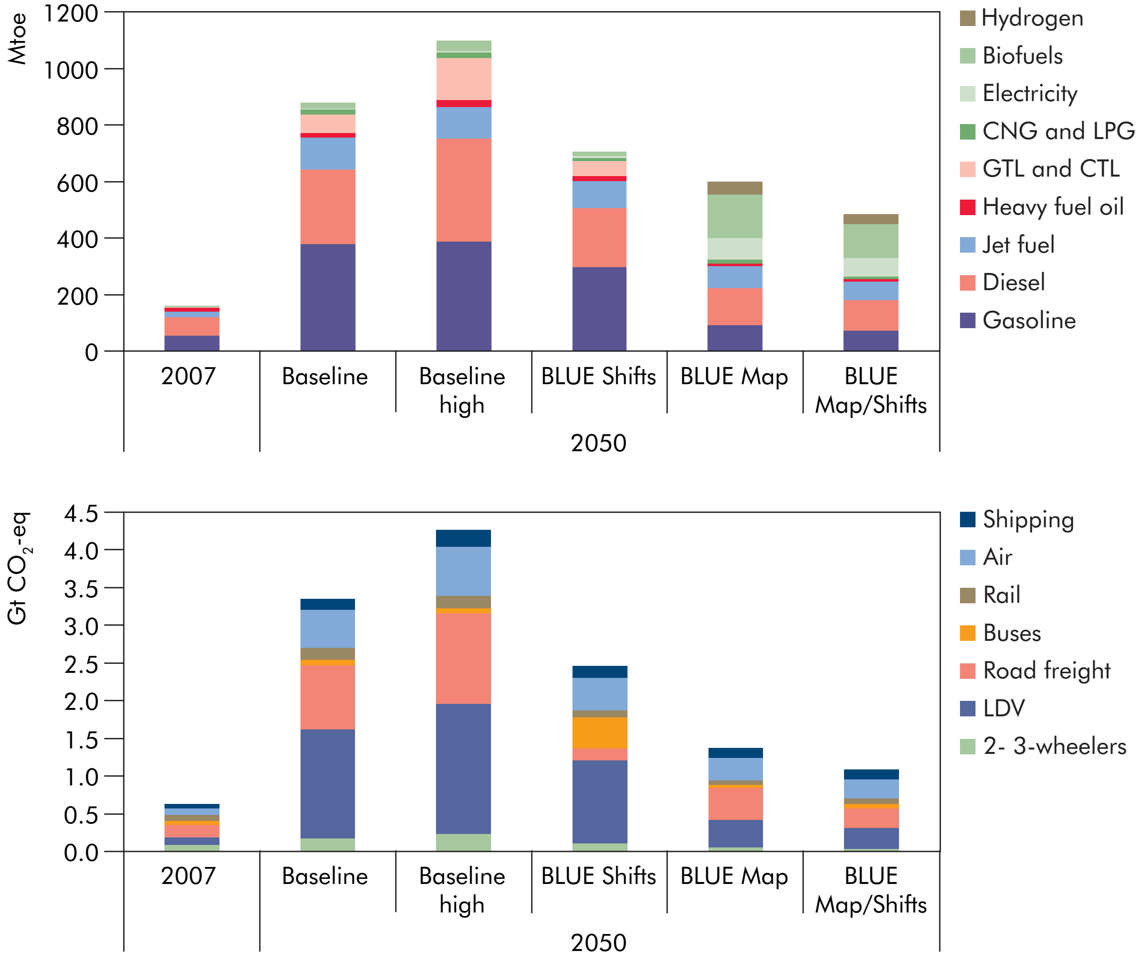
Based on recent and expected future trends, in particular related to population and GDP per-capita growth, the Baseline scenario results globally in about a doubling of passenger-kilometres (pkm) of travel worldwide between 2007 and 2050. This results in a near doubling of energy use.

In China, travel growth will be much higher, increasing nearly fivefold by 2050. The growth in freight activity is projected to be even greater. As a result, even with some efficiency improvements in the Baseline scenario, Chinese transport energy use grows by a factor of more than five from about 160 Mtoe in 2007 to 900 Mtoe by 2050 (Figure 10.21). This results in Chinese transport energy use increasing from 8% of the world total today to nearly 20% by 2050.

One reason for this is Chinese car ownership. It is assumed to rise from about 25 cars per 1 000 people to over 300 per 1 000 in the Baseline scenario. This strong growth may continue beyond 2050 in the absence of measures to curtail it, perhaps until ownership is closer to European levels of around 600 cars per 1 000 people or even United States levels of over 700 cars per 1 000 people. In a transport Baseline High demand scenario described in more detail in Chapter 7, China's energy use in the transport sector exceeds 1 000 Mtoe by 2050, reflecting higher assumed growth in car, truck and air travel than in the Baseline scenario. In the Baseline High demand scenario, Chinese car ownership is assumed to reach 400 cars per 1 000 people by 2050.

The impacts of the Baseline and Baseline High demand scenarios on China's greenhouse-gas emissions are similar in terms of overall growth to those for energy use (Figure 10.21). Chinese transport greenhouse-gas emissions on a well-to-wheel (WTW) basis, grow from about 0.6 Gt in 2007 to about 3.3 Gt by 2050 in the Baseline scenario and to over 4 Gt in the Baseline High demand scenario. This represents nearly 20% of world transport greenhouse-gas emissions in 2050 in the Baseline scenario, and 25% in the Baseline High demand scenario.

Figure 10.21 ▶ **China's transport energy demand and greenhouse-gas emissions**



Key point

Emissions in the Baseline could quadruple by 2050 as high growth is expected in energy demand for LDVs, but the wider deployment of low-carbon vehicles and other transport technologies could keep transport emissions below 1.5 Gt in 2050.

The BLUE scenarios: technological pathways for transport in China

As for all regions in the *ETP* analysis, the BLUE Map scenario for transport in China features strong vehicle efficiency improvements, the aggressive adoption of advanced vehicle technologies after 2020, and a transition to the use of fuels, including electricity, that become increasingly decarbonised between 2030 and 2050. A separate scenario, BLUE Shifts, looks at the energy savings and CO_2 emissions reductions associated with changes in the growth of travel by mode, with slower growth for car and air travel and higher growth for bus and rail mass transit modes. A BLUE Map/Shifts scenario combines the impacts of the BLUE Map and Shifts scenarios, to show the potential for combining vehicle and fuel technology changes with travel mode changes. These scenarios project different levels of transport energy use and greenhouse-gas emissions for China (Figure 10.21).

In the BLUE Map scenario, greenhouse-gas emissions are cut by about 60% relative to the Baseline scenario in 2050 and are only a little higher than their 2007 levels. This is achieved through:

- A 50% reduction in the energy intensity of LDVs, and 30% to 40% reductions in the energy intensity of truck and air travel relative to current levels. Some much smaller improvement also occurs in the Baseline scenario.
- The introduction of alternative fuels, mainly as a result of the use of EVs and FCVs as LDVs, and up to 30% displacement of fossil fuels by biofuels for trucks, ships and aircraft.

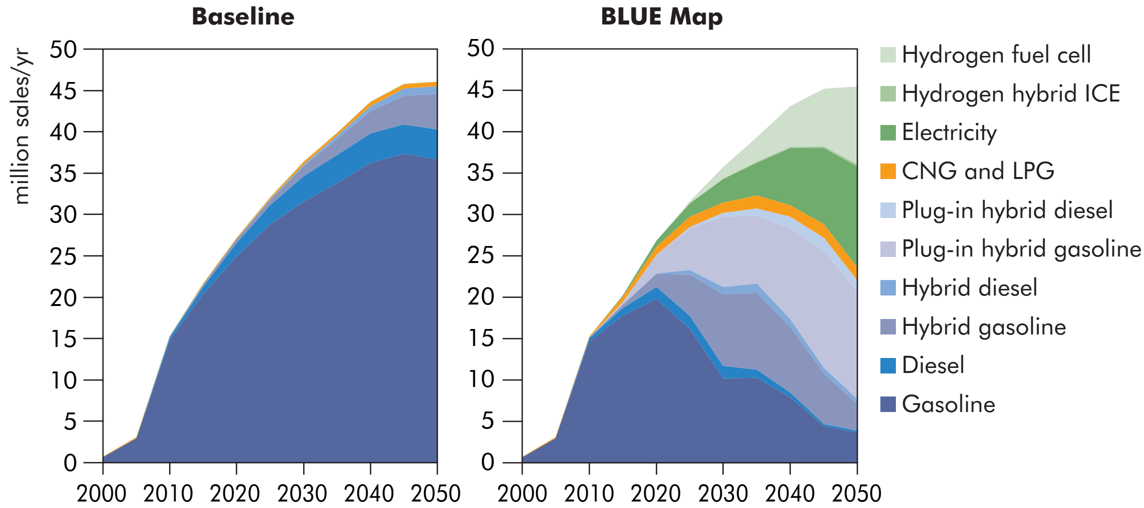
The difference between the Baseline and BLUE scenarios is very significant for China, and highlights the enormous potential for cutting CO_2 emissions through introducing new technologies and fuels into Chinese markets. The greenhouse-gas mitigation potential of the BLUE Map scenario in China amounts to around 2 Gt CO_2 in 2050.

China's adoption and recent tightening of fuel economy standards puts the country on an initial path to achieve strong reductions in fuel intensity for new LDVs by 2030 consistent with the BLUE Map scenario projections. But the current standards only apply until 2015 and it will be important that standards are continually tightened over time to ensure this trajectory continues. The scenarios also assume that improved fuel economy does not result in reduced fuel prices. As in OECD countries, it is assumed that most Chinese vehicles by 2030 are hybridised or use an advanced propulsion system such as an electric motor.

In the BLUE Map scenario, the sales profile of passenger LDVs by technology type in China changes rapidly (Figure 10.22). The market for EVs and PHEVs grows rapidly after 2015, and reaches combined sales of 11.5 million vehicles in 2030. By 2050, EVs dominate sales. Fast growth in China's battery manufacturing industry is likely to help the introduction of hybrids, PHEVs and EVs in the near- to mid-term.

China is emerging as one of the most proactive countries in respect of its approach to EVs and battery manufacturing. Electric two-wheelers (mainly e-bikes and mopeds) have achieved sales of over 20 million a year in recent years. Recent joint China-United States announcements of EV deployment programmes underline the willingness of China to play an important role in the electrification of the transport sector, with an interim goal of electric LDV sales of 500 000 a year by 2011 (IEA, 2009d). A critical issue will be the extent to which these EVs provide near-term greenhouse-gas reductions, given the current electricity generation mix in China. The impact will depend as well on the relative efficiency of the EVs, which remains to be seen. Over time, especially in the BLUE Map scenario, Chinese electricity generation becomes much less carbon-intensive. By 2030, when there may be millions of EVs on the road in China, they should provide relatively low CO_2-intensity driving.

Figure 10.22 ▶ Passenger LDV sales by technology in the Baseline and BLUE Map scenarios for China



Key point

The BLUE Map scenario envisions rapid successive introduction of new generations of advanced vehicles in China's rapidly growing market.

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Ten million electric two-wheelers were sold in China in 2005 and about 20 million in 2008. The total electric bike stock in China is estimated to be over 100 million units, perhaps three times as many as all other EVs worldwide. Assuming they are displacing sales of gasoline-powered two-wheelers, the growth in electric two-wheelers will have already helped to cut oil use. Many may, however, be replacing bicycles. A number of factors have made e-bikes particularly popular, including price incentives and their generally low cost of operation. They also received a boost when gasoline two-wheelers were prohibited in many city centres to reduce noise and pollution levels. But some big cities have made city centre access to e-bikes difficult or forbidden them, apparently for safety reasons.

China also will likely be well positioned to move towards advanced technologies such as FCVs, although this may take longer to mature. Fuel-cell vehicles are assumed to play an important role for LDVs in China after 2025, assuming a time-frame similar to that for most OECD countries and ahead of most developing countries.

The BLUE Shifts scenario: advanced rail and bus systems to help steer transport growth

In the BLUE Shifts scenario, much higher growth in rail and bus travel, coupled with better land-use planning that cuts motorised travel demand growth, leads to significant energy savings by 2030 and still more by 2050. In China, rail will play a particularly important role.

An ambitious national programme for the expansion of high-speed rail (MOR, 2004) involves plans for more than 12 000 km of high-speed rail by 2020. More than 4 000 km are already built or in construction (UIC, 2009), making China one of the leading countries for high-speed rail. Figure 10.23 shows the potential high-speed lines envisaged by the Chinese government.

China's railways were among the main beneficiaries of a stimulus package of RMB 4 trillion (USD 585 billion) announced in 2009. This will make the rail sector more attractive for passenger travel for medium and long distances, and appears likely to cut air travel growth. The rail sector will need to be further electrified, adding extra pressure on the electricity grid. Although high-speed rail is likely to take away passengers from the air sector, domestic and international air travel will still rise very significantly as demand for domestic and international tourism rises from a growing middle class.

Figure 10.23 ▶ High-speed rail corridors in China, 2009

Source: Freemark (2009).

Key point

China has ambitious plans to develop an extensive high-speed rail network.

In the BLUE Shifts scenario, it is assumed that strong investments in all forms of rail transport continue beyond 2020, and that they help dampen growth in car, truck and air travel. Rail capacity by 2050 would need to be between 50% and 100% higher than in the Baseline scenario, with a similar increase in bus transport, to achieve the 25% reduction in the growth of car and air travel implicit in the BLUE Shifts scenario.

Urban mobility in China

Chinese authorities are very proactive in urban planning, and many mass transportation initiatives are under way in China's biggest cities (Table 10.9). China is becoming a world leader in developing bus rapid transit (BRT) systems, using advanced technologies such as real-time bus schedule information and smart card ticketing systems. But even with strong investments in mass transit systems, urban travel is likely to be dominated by cars in many cities around the country in coming years. The reversal of current trends will depend on very strong policies that combine transit infrastructure with land use planning, on investments in non-motorised travel infrastructure, and on disincentives to car use such as road pricing. Road construction does not appear to be keeping pace in major urbanised areas, leading to growing traffic congestion and air quality problems.

Table 10.9 ▶ ***Mass transit in Chinese cities, 2009***

Number of cities	Metro	Tramways/LRT	BRT
In operation	9	3	5
Under construction	12 metro and tramways		5
Planned	6	12	3
Total		**55**	

Note: Light rail transit (LRT).

Sources: ITDP (2009); CityRailTransit (2010); and RailwayTechnology (2010).

In summary, the Chinese transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure construction, and the introduction of new technologies. Electrification is likely to play an important role in the development of transport in China. Although the total number of EVs will probably not put a significant additional load on the electricity system for some time, especially since most EVs will be recharged mainly at night, China will need to plan for a potentially very high electricity demand from vehicles and to decarbonise power generation in order to mitigate transport-related greenhouse-gas emissions.

Investment needs in the BLUE Map scenario

Significant additional investments in energy-efficient equipment, appliances, vehicles and buildings will be needed to transform the way energy is used in China (Figure 10.24). On the energy production side, the power sector will need

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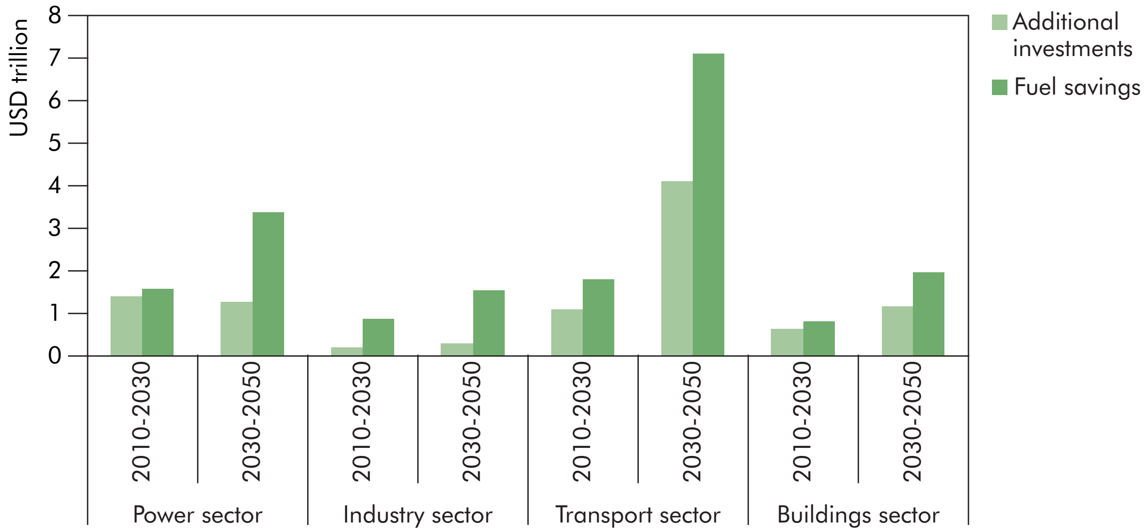
to be significantly decarbonised, which will require large investments in nuclear and renewable power generation and CCS. Additional technologies to reduce the CO_2 intensity of transport and industry will also be needed in the medium to long term.

Achieving the 30% emissions reduction in the BLUE Map scenario in 2050 compared to 2007 will require additional investments of USD 10.2 trillion between 2010 and 2050. Of this total, USD 5.2 trillion is required in the transport sector. Most of this will be needed after 2030 for low-carbon vehicles, extensive rail networks and biofuels. Additional investment needs in the buildings sector are estimated at USD 1.8 trillion, of which USD 0.64 trillion is required by 2030 and USD 1.16 trillion from 2030 to 2050. Decarbonising the power sector will require an additional USD 2.7 trillion in investments of which more than half is required by 2030 and the remainder from 2030 to 2050. Industry represents the smallest share of additional investment needs at USD 0.5 trillion. Given the large share of electricity use in industry, measures taken to decarbonise the power sector will help to reduce total emissions attributable to industry.

Figure 10.24 ▶ ***Additional investment needs and fuel savings for China***



Key point

Fuel savings offset higher investment costs in China.

Investments made in energy efficiency, in low-carbon vehicles and in technologies to decarbonise the power sector will yield significant savings in fossil-energy consumption. Many of the investments in energy efficiency are already competitive on the basis of life-cycle costs. Overall, total undiscounted fuel savings from 2010 to 2050 in China are estimated at USD 19 trillion. Investment needs and fuel savings in the BLUE Map scenario are estimated to save USD 8.8 trillion net, undiscounted, from 2010 to 2050. The transition to a low-carbon energy system will help to reduce the country's dependence on imports of foreign energy resources, leading to increased energy security and also important fuel savings.

Given the large share of additional investment that is needed for the transport and buildings sectors, the majority of these additional investments will be funded by consumers. During the COP-15 negotiations, China announced that it was not seeking direct financial assistance for mitigation efforts. However, international financing mechanisms such as carbon finance or sectoral crediting mechanisms could play an important role in the demonstration and early deployment of low-carbon technologies, particularly in the power sector and for heavy industry. As the world's largest producer of steel, cement and aluminium, China offers some of the least costly opportunities to reduce CO_2 emissions in heavy industry. It thus has an opportunity to develop solutions that may be applicable elsewhere, thus becoming a provider of low-carbon technologies worldwide.

With USD 220 billion committed to low-carbon technologies, China's economic stimulus plan is leading the way to a green recovery with more committed than any other country (HSBC, 2009). The bulk of these investments is aimed at expanding the country's rail network, electricity grid and water infrastructure.

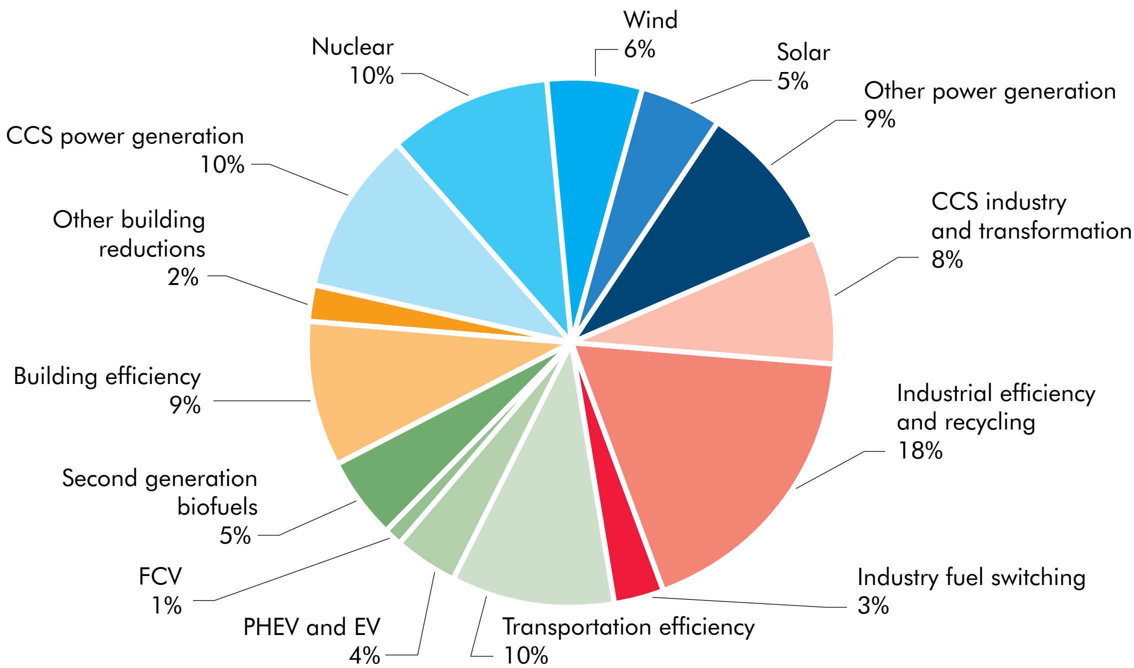
Transition to a low-carbon energy future

Future technology and policy priorities

Deep emissions reductions in China are achievable through the application of a mix of energy technologies which are already available today and through the development of a number of new technologies currently being developed. Different technologies have different contributions to make to achieve the 30% reduction in energy-related CO_2 emissions compared to 2007 levels that China needs to make in the BLUE Map scenario by 2050 (Figure 10.25). Compared to the Baseline scenario in 2050, this represents a reduction of 11.6 Gt CO_2. Measures to decarbonise the power sector will provide 40% of all emissions reductions. Energy efficiency in different end-use sectors would contribute another 37%. The single largest contribution to emissions reduction in China in the BLUE Map scenario is industrial energy efficiency and recycling which represent 18% of total savings.

China already has one of the most ambitious nuclear power programmes in the world with an official target of 70 GW of new nuclear capacity by 2020. Given the structure of the Chinese electricity market, the high expected growth in electricity demand and the country's financial strength, nuclear power represents one of the most attractive options to help reduce CO_2 emissions and at the same time improve the country's energy security. By 2050, nuclear capacity in the BLUE Map scenario reaches 320 GW, supplying 26% of China's total electricity production. China has the opportunity to develop a significant nuclear industry and once the current build of second-generation (GEN II) plants is completed and third-generation (GEN III and GEN III+) technologies are more widely deployed globally, China is likely to focus its efforts on developing more advanced nuclear technologies.

Figure 10.25 ▶ **CO_2 emissions reduction by technology area in the BLUE Map scenario for China, 2050**



Key point

Decarbonising the power sector contributes to the largest share of emissions reduction in China.

Table 10.10 ▶ **China's current energy technology priorities**

Resource exploitation technology	High efficiency coal mining technology Oil and gas exploration technology in complicated geographical conditions Ocean oil and gas exploration technology Exploration technology for coal-bed gas
Clean coal technology	Coal washing and depressing technology Clean and high efficiency power generation Coal-based liquid fuels and coal chemistry technology
Nuclear power station	Pressurised water reactors with capacity above 1 000 MW
Super large-scale electricity transmission and distribution network and electricity grid secondary system	Flexible AC transmission systems High-voltage transmission systems Interim electricity source connecting to grid technology Monitoring and controlling electricity quality Large-scale interconnected electricity grids security guaranteeing technology Electricity dispatching automation technology
Scaled development of renewable energy with low cost	Large wind power generation units Agricultural and forestry biomass power generation technology Biogas power generation technology Ethanol fuel Biodiesel and bio briquette fuel Solar energy technologies

Source: NDRC (2006).

The Chinese government's energy R&D priorities are for the most part consistent with the technology priorities identified in the BLUE Map scenario. One area that has not yet been prioritised in China is transport (Table 10.10). China could also benefit from the development of greater fuel economy, second-generation biofuels and PHEVs and EVs as priority targets.

The wide deployment of different renewable power technologies including wind, solar CSP, solar PV, hydro and biomass technologies will also be needed if China is to decarbonise its power sector. China is already a leading manufacturer of wind turbines and solar PV panels, although the bulk of this production has been geared for the export market. For example, of the 2 GW of PV cells produced in 2008, 95% was exported (IEA, 2010). Only in the last few years has it been focused on domestic deployment. Recent policies aimed at spurring investments in renewable power generation have helped to boost the levels of renewable power, but an even quicker expansion with greater shares of production aimed at expanding the domestic market will be needed if the levels of wind and solar in the BLUE Map scenario are to be achieved.

More detailed renewable power resource assessments are needed in China to help identify and develop a least costly pathway for renewables development. Greater attention will also be needed to extend and reinforce the grid to allow for greater shares of renewables to be integrated into the electricity network. Some of the most attractive renewables potential is located far away from major demand loads. China's plans to invest RMB 1.1 trillion in 2009/2010 to expand its electricity network shows that the country is aware of, and taking steps to address, these grid issues. Solar technologies in China have focused on solar PV development, but the results of the BLUE Map scenario analysis also show an important contribution from solar CSP. Greater attention should be given to developing both options.

Measures to decarbonise the power sector will have important benefits in all end-use sectors and will enable the development of electrification options in transport and industry. In transport, the development of PHEVs and EVs could contribute an estimated 0.4 Gt CO_2 of emissions reductions. It would also reduce oil consumption by an estimated 125 Mtoe, helping to reduce dependence on foreign oil imports. A decarbonised power sector will help to reduce total industry-related emissions and also provide an incentive to develop electrification options for industry. Indirect emissions in industry reached 1.4 Gt CO_2 in 2007 and are estimated to reach 5.0 Gt CO_2 in 2050 in the Baseline scenario. In the BLUE low-demand scenario, indirect emissions in industry amount to just 0.7 Gt CO_2.

The three largest sectors of iron and steel, chemicals and cement are responsible for about 50% of China's total emissions. Priority should be given to reducing the CO_2 intensity in these sectors. The demonstration of CCS in these industries is urgent. China's leading position in many of these industries offers an attractive opportunity for early demonstration, perhaps with international support. Achieving wider deployment may also require the implementation of sectoral crediting mechanisms which would encourage Chinese industries to invest in these technologies.

Chapter 11 INDIA

Key findings

- *In the Baseline scenario, final energy consumption increases in India by more than 3.5 times by 2050 and carbon dioxide (CO_2) emissions by nearly five times. India remains heavily dependent on fossil fuels. Coal, oil and natural gas use all increase by more than a factor of four. Emissions amount to 6.5 gigatonnes (Gt) of CO_2 in 2050.*

- *In the BLUE Map scenario, CO_2 emissions in 2050 are only 10% higher than in 2007. The share of fossil fuels declines to 49% of total primary energy supply (TPES) in 2050. The deployment of a wide range of low-carbon fuels and technologies increases significantly.*

- *Population growth, the modernisation of lifestyles, higher electrification rates and rapidly growing gross domestic product (GDP) drive a large increase in energy demand. Meeting these needs will require huge investments in new infrastructure in both the Baseline and the BLUE Map scenarios.*

- *The BLUE Map scenario entails considerable additional investment compared to the Baseline scenario, but it will also bring substantial benefits. Additional investments of USD 4.5 trillion are required between 2010 and 2050, but these result in fuel savings of USD 8.0 trillion over the same period. Energy security improves very significantly: oil use in 2050 is 56% lower than in the Baseline scenario.*

- *The need for very large investments in new power plants and infrastructure opens up significant opportunities for reducing energy requirements and associated CO_2 emissions while meeting the country's electricity needs. Priority should be given to deploying wind, solar and nuclear power generation and to deploying clean coal technologies, including coal washing, the development of integrated gasification combined cycle (IGCC), supercritical (SC) and ultra-supercritical (USC) power technologies and carbon capture and storage (CCS).*

- *Significant progress to improve the energy intensity of India has been achieved in the recent past. Despite this improvement, there is still a great potential to improve efficiency and reduce the growth in CO_2 emissions across all sectors by the application of best available technologies (BATs).*

- *India has some of the most efficient industrial plants in the world, but it also has a large share of inefficient plants. Improved energy efficiency has the potential to limit the growth in energy use and CO_2 emissions, but CCS will be required to achieve more significant savings. Other priority areas include moving away from coal-based direct reduced iron (DRI) in iron production and continue the substitution of oil feedstocks in the chemicals sector.*

- *Although the passenger vehicle stock is already relatively efficient in India, improvements in new vehicle technology and the penetration of hybrids, plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) will be required to limit the growth in transportation energy consumption and reduce the increase in CO_2 emissions seen in the Baseline scenario.*

- *Strong growth in energy demand is also expected in the buildings sector. Increasing standards of living, higher demand for services and migration from rural to urban areas will also play a role in increasing energy consumption. Large efficiency improvements will be essential if the growth in energy consumption is to be restrained. The near decarbonisation of the electricity sector will also need to play an important role in reducing CO_2 emissions.*

- *India already has ambitious targets in a number of technological areas, including energy efficiency, renewable energy and nuclear energy. The short-term priority should be to ensure that these targets are met. In the medium to longer term, they will need to be substantially strengthened and extended into new areas such as CCS and advanced vehicles.*

Regional description

The Republic of India is the seventh-largest country in the world. The land area covers 2.97 million square kilometres (km^2) with an elevated tableland in the south, deserts in the west, the Himalayan Mountains in the north and flat-to-rolling plains along the Ganges River.

India is the second most populous country after China, with a population estimated to be 1 123 million in 2007, about 17% of the world's total population; in 2008, 60% of the labour force was involved in agriculture, 12% in industry and 28% in services (CIA, 2010). India has the largest rural population in the world, with 828 million rural inhabitants (UNPD, 2008). In 2008, 71% of India's total population lived in rural areas. The rate of migration to urban areas, at 2.3% a year, is lower in India than in many other developing countries (UNPD, 2008).

India's GDP was USD 4 025 billion in 2007[1] (IEA, 2009a). Average annual growth of GDP has been high, averaging 7.7% from 2000 to 2007. In 2007, services accounted for 52.8% of total GDP, industry for 30% and agriculture for 18% (World Bank, 2009). The share of services in total GDP is much higher than that in most other developing economies.

While economic development has led to an increase in the average standard of living, it has largely bypassed most of the rural poor. So although the Indian economy has grown rapidly, poverty remains a major challenge.

1. In 2000 purchasing power parity (PPP) terms.

Only 65% of the Indian population has access to electricity (IEA, 2009b). Electrification reaches 93% of the urban population but only 53% of the rural population.

Recent trends in energy and CO_2 emissions

India's energy system is largely coal-based. Coal is the most important and abundant fossil fuel, accounting for about 55% of commercial energy supply in the country (MOC, 2010). About 7% of the world's proven coal reserve is located in India. Regionally, India's hard coal reserves are concentrated in the east, in a band that stretches from Chhattisgarh over Orissa, West Bengal, to the Bangladesh border. This band continues further north-east into Assam (Table11.1).

Only a small share of the world's proven reserve of crude oil is located in India. About half of India's reserve is located onshore, with most onshore oilfields being located in Gujarat and Assam (MPNG, 2009). Offshore oilfields are located in the west coast, in the Mumbai area. About 50% of the refining capacity is located in Mumbai, Assam and Gujarat.

Over 75% of India's natural gas reserves are located offshore, with gas fields on both the west coast and the east coast (MPNG, 2009).

The distribution of energy sources makes the transportation of energy and the generation, transmission and distribution of electricity major issues for the Indian energy supply system.

Table 11.1 ▶ **Proven energy reserves in India and in the world, 2008**

	Coal (bt)	Crude oil (Mt)	Natural gas (bcm)
Proven reserves: India	58.6	769	1 050
Proven reserves: world	826	170 800	185 020
Production in 2008: India	0.5	33.5	32.8
Reserve-to-production ratio: India	122	44	60

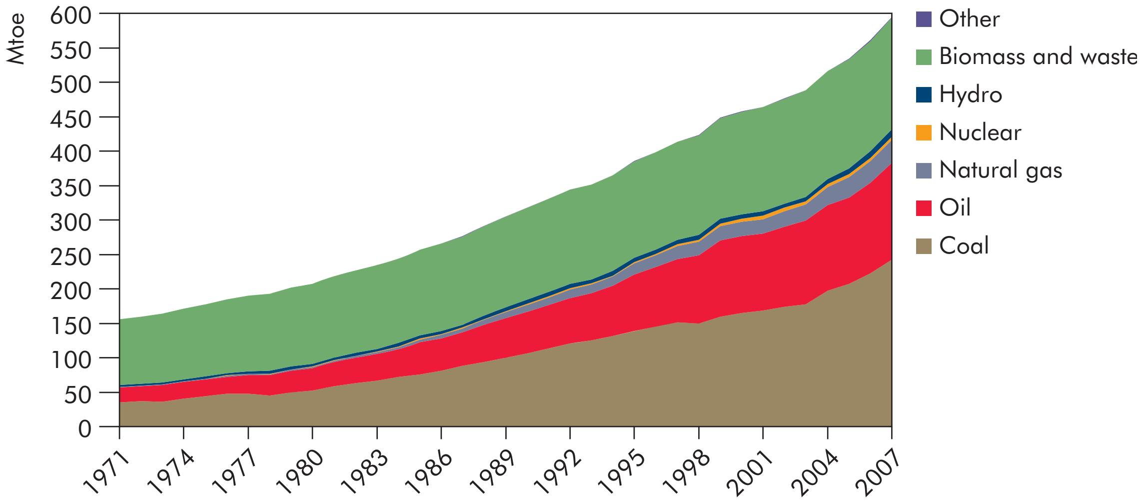
Note: Reserve-to-production ratio indicates the length of time that the recoverable reserves would last if production were to continue at current rates and if no additional reserves could be recovered.

Sources: BP (2009); MPNG (2009).

Energy production and supply

Primary energy supply in India has increased by 3.8% a year since 1971 (Figure 11.1). The energy supply mix has changed significantly over time. The supply is more diverse today. Oil and coal have increased their joint share of the total supply substantially since 1971, from 37% to 65%, and natural gas and nuclear have become more important in recent years.

Figure 11.1 ▶ **Total primary energy supply in India**



Note: Other includes non-combustible renewables. Oil includes international bunkers.

Source: IEA (2009a).

Key point

Coal and oil account for 75% of the growth in total primary energy supply.

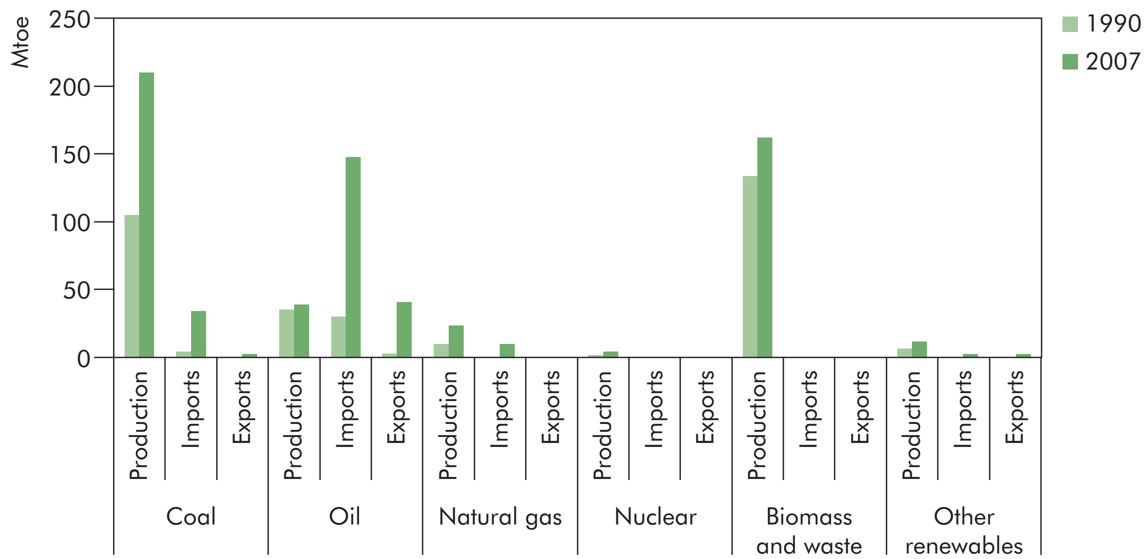
Primary energy production in India has increased at a slower rate, 3.3% per year, than energy supply since 1971. As a result, an increasing share of energy supply is now met by imports. In 2007, 32% of the country's energy supply came from imports, compared to 10% in 1971.

India is a net importer of all fossil fuels. Despite the doubling of domestic coal production between 1990 and 2007, imports have represented an increasing share of total primary coal supply, increasing from 4% to 14% (Figure 11.2). Part of the rapid increase in coal imports reflects the failure of indigenous coal production to keep pace with demand and the fact that the supply costs of indigenous coal on the west coast are higher than those for imported coal. Indigenous coal is also of low quality, with up to 50% ash content. This is detrimental to power plant efficiency and power production capacity.

India's New Exploration Licensing Policy (1999) was successful in attracting private investment, mainly from domestic investors, and several major oil and natural gas finds have been made since the launch of the policy. Even so, India has needed to import increasing volumes of petroleum and natural gas to meet demand.

All the increase in primary oil supply and about half of the increase in natural gas supply have been met by imports. Import of oil increased almost fivefold between 1990 and 2007.

Figure 11.2 ▶ **Energy production, imports and exports for India**



Note: Nuclear production refers to the heat produced in nuclear reactors, irrespectively of whether the nuclear fuel used is from domestic sources or imported. Other renewables includes non-combustible renewables.

Source: IEA (2009a).

Key point

About three-quarters of oil supply was imported in 2007.

Energy consumption

Industrial development has contributed significantly to economic growth in India over last few decades. Industrialisation has not been uniform. Large and modern urban centres coexist with a traditional rural and agrarian economy.

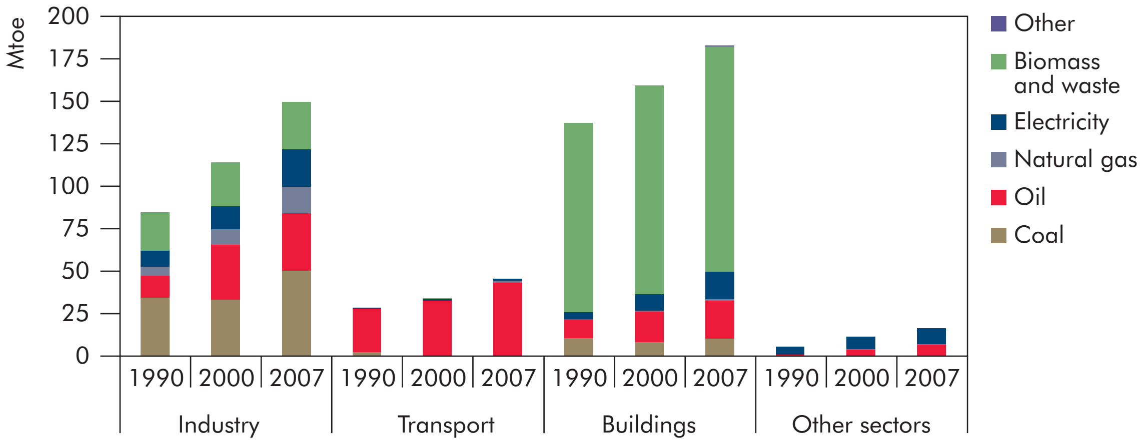
Energy use for the generation of electricity, both to sustain economic development and to provide electricity to all households, has increased by 9% a year since 1971. In 2007, one-third of the energy supply was used to generate electricity. About 75% of the coal supply in 2007 was used in power generation. Electricity now provides 12% of the end-use sectors' energy needs.

End-use energy consumption, including the final consumption of electricity, has also increased rapidly since 1971, at an average rate of 2.8% a year. The growth was mostly driven by the increase in the demand for energy from the agriculture sector which increased by 7.1% a year. Demand from other end-use sectors increased by between 1.9% and 3.4% a year. Since 2004, energy demand from the transport and industrial sectors has grown as much as demand from the agriculture sector. From 2004 to 2007, overall final energy consumption in India increased by 4.3% a year to 393 million tonnes of oil equivalent (Mtoe).

The fuel mix is quite different for different end-use sectors (Figure 11.3). Industry was the largest end user of coal, accounting for 83% of coal used by end-use sectors. The transport sector is a major user of oil, consuming about 40% of total final oil consumption. About 75% of the energy requirement of buildings is met by combustible biomass and waste. However, as rural areas become increasingly electrified and as improvements are made to the electricity system, the use of electricity is increasing. In 2007, electricity accounted for 9% of the energy used in buildings, up from 3% in 1990.

The industrial sector shows a more diversified energy mix, mostly related to the different energy requirements of different industries. Natural gas is slowly increasing its share in the industrial sector. The growing availability of natural gas through increased production and imports and the expansion of the chemicals sector, particularly for the production of fertilisers, have played a major role in the increased use of natural gas.

Figure 11.3 ▶ ***Final consumption by fuel and by sector for India***



Note: Other includes non-combustible renewables. Industry includes petrochemical feedstocks and coke ovens and blast furnaces. Transport includes pipelines, international marine bunkers and international aviation. Other sectors include agriculture, fishing and forestry.

Source: IEA (2009a).

Key point

The energy mix varies widely between end-use sectors.

End-use efficiency improvement

Final energy intensity in India was 98 kilotonnes of oil equivalent (ktoe) per USD 1 000 in 2007. Energy intensity has improved by 4.3% a year since 2000. This strong improvement in energy intensity is largely attributable to the rapid introduction of modern, efficient technologies and processes, and a structural shift between and within end-use sectors.

In the absence of detailed activity and energy consumption data for all the sectors at the end-use level, preliminary analysis at a more aggregate level suggests that the overall improvement in energy efficiency in India was at least 0.75% a year between

2000 and 2007. Without energy savings resulting from these improvements in energy efficiency, total final energy consumption would have been 10% higher (about 40 Mtoe) in 2007 than it actually was.

Carbon dioxide emissions

Energy-related CO_2 emissions in India increased by 125% between 1990 and 2007 to 1.34 Gt CO_2. This is much higher than the growth observed in TPES (87%) or in end-use energy consumption (54%), largely as a result of an increase in the share of coal used for the generation of electricity and a reduction in the share of combustible renewables and waste. The increased use of natural gas and oil also increased the overall CO_2 intensity of the fuel mix in end-use sectors.

Overall energy policy framework

India's energy sector is currently administered and managed through a complex multi-ministerial structure which involves the Union Ministry of Power, the Ministry of Coal, the Ministry of Petroleum and Natural Gas, the Ministry for New and Renewable Energy, the Department of Atomic Energy and the Planning Commission as well as other government bodies and agencies such as the Bureau of Energy Efficiency (BEE). The role of the Ministry of Environment and Forests in energy policy has also increased in recent years.

Reflecting India's federal governance structure, each of India's states and Union Territories (UTs) has significant constitutional rights in the power sector. The majority of states and UTs have established a state-level ministry or department for electricity, and some also have ministries or departments for energy. The pace of electricity reform varies considerably between energy sub-sectors and across the Indian states and UTs.

The Electricity Act (GOI, 2003) provides an enabling framework for the development of the power sector. The Act requires the central government to develop, in consultation with state governments and the Central Electricity Authority (under the Union Ministry of Power), a National Electricity Policy (NEP, notified in 2005) and a National Tariff Policy (NTP, notified in 2006). The NEP lays guidelines for accelerated development of the power sector, supplying electricity to all areas and protecting the interests of consumers and other stakeholders. The NTP offers general and uniform parameters to the State Electricity Regulatory Commissions for the formulation of regulation and for fixing tariffs for the respective legal entities, ensuring adequate returns and reasonable user charges.

A Rural Electrification Policy (REP) was also notified in 2006 under provisions in the Electricity Act. The REP sets out ambitious proposals to provide reliable electricity at reasonable rates to all households by 2012. Rural electrification is primarily the responsibility of each state and UT government. This is supported by central government policy funding provided through various financing schemes administered by the Rural Electrification Corporation under the Union Ministry of Power.

Policies on petroleum and natural gas are the sole responsibility of the central government. The Hydrocarbon Vision 2025 (GOI, 1999) set out to liberalise the market in hydrocarbons and to encourage private-sector investment in the upstream and downstream sectors.

Under the Petroleum and Natural Gas Regulatory Board Act (GOI, 2006b) the Petroleum and Natural Gas Regulatory Board was established in 2007 to promote competition and provide for access to pipelines on a non-discriminatory basis. The pricing of petroleum and natural gas is excluded from the Act and will remain under government control. Upstream activities are regulated by the Directorate-General of Hydrocarbons.

The government has also issued a policy for the Development of Natural Gas Pipelines and City or Local Natural Gas Distribution Networks. This is intended to facilitate the growth of the natural gas sector and to promote investment in the expansion of the pipeline infrastructure with a view eventually to creating a nationwide gas grid. The policy also seeks to encourage public and private investments and to protect consumers' interests. A central feature of the pipeline policy is the proposal to give third parties access to a common carrier on a non-discriminatory basis and the progressive unbundling of transmission and marketing activities.

The Ministry of Coal has overall responsibility for shaping policies and strategies with respect to coal. It also supervises Coal India and its subsidiaries which dominate India's coal sector. The Indian coal sector is the least reformed of all energy sectors. The coal industry requires huge capital injections and advanced technology deployment to maintain the coal supply needed to support India's economic growth.

The Ministry of New and Renewable Energy (MNRE) is responsible for the promotion of renewable energy technologies and their adoption throughout India. The ministry is also responsible for the implementation of a scheme which aims to provide electricity from renewable and alternative energy sources through its remote village electrification programme. Ministry of New and Renewable Energy collaborates closely with state-level agencies in creating demonstration projects and incentive schemes for renewable energy.

Current status of energy policies and climate change initiatives

Considerable progress has been made with reforms in the energy sector since overall economic reforms were launched in 1991. India's first Integrated Energy Policy (IEP) (GOI, 2006a) was approved by the government in 2006. It outlines a long-term vision for India's energy sector which addresses all energy sub-sectors. The broad vision behind the 2006 IEP is reliably to meet the demand for energy in India at the least cost in a technically efficient, economically viable and environmentally sustainable manner (GOI, 2006a). More specifically, the IEP states that:

- *in situ* gasification should be developed to tap the country's vast coal reserves;
- coal washing should become the norm;
- aggregate technical and commercial losses should be reduced through automated meter reading, Geographic Information Systems, and the separation of feeders for agricultural pumps;

- it should be possible to reduce India's energy intensity by up to 25% from current levels;
- the average gross efficiency of power generation should be raised from 30.5% to 34%;
- all new plants should adopt technologies that improve their gross efficiency from the prevailing 36% to at least 38% to 40%;
- electricity should be generated through wood gasifiers or by burning surplus biogas from community biogas plants;
- India needs to substantially augment the resources made available for energy-related research and development (R&D) and to allocate these strategically;
- energy policy modelling capability should be improved and modellers should be brought together periodically in a forum to address specific policy issues;
- international collaboration on research, development, demonstration and deployment (RDD&D) is required.

A number of actions are currently in hand in all sectors of the economy. The government is mandating the retirement of inefficient coal-fired power plants, and supporting R&D into IGCC and SC technologies. Under the Energy Conservation Act, large energy industries are required to undertake energy audits, and an energy labelling programme for appliances has been introduced. Under the Electricity Act and the NTP, the central and state electricity regulatory commissions must purchase a certain percentage of grid-based power from renewable sources. The Ministry of New and Renewable Energy aims to increase the contribution of renewable energy to 6% of India's generating capacity and to about 10% of the total electricity mix by 2022.

India's National Action Plan on Climate Change (NAPCC) was approved in 2008 (GOI, 2008c). The NAPCC identified eight priority national missions to address climate change mitigation and adaptation. Two of these, the National Mission on Enhanced Energy Efficiency (NMEEE) and the Jawaharlal Nehru National Solar Mission, focus specifically on the energy sector.

The NMEEE seeks to upscale efforts to create a market for energy efficiency. The missions will create a condusive regulatory and policy regime to foster innovative and sustainable business models to unlock this market. As a result of the implementation of the NMEEE over the next five years, it is estimated that by 2015 about 23 Mtoe of fuel savings will be achieved every year along with an expected avoided capacity addition of over 19 000 megawatts (MW). The consequential emissions reduction is estimated to be 98.5 million tonnes (Mt) of CO_2 annually.

The Ministry of New and Renewable Energy launched the Jawaharlal Nehru National Solar Mission in late 2009. The goal of the mission is to create an enabling framework for the deployment of at least 20 000 MW of solar power by 2022. The Solar Mission will adopt a three-phase approach: the immediate aim is to focus on setting up an enabling environment for solar technology penetration in the country.

The National Policy on Bio-Fuels (GOI, 2009) developed by MNRE and approved in late 2009 aims to accelerate the development and promotion of the cultivation, production and use of biofuels. The policy sets an indicative target of 20% blending of biofuels from biodiesel or ethanol with petrol and diesel by 2017.

Shorter-term energy policy is mainly driven by India's Five-Year Plans, prepared by the Planning Commission. The Five-Year Plans are developed from the bottom up with each ministry projecting its main development needs and proposing how best to achieve them. The Planning Commission is then tasked with ensuring that the individual plans result in a co-ordinated approach to meet the government's development and economic policies. Currently the Eleventh Plan (2007-2012) is being implemented (GOI, 2008b). Like its predecessors, it is predominantly supply-oriented and reflects the competing requirements of the diverse ministerial structure for energy policy.

In December 2009, India announced a 20% to 25% reduction of emission intensity by 2020 from 2005 levels. It is expected that this target will be part of the Low Carbon Growth Plan being embedded in the Twelfth Five-Year Plan.

Overview of scenarios and CO_2 abatement options[2]

Gross domestic product and population assumptions for India are the same in both the Baseline and BLUE Map scenarios. The different levels of energy supply and consumption between the two scenarios indicate the different degrees of decoupling between energy and economic activity driven by the assumptions in the relevant scenario (Table 11.2).

India's economic growth over the next 40 years will be one of the strongest worldwide. As a result, India's share in the world economy will rise considerably. Energy use and associated CO_2 emissions will increase significantly in both absolute and relative terms. In the Baseline scenario for India, GDP increases eightfold, primary energy use almost quadruples and CO_2 emissions grow by a factor of nearly five between 2007 and 2050. India's share of total global CO_2 emissions more than doubles from 5% to 11% between 2007 and 2050 under the Baseline scenario.

Per-capita consumption of electricity and oil is significantly lower in India than in China, the United States and OECD Europe, and well below the world average. But it is growing. The lower levels of electricity use per capita in the BLUE Map scenario than in the Baseline scenario throughout the period to 2050 reflect greater energy efficiency from all the end-use sectors.

Total primary energy intensity decreases by 1.8% a year in the Baseline scenario and 2.6% a year in the BLUE Map scenario, although primary energy per capita increases by 2.2% and 1.3% in the Baseline and BLUE Map scenarios, respectively.

2. Chapter 2 provides a full description of the different scenarios.

Total energy intensity improves by 26% and 29% between 2007 and 2015 in the Baseline and BLUE Map scenarios, respectively. In terms of CO_2 intensity, the BLUE Map scenario envisages reductions of 27% in emissions intensity by 2015 and of 66% by 2030. This is much more ambitious than the 25% reductions in the period between 2005 and 2020 announced by the government of India in December 2009 before the 15th Conference of the Parties (COP15) to the United Nations Framework Convention on Climate Change (UNFCCC). The 25% reduction announced by India is assumed to be achieved in the Baseline scenario.

Table 11.2 ▶ ***High-level indicators for India***

			Baseline		BLUE Map	
	2000	**2007**	**2030**	**2050**	**2030**	**2050**
TPES (Mtoe)	460	600	1 287	2 157	974	1 494
Total final consumption (Mtoe)	319	394	833	1 468	711	998
Electricity consumption (TWh)	408	610	2 132	3 440	1 633	3 453
CO_2 emissions (Gt)	0.98	1.34	3.36	6.45	1.86	1.47
GDP (billion USD using exchange rates)	460	771	3 131	6 026	3 131	6 026
GDP (billion USD using PPP)	2 402	4 025	16 340	31 453	16 340	31 453
Population (millions)	1 016	1 123	1 485	1 614	1 485	1 614
TPES/GDP (toe per thousand USD at PPP)	0.19	0.15	0.08	0.07	0.06	0.05
TPES/population (toe per capita)	0.45	0.53	0.87	1.34	0.66	0.93
Electricity consumption/population (kWh per capita)	402	543	1 436	2 131	1 100	2 140

Note: GDP is expressed in 2000 USD. Includes international bunkers.

Sources: IEA (2009a); IEA analysis.

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Energy and CO_2 emission scenarios

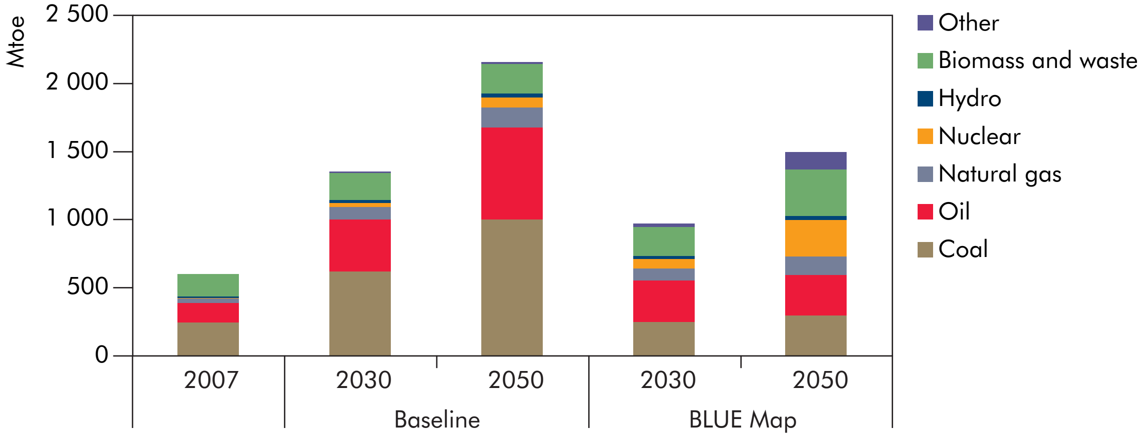
Total primary energy supply increases by 260% between 2007 and 2050 in the Baseline scenario and by 149% in the BLUE Map scenario.

In the Baseline scenario, the supply of all individual energy sources more than triples between 2007 and 2050, except for biomass and waste which increase by 35% (Figure 11.4). Nuclear power increases by a factor of 17 and non-combustible renewables by a factor of 11, mostly driven by the increase in demand for electricity. The fivefold increase in demand for oil comes mostly from strongly increased demand from the transport sector. Coal remains the main primary energy supply source in the Baseline scenario with a share of 47% of total supply, followed by oil at 31%.

Total primary energy supply is lower in the BLUE Map scenario than in the Baseline scenario by 2015, and remains so beyond that year. This rapid decrease is mainly due to a shift away from coal-based DRI in the iron and steel sector and to the increased electrification of the country. In the BLUE Map scenario, higher energy efficiency, the adoption of BATs and the use of more efficient energy sources (such as electricity and natural gas) limits the increase in TPES to 149% between 2007 and 2050, 31% below the Baseline scenario level. The energy mix is also quite different from that in the Baseline scenario. It is much more diverse, with coal, oil, nuclear and biomass and waste each accounting for approximately 20% of the energy mix. The use of non-combustible renewables, such as solar, wind and geothermal, also increases significantly, accounting for 9% of all supply in 2050, up from 0.2% in 2007.

In the Baseline scenario, CO_2 emissions from primary energy amount to 6.5 Gt CO_2 in 2050. In the BLUE Map scenario, CO_2 emissions only increase by 10% to 1.5 Gt CO_2 between 2007 and 2050 even though energy use more than doubles. This decrease in the carbon intensity of the energy used results from a significant increase in the use of non-fossil fuels, coupled with a strong decrease in the use of coal.

Figure 11.4 ► ***Total primary energy supply, Baseline and BLUE Map scenarios by fuel for India***



Note: Other includes non-combustible renewables. Oil includes international bunkers.
Sources: IEA (2009a); IEA analysis.

Key point

While coal and oil dominate in the Baseline scenario, nuclear and non-combustible renewables play an important role in the BLUE Map scenario.

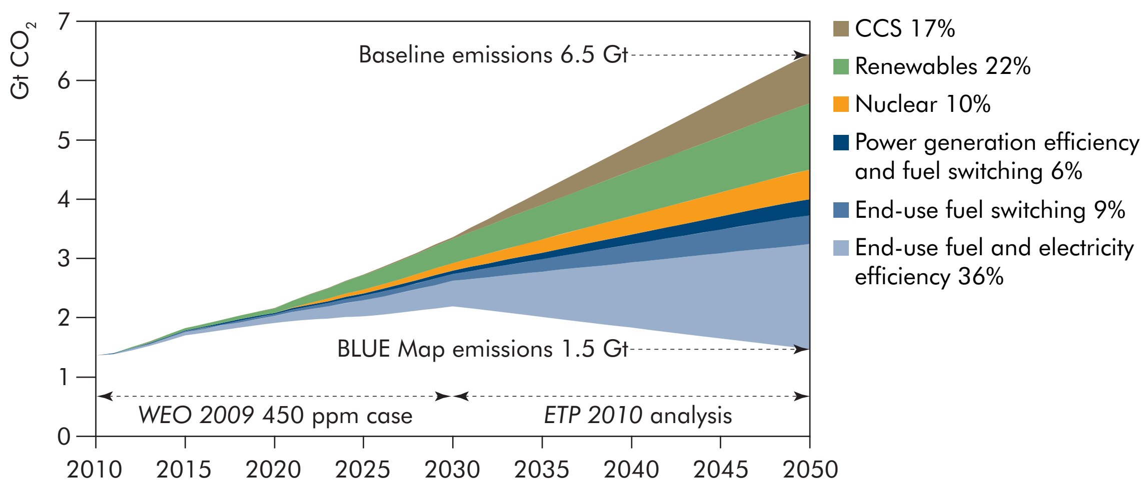
Carbon dioxide abatement options

The achievement of the ambitions of the BLUE Map scenario depends on India's emissions peaking in around 2030 (Figure 11.5). Given the expected strong growth in the Indian economy and the long lead times before new policies are put in place and have effect, there is an urgent need for effective action to bring this outcome about very soon.

Energy efficiency and fuel switching play an important role in restraining the growth in CO_2 emissions in the BLUE Map scenario over the entire period from 2010 to 2050. The increased introduction of zero- and low-carbon energy sources, such as nuclear, biofuels and renewables, will also play an important role, accounting for almost 50% of the reductions in 2030. Beyond 2030, additional measures to reduce the carbon intensity of electricity generation, CCS and the adoption of new technologies to reduce CO_2 intensity in industry and transport will also be required if deeper emissions reductions are to be achieved.

If CO_2 emissions are to peak around 2030, as envisaged in the BLUE Map scenario for India, CCS will need to play an increasingly important role. Without CCS, emissions will continue to grow throughout the period to 2050.

Figure 11.5 ▶ Contributions to emissions reduction in India



Sources: IEA (2009a and 2009b); IEA analysis.

Key point

In the BLUE Map scenario, CO_2 emissions will be 77% lower in 2050 than in the Baseline scenario.

Sectoral results

Power sector

The Indian electricity system today

India had 143 GW of generation capacity from utilities in 2008, made up of 53% coal, 25% hydro, 10% natural gas, 8% renewable energy sources,[3] 3% nuclear and 1% diesel (CEA, 2009a). In addition, industrial captive stations[4] generated a

3. Includes small hydro, wind power, biomass power, biomass gasifier and urban and industrial waste.
4. Captive stations are units set up by industrial plants for their exclusive supply.

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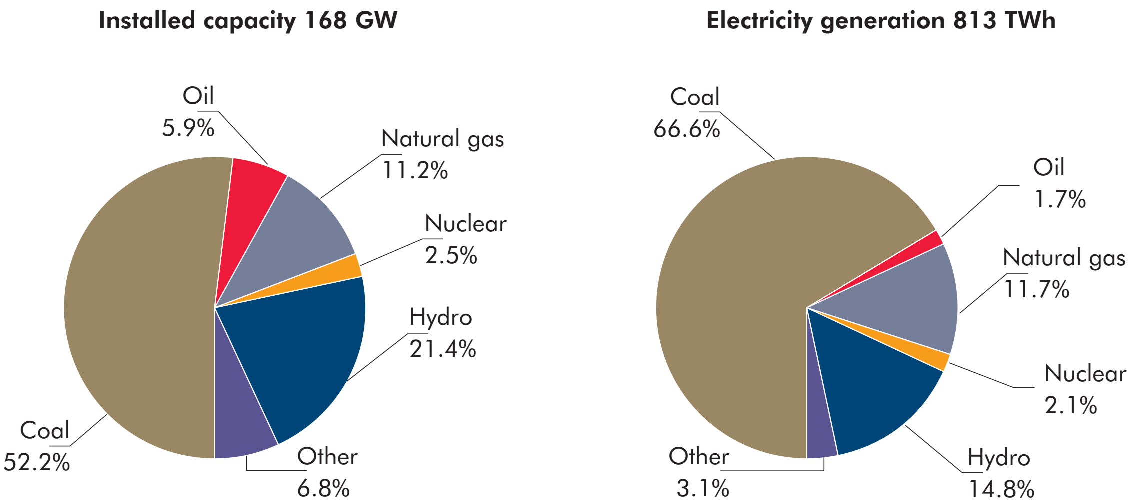
further 25 GW for direct use, 47% from coal, 35% from diesel, 17% from natural gas, 1% from wind and 0.2% from hydro.[5] In 2008, India generated 813 TWh of electricity in total (Figure 11.6). The capacity mix is different from the power supply mix because of varying load factors for different fuel sources and technologies.

Figure 11.6 ▶ Electricity generating capacity and generation for India, 2007/08



Note: Includes capacity and generation from utilities and captive power plants.
Source: CEA (2009a).

Key point

Two-thirds of electricity was generated from coal-fired plants.

The average efficiency of coal-fired public power plants was 32.7% in 2007/08 (CEA, 2009a). The auxiliary consumption of coal-fired plant ranged from 6% to 13% of total gross power produced, with an average of 8.4% (CEA, 2008b).

The Indian power sector has a number of important shortcomings:

- capacity shortages of the order of 15% of peak power demand and 10% of total demand;
- only 60% of households are connected to the grid;
- regular blackouts;
- structural under investment as a result of both market and institutional failures (Mathy and Guivarch, 2009).

5. Only includes power plants of 1 MW capacity or more.

In addition, the average price of electricity sold only partly covers the average production cost. The total under recovery of costs was estimated at 431 billion rupees in 2008, the equivalent of around USD 9.4 billion[6] (GOI, 2008a).

Most of these barriers are not technical in nature. But they will have an influence on the effectiveness and efficiency of the required technology transition.

Developments in renewable power generation

In 2008, India had a total of 12.6 GW of grid connected and distributed renewable capacity (Table 11.3). Wind power in particular has been growing at a rapid rate. Wind represented 75% of the target renewable power capacity additions, excluding large hydro, anticipated in the Eleventh Five-Year Plan (Verma, 2008).

Table 11.3 ▶ ***Indian renewable power generation capacities, status at 31 March 2008***

	Potential (MW)	Current capacity (MW)
Grid-connected		
Bio-power (agro-residues)	16 881	606
Wind power	45 195	8 757
Small hydropower (up to 25 MW)	15 000	2 180
Combined heat and power (CHP): bagasse	5 000	800
Waste-to-energy	2 700	55
Solar power		2
Total grid-connected	**84 776**	**12 400**
Distributed renewables		
Biomass power/CHP		95
Biomass gasifier		100
Waste-to-energy		27
Total distributed renewables		**222**

Note: Solar power potential is not included in the total.
Source: WEC (2009).

India added 27.3 GW of electrical capacity between 2002 and 2007, an average of 5.5 GW per year. The country aims to install on average 18.8 GW a year between 2007 and 2012, increasing the rate of capacity addition more than threefold (Verma, 2008).

6. Converted using nominal exchange rate of 11 March 2010.

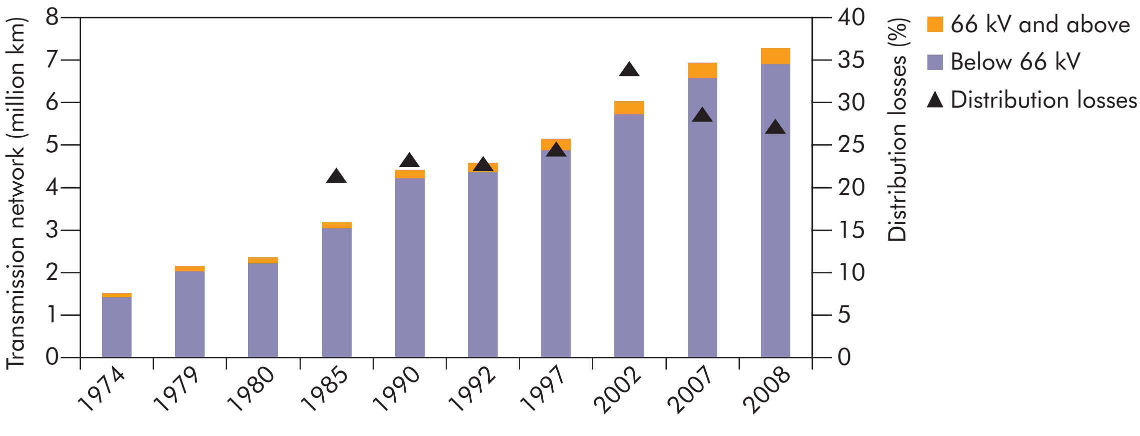
Electricity transmission and distribution

Since August 2006, four regional grids have been integrated into the northern, eastern, western and north-eastern grid (the NEWNE grid). Only the southern grid, covering the states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry and Lakshadweep islands, still operates independently. The southern grid is scheduled to be synchronously operated by the end of the Twelfth Five-Year Plan (2012-2017). It is currently connected to the western and eastern grid through a high-voltage direct current (HVDC) link and HVDC back-to-back systems. In 2007/08, power generation in India resulted in emissions of 520 Mt CO_2, 78% of which were associated with the NEWNE grid (CEA, 2008a).

Although 80% of India's villages are electrified, only 65% of the population and 60% of households have access to electricity. Power outages are common, and the unreliability of electricity supplies is severe enough to constitute a constraint on the country's overall economic development. Power shortages[7] increased from 9.9% in 2007/08 to 11.1% in 2008/09. It is estimated that the power shortage will be reduced to 9.3% by the end of 2009/10 (CEA, 2009b).

India's transmission and distribution losses are among the highest in the world, averaging 26% of total electricity generation in 2008 (Figure 11.7), with some states as high as 62%. When non-technical losses such as energy theft are included in the total, average losses are as high as 50% (Das, 2008).

Figure 11.7 ▶ Development of transmission network, and transmission and distribution losses for India



Source: CEA (2009c).

Key point

The transmission network is five times longer than it was in 1974; it increased by 4.7% a year from 1974 to 2008.

Improving grids should be a top priority in efforts to mitigate power supply constraints. In large, highly dispersed systems such as in India, the creation of a larger number of lower-capacity sub-stations, together with the conversion of single-

7. Total power requirement over total power availability.

phase supply to three-phase supply, can reduce distribution losses substantially. During periods of peak load, losses will be even higher than average. So there is advantage in designing systems with sufficient slack capacity to handle peak loads efficiently. This slack capacity adds to the upfront investment cost, and a balance between investment and distribution losses has to be struck.

Electricity demand scenarios

The power sector plays an especially important role in the growth of the Indian economy as electricity demand is projected to rise by a factor of 6.2 in the Baseline scenario and 5.6 in the BLUE Map scenario (Table 11.4). Within the power sector, coal-fired power generation is the dominant source of emissions.

In the BLUE Map scenario, as the economy grows eightfold, manufacturing activity expands significantly, as does its demand for electricity. Transport becomes the third-largest user of electricity in 2050. This strong increase is driven by the shift towards vehicles and technologies using electricity. The electrification of the entire country is in part responsible for the strong increase in electricity use in the residential sector; but in the BLUE Map scenario, the growth is limited by the penetration of more efficient electricity-using devices.

Table 11.4 ▶ Current and projected final electricity demand for India by end-use sector

(TWh/yr)	2007	Baseline 2030	Baseline 2050	BLUE Map 2030	BLUE Map 2050
Residential	121	491	1 311	384	994
Commercial	44	269	420	172	283
Industry	257	965	1 506	769	1 202
Transport	12	17	19	48	532
Other	133	223	257	145	156
Total	**567**	**1 965**	**3 513**	**1 518**	**3 168**

Sources: IEA (2009a); IEA analysis.

Electricity generation scenarios

Assuming that transmission and distribution losses can be reduced to 15%, about 3 700 TWh of electricity generation is needed in 2050 in the BLUE Map scenario. At full load, 114 GW of capacity can generate 1 000 TWh per year. However, in practice plants operate on average far below the maximum load. This is partially related to energy resource availability, for example in respect of variable renewables, and it is partially related to fluctuations in demand during the year.

India had 168 GW of total installed capacity in 2008, including captive power plants, with an estimated average load factor of 61%. The installed capacity is expected to grow significantly in both the Baseline and BLUE Map scenarios. Total capacity in 2050 is between 3.8 and 4.5 times the installed capacity in 2008. The generation mix in the Baseline and BLUE Map scenarios is very different (Table 11.5).

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Table 11.5 ▶ India's power generation capacity in the Baseline and BLUE Map scenarios, 2050

	Power generation share		Load factor	Capacity	
	Baseline (%)	BLUE Map (%)	(%)	Baseline (GW)	BLUE Map (GW)
Nuclear	7	27	95	33	122
Oil	0	1	50	0	7
Coal	70	2	90	359	7
Coal + CCS	0	16	90	0	77
Gas	11	12	40	126	133
Gas + CCS	0	4	65	0	27
Hydro	9	10	56	71	76
Bio/waste	1	4	50	12	32
Bio + CCS	0	1	65	0	3
Geothermal	0	0	85	0	2
Wind	2	5	30	33	66
Tidal	0	1	50	0	5
Solar	1	18	41	6	191
Total	**100**	**100**		**641**	**748**

Note: Unless otherwise indicated, all material derives from IEA data and analysis.

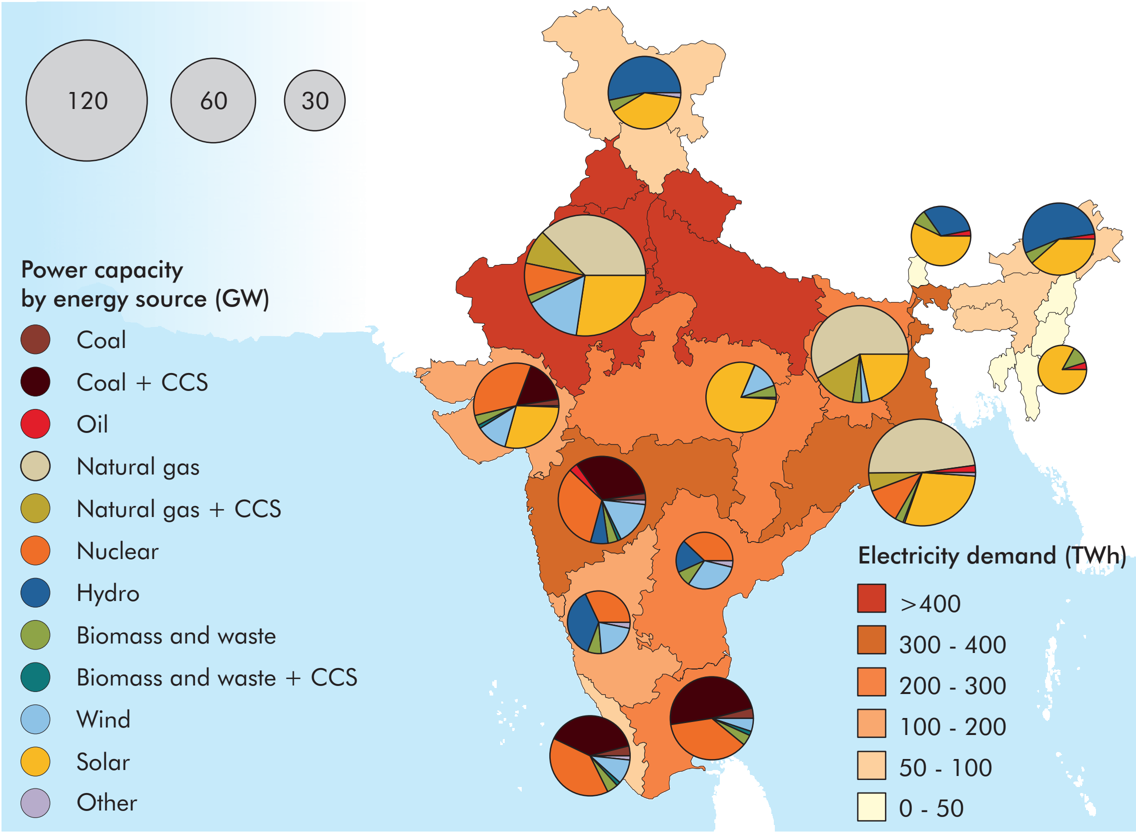
Different Indian regions have very different levels of power capacity and demand in the BLUE Map scenario in 2050 (Figure 11.8). Total capacity amounts to 748 GW. The full potential of biomass and wind is used. For hydro, about half of the potential is developed. Total coal-fired capacity is roughly at today's level, but most of this capacity is equipped with CCS. Solar increases from near zero in 2007 to 191 GW.

Decarbonising the power sector in India

The Indian power sector has a number of characteristics that make it very different from the power sectors in China, OECD Europe and the United States:

- The demand growth in India in percentage terms will be much higher than in the other regions.
- Coal is an important indigenous energy resource, but it is of lower quality in India than elsewhere. This means that Indian coal is not the most economic supply option. Coal imports or other power supply options are often cheaper.
- Indian renewable resources are limited compared to the demand growth that is forecast for the coming decades. Solar is the only option with a very large technical potential, but its use is starting from a very low level of installed capacity.

Figure 11.8 ▶ **Regional power capacity and electricity demand in the BLUE Map scenario for India, 2050**



Note: The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Key point

About 50% of electricity demand, and one-third of the capacity, is from the regions of Calcutta, Delhi and Mumbai.

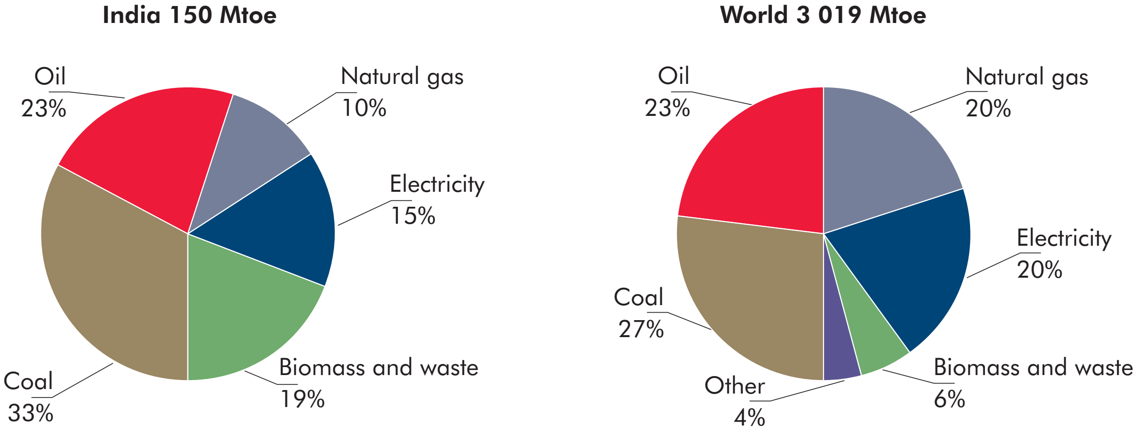
The government of India recognises the important potential for solar and, in late 2009, approved the Jewaharlal Nehru National Solar Mission. The Solar Mission has twin objectives to contribute to India's long-term energy security and to establish the country as a global leader in solar energy. By the end of 2022 the Solar Mission foresees total installed solar capacity of 20 GW.

The strong increase in electricity generation and demand means that almost none of India's power systems in 2050 are yet built. This opens up interesting opportunities for reducing energy requirements and associated CO_2 emissions.

Industry sector

Industry used 150 Mtoe of energy in 2007, accounting for 38% of the final energy used in India. From a global perspective, India is the fourth-largest industrial energy consumer with a 5% share of global industrial energy use, surpassed only by China, the United States and Russia. The final energy mix of industry is dominated by coal and oil (Figure 11.9). Industry accounts for 45% of total electricity consumption in India, a high share compared to other countries. In the industry sector, electricity accounts for 15% of the energy consumption. About 30% of the electricity used by industry is generated by captive power plants.

Figure 11.9 ▶ Industrial final energy mix in India and in the world, 2007



Note: Includes coke ovens, blast furnaces and petrochemical feedstock.
Sources: IEA (2009a and 2009d).

Key point

The share of biomass used in industry is large compared to other countries.

An important shortcoming of the Indian energy use data reported in the International Energy Agency statistics (IEA, 2009a) is that the consumption of electricity, natural gas and biomass and waste is not allocated to any specific industrial sector. More than 40% of industrial energy use in India is reported in the "non-specified industry". The IEA has developed estimates of industrial energy consumption for India by industrial sub-sector from a mixture of top-down and bottom-up sources (Table 11.6).

Energy and CO_2 savings potential with best available technologies

India, like many other countries, could achieve significant energy and CO_2 savings in industry through the application of BATs. The application of BATs in the five industrial sectors analysed (iron and steel, chemicals and petrochemicals, pulp and paper, cement and aluminium) could reduce final energy use in India by between 10% and 25%. This would save an estimated 17 Mtoe per year, equivalent to 11% of India's industrial energy consumption and 4% of its total final energy consumption in 2007. The estimated potential in India is slightly lower than that of most industrialised countries. The peculiarities of Indian indigenous resources and industry, such as the high silica content in iron ore, low-quality coal and the existence of numerous small-scale plants, means that these savings might be harder to achieve and may be overstated.

Table 11.6 ▶ **Industrial production, energy use and CO_2 emissions for India, 2007**

	Materials production (Mt)	Reported energy use (Mtoe)	Reported electricity use (Mtoe)	Estimated energy use (Mtoe)	Estimated electricity use (Mtoe)	Direct CO_2 emissions (Mt CO_2)
Total industry sector		**150**	**22**	**150**	**22**	**413**
Iron and steel	53	33		38	3.3	151
Chemicals and petrochemicals		27		27		48
Non-ferrous metals		0.4				
Total aluminium	*2*	-	-	*2.9*	*1.6*	*3.8*
Non-metallic minerals		11				
Cement	*170*	-	-	*13*	*1.1*	*128*
Pulp, paper and printing		1.4				8.2
Paper and paperboard	*8*	-	-	*1.4*	*0.4*	
Pulp	*4*	-	-	*1.7*	*0.3*	
Recovered paper	*1*	-	-	*0.1*	*0.0*	
Food and tobacco		10		n.a.	n.a.	n.a.
Textile and leather		1.3		n.a.	n.a.	n.a.
Other		2		66	15	74
Non-specified industry		65	22			

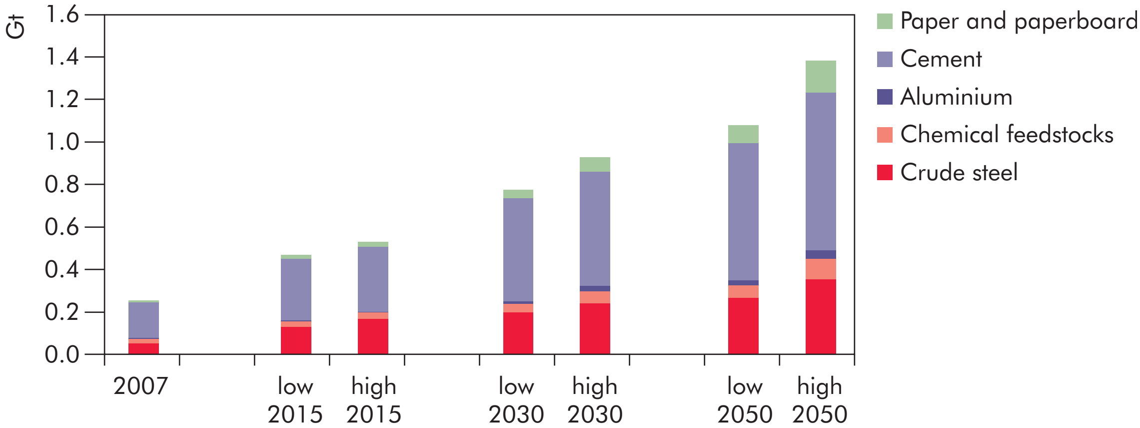
Note: Iron and steel includes energy use for coke-making and the energy data for chemicals and petrochemicals include feedstocks. The table has been compiled from a mixture of top-down and bottom-up sources and so the totals may not match.
Sources: World Steel Association (2009); USGS (2009); IAI (2009); IPMA (2010); IEA (2009a and 2009c); IEA analysis.

It will also take time to achieve savings this way. The rate of implementation of BATs in practice depends on a number of factors, including capital stock turnover, relative energy costs, raw material availability, rates of return on investment and regulation. The BAT analysis does not take into account the energy efficiency improvement potential from industrial captive power plants. Analysis of energy efficiency potential of those captive plants would be important to assess the overall potential for reducing energy consumption.

Scenarios for industrial energy use and CO_2 emissions

If India follows traditional pathways from an agricultural society to a highly urbanised society, the country's materials needs will be enormous. Production in India of the five key materials covered in this analysis is expected, in the low-demand scenario, to triple by 2030 and to more than quadruple by 2050 compared to 2007. In the high-demand scenario, productions are projected to rise by a factor of over 3.6 by 2030 and 5.4 by 2050 (Figure 11.10). These rates of growth will present issues around the availability of resources.

Figure 11.10 ▶ Materials production in India in the low-demand and high-demand cases



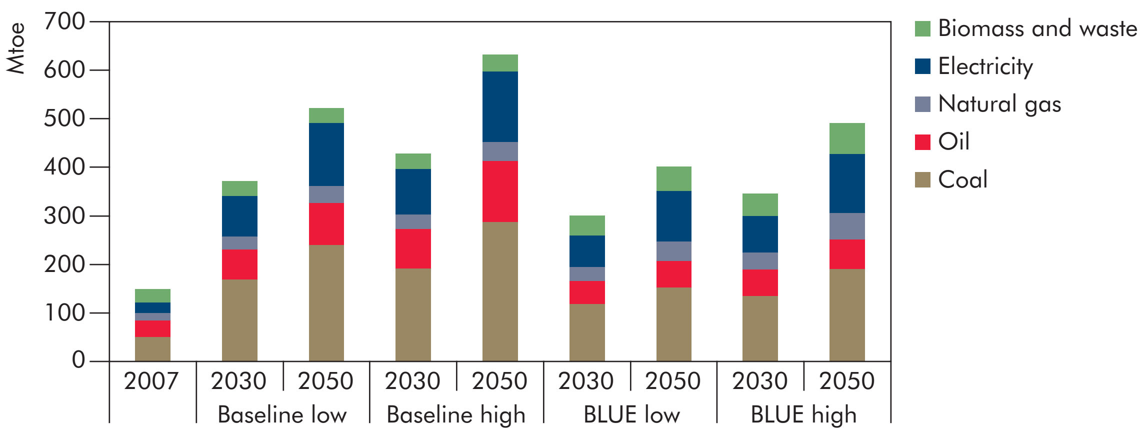
Note: Production of materials is the same for both the Baseline and BLUE scenarios.
Sources: World Steel Association (2009); USGS (2009); IAI (2009); IPMA (2010); IEA (2009a); IEA analysis.

Key point

Production of materials will increase between 4.3 times (in chemical feedstocks) and 19.5 times (in paper and paperboard) between 2007 and 2050 in the high-demand scenario.

Energy use and CO_2 emissions will rise as a result of this increase in industrial production. Industrial energy use reaches 372 Mtoe (low demand) and 428 Mtoe (high demand) in 2030 and 522 Mtoe (low demand) and 632 Mtoe (high demand) in 2050 in the Baseline scenario (Figure 11.11). Total direct energy- and process-related industrial CO_2 emissions are projected to rise from 413 Mt CO_2 in 2007 to between 1 563 Mt CO_2 and 1 852 Mt CO_2 in 2050 in the Baseline scenarios (Table 11.7).

Figure 11.11 ▶ Energy use in industry by fuel type in the Baseline and BLUE scenarios for India



Note: Includes coke ovens, blast furnaces and petrochemical feedstocks.
Source: IEA (2009a).

Key point

Energy consumption is about 23% lower in the BLUE scenarios than in the Baseline scenarios.

The BLUE scenario: a technological pathway for industry in India

The reductions envisaged in the BLUE scenarios require CO_2 emissions reductions across all industry sectors. But action is particularly crucial in the five most energy-intensive sectors analysed. These sectors currently account for 82% of direct CO_2 emissions and 56% of industrial energy consumption in India. In the BLUE scenarios, Indian energy consumption and emissions are higher in 2050 than in 2007 but lower than in the Baseline scenarios. India's total industrial energy consumption between 2007 and 2050 is expected to grow between 3.5 and 4.2 times in the Baseline low- and high-demand scenarios, respectively. By implementing measures and policies consistent with the BLUE scenarios, energy consumption in India would be between 121 Mtoe and 140 Mtoe lower in the BLUE scenario than in the Baseline scenario in 2050.

Table 11.7 ▶ Direct energy and process CO_2 emissions by industry sector in India

Mt CO_2	2007	Baseline low 2050	Baseline high 2050	BLUE low 2050	BLUE high 2050
Aluminium	4	14	21	13	16
Iron and steel	151	703	858	333	362
Chemicals	48	132	173	68	77
Cement	128	422	483	275	291
Pulp and paper	8	36	62	17	31
Other	74	256	256	122	129
Total	**413**	**1 563**	**1 852**	**828**	**906**

Sources: IEA (2009a and 2009b); IEA analysis.

A range of measures will be needed to reduce CO_2 emissions to the level envisaged in the BLUE scenarios, including the application of BATs, energy efficiency measures, fuel and feedstock switching and the application of CCS in the iron and steel, cement, pulp and paper and chemicals sectors (Figure 11.12). The implementation of these measures can also help to reduce India's rapidly rising dependence on oil and gas. Government policies are needed to facilitate a transition to more efficient and lower-carbon technologies.

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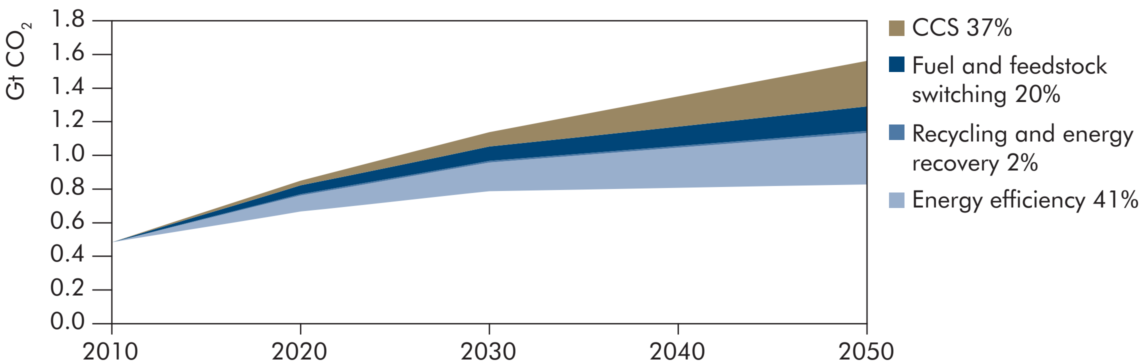
Figure 11.12 ▶ Options for reducing direct CO_2 emissions from Indian industry



Key point

Energy efficiency and CCS represent the main opportunities for India to limit the growth in CO_2 emissions from the industrial sector.

Each energy-intensive industrial sector has different characteristics. The options available to them, and the contribution of those options in reducing energy consumption and CO_2 emissions, will be different for different industries (Table 11.8).

Table 11.8 ▶ ***Indian industry status and options for reducing energy use and CO_2 emissions in the BLUE scenarios***

	Status	Energy efficiency options	Fuel and feedstock switching	Recycling and energy recovery	CCS
Cement	Efficiency is currently better than world average with large kilns being among the most energy efficient in the world	Deployment of BATs in smaller units	Expanding the use of clinker substitute Expanding the use of biomass and alternative fuels		CCS applied
Iron and steel	Largest DRI producer worldwide and one of few countries that have coal-based DRI High consumption of reducing agents in blast furnace owing to lack of suitable coal	Deployment of BATs Development of new technologies (e.g. smelting reduction)	Lower use of coal-based DRI Increased use of CO_2-free electricity and hydrogen	Higher recycling rate	CCS applied
Chemicals and petrochemicals	Ammonia production accounts for more than half of the energy use in chemicals; unlike in most other countries, oil feedstock plays an important role	Deployment of best practice technologies in the short term and new technologies in the long term	Continue to switch away from oil feedstock Expand the production of bio-based plastics and chemicals	Improved material flow management	CCS applied
Aluminium	Average energy intensity currently below the world average	Implementation of energy efficiency measures in refining and smelting Introduction of new smelting technologies	Increased use of low-carbon electricity sources	Higher recycling rate	
Pulp and paper	High share of small and medium-sized paper mills (about half of all production)	Deployment of BATs (including black liquor and biomass gasification, heat recovery)	Switching to combustible biomass	Increased use of recovered paper	CCS applied

Buildings sector

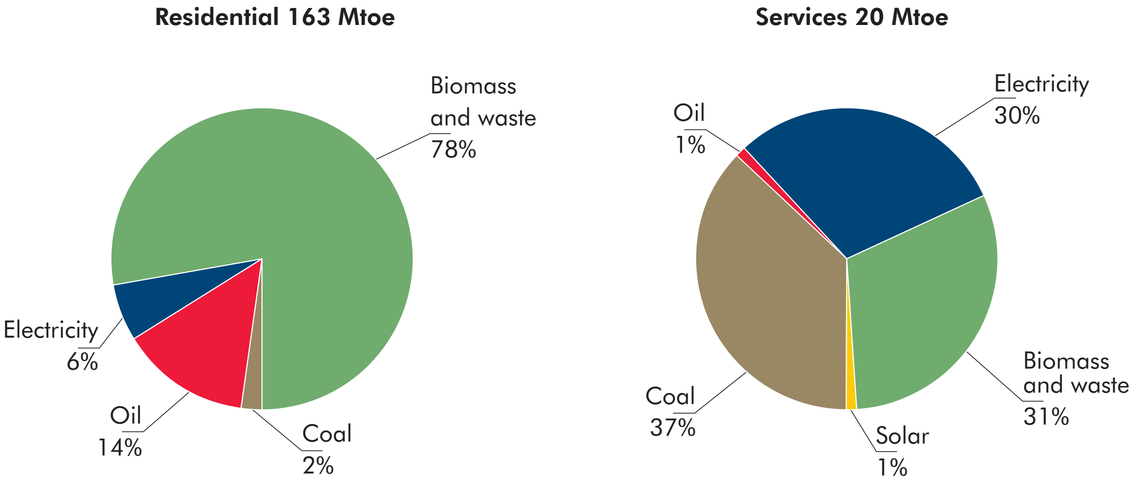
During the past decades, population growth, the increase in economic development and activity, greater access to diversified energy sources and migration from rural to urban areas has resulted in the buildings[8] sector experiencing many changes in energy consumption, in both quantitative and qualitative terms.

8. The buildings sector collectively refers to the residential and service sectors.

In 2007 the residential[9] and service[10] sectors accounted for about 47% of total final energy consumption in India. This was less than the share of 55% in 1990, partly as a result of stronger growth in the manufacturing and transport sectors. Between 1990 and 2007, energy demand grew by 1.7% a year in the residential sector and by 2.1% a year in the service sector.

The use of biomass and waste still accounts for a large share (78%) of final consumption in the residential sector (Figure 11.13). But a move towards commercial, high-quality fuels is increasingly evident. The consumption of oil (mainly liquefied petroleum gas [LPG] and kerosene) and electricity grew rapidly at 4.3% and 8.1% a year, respectively, between 1990 and 2007.

Figure 11.13 ▶ Residential and service sectors energy consumption by fuel in India, 2007



Source: IEA (2009a).

Key point

Biomass represents an important share of the energy used in the buildings sector.

Box 11.1 ▶ Data for the buildings sector in India

Collecting accurate energy statistics for the residential and service sectors is a challenge for any nation, but a particular challenge in India. India has to deal with a large number of small businesses involved in energy supplies other than electricity, as well as a very large proportion of energy coming from traditional biomass for which non-commercial use is very difficult to estimate.

.../...

9. The residential sector include activities related to private dwellings; it covers all energy-using activities in apartments and houses, including space and water heating, cooling, lighting and the use of appliances. It does not include personal transport.

10. The service sector includes activities related to trade, finance, real estate, public administration, health, education and commercial services such as hotels and restaurants.

For example, IEA statistics for 2005 report residential energy consumption of 157 Mtoe, of which 33 Mtoe was commercial fuels. In its IEP, the government of India reported 135.3 Mtoe of energy use in the residential sector in 1999-2000. In contrast, a bottom-up analysis by Lawrence Berkeley National Laboratory (LBNL) (de la Rue du Can et al.*, 2009) estimated energy consumption in 2005 at just 116 Mtoe. The Energy and Resource Institute (TERI) estimates that around 77% of household energy consumption is biomass and that the consumption of commercial fuels was 29 Mtoe in 2004/05 (TERI, 2006). The wide disparities in these figures demonstrate the difficulty of establishing robust estimates in this area (Table 11.9).*

Table 11.9 ▶ Residential energy use in India

Mtoe	Government of India (IEP) (1999/2000)	IEA (2005)	LBNL (2005)	TERI (2004/05)
Coal	1.1	2.7		
Oil	16.5	21.1	23.8	20.4
Natural gas		0.6		0.3
Electricity	8.4	8.6	13.2	8.2
Biomass	109.2	123.6	78.8	96.6
Total	135.3	156.6	115.7	125.5

Note: Biomass in IEP includes 29.6 Mtoe of dung cake.
Sources: GOI (2006a); TERI (2006); IEA (2009a); de la Rue du Can *et al.* (2009).

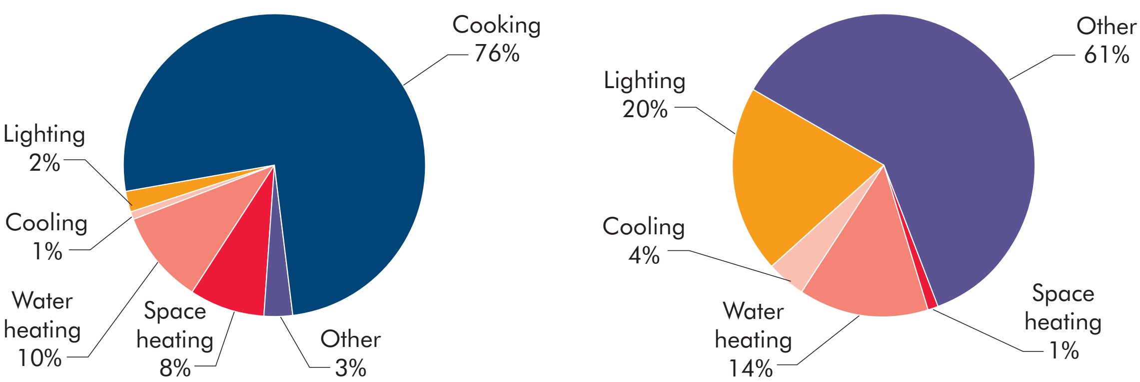
In the service sector, according to the Indian data on energy use as reported in IEA (2009a), coal, electricity and biomass and waste account for 98% of energy use. Liquefied petroleum gas and kerosene are undoubtedly also used. Estimates of oil product consumption in the service sector are around 12 Mtoe (de la Rue du Can et al.*, 2009). This emphasises the need to improve data collection in this sector to improve the analysis and better inform policy makers.*

The IEA is continuously working with its member and non-member countries to improve the breadth, quality and timeliness of collected energy statistics. Such efforts are essential in order to improve the accuracy and utility of analyses and projections in the energy sector.

An understanding of the energy consumption in India associated with different end uses and technologies would enable a proper assessment of the options for reducing energy use and CO_2 emissions. Unfortunately, data that would allow a complete view of energy consumption by end use in the residential and service sectors are not collected systematically in India. Regular, reliable surveys are available for cooking and lighting in the residential sector, but other data are only available from bottom-up estimates or from surveys conducted periodically that are sometimes many years old. More systematic data collection would help analysis of the buildings sector.

The breakdown of the residential and service sectors' end-use energy consumption that has been used to analyse the energy trends and reduction potential in the Baseline and BLUE Map scenarios is set out in Figure 11.14.

Figure 11.14 ▶ Residential and service sectors energy consumption by end use for India, 2007



Sources: IEA (2009a); IEA analysis.

Key point

Cooking, mostly using biomass, accounts for three-quarters of residential energy use.

Scenarios for buildings energy use and CO_2 emissions

Between 1990 and 2007, India's population grew by 1.7% a year. Population growth is expected to slow to an average of 0.8% a year between 2007 and 2050, but this still means a population increase of 490 million. The average household size in 2005 was around 4.3 persons in urban areas and 4.9 in rural areas (NSSO, 2008). Continued reductions in household size are assumed in the Baseline and BLUE Map scenarios, with the total number of households assumed to increase by 340 million between 2007 and 2050. Floor area in the service sector is expected to grow by 3.1% a year, with growth slowing over time in line with population and GDP growth.

Box 11.2 ▶ Energy efficiency actions taken by the Government of India

Recognising the impact of economic growth and the increased penetration of energy-consuming appliances on the energy sector and the environment, the government of India enacted an Energy Conservation Act in 2001 under which the BEE was established. The BEE is tasked with co-ordinating energy efficiency programmes throughout the country and across all economic sectors through various regulatory instruments. Since its creation in 2002, the BEE has launched various programmes, including the Standard & Labelling Programme in 2006 and the Energy Conservation Building Act in 2007. Both were implemented on a voluntary basis and plans to make them mandatory in a phased manner are discussed. Since January 2009, energy labelling for air conditioners and refrigerator is mandatory.

.../...

The Standard & Labelling Programme covers the most widely used appliances and equipment such as colour TVs, ceiling fans, LPG stoves, refrigerators and air conditioners. Since 2007, the BEE has published an annual report on its performance which is verified by an independent third party, the National Productivity Council.

Under the NAPCC, approved in 2008, the BEE has prepared the NMEEE, implementation of which is expected to commence in April 2010 over a five-year period. The Mission aims to stimulate a market transformation in favour of energy-efficient technologies and products. It builds on existing work undertaken by the BEE but will scale up activities and enlarge the scope of ongoing initiatives and activities.

Four major initiatives are foreseen under the NMEEE. These initiatives will use market-based mechanisms to enhance cost effectiveness of improvements in energy efficiency for energy-intensive large industries and facilities, accelerate the shift to energy efficient appliances, and enable innovative financing and funding for demand-side management initiatives in all sectors.

The Baseline scenario

Energy consumption in buildings grows by 1.8% a year in the Baseline scenario, increasing from 183 Mtoe to 391 Mtoe between 2007 and 2050 (Figure 11.15). Energy consumption in the service sector will be the fastest growing, with a 178% increase over the period. Energy use in the residential sector also grows rapidly, from 163 Mtoe in 2007 to 336 Mtoe in 2050.

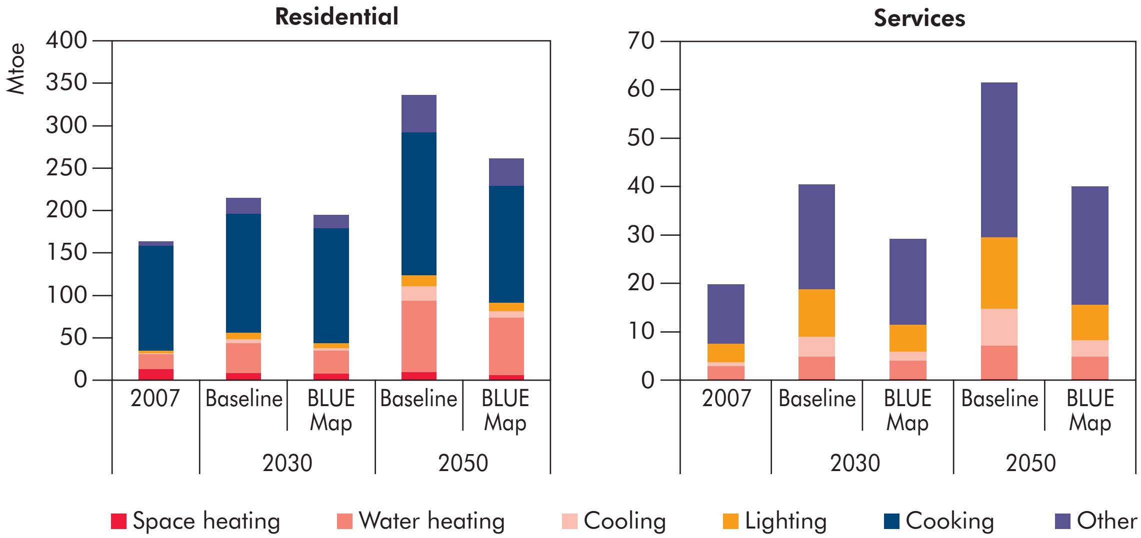
In the Baseline scenario, the CO_2 emissions attributable to the residential and service sectors are projected to increase by 4.5% a year between 2007 and 2050 from 281 Mt CO_2 in 2007 to 1 856 Mt CO_2 in 2050.[11] The most rapid growth in CO_2 emissions comes from the increased use of natural gas. Emissions attributable to electricity consumption represent the largest share of the growth, increasing by 1 336 Mt CO_2 between 2007 and 2050. Electricity's share of overall emissions from the residential sector increases from 63% in 2007 to 82% in 2050.

The BLUE Map scenario: technological pathways for buildings in India

Residential energy consumption in the BLUE Map scenario is reduced by around 72 Mtoe below the Baseline level in 2050, and by 16 Mtoe in the service sector.

11. In this section, for the purposes of assessing current CO_2 emissions and the savings potential, the upstream CO_2 emissions in the electricity and heat generation sector are attributed to electricity consumption in the buildings sector at the 2007 CO_2 emissions intensity of electricity generation (around 930 gCO_2/kWh). Any reduction in the intensity of CO_2 emissions from electricity generation is therefore credited to the electricity generation sector.

Figure 11.15 ▶ Energy use in the buildings sector in the Baseline and BLUE Map scenarios for India



Sources: IEA (2009a); IEA analysis.

Key point

Energy use in 2050 in the BLUE Map scenario is 21% and 29% lower than in the Baseline scenario in the residential and service sectors, respectively.

In the residential sector, about two-thirds of the savings come from cooking and water heating, as the very large-scale deployment of more efficient cooking stoves and solar thermal water-heating systems offers significant energy savings potential (Figure 11.16). The use of biomass-derived dimethyl ether and liquid biofuels also helps to improve the efficiency of energy consumption for cooking and water heating. In the service sector, improvements in the miscellaneous end uses account for about 37% of the reductions (Figure 11.17).

Overall, CO_2 emissions for the buildings sector are reduced by 28%, 528 Mt CO_2, below the Baseline level in 2050. A large share of this reduction is attributable to reduced consumption of electricity. The savings from electricity are somewhat offset by the switching from fossil fuels to electricity for cooking and water heating in the BLUE Map scenario.

The CO_2 emissions reductions below the Baseline scenario in the BLUE Map scenario in 2050 are dominated by savings from electric end uses, particularly appliances and space cooling. Improvements in appliances and miscellaneous end-uses over and above that in the Baseline scenario are estimated to account for 22% of the total CO_2 savings in the BLUE Map scenario. Reduced electricity consumption for space cooling, through the improved efficiency of cooling systems and improvements in building shells, accounts for 19% of the total CO_2 savings. Improvements in the efficiency with which energy is used for cooking account for 7% of the savings. Heat pumps for water heating, CHP in the residential and service sectors and solar heating and cooling also yield significant savings.

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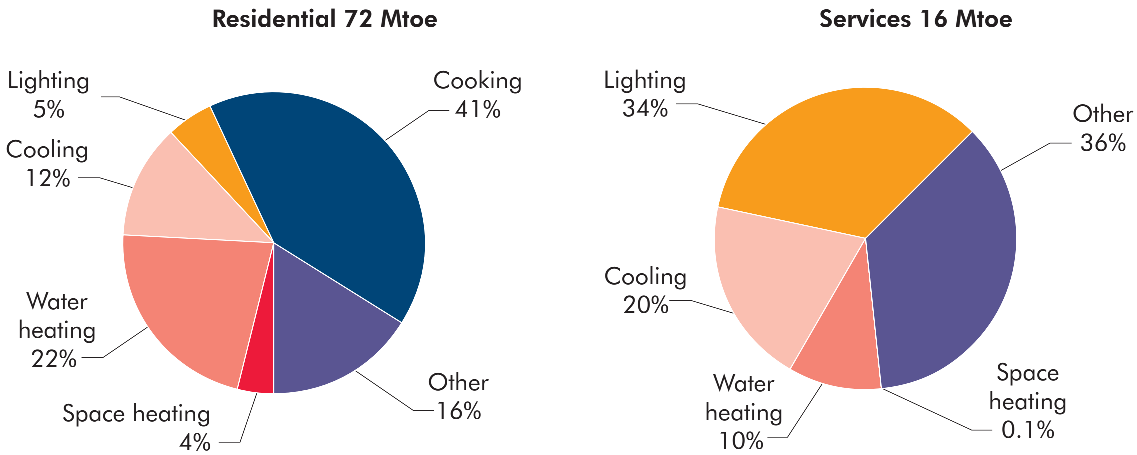
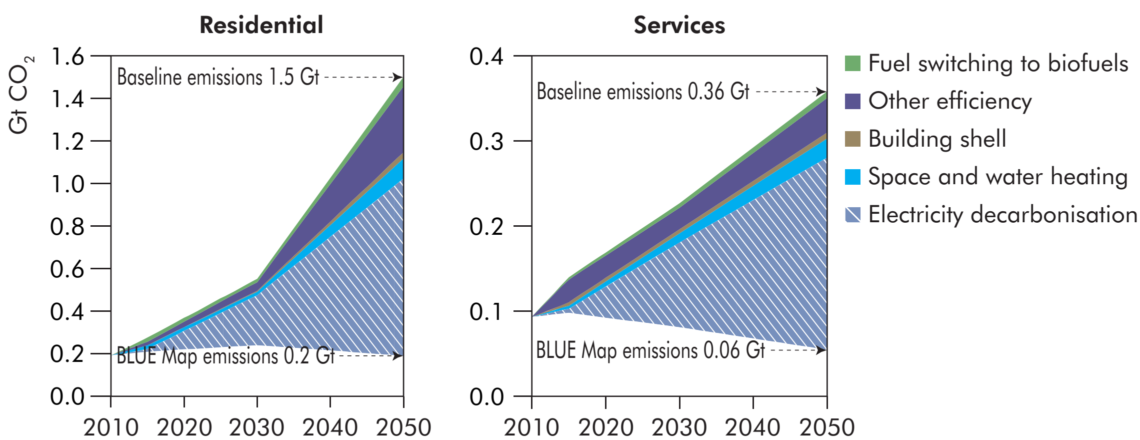
Figure 11.16 ▸ Contribution to reductions in energy use in the buildings sector in the BLUE Map scenario for India, 2050



Key point

While reductions will be achieved in all end uses, cooking in residential and other equipment in services offer the largest potential for energy reduction.

Figure 11.17 ▸ Contribution to reductions in CO_2 emissions in the buildings sector in the BLUE Map scenario for India, 2050



Key point

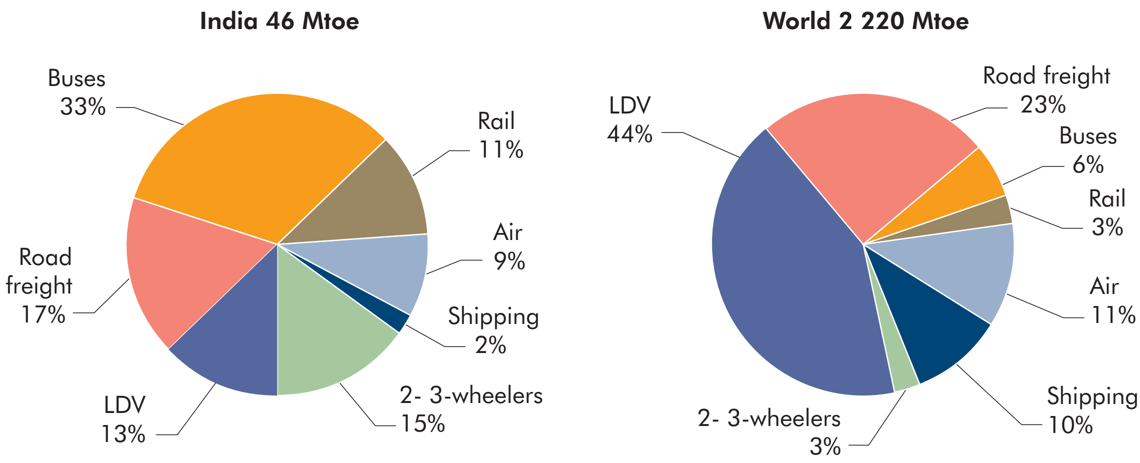
More than 60% of the direct emissions reductions in the buildings sector come from improvements in energy efficiency. However, achieving important emissions reductions will require a near-decarbonisation of the electricity sector.

Transport sector

In India, transport energy use is dominated by buses and freight trucks, with smaller but fairly equal shares for most other modes except rail (Figure 11.18). The light-duty vehicle (LDV) share of energy use is far smaller than the world average.

This reflects the current dominance of trucks over cars on India's roads and the dominance of bus and two-wheeler travel over LDV travel for urban, regional and intercity passenger travel.

Figure 11.18 ▶ ***Transport sector final energy use by mode in India and in the world, 2007***



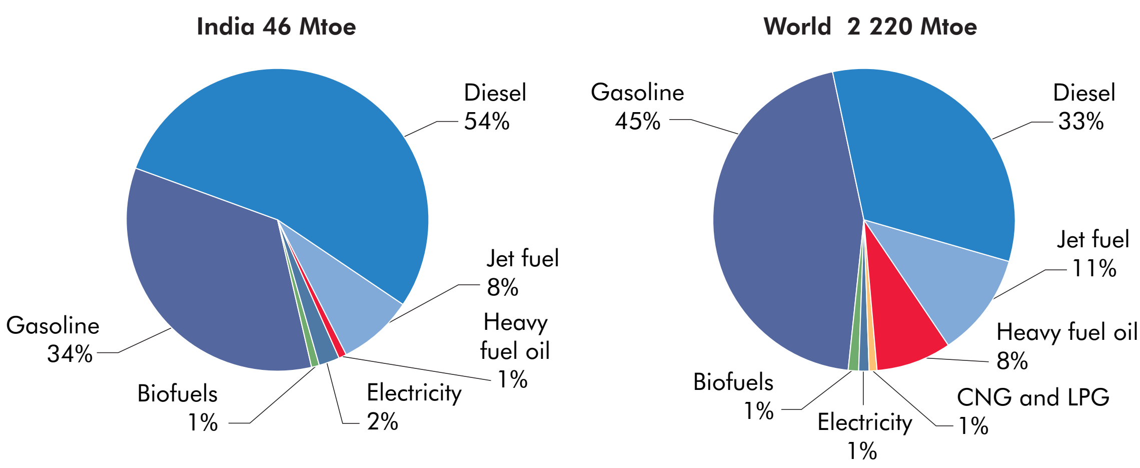
Source: IEA Mobility Model database.

Key point

India has much higher shares of bus and two- and three-wheeler energy use than the world average.

The energy mix of Indian transport is dominated by gasoline and especially diesel fuel (Figure 11.19). Although some other fuels such as biofuels and compressed natural gas (CNG) are used in transport, their shares are a small fraction of total energy use.

Figure 11.19 ▶ ***Transport sector final energy mix in India and in the world, 2007***



Source: IEA Mobility Model database.

Key point

Diesel fuel accounts for more than 50% of Indian transport fuel use.

A breakdown of transport indicators by mode, including activity, intensity and fuel use variables, is shown in Table 11.10. A significant shortcoming of the data on Indian energy use as reported in the IEA statistics is that road fuel use is not specified in terms of vehicle type. Fuel use is allocated to types of transport by the IEA using data and assumptions on vehicle stocks, efficiency and average travel. These estimates are based on current production levels and energy intensities from a range of sources. These data need to be validated.

In 2007, buses carried more than half of all motorised passenger-kilometres (pkm) of travel in India, with urban, regional and national rail accounting for the second-largest amount. Two- and three-wheelers carry more passengers than LDVs. Rail carries more freight in tonne-kilometres (tkm) than trucks, although trucking volumes are growing much faster. Light-duty vehicle average energy intensity per pkm is about twice that of two- and three-wheelers, and four times higher than that of buses. Freight trucks are about ten times more energy-intensive than rail.

Table 11.10 ▶ ***Transport energy and CO_2 indicators in India, 2007***

	Passenger travel (bn pkm)	**Freight travel** (bn tkm)	**Stock average energy intensity**		**Fuel use** (Mtoe)	**Passenger** (Mt CO_2)	**Freight** (Mt CO_2)
			(MJ/pkm)	(MJ/tkm)			
LDVs	180		1.6		6	23	
2- 3-wheelers	419	6	0.7	5.5	7	24	
Buses	1 612		0.4		15	57	
Freight trucks		157		2.3	8		33
Rail	565	385	0.3	0.2	5	21	6
Air	64		2.7		4	14	
Water		n.a.	n.a.	n.a.	1		3
Total/average	**2 840**	**548**	**0.6**	**0.9**	**46**	**139**	**43**

Note: n.a.= not applicable.
Source: IEA Mobility Model database.

Scenarios for transport energy use and CO_2 emissions

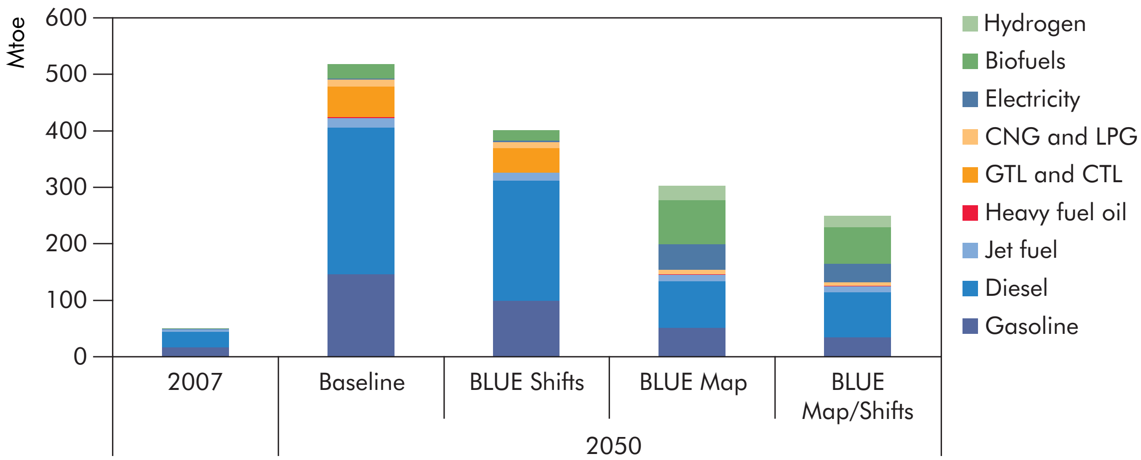
Although India currently accounts for a small share of the world's transport energy use and CO_2 emissions, travel growth is expected to change this picture rapidly. In the Baseline scenario, passenger travel and goods transport increases by an order of magnitude between 2007 and 2050, with accompanying large increases in energy use and CO_2 emissions (Figure 11.20). The growth in travel is driven largely by increasing car ownership and air travel, both being driven by rising incomes. By 2050, India consumes about 12% of the world's energy consumption for transport in the Baseline scenario. It will be imperative for economic, energy security and environmental reasons that India finds ways to enable the travel growth it needs while restraining the consequent increases in fuel use and CO_2 emissions.

In the Baseline scenario, the mix of fuels remains fairly constant, with petroleum fuels dominant and complemented by the growth of synthetic fuels based on fossil resources, as well as natural gas and biofuels. The use of coal- and gas-to-liquids (CTL and GTL) reflects an expected reduction in the availability of conventional sources of crude oil and the need to produce synthetic liquid hydrocarbons. These fuels may be competitive in the future, but have very high CO_2 emissions.

The BLUE scenarios: technological pathways for transport in India

To change the direction of future energy use and CO_2 trends in India, it will be necessary to significantly alter trends in transport activity and technology adoption. The IEA has explored several scenarios which envisage a low-CO_2 future. Three of these scenarios are reviewed in respect of India. These are the BLUE Map scenario, which is largely optimistic for technology change, the BLUE Shifts scenario, which assumes a shift in travel patterns towards more efficient modes, and a combined BLUE Map/Shifts scenario, which applies the assumptions in both the BLUE Map and the BLUE Shifts scenarios together.

Figure 11.20 ▶ *Transport energy use by fuel in the Baseline and BLUE scenarios for India*



Source: IEA Mobility Model database.

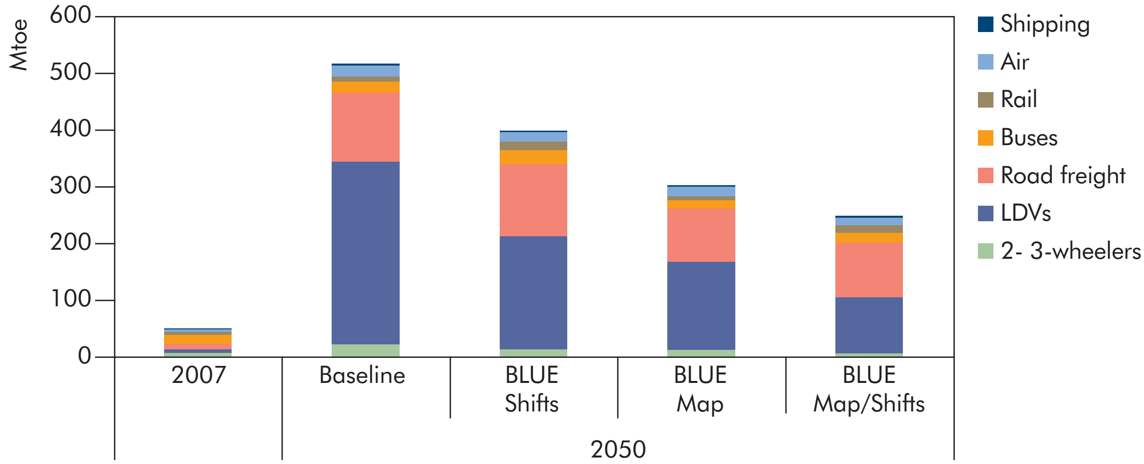
Key point

Compared to the Baseline, energy use in 2050 is cut by nearly 25% in the BLUE Shifts scenario, 42% in the BLUE Map scenario, and 52% in the BLUE Map/Shifts scenario.

Each scenario has different impacts in terms of the reductions in transport energy use in India in 2050 compared to the Baseline scenario (Figure 11.21). Worldwide, the BLUE Map scenario projects a 70% reduction in well-to-wheel CO_2 emissions in 2050 compared to the Baseline scenario in that year. For India, the BLUE Map scenario projects a 42% reduction in energy use compared to the Baseline scenario in 2050, but still nearly a sixfold increase in energy use compared to 2007 levels.

This reflects the very strong growth in Indian transport activity and energy use in the Baseline scenario. Cutting this growth from a factor of nearly twelve to a factor of less than seven will be a considerable achievement.

Figure 11.21 ▶ *Transport energy use by mode in the Baseline and BLUE scenarios for India*



Source: IEA Mobility Model database.

Key point

LDVs offer the largest opportunity to limit the increase in energy consumption.

Improvements in incremental transport energy efficiency offer the largest and least expensive reductions in Indian energy use for transport, at least over the next 10 to 20 years. Adoption of advanced vehicle technologies and new fuels also provide important contributions, especially after 2030.

Vehicle efficiency improvements

Most Indian cars, trucks and two-wheelers are typically cheaper, smaller and less powerful than similar vehicles in most other countries, particularly in the OECD member countries. As a result, the cost-effective level of efficiency improvement in India may be less than that of many other countries. That said, the Baseline scenario assumes that by 2050 or well before, India will have large numbers of vehicles of similar size, weight, power and perhaps cost, as those in most other parts of the world. This suggests that technological advances are likely to become increasingly cost effective in India as elsewhere.

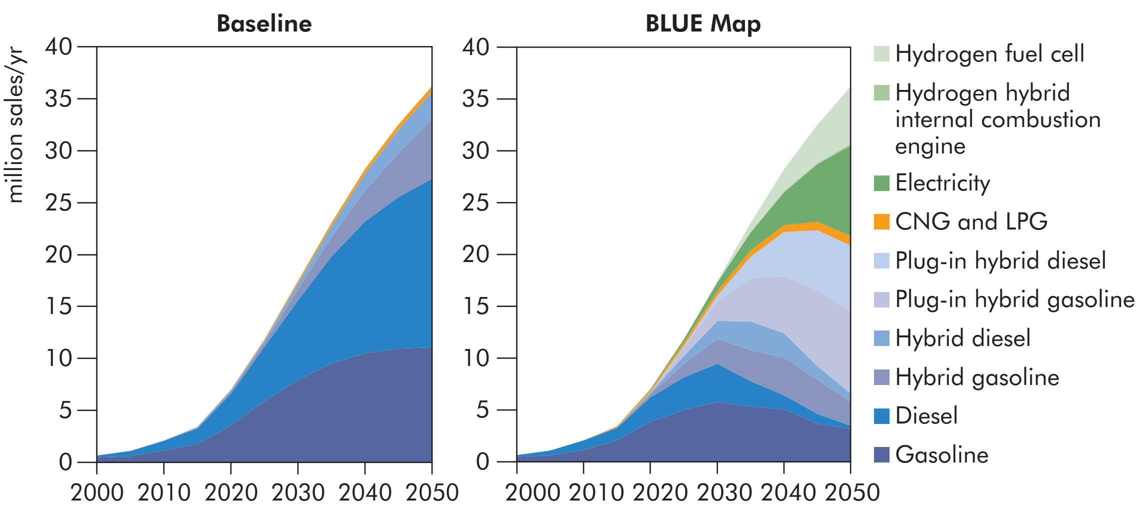
A 30% to 50% improvement in new vehicle efficiency across modes by 2030 is not out of the question for India, despite its relatively efficient starting point of about 6.6 litres (L) of fuel per 100 km. In the BLUE Map scenario, efficiency improvements and advanced technologies for vehicles (Figure 11.22) help to slow the growth of energy use and CO_2 emissions in India.

Data on the efficiency of Indian trucks suggest that they tend to be small and fairly energy intensive. In practice, many are also overloaded and unsafe. So they may achieve better energy intensity than the statistics would suggest. There is likely to be a great potential for cutting fuel use per tkm by moving to larger trucks with modern, high efficiency diesel engines. Similarly, aircraft in India are likely to become more efficient as newer, larger models are introduced. As with most countries, an estimated 30% to 50% improvement potential exists for trucks, ships and aircraft in India.

Advanced vehicles and fuels

Figure 11.22 shows the changes in LDV sales in the Baseline and BLUE Map scenarios. In the Baseline scenario, the share of diesel and gasoline vehicles grows rapidly to 2020, after which hybrid vehicles begin to be sold in increasing numbers. Compressed natural gas vehicles also account for a small but growing share of vehicles over time. In the BLUE Map scenario, hybrid vehicles begin to be sold in large numbers after 2015, and EVs and PHEVs start to make a serious impact on the market after 2020. Electric vehicles may play a particularly important role in India if the dominance of small cars continues, as EV technologies are particularly well suited to smaller cars.

Figure 11.22 ▶ Passenger LDV sales by technology for the Baseline and BLUE Map scenarios for India



Source: IEA Mobility Model database.

Key point

In the BLUE Map scenario, new technology vehicles such as EVs reach significant sales shares after 2020.

The impact of EVs on CO_2 emissions depends on the CO_2 intensity of electricity generation. It would therefore make sense to deploy EVs first in those parts of India with relatively low-CO_2 power generation. But EVs provide other important benefits besides CO_2 reduction, including a complete elimination of tailpipe pollutants. In India's cities this is extremely important and valuable, and decisions regarding the timing and location of EVs deployment in India should take this into account.

For those modes that are more difficult to electrify such as trucks, ships and planes, biofuels will need to play a role in helping to reduce emissions. They are assumed to be blended up to 30% with petroleum fuels by 2050. Biofuels such as cane ethanol may be produced in a large volume in India but probably only if food security is achieved first. Advanced, sustainable biofuels such as ligno-cellulosic ethanol and biomass to diesel may be widely available from global markets from a variety of sources.

The BLUE Shifts and BLUE Map/Shifts scenarios

The BLUE Shifts scenario looks at the potential to cut energy use and CO_2 emissions through changes in the pattern of future travel growth, directing more travel towards the most efficient modes such as rail, bus and non-motorised travel. This is coupled with policies to reduce overall travel demand by, for example, more efficiently organising and interconnecting cities and regions, thereby lowering the volume and length of trips undertaken.

Substantial investment in sustainable transport, such as high-quality bus and rail transit systems, and building much better infrastructure for cycling and walking, can help put India on the path to a sustainable future. It can also help improve mobility for millions of people in the near term. The need to ensure that India's cities are not clogged with traffic, and that people without access to private vehicles can have full mobility, are important considerations beyond energy and CO_2 emissions. The overwhelming evidence is that cities that develop urban transport systems that facilitate walking and cycling and reduce the need for motorised transport are more sustainable and better to live in than cities dominated by private vehicles. These features may help slow the growth in car use, particularly in urban areas, relative to the Baseline scenario. The BLUE Shifts scenario assumes 25% lower levels of car and air travel in 2050 than in the Baseline scenario, with fuel savings of about 20% in 2050. But even with such modal shifts, car ownership in India is likely to rise by a factor of five to ten in the coming decades.

If the approaches in the BLUE Map and BLUE Shifts scenarios are pursued in parallel, car and air travel will be reduced and shifted to more efficient modes, and strong improvements in vehicle efficiency and the adoption of new technology vehicles and new fuels will be pursued. Such an approach underpins the BLUE Map/Shifts scenario. In this scenario, India cuts its transport energy use by about half, and its fossil energy use by about three-quarters in 2050 compared to the Baseline scenario. CO_2 emissions are cut by around 70%.

Investment needs in the BLUE Map scenario

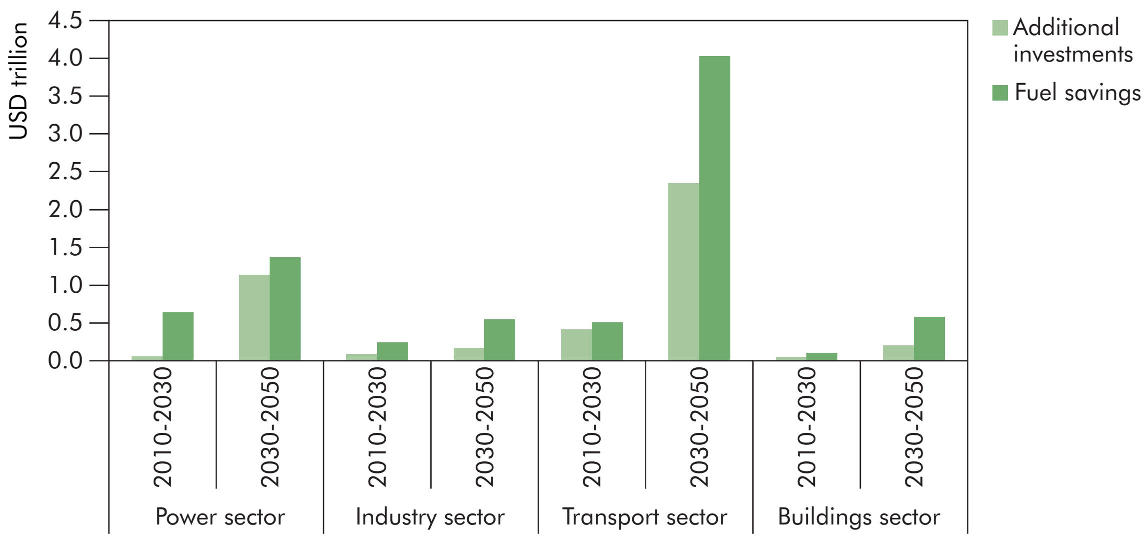
India's GDP is projected to increase by 5% a year from 2007 to 2050. This growth in the economy is expected to drive higher demand for goods, services and leisure activities requiring energy. Given this expected strong growth in energy demand, reducing CO_2 emissions in India will be difficult, although the rapid deployment of low-carbon technologies will help to limit the growth in emissions. Significant investments will need to be made in energy-efficient equipment, appliances, vehicles and buildings. The power sector will need to be significantly decarbonised, which will require large investments in nuclear, clean coal technologies, renewables and CCS. In the medium and long term, additional technologies will also be needed to reduce the CO_2 intensity of transport and industry.

Limiting the growth in India's CO_2 emissions in the BLUE Map scenario in 2050 to 10% above 2007 will require additional investments of USD 4.5 trillion between 2010 and 2050 (Figure 11.23). Of this total, USD 2.8 trillion is required in the transport sector and USD 1.2 trillion in the power sector, almost all of it after 2030. For transport, most investments are for low-carbon vehicles and biofuels. Additional investment needs in the buildings sector and the industry sector are estimated at USD 0.3 trillion each.

Additional investment in efficient and low-carbon technologies will also enable a reduction in fuel requirements[12] estimated at USD 8.0 trillion from 2010 to 2050. If the fuel savings are taken into account, net savings from the additional investments from 2010 to 2050 are USD 3.5 trillion. As fuel savings from the additional investments will continue beyond 2050, in practice the long-term net additional savings are likely to be higher than this.

As most additional investments are required in the transport sector, it is expected that the financing will be funded by consumers. Beyond that, however, there will be a need for India to engage with others internationally to secure the benefits of RDD&D, technology transfer and appropriate financing mechanisms, especially in the power and industry sectors.

Figure 11.23 ▶ *Additional investment needs and fuel savings for India*



Key point

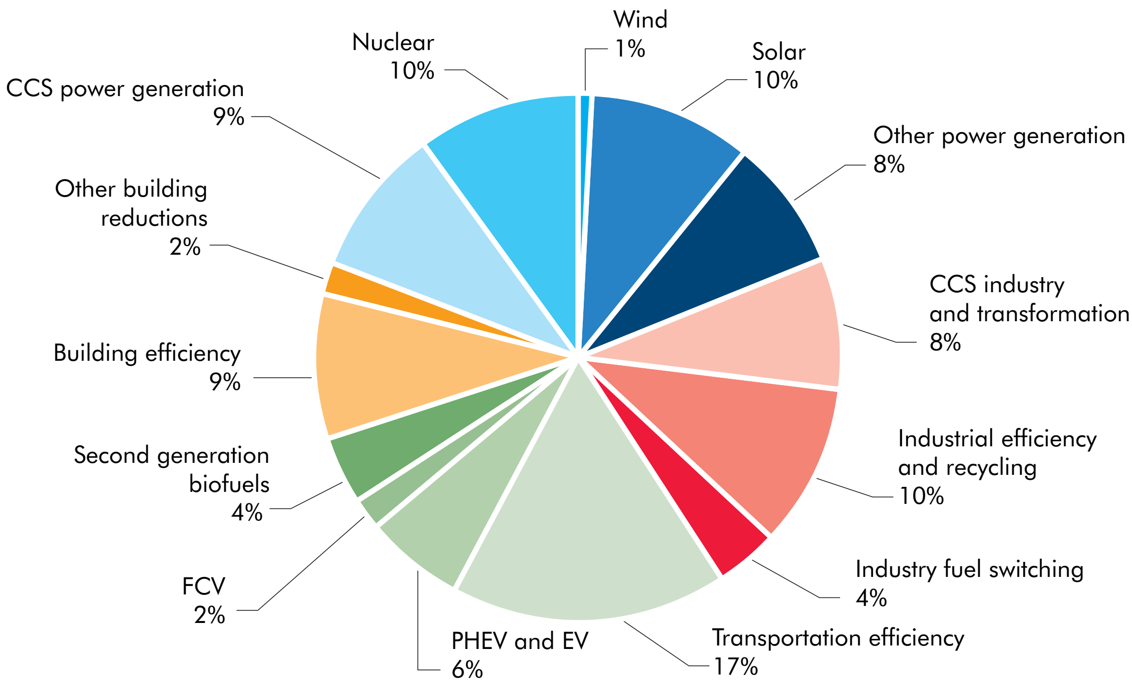
The fuel savings in the transport sector will significantly more than offset the additional investments required in that sector.

12. The estimations are based on undiscounted fuel savings.

Transition to a low-carbon energy future

For India to play its part in realising the global goals of the BLUE Map scenario, it will need to achieve rapid economic development over the next 40 years with only a very small increase in CO_2 emissions. Currently there is no precedent for such a low-CO_2 development path. It will need to be based on meeting the increasing energy needs of India's growing population through the widespread deployment of a range of existing and new low-carbon technologies (Figure 11.24). Compared to the Baseline CO_2 emissions in 2050, the BLUE Map scenario envisages a reduction of 5.0 Gt CO_2.

Figure 11.24 ▶ CO_2 emissions reductions by technology area in the BLUE Map scenario for India, 2050



Key point

About 40% of the reductions in the BLUE Map scenario come from the power sector.

Improved energy efficiency across both supply and end-use sectors is the single largest source of CO_2 reductions. But even in the BLUE Map scenario, energy use in India still grows 2.5 times over the period to 2050. The challenge will therefore be to move to sources of energy and technologies that have much lower CO_2 emissions than those used today and to achieve a near decarbonisation of the power sector. On a sectoral basis, the largest potentials for reducing CO_2 emissions lie in the power generation and transport sectors, with 38% and 27% of the overall reductions in 2050, respectively.

In the power sector, the development of solar energy, nuclear power and efficiency improvement in generation from fossil fuels represents about 65% of the reductions from the sector. The recently announced Solar Mission sets ambitious targets for photovoltaic and concentrating solar power by 2022. But deployment will need to increase even faster after this date. The BLUE Map scenario suggests that by 2050 almost 200 GW of solar capacity will be required. The prospects for nuclear power in India have improved with the 2008 agreement with the United States and the consent of the Nuclear Suppliers Group.[13] But India may still need to deploy new reactor designs if it wants to expand its nuclear production capacity to levels significantly higher than 100 GW.

Electricity access for poor rural areas may be improved through decentralised solar systems with storage and other types of decentralised renewable supply options. Improving transmission and distribution efficiency should be a priority. Fundamental to this will be moves to make sure that prices reflect supply costs. Proper electricity pricing, together with steps to support more energy-efficient equipment and lighting, may result in substantial savings and reduced demand growth.

Steps to increase oxyfuelling and to accelerate the work on IGCC technologies for Indian coal can help improve the efficiency of coal-fired generation. It will also provide a useful step towards applying CCS in the longer term. The development of a CCS technology in the power generation sector that is suited to Indian coal will require particular attention. The complexity of this technology and its impact on electricity cost make this one of the less attractive abatement options for India. Even so, CCS will have to play a vital role in helping India to decarbonise its electricity system.

In transport, the development of new technologies such as PHEVs and EVs will be essential in realising emissions reductions. However, the emission benefits of these technologies depend on the successful decarbonisation of the power sector. In the BLUE Map scenario, the growth in electricity demand for transportation occurs after 2030, so there is still some time for India to increase the share of low-emission generation technologies. Vehicles fuelled on natural gas and, in the longer term, hydrogen could also be important.

Box 11.3 ▶ *India's technology innovation targets*

A number of plans and strategies have been developed in recent years by the government of India and its agencies and institutes relevant to energy-related technology planning. India has recently allocated a budget of over USD 1 billion from its stimulus package for clean energy and other climate-related measures.

.../...

13. The Nuclear Suppliers Group is comprised of 46 nuclear supplier states, including China, Russia and the United States, that have voluntarily agreed to co-ordinate their export controls governing transfers of civilian nuclear material and nuclear-related equipment and technology to non-nuclear-weapon states.

India recognises the power sector as a key driver for the overall social-economic development of the country and as a major input for delivering targeted levels of GDP growth. Numerous policies and programmes have been put in place, or are being developed, to increase the availability, accessibility and affordability of electricity for all the sectors of the economy. Current technology priorities in India include:

- *development of clean coal technologies;*
- *development of nuclear power through a three stage nuclear programme;*
- *energy efficiency in industry and buildings through such approaches as audits, trading schemes and labelling;*
- *increased use of biodiesel and ethanol in transportation fuels;*
- *improved electricity transmission and distribution networks.*

In the industrial sector, the application of BATs and the development of breakthrough technologies will help in reducing emissions. CCS will be needed in both the industry and the transformation sectors to keep the increase in emissions in line with the overall reduction targets.

The three largest industrial sectors of iron and steel, chemicals and cement are responsible for about 25% of India's total emissions and priority should be given to reducing the CO_2 intensity in these sectors. Special attention should focus on coal-based DRI, pulp and paper making and small-scale cement kilns. These three areas offer interesting opportunities to increase efficiency and limit the growth in energy consumption. These industries also offer attractive opportunities, with international support, for the early demonstration of CCS. Achieving wider deployment may also require the implementation of sectoral crediting mechanisms which would encourage Indian industries to invest in these technologies.

The increase in living standards anticipated in India as it grows richer will place a strong upward pressure on energy consumption in the residential and service sectors. The higher penetration of energy-using appliances and equipment will more than offset the energy efficiency gains seen in the BLUE Map scenario. The greater use of commercial energy sources, such as electricity and kerosene, will play a major role in restraining the growth in energy consumption for buildings, as the efficiencies associated with these fuels are much higher than traditional biomass. However, a substantial decarbonisation of electricity generation will be required to limit the increase of CO_2 emissions from greater electricity use. Development of more efficient cooking stoves, lighting and air conditioners will be key in restraining the growth in energy consumption and CO_2 emissions.

The development of many of these low-carbon technologies has already been identified in India's technology innovation targets. More is required to limit the growth in emissions to 10% over the 2007 level. In addition to the priorities that have been identified, more focus should be placed on the development of CCS, deployment of wind power, greater fuel economy in vehicles and RDD&D for PHEVs and EVs.

In identifying the step towards achieving energy security and carbon reductions in India, national technology roadmaps for the most promising low-carbon technologies should be developed. Achieving the ambition of the BLUE Map scenario will also require international collaboration on a number of initiatives. Enhanced international co-operation for research, development, sharing and transfer of technologies will be required. International carbon reduction mechanisms such as the Clean Development Mechanism (CDM) will need to play a role in the deployment of low-carbon energy technologies in India.

PART 2 THE TRANSITION FROM PRESENT TO 2050

Chapter 12 POLICIES TO ACCELERATE A LOW-CARBON TECHNOLOGY TRANSITION

Key findings

- *A step change is needed in the pace and scale of low-carbon energy technology development and deployment across all sectors. Global climate change goals cannot be achieved without all technologies in the low-carbon portfolio making a full contribution.*

- *Although some low-carbon and energy-efficient technologies are competitive today, many others are considerably more expensive than their fossil-based alternatives. Carbon pricing will be important in helping to redress this gap, but it will not be sufficient on its own. To avoid the lock-in of high-emitting, inefficient technologies during the next decade, governments will need to intervene on an unprecedented level with targeted technology policies to address the cost-competitiveness gap.*

- *Policies should be tailored to reflect the maturity and market competitiveness of individual technologies. Where appropriate, they will need to include support for research, development, demonstration and deployment (RDD&D).*

- *Government, industry and civil society need also to enable technology transition by:*
  - *facilitating greater industry leadership through the development of sector-specific roadmaps and public-private partnerships;*
  - *investing in training and education to develop and deploy the human capacity that will be needed to exploit the low-carbon energy technologies of the future;*
  - *engaging the public and communicating to them the urgency of the need to deploy low-carbon energy technologies on a large scale, and the costs and benefits of doing so;*
  - *strengthening international technology collaboration to accelerate RD&D, diffusion and investment.*

- *There is a significant gap between the current level of investment in low-carbon technology RD&D and the investment needed to bring forward the technologies that will underpin the successful achievement of the BLUE Map outcomes. Addressing this gap will require annual public-sector spending two to five times as high as current levels. There is a need for governments, in close collaboration with industry, to reassess their spending priorities for low-carbon energy technology RD&D.*

- *Governments also need to accelerate innovation by implementing best practices in energy RD&D programme design and implementation. This includes the design of strategic programmes to fit national policy priorities and resource availability; the rigorous evaluation of results and adjusting support if needed; and increasing the linkages between the basic science and applied energy research communities to accelerate innovation.*

12

Introduction

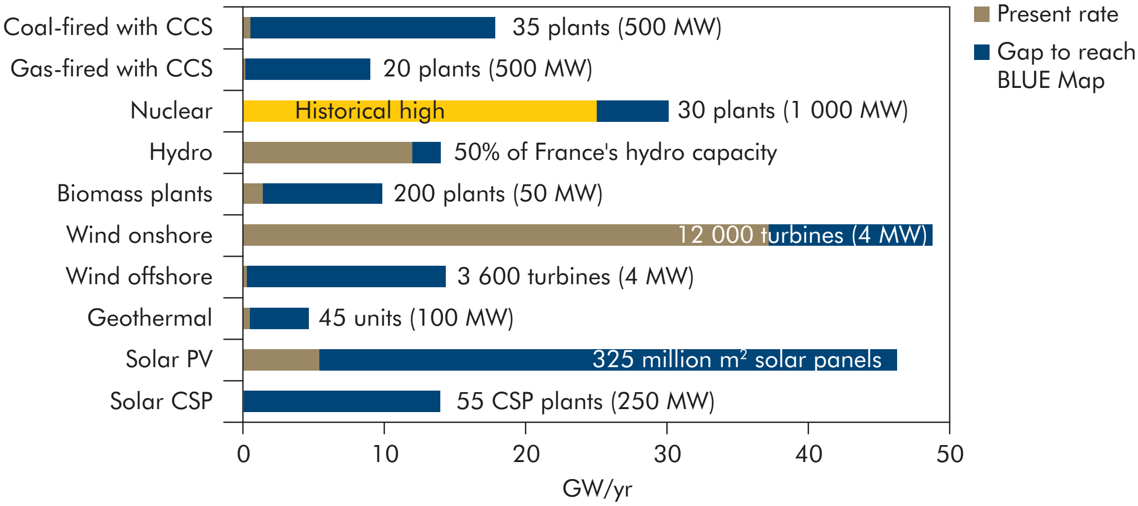
The BLUE Map scenario provides a sense of the scale on which low-carbon energy technologies will need to be deployed to meet global climate change goals. Such an energy technology "revolution" will require major improvements in energy efficiency, the near-decarbonisation of the electricity sector and the introduction of new low-carbon technologies in the industry, buildings and transport sectors. Although there are signs that some of the necessary changes may be starting to happen, sustaining and accelerating this transition will depend on a very significant expansion in the development and deployment of all available low-carbon technology options. It will require unprecedented intervention by governments in developing policies that work with and influence energy and consumer markets to achieve this outcome.

Current rates of investment in capital plant fall well short of the annual rate of investment necessary to achieve the 50% reduction in energy-related carbon dioxide (CO_2) emissions by 2050 envisaged in the BLUE Map scenario. Figure 12.1, which addresses low-carbon investment needs for the electricity sector, shows that for emerging technologies such as offshore wind and coal-fired power generation with carbon capture and storage (CCS), more than 40 times the current annual rate of investment needs to be achieved. Even in more mature technologies such as onshore wind, rates of investment need significantly to increase. Only in respect of hydroelectric power is the current rate of investment, if sustained, anywhere near sufficient. Low-carbon transport, smart grids and end-use energy efficiency also require significant increases in annual investment from today's levels. For example, under the BLUE Map scenario, about 100 million electric and plug-in hybrid vehicles will be sold annually in 2050, compared to virtually none today. This is about 10% over the expected baseline level of investment in light-duty vehicles of USD 140 trillion between 2010 and 2050. For solar thermal water heating, the annual rate of installation is currently about 20 GW_{th} (Weiss, Bergman and Stelzer, 2009), but this increases in the BLUE Map scenario to an average rate of 88 GW_{th} per year between 2010 and 2050, just for the residential and service sectors.

Governments and industry, therefore, need to accelerate the transition to a portfolio of energy solutions which must include energy efficiency in all end-use sectors, renewable energy, nuclear power, low-carbon transportation options, CCS, and low-carbon industrial strategies. Enabling technologies such as smart grids and utility-scale energy storage will also be important. The failure effectively to develop any one of these options could potentially result in additional costs or delays in the achievement of the overall mitigation goals, with negative consequences for the global climate.

Improved energy efficiency. In the BLUE Map scenario, the largest share of the total emissions reduction (38%) comes from an increase in energy efficiency. To achieve this, the annual rate of improvement in global final energy intensity will need to increase from 1.7% to 2.6%. This will require a doubling of the rate of energy efficiency improvement, from 0.7% a year in the Baseline scenario to 1.5% a year in the BLUE Map scenario. Such rapid improvements in end-use efficiency will require the immediate implementation of stronger national energy efficiency policies and measures (IEA, 2009a). In the industrial sector, national policies and measures and international sectoral agreements will be needed to encourage the implementation of best available technologies (BATs) to deliver further substantial savings in emissions (IEA, 2009b).

Figure 12.1 ▶ ***Annual capacity additions needed in the electricity sector to achieve the BLUE Map scenario***



Notes: Unless otherwise indicated, all material derives from IEA data and analysis. Current rates of capacity additions for gas-fired and coal-fired CCS plant, nuclear plant, and hydropower are taken from IEA (2008a); renewable energy rates are taken from REN21 (2009).

Key point

Annual rates of investment in low-carbon technologies must be significantly increased from today's levels.

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Widespread introduction of CCS. The second-largest share (19%) of least-cost emissions savings in the BLUE Map scenario comes from the rapid and widespread introduction of CCS in power generation, emission-intensive industry and fuel transformation. Given the long life of boilers and power generating equipment, CCS capacity will need to be retrofitted to some existing facilities to achieve the levels of penetration needed. Other plants will need to be built with CCS fitted from the outset. The BLUE Map scenario envisages the completion of 100 large-scale projects by 2020 and 3 400 projects by 2050.

Increased deployment of renewable energy. The third-largest share (17%) of the overall reduction in emissions in the BLUE Map scenario comes from the substantial further deployment of renewable energy technologies. By 2050, almost half of total electricity generation comes from renewable energy sources, up from 18% today. Wind, solar photovoltaic (PV), concentrating solar power (CSP), biomass and hydro will all have to make an important contribution. For example, the BLUE Map scenario envisages the bringing onstream of an average of 48 gigawatts (GW) of onshore wind every year for the next 40 years. Over the same period an average of 325 million square metres (m^2) of PV panels would need to be installed every year, totalling more than 13 billion m^2 of panels by 2050.

A renewed focus on nuclear power. An important part of the emissions reductions in the BLUE Map scenario comes from an increase in the share of nuclear power. This would require around 30 nuclear plants, each of 1 000 megawatts (MW) capacity, to be built every year from 2010 to 2050.

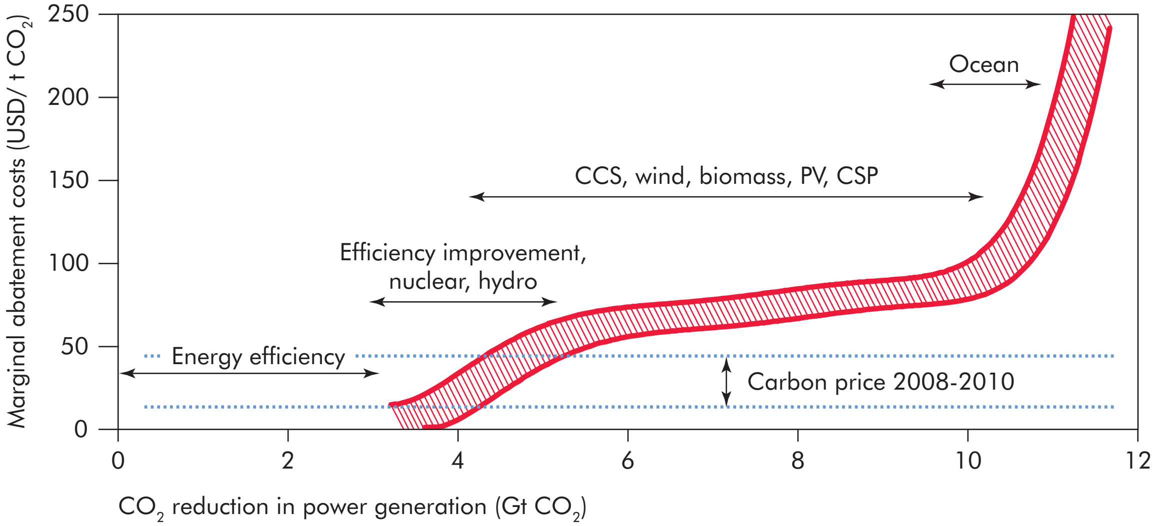
Addressing transport. Despite very significant increases in transport volumes, the transport sector will need to reduce its emissions well below 2007 levels worldwide if overall emissions are to be halved by 2050. Reducing emissions from the sector will require rapid advancement in three areas: achieving a 30% to 50% reduction in energy intensity by 2050 for all transport modes; rapidly adopting new technologies including plug-in hybrid electric vehicles (PHEVs) and full electric vehicles (EVs) after 2015 and fuel-cell vehicles (FCVs) after 2025; and producing around a quarter of transport fuel from sustainable biofuels by 2050. Sustainable transport systems will also be critical to the enabling of much wider use of the most efficient travel modes such as rail, air, shipping, bus, and non-motorised travel.

Support for enabling technologies. A number of important cross-cutting enabling technologies will be needed to underpin these transformations. For example, to make the maximum use of energy efficiency, renewable power generation and EVs, substantial investment will be needed in smart electricity grids and in utility-scale energy storage. It will be critical for investors, together with national and regional regulators and planning experts, to develop an integrated vision for the role of smart grids at national and regional levels (see Chapter 4).

One of the main obstacles to these technology transitions is cost. Many low-carbon technologies currently cost more than conventional alternatives. One way to help redress this balance is to establish a price on CO_2 emissions. Countries are pursuing this goal through a range of multilateral and regional/national schemes, including through the United Nations Framework Convention on Climate Change (UNFCCC) process. A number of new and innovative financing products are also being developed, as described in Chapter 14.

A firm, predictable carbon price is likely to be an important driver of change. But it is unlikely to be sufficient on its own to drive short-term investment in the more costly technologies that have longer-term emissions reduction benefits (Stern, 2007). A truly global carbon market is also likely to be many years away. Many energy-efficient and some low-carbon energy supply technologies are available today at zero or low additional net cost. But a number of other technologies will not enter the market in a substantial way until prices are between USD 25 per tonne (t) of CO_2 and USD 75/tCO_2. This is much higher than the CO_2 prices seen today (Figure 12.2). Therefore, to avoid locking in inefficient, carbon-intensive technologies during the next decade, governments will need to intervene with targeted policies to bring down the cost of low-carbon alternatives and to create markets for technologies that are not yet fully commercial.

Figure 12.2 ▶ ***CO_2 mitigation costs in the electricity sector (2010-20) and current CO_2 prices***



Source: CO_2 price data from the European Climate Exchange; accessed at www.ecx.eu.

Key point

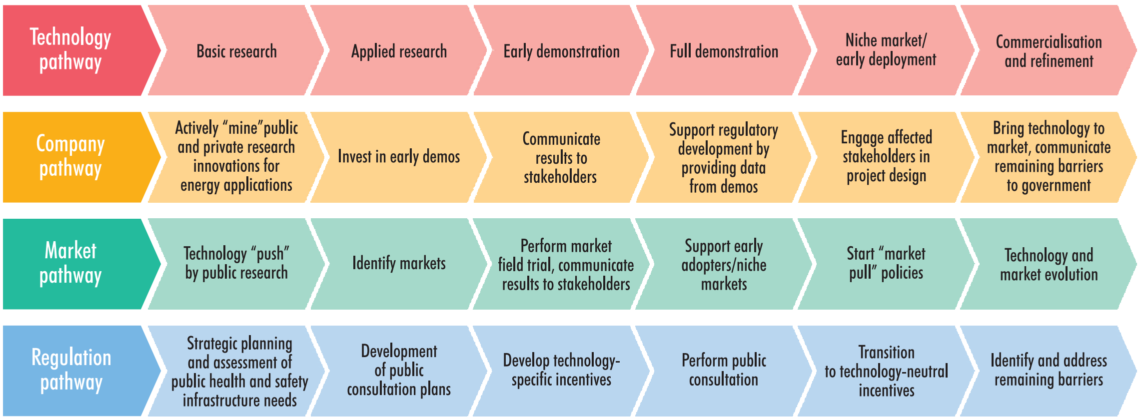
There is currently a sizeable gap between CO_2 prices and the mitigation costs of many low-carbon technology options.

The need for energy technology policies

To achieve a halving of CO_2 emissions by 2050, governments will need to complement carbon pricing measures with an integrated set of energy technology policies and RD&D programmes that are tailored to the different stages of development of individual technologies. International collaboration will be fundamental to achieving these outcomes cost-effectively. Issues of public engagement and workforce development also need to be tackled.

Markets, companies and governments pursue energy technology innovation through a number of parallel and interrelated pathways (Figure 12.3). Most existing government programmes focus on technology development. Governments also have a much wider role to play in ensuring the integration of market development measures, regulation and steps to ensure the creation of strong private-sector business models for technology. Small and medium-sized firms developing low-carbon technologies need to grow their capabilities in marketing and fund-raising, management and operations, supported by government efforts to develop regulatory standards for safety and performance which can command public support. In addition, governments can help achieve cost savings in the transition from R&D to demonstration by providing funding for important activities such as small-scale and component testing before technologies move to full-scale demonstration. Increased investments are also needed to improve research infrastructures, especially laboratories and test facilities that are available to a wide range of industry and research institutions.

Figure 12.3 ▶ Pathways for low-carbon technology development and deployment



Source: IEA analysis based on Carbon Trust (2009).

Note: Processes are presented in a linear way. In practice, a number of non-linear feedbacks occur along the transition pathway that accelerate innovation.

Key point

Low-carbon technology development and commercialisation requires integrated support from markets, companies and governments.

Tailoring policies to the stage of technology development

Technologies at different stages of development need different types and levels of support:

- **For promising but not yet mature technologies (Stage 1),** governments need to provide financial support for additional research and/or large-scale demonstration and to start to assess infrastructure and regulatory needs.

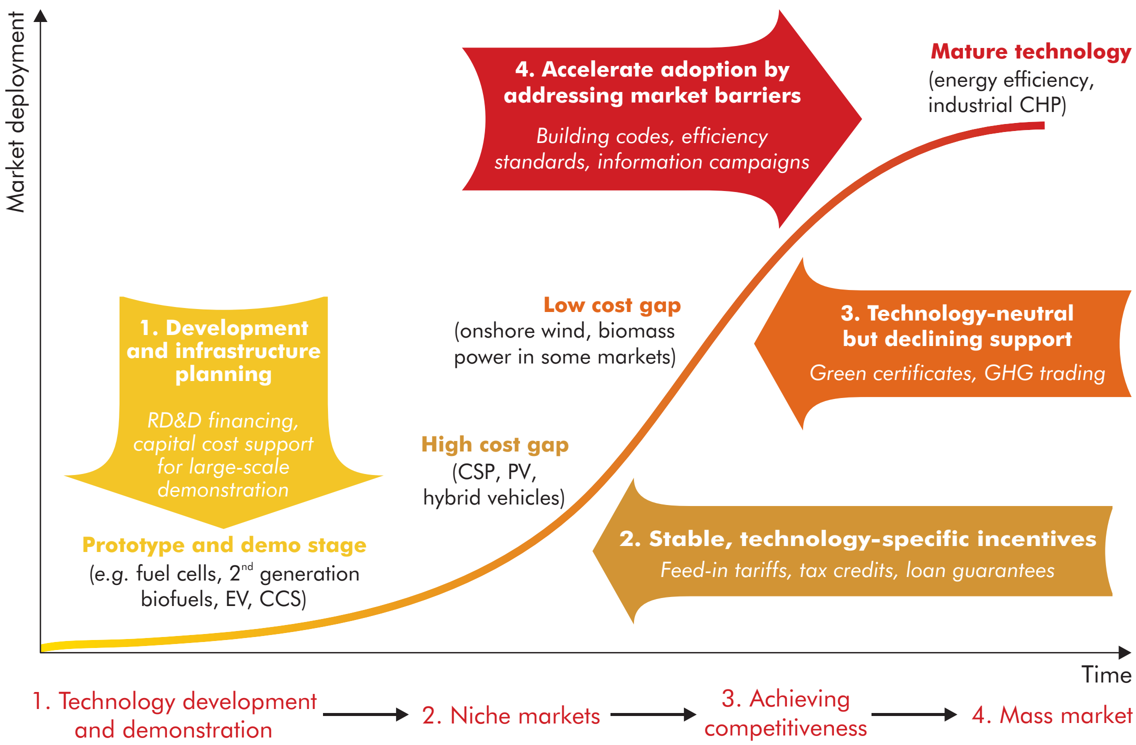
- **For technologies that are technically proven, but require additional financial support (Stage 2),** governments need to provide support with capital costs, or to introduce technology-specific incentives such as feed-in tariffs, tax credits and loan guarantees, and appropriate regulatory frameworks and standards, to create a market for the relevant technologies.

- **For technologies that are close to competitive (Stage 3),** governments need to move towards technology-neutral incentives that can be progressively removed as technologies achieve market competitiveness.

- **For technologies that are competitive (Stage 4),** governments can best help scale up public and private investment by tackling market, informational and other barriers and by developing effective intervention policies and measures.

Many technologies in practice straddle two or more stages of development. Government intervention needs to be tailored accordingly, in some cases providing support to all four phases of technology development simultaneously (Figure 12.4 and Box 12.1).

Figure 12.4 ▶ Policies for supporting low-carbon technologies



Source: Adapted from IEA (2008b).

Note: The figure includes generalised technology classifications; in most cases, technologies will fall in more than one category.

Key point

Government support policies need to be appropriately tailored to the stage(s) of development of a technology.

A number of energy technologies such as CCS, second-generation biofuels, EVs and smart grids are at Stage 1 on this spectrum. They offer very good promise but require large-scale demonstration, together with the development of regulatory frameworks, the strategic planning of appropriate infrastructure needs and public outreach and engagement (Box 12.2).

12

Box 12.1 ▶ Wind energy technologies span development categories

Wind is a good example of the way in which government support needs to be tailored to the stage of a technology's development.

- ***Stage 1: Promising but not technically proven wind technologies – deep offshore***
  Floating subsurface structures are being tested to support wind turbines at water depths greater than around 60 metres.

- ***Stage 2: Technically proven, but strong financial support needed – shallow offshore***
  High investment costs compared to onshore, and low wind availability relative to onshore, signal a continuing need for capital investment in shallow onshore R&D to drive cost reductions.

- ***Stage 3: Close to market competitiveness but some support still needed – onshore***
  Significant potential remains for incremental reductions in the cost of electricity from existing technology, equivalent to around 23% by 2050. This can be driven by continued incentives or other financial support.

- ***Stage 4: Competitive technology – onshore***
  Although onshore wind technology is competitive in many markets, public support is still needed to ensure its deployment. Governments need to ensure that permitting procedures, trade controls, grid access, and public support enable further growth in capacity.

Box 12.2 ▶ Examples of policies to support promising but not yet mature technologies

The development of "early adopter" EV cities and driving corridors. *A number of cities and regions are actively developing corridors to accelerate EVs from niche markets to competitive production and use. In Yokohama Japan, a detailed plan has been developed to support EV use and operation throughout the city with a range of recharging options. In Sweden, the Green Highway venture will create a green transport environment that includes municipal and utility investment in EVs, charging infrastructure, renewable fuels, testing and development. The initiative is taking place in an area between the Gulf of Bothnia and the Norwegian Sea which is home to 350 000 inhabitants and 150 000 vehicles.*[1]

1. See http://www.greenhighway.nu/index.php?Itemid= 74.

Box 12.2 ▶ Examples of policies to support promising but not yet mature technologies (continued)

The strategic development of smart grids. *An international collaborative project in Denmark called the Cell Project is designed to help the Danish power system adapt to future requirements.*[2] *The overall electricity grid is divided into smaller cells in which all generation and substation switches are monitored and controlled individually. Combining cells results in a large system with more flexibility and reliability, for example by enabling a cell to be isolated from the rest of the system in the event of a fault. This approach could be extended to include the monitoring and control of loads in addition to generation. Consideration is being given to technological, market and environmental aspects to ensure that any barriers to such an approach will be removed when carried out on a full-scale basis.*

Strategic planning to link major CO_2 sources to storage sites. *The Port of Rotterdam in the Netherlands is taking an integrated and incremental approach to CO_2 pipeline planning. This involves the collection and transport of CO_2 from existing small-scale sources that emit pure CO_2. The scheme will expand to include demonstration CCS power plants and commercial-scale power plants, and in due course industrial sources. At the end of 2020, up to 20 Mt CO_2 will be stored in the Dutch continental shelf (Rotterdam Climate Initiative, 2009).*

Offshore wind transmission and distribution systems. *The Dutch government has prepared a draft National Water Plan that seeks to integrate wind power development in the North Sea alongside fisheries, shipping, nature conservation and coastal defences (IEA, 2009c). The Danish government has produced an action plan for offshore wind power which plans 26 potential sites for wind farms comprising 5 200 megawatts (MW) in total. The Danish plan is part of the larger North Sea Countries Offshore Grid Initiative, which involves nine EU member states and the European Union.*[3]

Forward-looking regulation to ensure a safe, effective low-carbon economy. *Governments need to begin developing forward-looking, adaptive regulations to facilitate the effective and safe use of low-carbon energy technologies. For example, the United Kingdom Health & Safety Executive's (HSE) Emerging Energy Technologies Programme (EET) has recognised that the transfer to new technologies will require rapid and effective health and safety regulation. The EET seeks to provide guidance that enables the safe introduction and expansion of new energy technologies, including renewable energy, CCS, small-scale distributed generation, natural gas storage and liquefied natural gas (LNG) imports, and cleaner coal technologies. The HSE is developing advance health and safety standards to ensure that the risks from these new energy systems can be managed. The EET also includes an element of skills development, to ensure that the people needed to regulate the industry are available as new energy systems reach the market (UK HSE, 2009).*

2. See http://www.energinet.dk/en/menu/R+and+D/The+Cell+Project/The+Cell+Project.htm.
3. See http://ec.europa.eu/avservices/services/showShotlist.do?out=PDF&lg=En&filmRef=67310.

As the capabilities of technologies become proven through R&D and start to enter the market (Stage 2), they need government support that is technology-specific. Solar PV, offshore wind and biomass power are technologies that are at the beginning of this phase. They currently need support in the form of tax credits or incentives for generators or customers and from regulations that mandate energy suppliers to purchase the output of a specific type of technology at higher-than-market rates, for example through feed-in tariffs or renewable energy portfolio standards. These mechanisms seek to establish a financial return from renewable generation that is competitive with other energy sources and sufficient to attract private investment. Government policies and programmes should target support on initial costs, recognising that many of these renewable energy technologies are more capital-intensive than their conventional fuel counterparts, but with lower variable costs in operation.

As technologies become competitive (Stage 3), governments should look to support them through market mechanisms which, while supportive of lower-carbon technologies in general, become progressively more technology-neutral. These would include such mechanisms as tradable green certificates or greenhouse-gas emissions trading. At this stage, governments should reduce technology-specific support.

Regardless of the type of support, government mechanisms should satisfy certain design principles:

- Policies should be transparent, stable and predictable in the long term to minimise investor uncertainty. They should also be easy to unwind or remove when the technology has achieved set competitiveness milestones.
- Incentives and mandates should reflect the maturity of different technologies. Levels of support should decrease over time as the technologies become competitive.
- Policies should encourage the development of both generation and transmission technologies.
- Technology push and market pull incentives should be part of a coherent, strategic framework and supported by measures that address administrative or other barriers faced by technologies.
- Governments should encourage energy output rather than the installation of technology. This will encourage investors to maximise energy output and greenhouse-gas emissions reductions over the lifetime of the project.
- Policies should be easy to implement and enforce, with appropriate penalties for non-compliance.

Above all, the objective should be to reduce risk and stimulate deployment while encouraging technologies to reduce costs and become more market-competitive

A further group of technologies – including energy efficiency, industrial combined heat and power (CHP) and onshore wind in some markets – are already commercially viable (Stage 4), particularly where emissions trading systems create a cost for greenhouse-gas emissions. But they are susceptible to market and other barriers that prevent their full use. For these technologies, government support should include specific measures to address information, market, legal, regulatory or financial barriers. Examples of government policies and actions taken in these respects include:

- Regulatory or control mechanisms such as energy building codes or minimum energy performance standards for appliances through which governments can impose requirements to invest in energy-efficient technologies and infrastructure.
- Fiscal or tax policies through which governments offer consumers tax incentives for investment in energy-efficient technologies or procure energy-efficient technologies themselves.
- Promotion and market transformation programmes through which governments or energy providers influence consumers to purchase energy-efficient technologies.
- Financial remediation measures through which governments or energy providers offer special financing or lines of credit for energy-efficient technology investments.
- Commercial development and industry support mechanisms through which governments or energy providers partner with the private sector to increase the deployment of energy-efficient commercial buildings (IEA, 2008b).

Enabling actions: addressing the business and human aspects of a low-carbon technology revolution

In addition to tailoring policies to the stage of a technology's development, there are other important enabling actions that need to be taken to ensure wider industry and public support for low-carbon technologies, and to ensure that these technologies rapidly diffuse throughout the world. These include:

- fostering industry leadership;
- developing a skilled low-carbon energy workforce;
- expanding public outreach and engagement;
- strengthening international collaboration.

Fostering industry leadership

As discussed in Chapter 13, the IEA has been working with government and industry to develop roadmaps for many of the low-carbon technologies. Many of the roadmaps recommend accelerating private-sector innovation and greater industry leadership to address technology development goals. Public-private partnerships aimed at speeding the transition from demonstration to the commercial deployment of clean energy technologies can play a part in this respect. Such partnerships may be particularly appropriate for technologies such as CCS and EVs that will depend on the development of new business models for industries and technologies (Box 12.3). There is evidence that a large proportion of breakthrough innovations come from new firms that challenge existing business models. Government steps to remove barriers to the entry, exit and growth of new firms may have an important part to play in low-carbon energy technology development.

Box 12.3 ▶ Accelerating technology developments through public-private collaboration and innovation

*The **Global Carbon Capture and Storage Institute** (GCCSI) was established by the Australian government in 2009 to build confidence in CCS technologies. With over 160 members from national governments, corporations and non-government bodies, the GCCSI's central objective is to accelerate the commercial deployment of CCS projects and to advance the use and application of CCS technology. To achieve this goal, the Institute is establishing a portfolio of integrated projects that encompasses different CCS technologies and approaches in various geographic regions. Through advancing industry-government collaboration on actual projects and facilitating the sharing of both knowledge and lessons learned, the GCCSI is playing an important role in fostering global technology co-operation and inspiring confidence that CCS can become a commercial reality.*[4]

*The United Kingdom has two entities focusing on low-carbon innovation. The **Carbon Trust** is a not-for-profit company that provides targeted support by leading industry collaborations and investing in early stage low-carbon companies to help business commercialise low-carbon technologies. The Carbon Trust has invested in 16 companies and 170 different projects, of which 100 are completed (Carbon Trust, 2009). The **Energy Technologies Institute** (ETI) is a company established in 2007 that partners with global industries and the United Kingdom government to develop large-scale demonstrations for low-carbon energy technologies, including CCS, EVs, smart grids, offshore marine and wind energy, and distributed generation. The ETI has access to a potential fund of GBP 1 billion (USD 1.5 billion) over 10 years. The ETI also performs modelling scenarios and is defining a roadmap for 2050 on low-carbon energy technologies (ETI, 2009).*

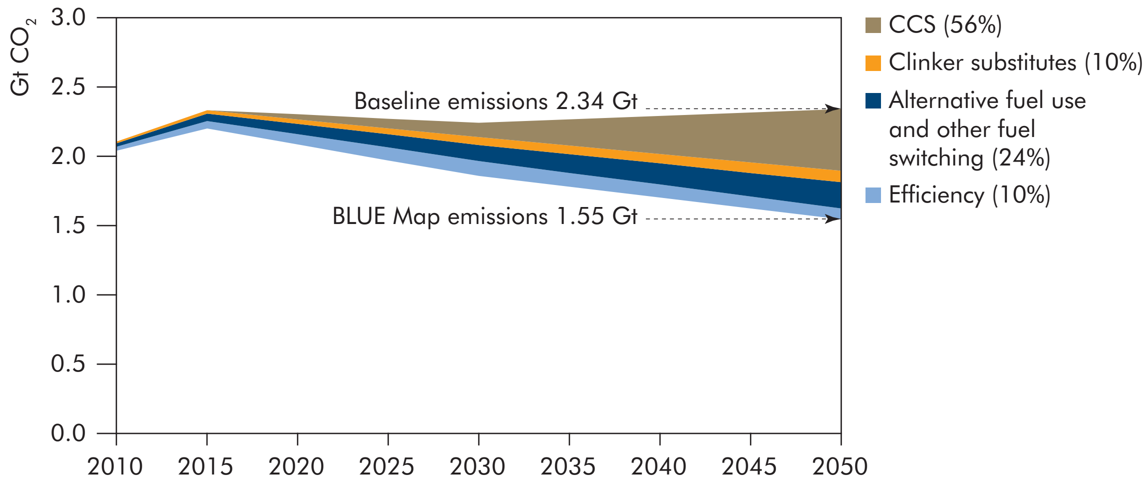
*Finland's **Clusters for Energy and the Environment** (CLEEN) programme started in 2008. It has 40 partners in Finland and overseas. The partners have developed focus areas for technology innovation and collaboration, including smart grids, distributed energy systems, carbon-neutral electricity generation, and energy efficiency. RD&D ranges from basic science to applied research and includes demonstration activities.*[5]

The IEA roadmaps have also identified a need for governments and industry to work more closely together in support of technologies that have a large future potential but are currently unable to attract significant investment. For example, the oil and gas industry has extensive knowledge about the prospects for CO_2 storage in oil and gas fields. The industry may be willing to offer reduced-cost geologic modelling and prospecting capabilities to help governments improve their knowledge of prospects of geologic CO_2 storage in exchange for accelerated access to promising CO_2 storage sites. Increased government/financial sector risk-sharing to support small-scale energy technology companies, on the lines of the United Kingdom's Carbon Trust, also warrants further examination.

4. See www.globalccsinstitute.com.
5. See www.aka.fi/en-gb/A/Academy-of-Finland/The-Academy/News/CLEEN-to-renew-cooperation-in-the-energy-and-environment-sector-/.

Companies within industry sectors can help advance low-carbon energy technologies by working collaboratively with each other to develop sector visions for the future. The publication in 2009 of the joint IEA-cement industry roadmap shows how industry can provide leadership and guidance to government and civil society about the actions that need to be taken to transition to a low-carbon future (Figure 12.5). This may be particularly important when considering technology solutions such as CCS that add significant costs. There may be considerable value in other emission-intensive sectors undertaking similar initiatives to help identify and progress low-carbon pathways.

Figure 12.5 ▶ Cement sector emissions reduction pathway



Source: IEA (2009d).

Key point

Industry can help to define practicable low-carbon technology pathways.

12

Developing a skilled low-carbon energy workforce

Many roadmaps have identified human workforce development as an important near-term priority. Governments need to create educational incentives and to work with industry to foster viable career paths for skilled people in low-carbon technology fields. This includes the development of academic curricula and training of experts, including geologists to facilitate CO_2 storage, nuclear power technicians, and people with expertise in renewable energy and smart grids. There is also a need to adapt existing vocational and higher education institutions to develop the energy skills that will be needed. Several governments and non-governmental organisations (NGOs) are actively pursuing these training opportunities. These efforts need to be accelerated and replicated globally (Box 12.4).

Box 12.4 ▶ Examples of low-carbon training programmes

*Capacity building and training activities in CCS are undertaken by several international bodies. The **IEA Greenhouse Gas Programme** has developed a CCS Summer School geared towards young scientists from developed and developing countries. The course was held for the first time in 2007 in Germany.[6] At the national level, a CCS School was started by research centre CO2CRC in Australia in July 2008.[7]*

*The United States **Solar Instructor Training Network** was launched in October 2009 to address the need for training in solar system design, installation, sales and inspection. The programme has been designed in partnership with the United States Department of Energy (US DOE). In addition to increasing the number of trained workers in the solar industry, US DOE finances the accreditation of solar training programmes, the certification of solar installers, and the distribution of best practices for training programmes. US DOE plans to invest USD 27 million over five years in the network of regional resource and training providers.[8]*

*The **California Green Corps** programme utilises USD 10 million in federal economic stimulus funding from the United States Department of Labor and an additional USD 10 million from public-private partnerships to help stimulate green technology while helping to place more than 1 000 at-risk young adults into jobs. The programme consists of ten regional Green Corps in different parts within California. Participants receive a stipend and must complete job training focused on green jobs, continue their education and contribute to their communities through community service.[9]*

*The **Joule Centre**[10], funded by the United Kingdom Northwest Regional Development Agency, aims to increase the Northwest region's RD&D capacity in key disciplines in the energy sector and to build the skills that are needed to support the work of the Northwest Energy Council on energy policy and economic development.*

*The **Green Jobs Initiative** started in 2007 as a joint initiative by the International Labor Organization (ILO), the United Nations Environmental Programme (UNEP), the International Employers Organization (IOE) and the International Trade Union Confederation (ITUC) to help countries to realise the potential for green jobs. In **Bangladesh**, the ILO initiative will partner with the Grameen Shakti programme, which is currently providing training, particularly to women, on servicing and repairing renewable energy technologies such as solar PV. The initiative will also introduce entrepreneurship and skills training for men and women promoting the use of renewable energy technologies.[11]*

*In **China**, the government adopted a 2003 to 2010 National Rural Biogas Construction Plan, which provides new employment opportunities for many unemployed farmers in rural areas. In order to meet the shortage of technical capacity for the operation and maintenance of the digesters in Shanxi Province, 40 training courses were held. By 2005 over 4 000 people had been awarded the National Biogas Professional Technician Certificate (Kuhndt and Machiba, 2008).*

6. See www.co2captureandstorage.info/summerschool/organisation%202008.html.
7. See www.co2crc.com.au.
8. See www1.eere.energy.gov/solar/instructor_training_network_faq.html.
9. See http://gov.ca.gov/fact-sheet/11753.
10. See www.joulecentre.org/index.htm.
11. See www.ilo.org/integration/themes/greenjobs/lang-en/inep.htm.

Box 12.4 ▶ **Examples of low-carbon training programmes** (continued)

The ***United States Agency for International Development (US AID)*** *runs, through the Institute for Sustainable Development and Renewable Energy, a programme in the city of Fortaleza, in Brazil, to train students from the poorest neighbourhoods in building renewable energy capacity. The programme recruits 16 to 24 year-olds to attend an eight-month training which includes technical courses, networking and presentation skills, project development and marketing. Students also receive field training on renewable energy at private firms.*[12]

Expanding public outreach and engagement

Achieving the technology transitions envisioned in the BLUE Map scenario will depend, among other things, on people supporting and adopting low-carbon technologies. The roadmaps point to a need for expanded public outreach and engagement to facilitate the transition to a low-carbon energy system. A first priority should be for governments, industry and civil society to develop a common vision for the transition to low-carbon energy. The process of developing the vision should involve sharing information and views on the importance of using a portfolio of low-carbon technologies, the costs and benefits of various technology options, and the need for infrastructure and technology change. This shared vision will be important in helping to secure public support for low-carbon technology spending and subsidies.

Some countries have developed transition strategies on these lines that include:

- Analysis of the need for a process of transition management that identifies stakeholders, processes and institutions to support the development of low-carbon technologies (Kemp and Rotmans, 2005; Loorbach and Kemp, 2008).
- Implementation of an energy transition programme that involves public and private actors working in partnership to develop transition pathways and experiments for key technologies. These experiments provide critical learning about the feasibility and social acceptability of particular technologies (Energy Transitions Task Force, 2006; Dietz, Brouwer and Weterings, 2008).

Governments and the private sector will need to complement this with expanded community engagement. When announcing major investments in technologies such as CCS, wind energy and nuclear power, governments and companies often fail to explain to the public why they are doing so and to secure the support of critical stakeholders. This has led to local opposition to planned projects. Communities near, for example, CO_2 transport and storage sites, wind or solar farm developments, and nuclear waste disposal projects need to be engaged early in the process of site selection. NGOs, together with local environmental and public health officials, may have an important role to play. There are a number of proven principles and procedures which can help to incorporate public concerns into project design and development, and some good examples of projects in which these principles have been very effectively followed (Table 12.1).

12. See www.usaid.gov/stories/brazil/ss_br_youthenergy.html.

Table 12.1 ▶ Examples of public engagement projects

Project name	Applications	Features
European Union *Create Acceptance* project [1]	Energy projects	Includes the ESTEEM tool, which proposes a six-stage framework for public engagement
World Resources Institute (WRI)[2] *Breaking Ground* public engagement guide	Extractive and infrastructure projects	Presents seven principles for effective community engagement
US National Institute for Standards and Technology's *Communicating the Future* study[3]	All science and technology projects and/or programmes	Presents a set of best practices for communicating science and technology to the public
University of Calgary, IISD, Canada – Climate Change Central *CCS Communication Workshops*[4]	CCS projects	A guide to communicating CCS to the public from a range of different perspectives. Discusses how to build trust via actions designed to ensure commitment, accountability, disclosure and acknowledgement
Centre for Low Emission Technology, CSIRO, *An Integrated Roadmap of Communication Activities around CCS in Australia and Beyond*[5]	CCS projects	Recommendations to industry on how to devise communication strategies on CCS, including proactivity, partnering with credible organisations, developing education tools, engaging public figures, and linking CCS to larger climate change solutions such as renewable energy
US National Wind Coordinating Committee, *Wind Siting Case Studies – Community Response*[6]	Wind projects	Uses an access study approach to evaluate public acceptance of local wind development projects and identifies approaches used by developers to successfully address community concerns

[1] Jolivet, E. *et al.* (2008), Create Acceptance Deliverable 5 ESTEEM Manual, http://www.createacceptance.net/fileadmin/create-acceptance/user/docs/D5_WP3_web.pdf.
[2] Herbertson, K. *et al.* (2009), Breaking Ground – Engaging Communities in Extractive and Infrastructure Projects, WRI, http://pdf.wri.org/breaking_ground_engaging_communities.pdf.
[3] See http://www.nist.gov/public_affairs/bestpractices/practices.html.
[4] Climate Change Central (2007), Carbon Capture and Storage Communication Workshops Final Report, http://www.climatechangecentral.com/files/CCSWorkshop_Final_Report.pdf.
[5] Ashworth, P. *et al.* (2007), "Kyoto or non Kyoto People or Politics: Results of recent public opinion surveys on energy and climate change", in *Greenhouse 2007*. Sydney.
[6] National Wind Coordinating Committee (2005), Wind Power Facility Siting Case Studies: Community Response, BBC Research & Consulting.
www.nationalwind.org/assets/publications/Wind_Power_Facility_Siting_Case_Studies.pdf.

Designing new models for international collaboration

A number of roadmaps have also identified an urgent need for greater international collaboration to accelerate the global diffusion and adoption of low-carbon energy technologies. There is a common need for greater knowledge sharing and RD&D collaboration among countries to accelerate technology advancement along the curve from demonstration to commercialisation. There is also a need to target some emerging and developing economies with specialised approaches to ensure capacity building and appropriate enabling environments (see Chapter 15).

Shared international learning may also help to lower the costs of technology demonstration and commercialisation by enabling national budgets to be co-ordinated in a more efficient manner. There are many models for collaboration, from broad, multilateral cross-cutting efforts to technology-specific efforts. An early need is to develop an inventory of existing low-carbon technology activities to identify areas of duplication and potential opportunities to make better use of investments.

The Asia-Pacific Partnership on Clean Development and Climate (APP) brings together seven leading developed and developing nations to address climate change, energy security and air pollution challenges in a way that encourages economic development and reduces poverty.[13] The members are Australia, Canada, China, India, Japan, South Korea and the United States. This grouping represents around half the world's emissions, energy use, gross domestic product (GDP) and population, and engages many of the largest greenhouse-gas emitters in the Asia-Pacific region. Eight task forces have been established, covering cleaner fossil energy; aluminium; steel; cement; coal mining; renewable and distributed energy; buildings and appliances; and power generation and transmission. These task forces have both government and private-sector members and are responsible for progressing the work of the Partnership. For example, the APP Steel Task Force promotes the effective reduction of emissions by compiling a collection of high-performance technologies, developing a methodology to assess energy efficiency, analysing reduction potentials and identifying areas for improvement.

The Major Economies Forum on Energy and Climate (MEF) uses a similar structure. The Forum, which comprises 17 major developed and developing economies, was launched in March 2009. Its goal is to advance the exploration of initiatives and joint ventures that increase the supply of clean energy and cut greenhouse-gas emissions.[14] At the UNFCCC Conference of the Parties to the Convention, 15th session (COP-15) in Copenhagen in 2009, the MEF countries published a series of Technology Action Plans for a number of specific low-carbon technologies, including advanced vehicles, solar energy, ocean energy and CCS.

Negotiations on a new climate change treaty under the UNFCCC are addressing the need for greater international collaboration across the technology development cycle. Progress was made at COP-15 to establish a new technology mechanism that would promote and channel finance to national and collaborative technology initiatives, catalyse the development and use of technology roadmaps or action plans at international, regional and national levels through co-operation between relevant stakeholders, and enhance co-operation between national, regional and international technology centres and institutions.

At the request of G8 leaders and IEA countries' energy ministers, the IEA is taking forward plans for an international low-carbon energy technology platform. The platform will bring together policy makers, business representatives and technology experts to discuss how best to encourage the spread of clean energy technologies. It will pull from lessons learned from the 42 IEA Implementing Agreements, which have been operating for more than 30 years with a focus on technology-specific research, development and deployment (see Annex B).

13. See www.asiapacificpartnership.org.
14. See www.majoreconomiesforum.org.

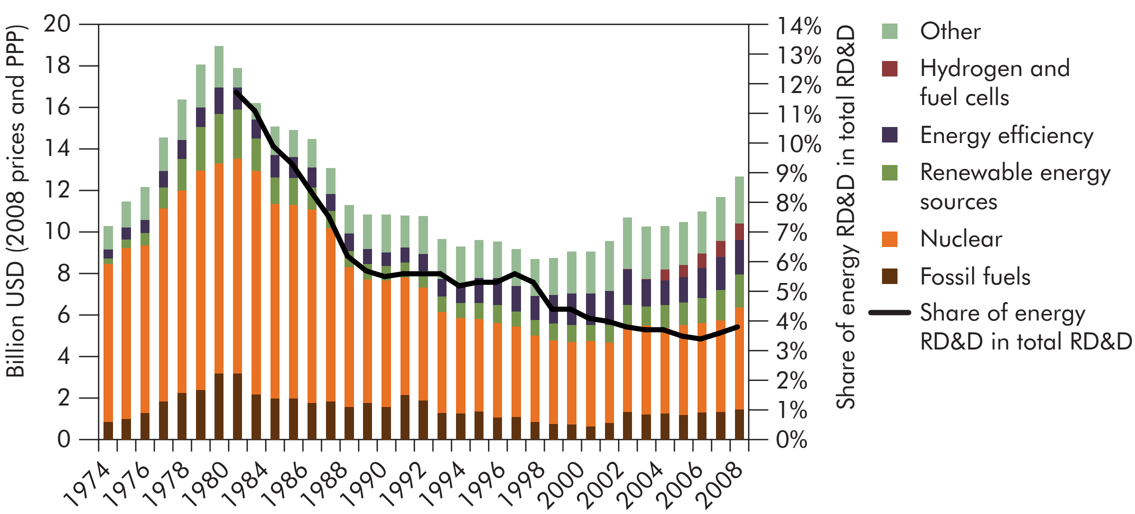
Energy technology research, development and demonstration

More investment in low-carbon energy technology RD&D is needed at all stages of technology development. This should include direct government funding, grants and private-sector investment. After years of stagnation, government spending on low-carbon energy technologies has risen. But current levels still fall well short of what is needed to deliver significant greenhouse-gas emissions reductions in the longer term. Private-sector spending is very uncertain.

Current public-sector low-carbon RD&D expenditure

Government energy RD&D budgets in IEA member countries declined between the early 1980s and the 1990s from USD 19 billion in 1980 to USD 8 billion in 1997. The decline was associated with the difficulties of the nuclear industry and with the decrease in oil prices from 1985 to 2002. Since 1998, government expenditures on energy RD&D have started to recover, particularly between 2005 and 2008. Expenditure in 2008 was about USD 12 billion. The share of energy RD&D in total RD&D in IEA member countries declined from 11% in 1985 to about 3% in 2006 but appears to be rising again (Figure 12.6).

Figure 12.6 ▶ Government RD&D expenditure in IEA member countries, 1974-2008



Note: PPP = purchasing power parity.

Key point

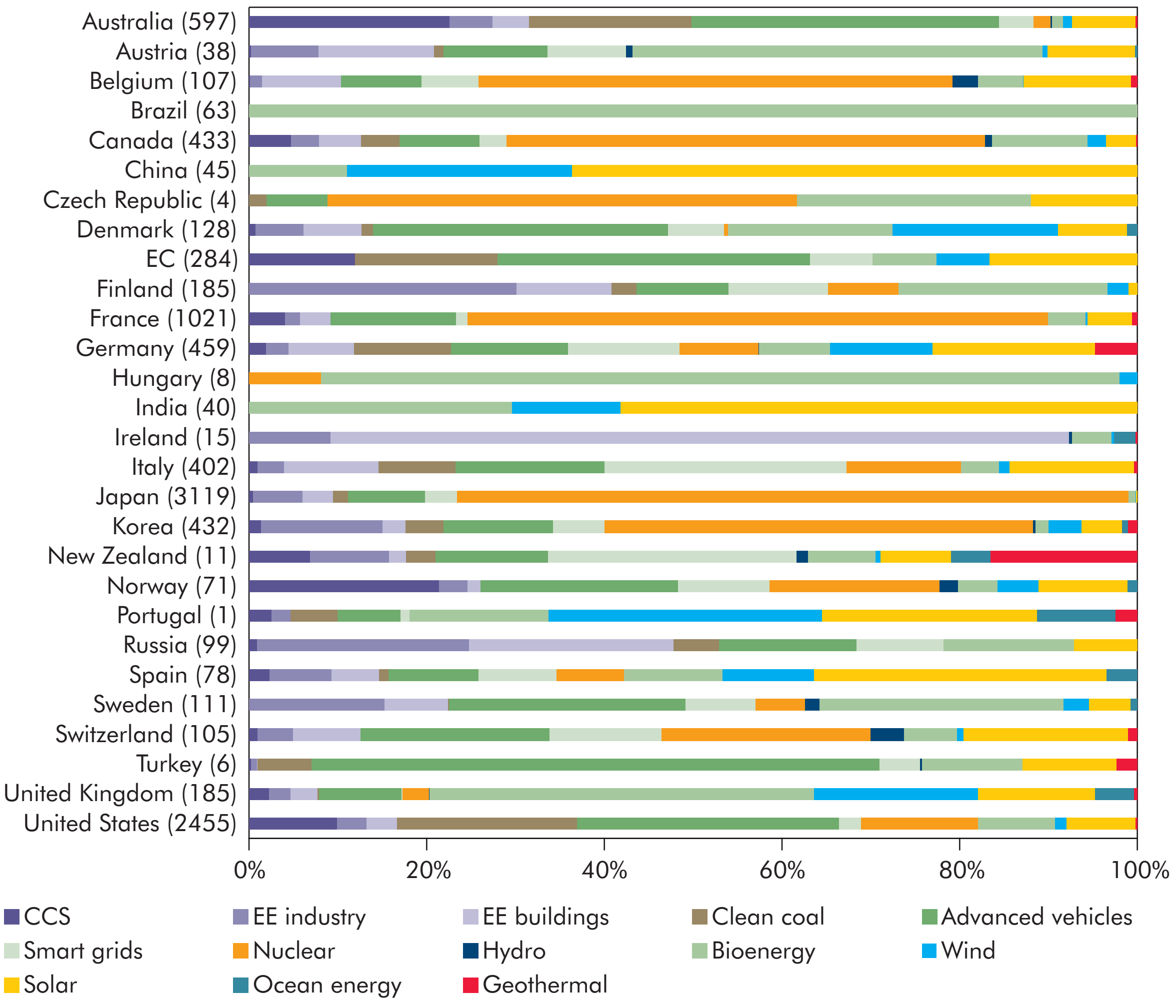
There are signs of increases in government energy RD&D budgets following a period of stagnation.

Countries spend very different amounts on low-carbon energy technology RD&D, and devote their investment to different ranges of technology in different proportions (Figure 12.7). Nuclear technologies[15] attract around 40% of public RD&D spending.

15. The statistics in this paragraph refer to spending on all types of nuclear energy (fusion and fission); Figures 12.7 and 12.8 and Table 12.2 only include nuclear fission spending, as the BLUE Map scenario only includes nuclear fission.

This remains the largest single share, although it is down from about 50% in 1992. Government expenditure on fossil fuel research experienced the largest drop in share from 1992 to 2006 although annual expenditure in this sector increased by 12% between 2006 and 2008 as a result of increased interest in CCS. There were also increases in annual budgets over this period for renewables (28%), energy efficiency (17%), hydrogen and fuel cells (10%) and, for the first time in many years, nuclear technologies (12%). The countries in the MEF and the IEA member countries have announced their intention to at least double RD&D budgets.

Figure 12.7 ▶ ***Low-carbon energy technology: public-sector spending (million 2008 USD) in major countries by technology, 2007***



Note: Amounts in parentheses at left are total expenditures in million 2008 USD. Spending amounts for Australia, Canada, Germany, Russia and the United States are 2009 estimates based on country submissions. The table includes all of those IEA member countries and other major economies for which data are available. No data are available for Greece, Luxembourg, the Netherlands, Poland and the Slovak Republic. Only includes nuclear fission spending.

Source: IEA statistics and analysis.

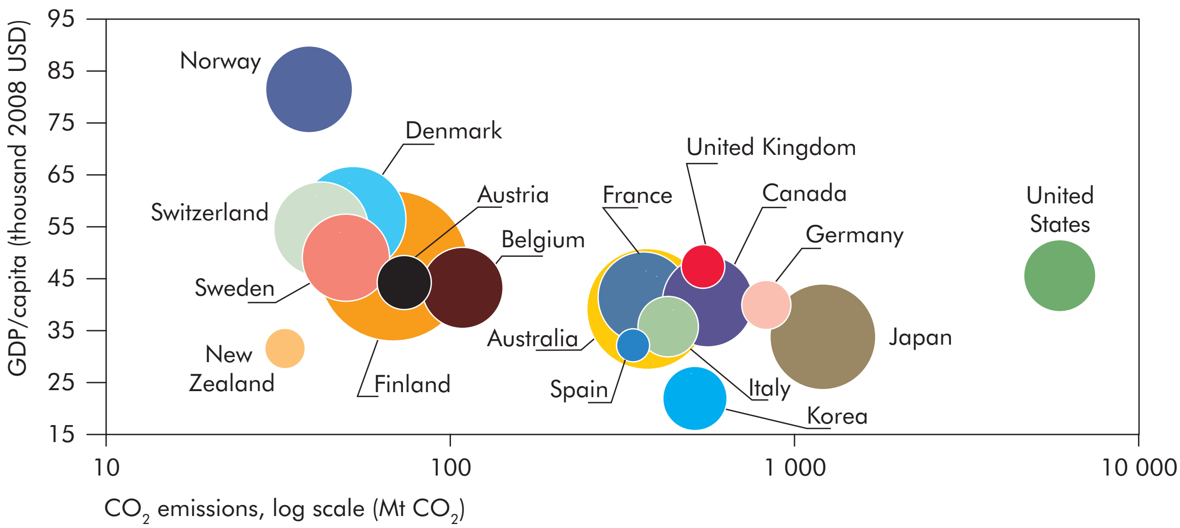
Key point

Countries have very different low-carbon energy RD&D portfolios as a result of policy goals and resource availability.

12

There are significant differences in national energy RD&D expenditures as a proportion of gross domestic product (GDP), population and CO_2 emissions. For example, in Figure 12.8, which shows public-sector low-carbon energy RD&D spending on a per-capita basis, Finland, Japan and Australia spend the highest proportion (between 0.07% and 0.08% of GDP in 2008) of all IEA countries for which information is available. Korea, Denmark and France spent about 0.04% of GDP on low-carbon technology RD&D in 2008. In terms of levels of low-carbon RD&D investment compared to CO_2 emissions, Switzerland, France and Finland spend most, closely followed by Japan, Denmark and Sweden. Scandinavian countries have RD&D expenditures on a per-capita basis that are up to ten times higher than those of countries such as the United Kingdom or Spain. Overall average expenditure on energy RD&D in IEA countries is about 0.03% of GDP.

Figure 12.8 ▶ Public-sector low-carbon RD&D spending per capita as a function of GDP per capita and CO_2 emissions



Note: The size of the bubble indicates public spending on a per-capita basis. GDP and population statistics are taken from the World Bank; RD&D spending data are taken from the most recent IEA statistics (2009/2010). All data expressed in 2008 USD. CO_2 emissions from IEA CO_2 *Emissions from Fuel Combustion*, 2009 edition.

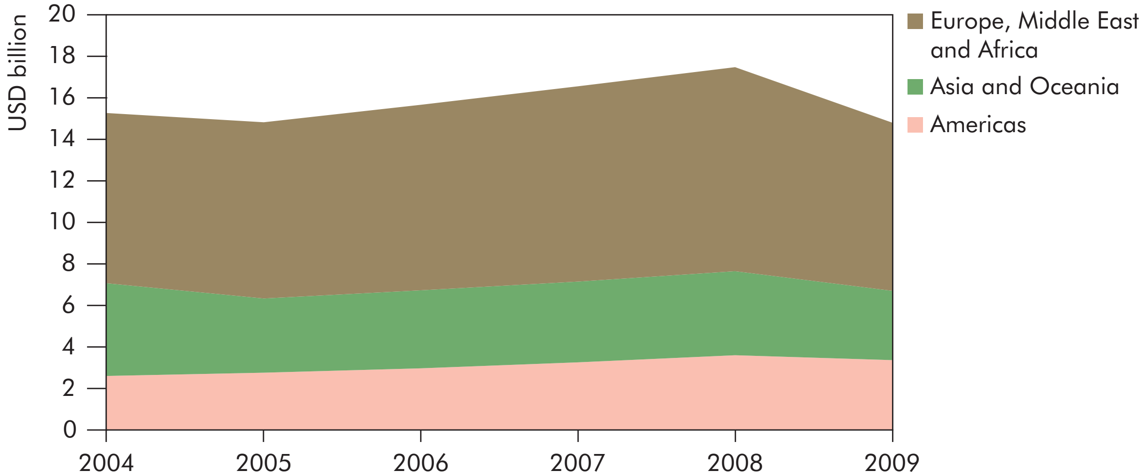
Key point

There are significant national differences in public-sector low-carbon energy RD&D expenditures.

Private-sector RD&D spending

Data on private energy RD&D investments is more limited than on government spending because it is not widely reported. Where it is, it is usually reported at the level of industry sector. This does not allow for a breakdown by low-carbon technology area. Similarly, much private RD&D is reported at an aggregate level, making it difficult to identify the share of energy RD&D within a company's full range of RD&D activities.

Figure 12.9 ▶ **Private-sector low-carbon energy RD&D expenditure, 2004-09**



Source: Bloomberg New Energy Finance (2010).

Key point

The recent economic downturn has adversely affected private-sector expenditure on energy RD&D.

Surveys of major companies with combined total assets valued at over USD 37 trillion in 2009 suggest that private industry expenditure on energy RD&D increased year-on-year between 2005 and 2008 but has started to drop away in the last year as a consequence of the economic downturn (Figure 12.9). Total global private low-carbon energy RD&D investments totalled nearly USD 15 billion in 2009, with companies headquartered in Europe, the Middle East and Africa accounting for over half of this. There are some uncertainties in these data as it is very difficult to define what is energy RD&D and what is not, other than for companies in the oil and power generation sectors, and different companies may report different activities as RD&D expenditure.

12

Assessing the gap: global low-carbon energy technology RD&D needs

Global energy RD&D expenditure needs to increase substantially if the energy revolution necessary to address the challenges of climate change and energy security is to be achieved. Current low-carbon energy technology RD&D spending falls well short of the investment needed to achieve the ambitions of the BLUE Map scenario (Table 12.2).[16] The estimating method suffers from some limitations, particularly in relation to the assumptions on the relationship between RD&D and deployment investment needs and the ratio between public and private expenditures. But the results give at least a feel for the scale of investment needed. They should be refined as more data become available.

16. A similar analysis was included in IEA (2009e); the amounts in Table 12.2 are different because they include a wider range of countries and nuclear fission spending.

Table 12.2 ► ***Estimated public-sector low-carbon energy technology current spending, needs and gap to achieve BLUE Map outcomes in 2050***

	Annual investment in RD&D needed to achieve the BLUE Map scenario outcomes in 2050	Current annual public RD&D spending	Estimated annual RD&D spending gap
	(USD million)[1]	(USD million)[2]	(USD million)
Advanced vehicles (includes EVs, PHEVs + FCVs; energy efficiency in transport)	22 500 – 45 000	1860	20 640 – 43 140
Bioenergy (biomass combustion and biofuels)	1 500 – 3 000	740	760 – 2 260
CCS (power generation, industry, fuel transformation)	9 000 – 18 000	540	8 460 – 17 460
Energy efficiency (industry)[3]	5 000 – 10 000	530	4 470 – 9 470
Higher-efficiency coal (IGCC + USCSC)[4]	1 300 – 2 600	850	450 – 1 750
Nuclear fission	1 500 – 3 000	4 030	0[5]
Smart grids	5 600 – 11 200	530	5 070 – 10 670
Solar energy (PV + CSP + solar heating)	1 800 – 3 600	680	1 120 – 2 920
Wind energy	1 800 – 3 600	240	1 560 – 3 360
Total across technologies	50 000 – 100 000	10 000	40 000 – 90 000

1 RD&D investment needs derived using 10% to 20% of average deployment costs for BLUE Map scenario and adjusted by a factor of 90% to reflect country coverage.
2 IEA 2007 data with the following exceptions: Australia (2009-2010 estimated); Canada (2009 estimated); France (2007 revised via direct submission); Germany (2009 estimated); USA (2009 estimated). The non-member country data were taken from IEA (2009e). When necessary, spending calculated using 2008 exchange rates.
3 Estimates for buildings energy efficiency RD&D needs were not available.
4 Integrated gasification combined cycle and ultra-supercritical steam cycle.
5 The gap for nuclear fission is assumed to be zero excluding any additional RD&D for Gen IV technologies. Therefore the sum of the estimates for the gap by technology do not sum to the total.

The shortfall between the investment estimated to be required for RD&D and existing levels is between USD 40 billion and USD 90 billion, of which half is assumed to come from public sources. Therefore, if current annual public spending is USD 10 billion, achieving the BLUE Map scenario will require a twofold to fivefold increase in public RD&D spending. The gap appears to be much larger for some technologies, including advanced vehicles, CCS and smart grids, than for others such as bioenergy and nuclear fission.

While these results are somewhat incomplete – data are lacking for some important countries, and industry spending levels are not considered – other analyses are consistent with this conclusion. The UNFCCC has proposed a doubling in global expenditure on energy R&D to about USD 20 billion a year. A recent publication (IEA, 2009e) highlights other studies that recommend between two and ten times current energy RD&D expenditures.

Further work is in hand at the IEA and elsewhere better to understand the levels of RD&D expenditure needed to achieve a given level of technology deployment. The quality and availability of global low-carbon energy RD&D spending and investment data suffer from a number of very significant constraints (Box 12.5). Much more should be done at an international level to improve the relevance, quality and comparability of international energy RD&D statistics.

Box 12.5 ▶ *Quality and availability of RD&D spending data*

To help the public and private sectors focus on future low-carbon energy technology priorities, it is important first to understand the current status of low-carbon energy RD&D expenditure data.

The quality and scope of energy RD&D spending data are constrained by a number of factors, including:

- *Countries use different definitions/methods in their RD&D reporting:*
  - *Countries often report budget and expenditure data in the same year, making it unclear whether there is double-counting. It also makes it difficult to assign a single year to the spending activity, resulting in significant year-to-year changes for a particular energy technology area.*
  - *Some technology areas (particularly smart grids and advanced vehicles) are insufficiently disaggregated.*
  - *There are discrepancies between governments in the way in which they report multi-year projects. The budget is often defined for the whole project period rather than being reported on a yearly basis.*
  - *The degree (and transparency) to which regional and local expenditures are included varies considerably. Some countries reliably report non-national RD&D expenditures, while others do not.*
- *There are gaps in IEA time series RD&D data for some countries owing to a lack of reporting.*
- *There is no centralised, reliable source of RD&D spending data for non-OECD countries.*
- *There is a lack of reliable data on private RD&D spending and trends:*
  - *In some technology areas such as energy efficiency, the private sector is believed to be the largest funder of RD&D. However, there is no internationally accepted source of private-sector low-carbon energy RD&D data.*
  - *The fraction of venture capital and private equity investment dedicated to RD&D rather than deployment alone is difficult to identify.*

Accelerating energy technology RD&D

Successfully addressing the RD&D investment gap presents a major challenge, particularly in the light of the current financial crisis. A number of national stimulus packages include important new commitments to public-sector low-carbon energy RD&D spending. These amount to at least USD 38 billion (IEA, 2009e). Some of this funding is for one-time stimuli, but other commitments reflect the increasing importance of clean energy and emissions abatement. Even so, these commitments do not amount to the sustained level of public investment that will be needed.

There are historical precedents for the rapid acceleration of RD&D efforts to meet pressing national objectives. For example, the United States has undertaken a number of so-called "crash" RD&D programmes, including the Manhattan Project (1940 to 1945) and the Apollo Project (1963 to 1972) that focused on the defence and space sectors, respectively. A recent study for the US Congress (Stine, 2009) has compared these projects with the US DOE technology programmes over the period 1974 to 2008. Peak expenditure on the Apollo Project was about twice that of the US DOE programmes in real terms and more than five times today's level of spending. However, while these examples offer positive lessons, the scope of RD&D needed to successfully make a transition to a low-carbon economy is arguably much greater than historical precedents.

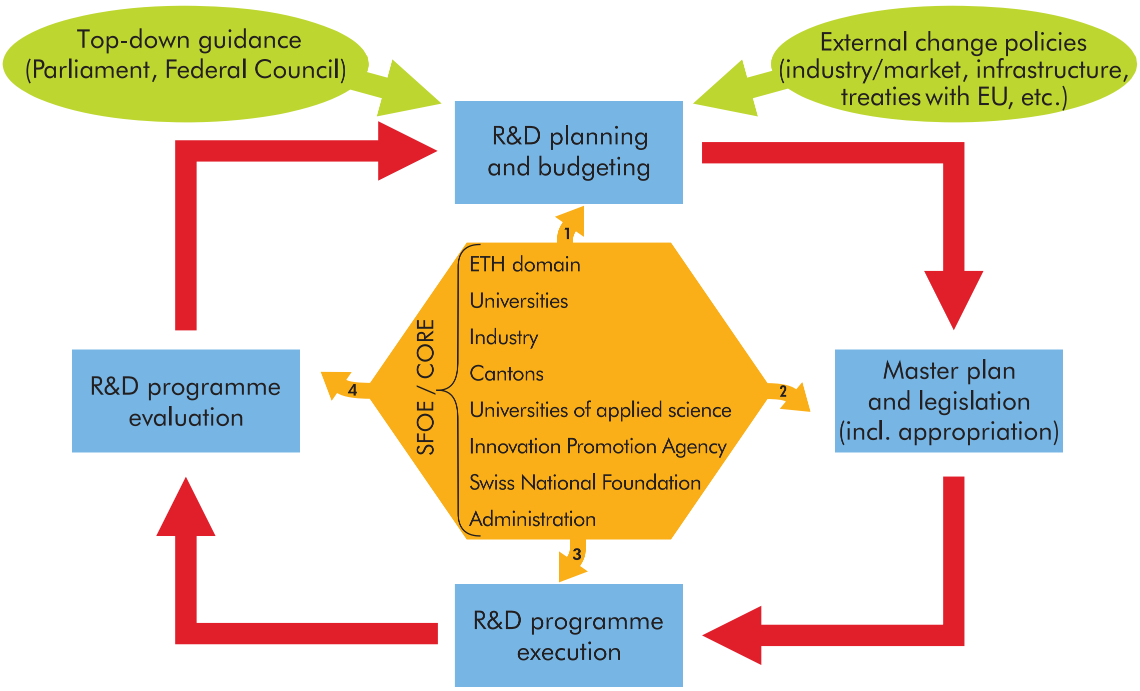
Research, development & demonstration best practices

The availability of sufficient funding is not all that is needed for the acceleration of global low-carbon energy technologies. RD&D programmes and policies also have to be improved by adopting best practices in design and implementation. New policies or programmes need to demonstrate the following features if they are to be effective (IEA, 2007):

- A **strategic, long-term focus** that takes into account national policy objectives, energy resource availability, human and manufacturing skills availability, international collaboration and outreach to the public on the costs and benefits of different energy pathways.
- A **supportive policy framework** in which government programmes, venture capital and markets all support tailored and consistent policy frameworks with sustained, higher levels of funding.
- A **portfolio approach** that recognises that a mix of technologies will be needed in the longer term and that no one research project or programme is guaranteed to succeed.
- **Flexibility** to adapt and modify RD&D programmes in the light of scientific and policy developments, viewing RD&D priority setting as an ongoing process.
- The **monitoring and evaluation** of outputs.
- **Strong linkages between basic science and applied energy research communities** to maximise the chance of material breakthroughs.

The existence of a clear national energy policy is the most important precondition for a successful public energy RD&D strategy. Energy RD&D should be seen as an important instrument to achieve larger climate change, economic development and energy security goals. Targets should be clear and quantified and preferably categorised by short- medium- and long-term objectives. Many of these features are shown in the Swiss government's 2006 top-down stakeholder process to develop a coherent national energy R&D policy that would achieve its higher-level goal of a "2000 Watt Society" (Figure 12.10).

Figure 12.10 ▶ Swiss strategic policy approach to achieve the 2000 Watt Society



A vision of a 2000 Watt Society

This vision serves as a long-term aim to direct R&D activities and the Swiss climate change strategy. " 2000 Watt Society" is seeking to bring about the gradual introduction of a way of living and working that requires only one-third of current energy consumption but still delivers an improved quality of life. Using a phased approach, it will use the latest efficient technology and draw on experience from the world of economics, social sciences and politics."

Source: Gut (2006).

Key point

A successful national energy technology policy has a clear linkage between energy policy and other policy priorities, including national security, economic development and sustainability.

12

Similarly, the Norwegian government has established a broad, co-ordinated RD&D strategy to achieve its climate and energy goals known as Energi21.[17] This started with a stakeholder process to set a baseline of current resource use, emissions and performance. It followed this with a set of recommendations to achieve climate and energy goals, including clearly identified R&D goals, a doubling of national R&D spending, skilled workforce development, funding for demonstration and commercialisation, and the establishment of a government body to oversee greater co-ordination on energy RD&D and to ensure that the targets are achieved. Since its launch, the Norwegian government has established Energi21 as a permanent advisory body on strategic energy RD&D questions, and funding for energy R&D has been more than doubled over the last two years. The Research Council Norway has implemented this funding increase through national R&D programmes and

17. See www.energi21.no.

through the establishment of eight Centres of Excellence covering renewable energy and CCS. These centres include clusters of main industrial actors, R&D institutions and universities. Long-term funding (up to eight years) ensures that the centres can focus on ambitious R&D goals in technology areas where Norway has a strong position.

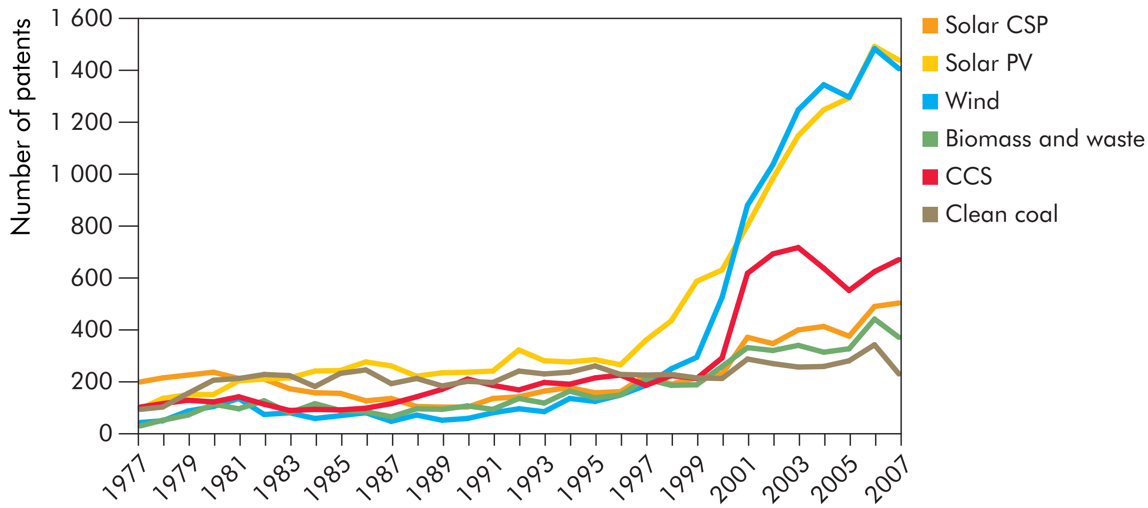
Governments should also be strategic in targeting their limited energy RD&D funds. Countries need to decide their particular areas of strength, based on existing natural and human resources, geography and international partnerships. Future policy goals are also important in this assessment. The Australian government's 2004 Energy Technology Assessment is a good example of a strategic approach, in which the government determined the technologies it wanted to be a market leader for, those in respect of which it wanted to keep up-to-date with developments, and those in respect of which it was content simply to monitor progress (IEA, 2005). The government is currently updating this assessment.

In addition to strategic planning and funding, the performance of programmes needs to be effectively monitored and evaluated. New programmes should specify performance milestones and demonstrate their consistency with national policies. Existing efforts also need to be re-evaluated on a regular basis, and modified, redirected or terminated depending on whether they are meeting their milestones and indicators for success.

Evaluation may include self-evaluation by programme managers, evaluations by external experts, or a hybrid of these two approaches. Statistical data may be collected, together with more qualitative measures such as interviews of key stakeholders to gain a more comprehensive view. The Board on Energy and Environmental Systems of the United States National Academies has developed an assessment framework to evaluate the qualitative and quantitative costs and benefits of energy technology R&D. It is designed to capture public and private economic, environmental and energy security benefits. The framework further distinguishes among three levels of benefit: realised benefits, *i.e.* those that result from the full commercialisation of a technology innovation; option benefits, *i.e.* those that accrue from the successful development of a technology without commercialisation; and knowledge benefits, *i.e.* advances in scientific, technological or other knowledge that may aid future innovation (National Science Foundation, 2010).

Other external indicators may also prove useful in assessing the success of technology RD&D. For example, energy patents are seen as an important output measure from R&D, as they are evidence of a technology's progression along the innovation chain. The year-by-year patenting rate in PV, wind, CCS, CSP, biomass and cleaner coal technologies demonstrates rapid growth in the number of patents from 1998 onwards, with wind and PV showing the greatest increase (Figure 12.11). The increase in patent activity is not driven solely by RD&D. It is also driven by the commercial value associated with the patent and the ability of new competitors to enter the market (Chatham House, 2009). The use of patents as a measure of innovation is, however, subject to limitations, particularly when comparing between countries. Some countries have more positive attitudes than others towards patenting and there are also different barriers to patent applications.

Figure 12.11 ▸ Number of patents in six energy technology fields, 1977-2007



Source: Chatham House (2009).

Key point

Low-carbon energy patents, an important R&D output measure, have risen dramatically in the last decade.

Patent activity is directly relevant to only one part of the innovation chain. For wind and PV, there is evidence that the number of patents and deployment are positively correlated (Chatham House, 2009). Other studies have suggested that market interventions to accelerate deployment do not always lead to increased R&D or patenting activity. A study of the implications of increased funding for onshore wind deployment in California found little evidence of increased wind-related patenting activity among California-based companies and research institutes, although it is possible that additional RD&D was stimulated in other parts of the United States or in other countries (Nemet, 2008). Many companies patent only those technologies or elements of technologies that have the potential to produce returns that outweigh the annual costs of patent registration. Patenting can also disclose a company's R&D strategy and may attract unwelcome competition. Some companies will offer details of particular technologies freely, relying on their company's unique capacity to build and sell the technology to maintain their market advantage.

Other energy technology innovation metrics include the number of published articles in peer-reviewed journals or the share of new products in the total number of products in a marketplace. Analysis of R&D outputs may also be based on the transfer or export of a technology to another country, although this may overstate national production as it may include foreign affiliates. In addition, many companies that appear to be national, such as Vestas in Denmark, are actually transnational, with many primary and component facilities located not only outside the country of origin but also in some cases even in a different region.

One indicator of the commercial viability of a particular technology is the extent to which it can attract venture capital. There may be a correlation between the amount of private capital invested and the stage in the technology R&D process that the technology has reached. More robust and commonly acceptable approaches to energy technology RD&D evaluation need to be developed.

Advances in basic science will be the foundation for progress in a number of energy technologies. Promising technologies such as advanced solar PV, advanced materials for energy storage and batteries, and the storage of CO_2 from bioenergy sources offer potential opportunities for breakthroughs in the longer term (Box 12.6). The US DOE has identified in the US Climate Change Technology Program a set of strategic basic science and energy research priorities (Figure 12.12). For longer-term technologies such as these, government involvement should be focused on expanding R&D, on linking basic science with applied energy research, and on defining the most pressing priorities in order to ensure the effective allocation of human and financial resources.

Box 12.6 ▶ Examples of recent funding announcements for basic science in the area of energy

The European Commission's Communication "Investing in the Development of Low-Carbon Technologies" [COM(2009)519/4], published on 7 October 2009, estimates that an additional investment of EUR 50 billion in energy technology research will be needed over the next ten years. This means almost tripling current levels of annual investment in the European Union, from EUR 3 billion to EUR 8 billion. Investment should cover basic and applied research, pilot projects (small-scale trials), demonstration programmes (large-scale trials) and market replication measures to achieve the successful transfer into fully viable, profitable low-carbon technologies available for public use. The costs of deployment are excluded in these estimates.

In addition, the Communication recommends that a further investment of around EUR 1 billion should be made in basic research in energy-related programmes. The bulk of the funds required will have to come from the private sector and from member states, with a contribution from the EU budget towards some of it.

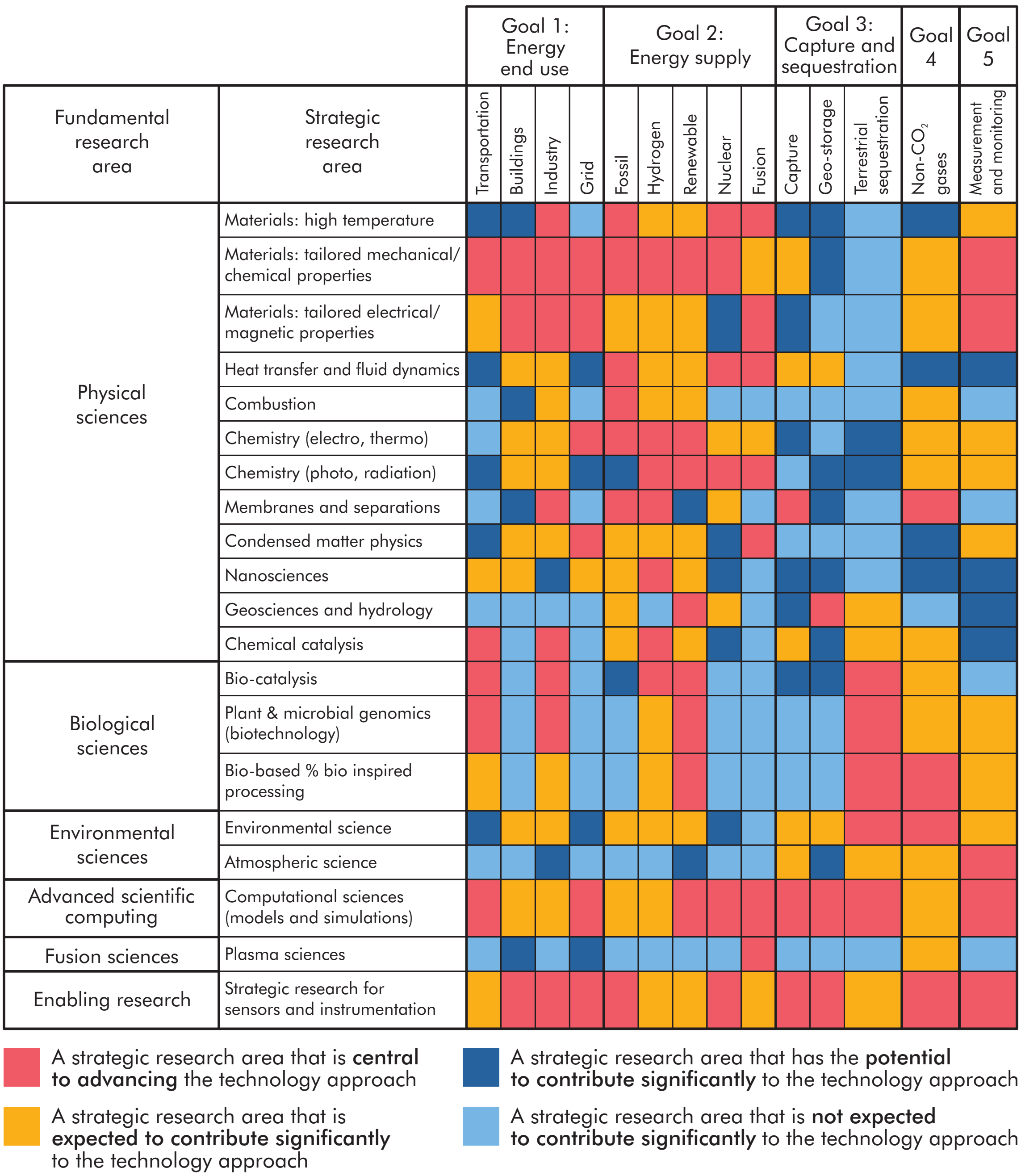
President Obama has committed to doubling United States federal investment in basic research over a ten-year period. The US DOE has announced USD 377 million to initiate 46 Energy Frontier Research Centers (EFRCs) to accelerate the rate of scientific breakthroughs needed to create advanced energy technologies for the 21st century. The EFRCs will pursue the fundamental understanding necessary to meet the global need for abundant, clean and economical energy.[18]

To maximise the pull-through of opportunities from fundamental research into the market, basic science and applied energy researchers need to work more closely together to share information. Many governments are beginning to recognise the need for increased linkages to speed up the time from basic research to market. Possible strategies to enhance basic scientific research for energy may include bringing private corporations more directly into the basic research process, thereby

18. See www.energy.gov/news2009/7768.htm.

leveraging their creativity and experience to identify and maximise the potential of advances in energy science and technologies, and informing basic researchers about the most pressing needs of industry.

Figure 12.12 ▶ *US Climate Change Technology Program: Integrating basic science and applied energy research*



Source: US DOE (2006).

Key point

Best-practice energy RD&D policy links basic science to applied energy research across low-carbon energy technologies.

12

International collaboration in basic science has the potential to enable cost-sharing and cost-reductions, to scale up research efforts, and to build up pools of common knowledge. For more than 30 years, the IEA Implementing Agreements (IAs) have allowed interested member and non-member governments or other organisations to pool resources in a network of international technology collaborations, including basic science research for energy. The IEA Expert Group on Science for Energy (EGSE), whose focus is on bridging the gap between basic science and applied energy R&D, is working to identify and document examples of international collaboration in basic science for energy.[19]

19. Additional information on EGSE's activities can be found at: http://www.iea.org/about/egse.as

Chapter 13 TECHNOLOGY ROADMAPS

Key findings

- A full portfolio of energy technology solutions is needed to address energy security and climate change. Roadmaps can help to develop a common vision that can be implemented by different stakeholders at international and national levels, thereby maximising the net benefit of investment in the research, development, demonstration and deployment (RDD&D) of new technologies.

- To address the need for greater international collaboration on specific technologies, the International Energy Agency (IEA) is developing a series of low-carbon energy technology roadmaps. The seven completed roadmaps are summarised in this chapter. The IEA is developing several more that will be published in 2010 and 2011.

- The international energy technology roadmaps completed to date reveal a number of cross-cutting issues that need to be addressed to maximise the prospects of the successful exploitation of a range of technologies. These include:
  - The need for the international community to improve co-ordination and knowledge sharing to accelerate the transition from demonstration to commercialisation for many low-carbon technologies.
  - The need to help emerging economies to exploit the potential of clean energy technologies. They require technology-specific capacity building and tailored approaches that properly reflect their individual needs, challenges and opportunities.
  - The need strategically to plan capital-intensive low-carbon infrastructure such as carbon dioxide (CO_2) pipeline networks and smart grids on a regional basis.
  - The need for early consultation with local communities on plans for proposed large-scale, low-carbon demonstration and infrastructure projects, in order to ensure that their needs are taken into consideration in the design of the project.
  - The need for increased outreach and public education to communicate the scale of the changes required to achieve low-carbon energy outcomes and the associated costs and benefits over the next 40 years.

13

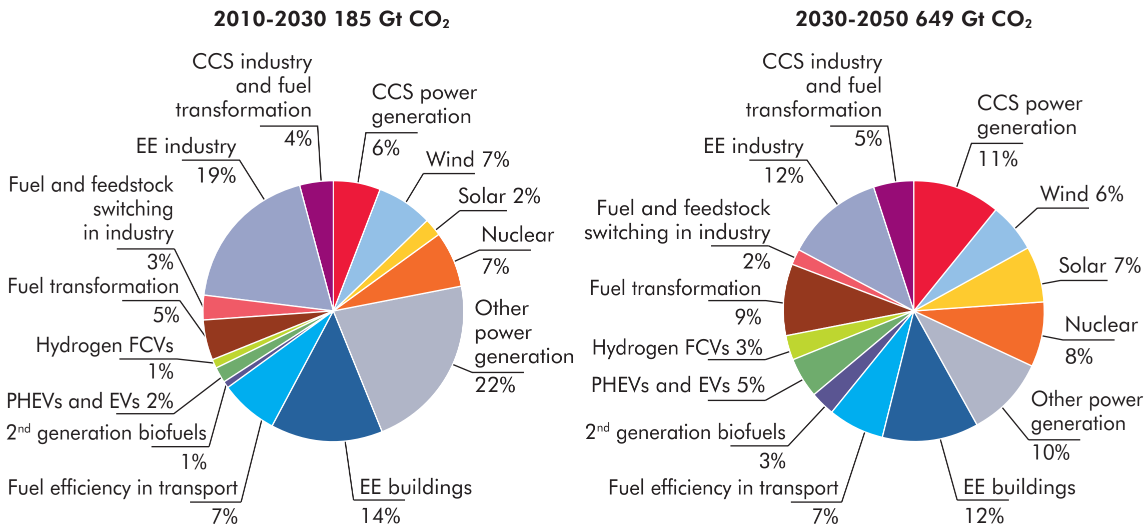
A portfolio of technologies is needed

The results in Chapter 2 demonstrate the tremendous challenge that the global economy faces, if CO_2 emissions are to be halved by 2050, in making a rapid transformation to low-carbon energy production, transmission, distribution and use. Chapter 2 also concludes that achieving this transformation at lowest cost will depend on the deployment of all the relevant technologies that are available. The absence or failure of any will increase overall mitigation costs.

Governments and industry therefore need to pursue a portfolio of energy solutions which must include energy efficiency in all end-use sectors, renewable energy, nuclear power, low-carbon transportation options, carbon capture and storage (CCS), and low-carbon industrial strategies. Enabling technologies such as smart grids and utility-scale energy storage will also be important. Long-term research into breakthrough technologies such as biotechnology, nanotechnology and advanced materials will need to be pursued to provide cross-cutting benefits to help many technologies achieve cost and efficiency targets.

Figure 13.1 shows the contribution different technology options need to make to achieve a 50% reduction in energy-related CO_2 emissions by 2050 compared to 2005 levels. The chart on the left shows the BLUE Map scenario results in terms of the cumulative emissions reductions from the Baseline scenario attributable to different low-carbon energy solutions in 2030; the one on the right shows the contributions in 2050. The current and planned roadmaps closely match these technology families.

Figure 13.1 ▶ The BLUE Map scenario portfolio of technologies and their contributions to CO_2 emissions reductions



EE: energy efficiency; EVs: electrical vehicles; FCVs: fuel-cell vehicles.

Key point

A wide range of low-carbon technologies will be needed.

Table 13.1 shows the aggregate investment needed from 2010 to 2050 in RDD&D to achieve BLUE Map scenario results for the different roadmap technologies, along with the annual CO_2 emissions reduction potential in 2050.

Each country and each region has a unique set of energy resources, climate, technology and market development and regulatory frameworks. And each group of low-carbon technologies presents a unique set of technological challenges and opportunities. These need to be tackled appropriately if each is to achieve its maximum potential. Energy technology roadmaps are a tool to help policy makers, industry and civil society to understand the optimal pathways through which individual technologies can cost-effectively be pursued.

Table 13.1 ▶ ***CO_2 emissions reductions and RDD&D spending needs[1] in the BLUE Map scenario***

	Annual CO_2 savings in 2050 (Gt)	RDD&D spending needs (USD bn) (2010-2050)
Buildings		
Energy efficiency in buildings	5.1	n.a.[2]
Industry[3]		
CCS – industry and fuel transformation	4.2-5.0	1 700-2 200
Cement	0.3-0.4	n.a.[2]
Chemicals	1.0-1.4	n.a.[2]
Iron and steel	0.7-0.9	n.a.[2]
Power generation		
CCS – power generation	4.4	1900-2200
Biomass for heat and power production	0.3	250-350
Cleaner, high-efficiency coal	1.0	500-700
Concentrating solar power (CSP)	1.2-3.1	400-600
Geothermal	0.4	90-110
Nuclear power	2.6-7.5	650-750
Smart grids[4]	0.8-2.2	2 000-3 000
Solar photovoltaic (PV) power	1.0-2.7	250-350
Wind energy	1.5-4.8	750-900
Transport		
Electric and plug-in vehicles	2.6-3.1	6 000-9 000
Natural gas, hydrogen and fuel-cell vehicles	1.7	2 000-3 000
Second-generation biofuels	2.0	320-480
Vehicle efficiency (all modes)	3.1	n.a.[2]

1. Table 13.1 shows the contribution of select technologies/sectors; it does not cover all of the technologies included in the BLUE Map analysis.

2. Estimating RDD&D investments for energy efficiency in buildings, industry and vehicles is problematic owing to the wide range of technologies and applications involved, as well as regional differences in costs. Further analysis will be required before these figures can be calculated with confidence. Total investment figures for these individual end-use sectors can be found in Chapters 5, 6 and 7.

3. For the industrial sectors, the CO_2 savings exclude reductions from CCS which have been included in CCS – industry and fuel transformation.

4. Smart grids emissions reductions and RDD&D spending needs overlap with other technology categories, so there is some double-counting in the totals.

13

The role of roadmaps

Energy technology roadmaps provide a solid analytical footing that enables the international community to move forward on specific technologies. Each roadmap presents the growth path for a particular technology from today to 2050, and identifies milestones in terms of technology development, financing, policy and public engagement that need to be achieved to realise the technology's full potential. Given the expected growth in energy use and related emissions outside IEA member countries, the roadmaps also identify needs for technology development and diffusion in emerging economies. International collaboration will be critical to achieve these goals. In this respect, the roadmaps can play an important role in facilitating greater collaboration among governments, business and civil society in both industrialised and developing countries.

Box 13.1 ▶ What is a low-carbon energy technology roadmap?

Roadmaps are an important strategic planning tool for governments and industry to address future challenges, including energy security and climate change. A number of governments, industry organisations and other groups have developed energy technology roadmaps. The IEA low-carbon energy technology roadmaps build on, and add value to these roadmaps by establishing the basis for an international consensus about the priority actions and milestones that must be achieved to reach a technology's full potential. The roadmap process brings together experts from government, industry and civil society to develop a common vision for achieving the levels of a technology's growth identified in the BLUE Map scenario.

There are several common elements to a low-carbon energy technology roadmap, including:

- ***Rationale:*** *why is the technology important for climate change mitigation and energy/ economic growth?*
- ***Baseline:*** *how does the technology perform today (in terms, for example, of USD/kWh, energy conversion efficiency and installed capacity)? Which countries are leaders in research, development and demonstration (RD&D) and deployment?*
- ***Vision for deployment and CO_2 abatement potential:*** *what is the pathway from 2010 to 2050 for the technology to achieve its climate change mitigation potential? How much investment does this require? How many projects will this require? Which countries and regions hold the greatest potential?*
- ***Technology development milestones and actions:*** *what performance and cost reduction milestones must the technology achieve to meet this vision? Which stakeholders can best make sure those milestones are achieved?*
- ***Policy framework milestones and actions:*** *what types of policy and regulation will be needed to advance the technology? Are there regulatory frameworks that must be developed?*
- ***Financing milestones and actions:*** *are there near-term demonstration funding requirements? For more competitive technologies, what is the role for greenhouse-gas markets and other incentives?*
- ***Public outreach and engagement:*** *what role does the technology play in climate change mitigation? What are other air, water or land use impacts related to the technology? What role can governments play in educating the public? Are there public engagement needs related to large infrastructure projects?*
- ***International collaboration:*** *what are the opportunities to share the technology across borders? Are existing collaboration mechanisms sufficient, or do new approaches need to be taken?*

Roadmaps are providing important input to climate change mitigation initiatives, including the Major Economies Forum Technology Action Plans released in December 2009, and multilateral banks' Clean Technology Fund investments. The technology milestones, and specific actions, can serve as a checklist to help ensure that technology RD&D, financing, policy/regulatory, public engagement and international collaboration aspects are given proper consideration. In addition, the IEA is beginning to tailor international technology roadmaps for use as a strategic planning tool in some emerging economies.

To date, the IEA has published the following low-carbon energy technology roadmaps:

- carbon capture and storage;
- cement sector;
- electric/plug-in hybrid electric vehicles;
- nuclear power;
- concentrating solar power;
- photovoltaic power;
- wind energy.

The IEA is developing additional roadmaps that will be published in 2010 and 2011. These roadmaps include:

- biofuels;
- biomass for heat and power generation;
- cleaner, high-efficiency coal;
- efficient industry processes in other emissions-intensive sectors;
- energy efficient/low-carbon buildings: heating and cooling;
- energy efficient/low-carbon buildings: design and operation;
- geothermal energy;
- hydrogen production and fuel-cell vehicles;
- smart grids;
- vehicle efficiency.

These technologies were selected for their CO_2 emissions reduction potential, market readiness, and coverage of demand-side and supply-side emissions in the buildings, industrial and power sectors. The IEA will revisit this list and update the roadmaps on an ongoing basis.

Roadmap summaries[1]

Each roadmap summary provides the reader with a summary assessment of the featured technology and the steps needed to accelerate the technology's adoption as required to deliver the outcomes in the BLUE Map scenario. Each roadmap summary includes:

- key findings;
- current status of technology development;
- potential CO_2 reduction achievable by 2050;
- projected distribution of the technology by region in 2050;
- technology, policy, financing and public engagement/outreach milestones;
- international collaboration opportunities.

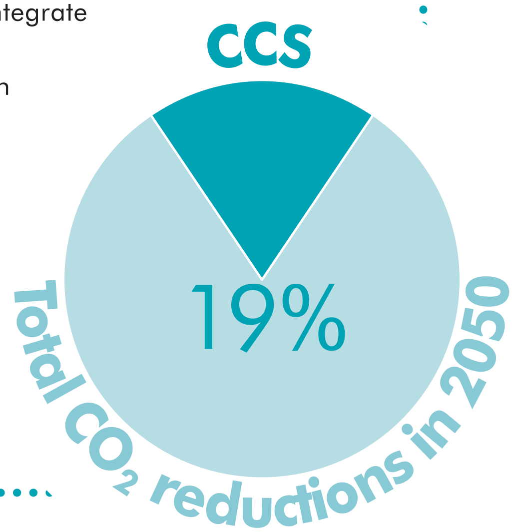
1. The roadmap summaries were developed using the *ETP 2008* BLUE Map scenario, with the exception of solar CSP, solar PV and nuclear power. These roadmaps are consistent with current *ETP 2010* scenarios: solar PV and CSP on the BLUE high Renewables variant, nuclear on the BLUE Map scenario (see chapter 3). As a result, the numbers in the roadmap summaries may differ slightly from the results reported in other chapters of this book.

Carbon capture and storage roadmap

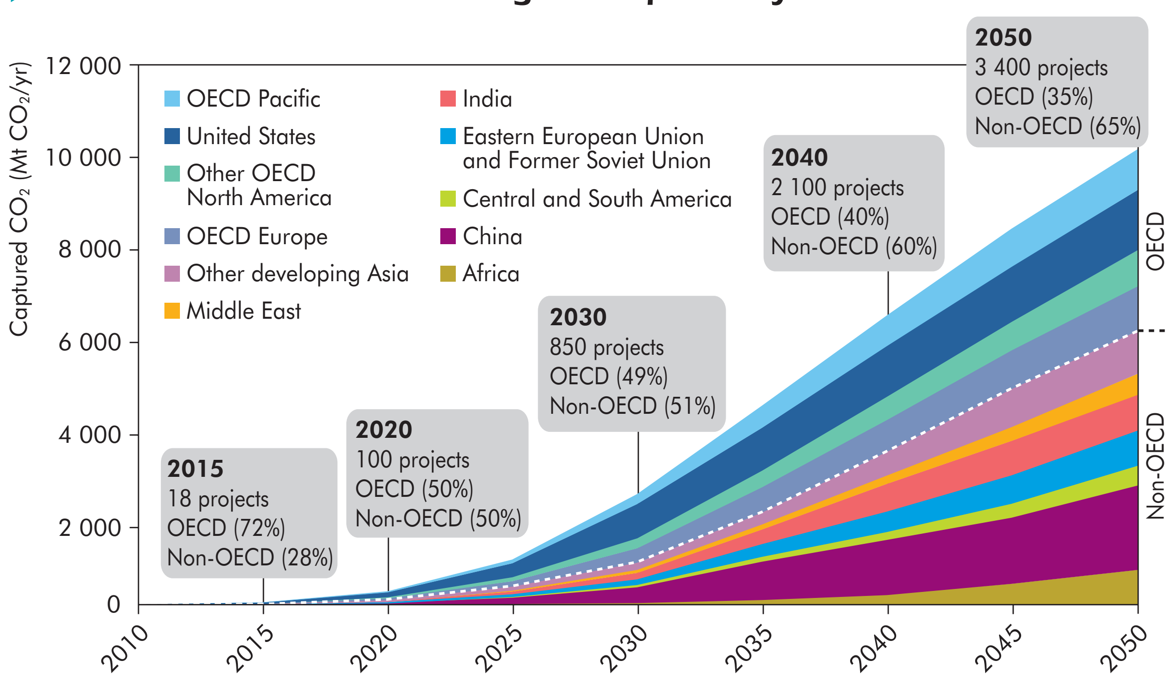
Carbon capture and storage (CCS) will need to contribute nearly one-fifth of the necessary emissions reductions to achieve cost-effective greenhouse-gas stabilisation. If CCS technologies are not used, the overall cost to achieve stabilisation will increase by 70%. Achieving rapid CCS demonstration and deployment is a tremendous global challenge. While five commercial-scale operational CCS projects are providing evidence that these technologies are viable at scale, several dozen additional commercial-scale projects are needed in a variety of countries and sectors.

During the next decade, to achieve the targets included in the CCS roadmap, governments, industry and public stakeholders must:

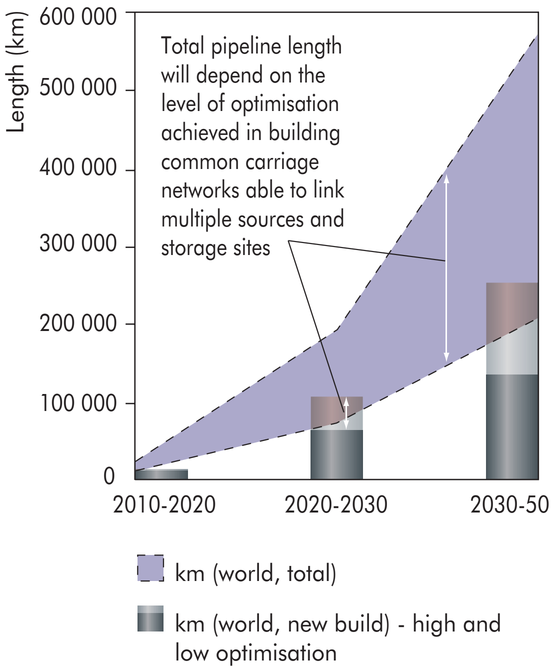
- finance 100 large-scale demonstration projects and integrate CCS into greenhouse-gas policies;
- address higher costs and efficiency penalties through accelerated research and demonstration;
- explore, develop and finance adequate CO_2 storage capacity and pipeline infrastructure;
- develop appropriate legal and regulatory frameworks to ensure safe, permanent CO_2 storage;
- provide public communication efforts about CCS, with a priority on public engagement at planned projects;
- foster expanded international collaboration, particularly via expanding capacity and awareness in developing countries with large fossil fuel use.



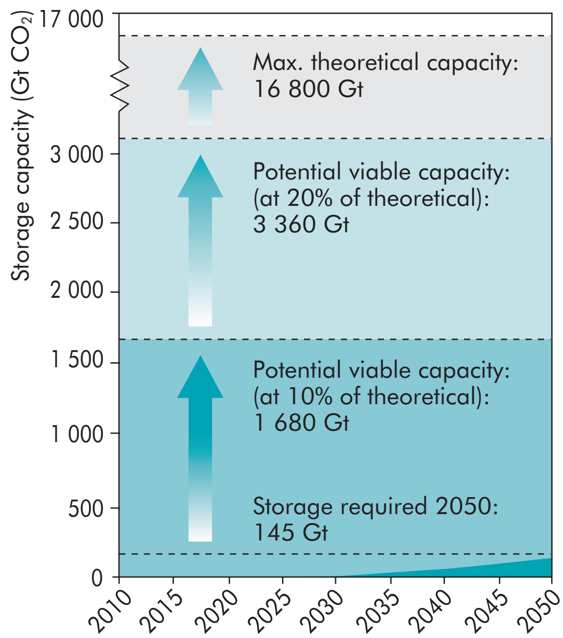
CCS follows an ambitious growth pathway to 2050



CO_2 pipeline needs



CO_2 storage needs are less than 1% of theoretical global capacity



Key findings

- CCS is an important part of the lowest-cost greenhouse-gas mitigation portfolio. Without CCS, overall costs to halve emissions by 2050 rise by 70%. This roadmap envisions 100 projects globally by 2020 and over 3 000 projects in 2050.
- This roadmap's level of project development requires an additional investment of over USD 2.5 to USD 3 trillion from 2010 to 2050, which is about 6% of the overall investment needed to achieve a 50% reduction in greenhouse-gas emissions by 2050.
- The developed world must lead in the next decade by investing an average of USD 3.5 to USD 4 billion annually between 2010 and 2020. However, CCS technology must spread rapidly to the rest of the world through expanded international collaboration and financing for CCS demonstrations in developing countries at an average annual level of USD 1.5-2.5 billion between 2010 and 2020.
- CCS is more than a strategy for "clean coal". CCS technology must be adopted by biomass and gas power plants, in the fuel transformation and gas processing sectors, and in emissions-intensive sectors like cement, iron and steel, and chemicals manufacturing.
- The milestones in this roadmap will only be achievable via expanded international collaboration. New efforts to provide developing country knowledge/technology transfer are needed. Industry sectors with a global reach should also expand their CCS collaborative efforts.

2010	2020	2030
	100 projects	850 projects

CCS roadmap milestones

Technology

Prove technologies at large scale	Reduce CO_2 capture energy penalty to 7% points	All power plants operating over 45% efficiency (low heating value, including CO_2 capture)
Identify industrial applications	Demonstrate H_2 combustion with high-efficiency CCGTs	Reduce capital costs by further 10%
Demonstrate retrofit at 85% capture	Widespread availability of commercial plant (new and retrofit)	Demonstrate chemical looping for coal and gas, pressure and electrical swing absorption, cryogenics
Fund R&D for biomass CO_2 capture	Reduce capital costs by at least 10%	

Regulatory

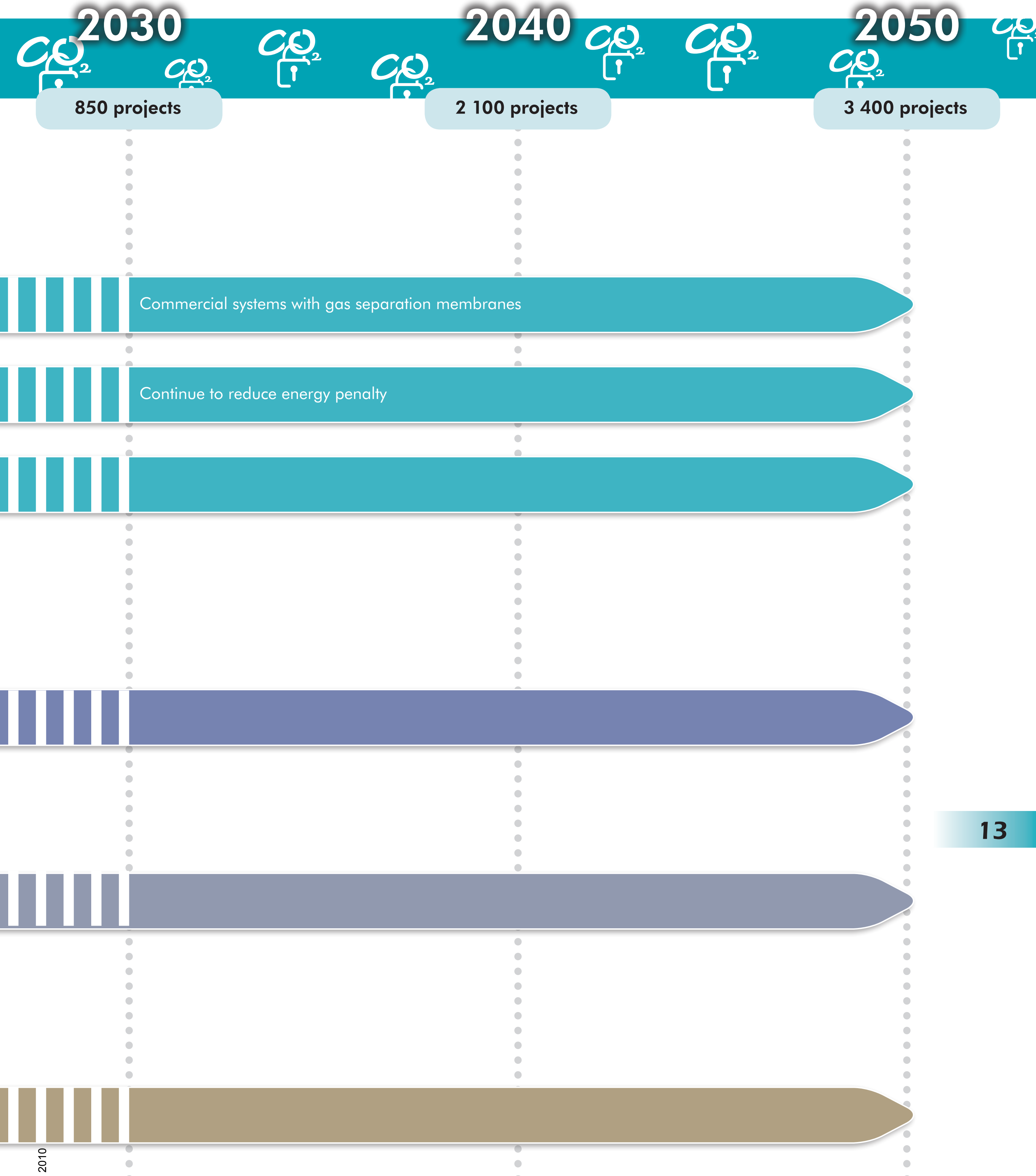
Regulatory frameworks in place for CCS demonstration	Comprehensive regulatoty frameworks in place for commercial deployment	Continue to review and refine legal and regulatory frameworks in all regions as CCS experience increases

Finance

Provide an average of USD 3.5-4 billion annually for CCS demonstration in OECD countries	Continue to monitor and adapt CCS financing strategies as experience increases
Provide USD 1.5-2.5 billion annually for CCS demonstration in non-OECD countries	

Public engagement

Provide greater governmental resources	Develop and apply a toolkit of best practice public engagement techniques to CCS demonstration projects	Refine public engagement strategies in all regions as CCS experience increases

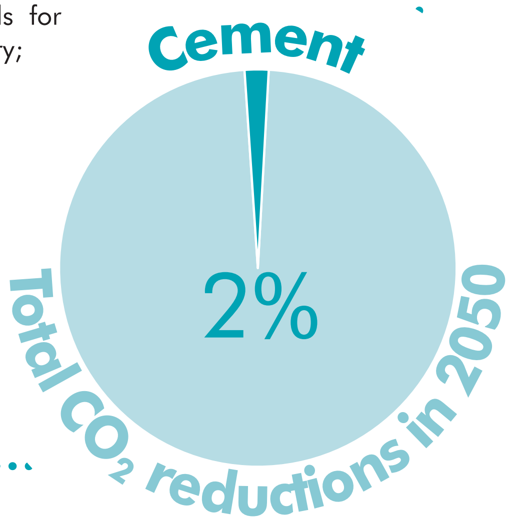

2030
850 projects
2040
2 100 projects
2050
3 400 projects
Commercial systems with gas separation membranes
Continue to reduce energy penalty

Cement sector roadmap

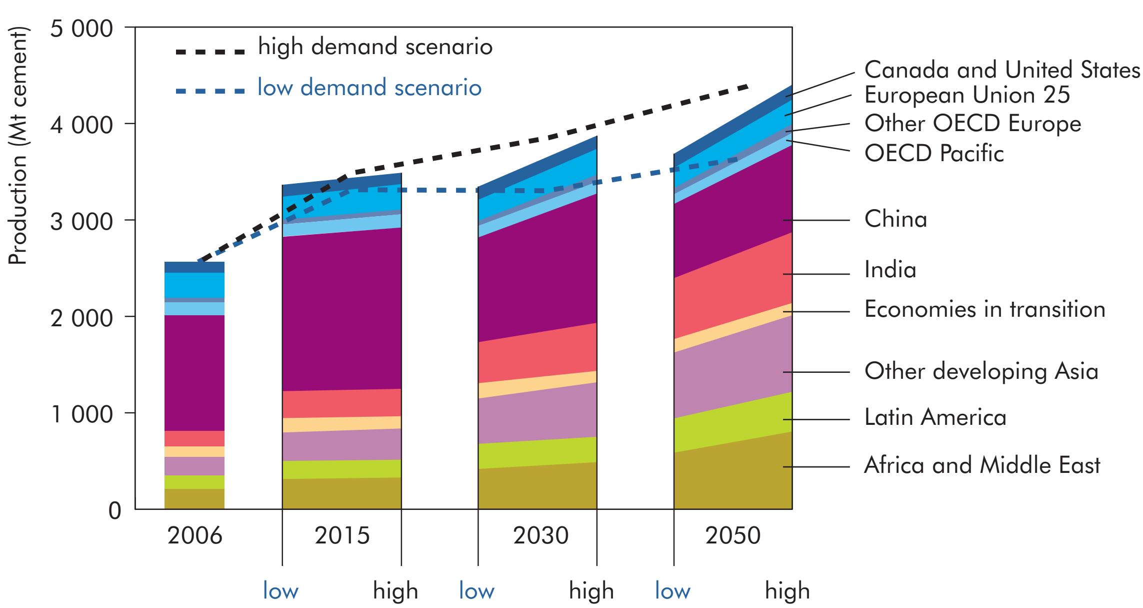
Carbon dioxide emissions from cement production currently represent about 5% of global anthropogenic CO_2 emissions. The Cement Technology Roadmap 2009 outlines a possible transition path for the sector to make continued contributions towards a halving of global CO_2 emissions by 2050. As part of this halving, this roadmap estimates that the cement industry could reduce its emissions by 18% from 2005 levels.

The next 10 to 15 years are critical for developments in the cement sector; milestones include:

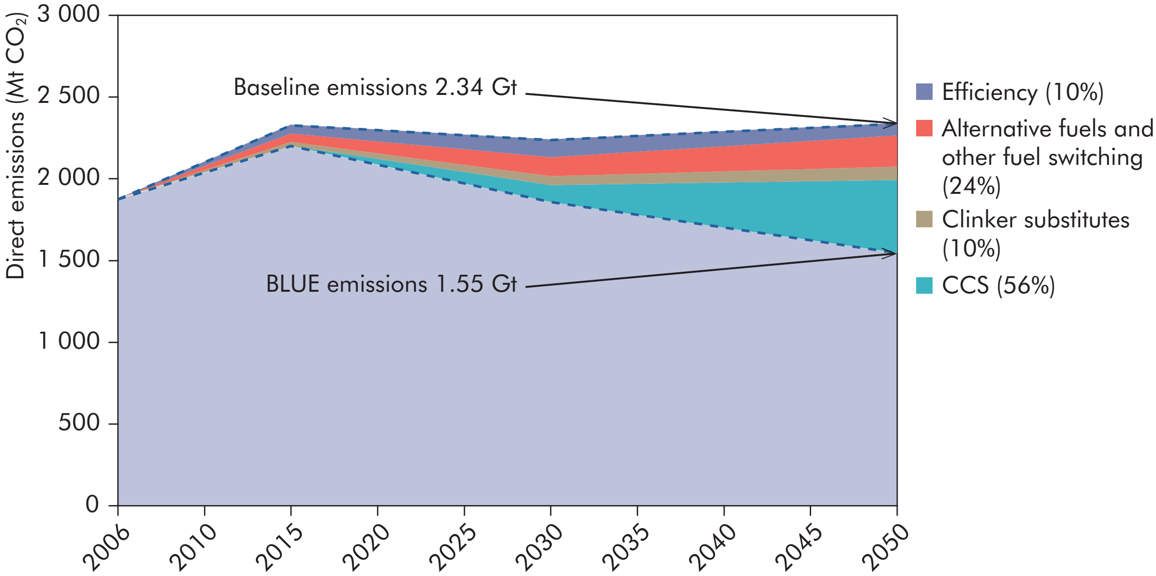
- phasing-out of inefficient long-dry kilns and wet production processes in both developed and developing countries;
- developing and implementing international standards for energy efficiency and CO_2 emissions in the cement industry;
- reviewing and updating regional, national and local level legislation, to ensure the use of alternative fuels and biomass is encouraged by policy, not limited;
- developing new or revising existing cement standards and codes in some countries to allow more widespread use of blended cement;
- government support for funding of cement sector carbon capture pilot and demonstration projects, leading to commercial scale demonstration plants and storage site accessibility.



Global cement production, 2006 to 2050



Cement sector CO_2 emissions reduction below the Baseline low-demand scenario, 2006 to 2050



Key findings

Four distinct "reduction levers" are available to the cement sector to reduce CO_2 emissions:

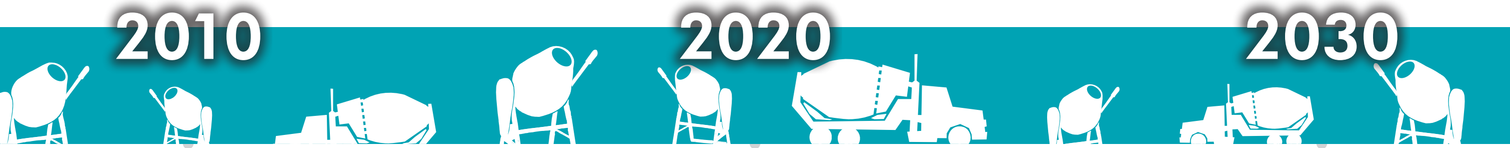
1. Thermal and electric efficiency: deployment of existing state-of-the-art technologies in new cement plants, and retrofit of energy efficiency equipment where economically viable.

2. Alternative fuels: use of less carbon-intensive fossil fuels and more alternative (fossil) fuels and biomass fuels in the cement production process.

3. Clinker substitution: substituting carbon-intensive clinker, an intermediate in cement manufacture, with other, lower-carbon materials with cementitious properties.

4. Carbon capture and storage (CCS): capturing CO_2 emissions in cement production.

- Cement is a key material for building society's infrastructure. Demand reduction and/or substitution are not realistic options given growth in developing countries, increasing urbanisation and climate change adaptation needs.
- Existing options to reduce emissions in the sector, while helpful, are not sufficient to counteract growth in demand. New products and technologies are needed, including CCS and new cement types.
- These new technologies will require a step change in RD&D efforts; the roadmap provides a vision for what is needed between today and 2050.
- CCS is a particularly important technology for the cement sector, required to deliver up to half of the emissions reductions needed by 2050. This will require advancement of demonstration projects in the cement sector over the next decade, to learn in parallel with other sectors how best to apply CCS technology at the scale necessary.
- The high cost of reducing CO_2 emissions in the sector will require markets with long-term stability and resultant confidence in the pricing of CO_2 by those markets.
- International collaboration and public-private partnerships must be encouraged to help speed up research, design, development and deployment of necessary new technologies.



Cement roadmap milestones

BAT: best available technology; C.A.: chemical absorption

Energy efficiency

- R&D on fluidised bed technology
- Diffusion of BAT: phase-out of wet kilns in OECD
- Diffusion of BAT: phase-out of wet kilns in non-OECD
- R&D into new grinding equipment and additives
- Diffusion of BAT: international standard for new kilns

Alternative fuel use and fuel switching

- Ongoing identification and classification of suitable alternative fuels

Clinker substitution

- Assess substitution material properties and evaluate regional availability
- Implement international standards on blended cement use
- Develop international standards on blended cement use

Carbon capture and storage

R&D - oxyfuelling, gas cleaning: 1st CCS pilot plant

R&D - oxyfuelling, gas cleaning: develop oxyfuelling and chemical looping

Demonstration 2 chemical absorption demonstration plants

Mitigation costs USD/tCO_2 cement (post combustion/ oxyfuelling): 125/na

Demonstration 3 oxyfuel demos, 3 chemical looping demos

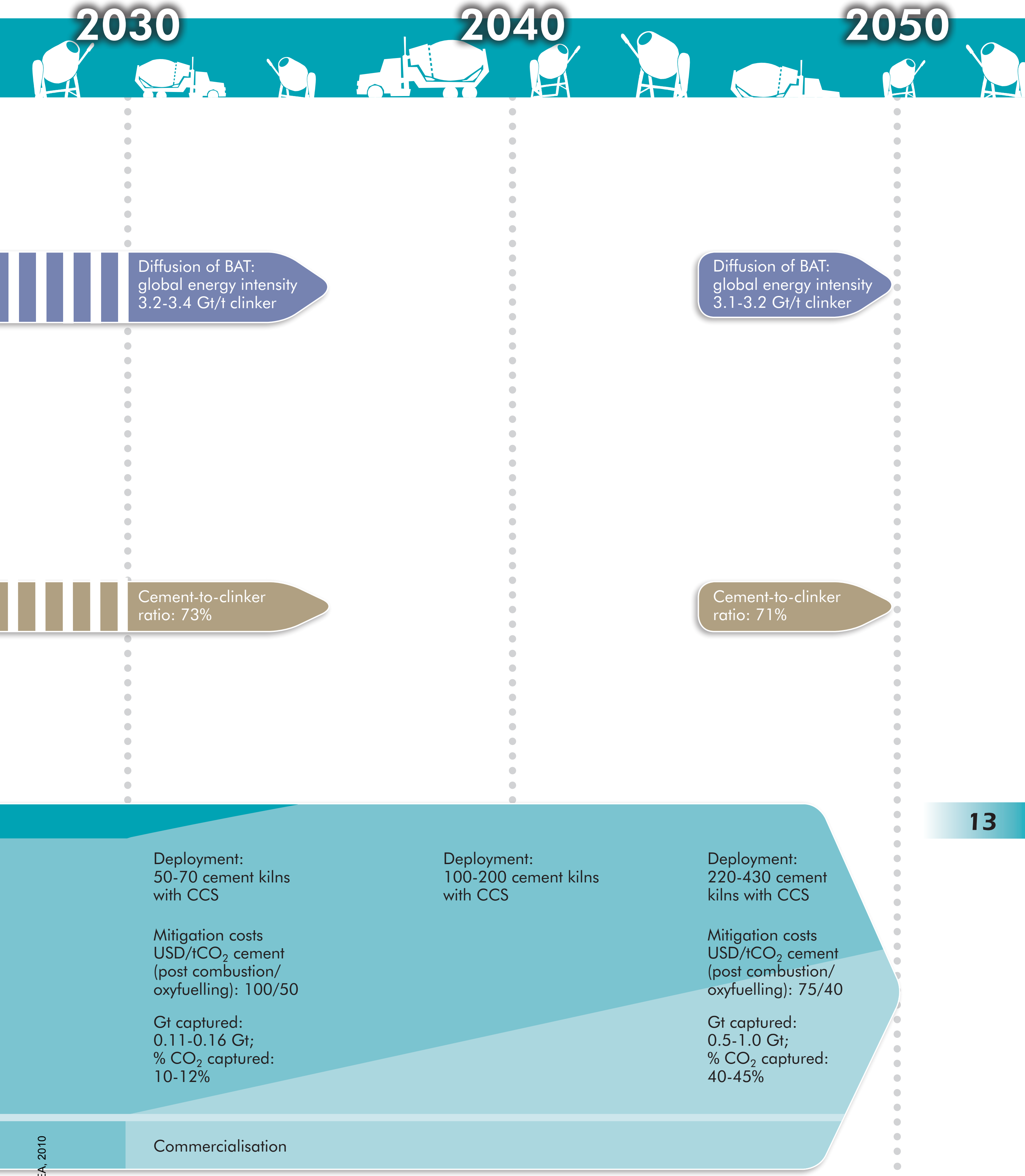
R&D - oxyfuelling, gas cleaning: C.A. energy use to fall to 2.2 GJ/t

Deployment: all large new kilns with CCS

Mitigation costs USD/tCO_2 cement (post combustion/ oxyfuelling): 100/60

Commercial use of membrane technology

Research and development (R&D) | Demonstration | Deployment

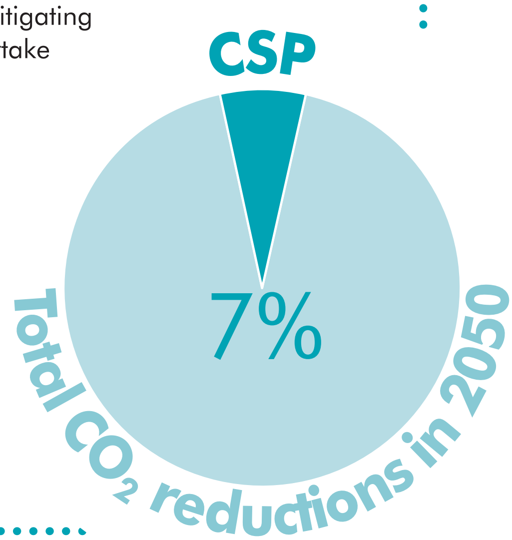

2030
2040
2050
Diffusion of BAT:
global energy intensity
3.2-3.4 Gt/t clinker
Diffusion of BAT:
global energy intensity
3.1-3.2 Gt/t clinker
Cement-to-clinker
ratio: 73%
Cement-to-clinker
ratio: 71%
Deployment:
50-70 cement kilns
with CCS
Mitigation costs
USD/tCO_2 cement
(post combustion/
oxyfuelling): 100/50
Gt captured:
0.11-0.16 Gt;
% CO_2 captured:
10-12%
Deployment:
100-200 cement kilns
with CCS
Deployment:
220-430 cement
kilns with CCS
Mitigation costs
USD/tCO_2 cement
(post combustion/
oxyfuelling): 75/40
Gt captured:
0.5-1.0 Gt;
% CO_2 captured:
40-45%
Commercialisation

Concentrating solar power roadmap

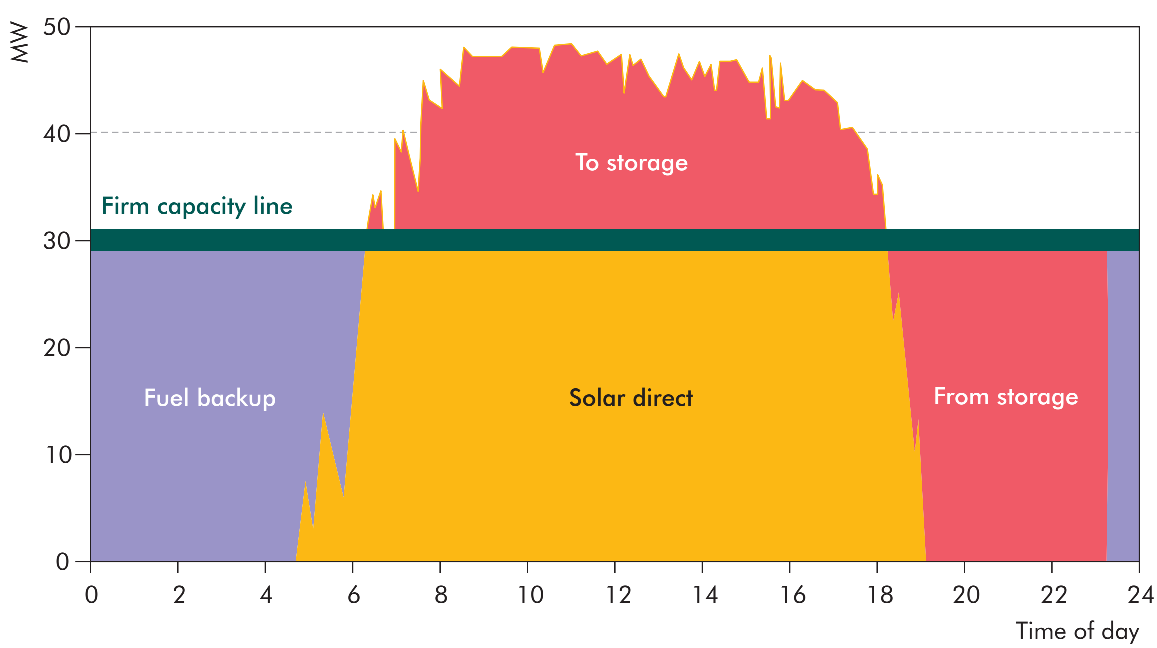
Concentrating solar power (CSP) plants concentrate energy from the sun's rays to heat a receiver to high temperatures. This heat is then transformed into electricity. CSP also holds potential for producing other energy carriers (solar fuels). CSP plants offer considerable flexibility and energy security in countries or regions with strong sunshine and clear skies. They can store solar energy cheaply and effectively in the form of heat and use it to produce electricity later and be backed up with heat generated by burning combustible fuels, whether fossil or biomass. CSP thus provides reliable electricity that can be dispatched to the grid when needed. CSP plants can also be designed to provide power after sunset to match late evening peak demand, or even round the clock if they are required to meet baseload demand.

To help the CSP industry achieve its contribution to mitigating climate change, governments need in particular to undertake the following actions:

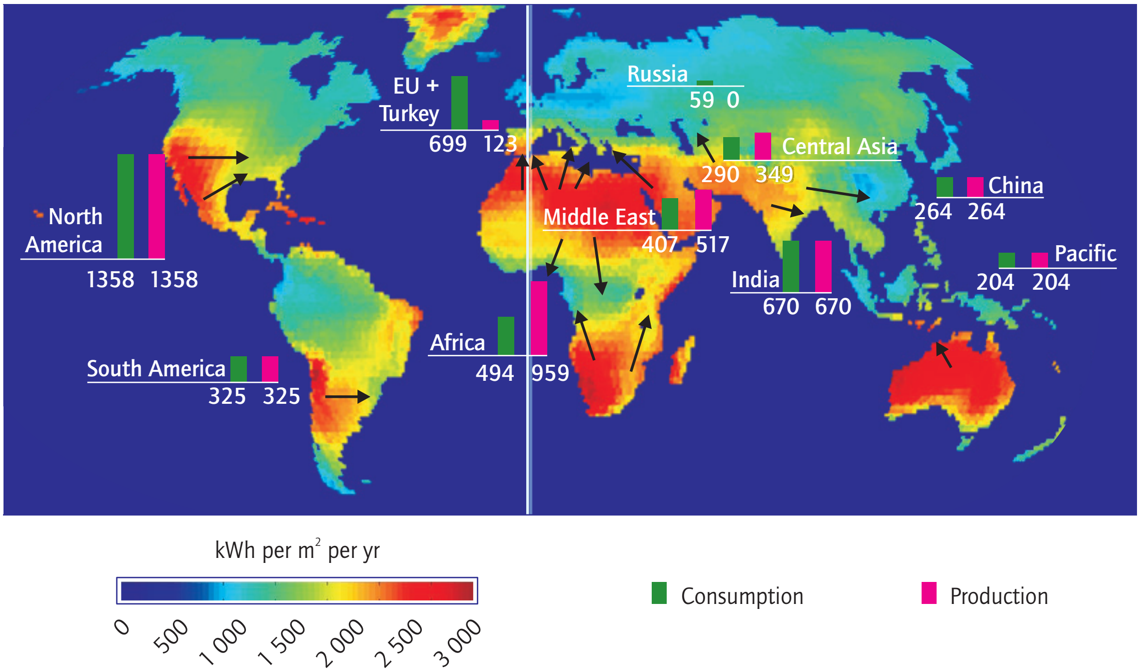
- ensure long-term funding for additional RD&D;
- facilitate the development of measurement/modelling of global solar resources;
- establish long-term oriented, predictable solar-specific economic incentives;
- where appropriate, require state-controlled utilities to bid for CSP capacities;
- avoid establishing arbitrary limitations on plant size and hybridisation ratios;
- streamline procedures for obtaining permits for CSP plants and access lines.



CSP offers firm capacity and dispatchable energy



Production and consumption of CSP electricity by 2050



Repartition of the direct norma (irradiance in kWh/m²/yr) and of the production and consumption of CSP electricity (in TWh) by world region in 2050. Arrows represent transfers of CSP electricity.

Key findings

- By 2050, with appropriate support, CSP could provide 11.3% of global electricity, with 9.6% from solar power and 1.7% from backup fuels (fossil fuels or biomass).
- In the sunniest countries, CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and of baseload power by 2025 to 2030.
- North America will be the largest producing and consuming region for CSP electricity, followed by Africa, India and the Middle East. Northern Africa has the potential to be a large exporter (mainly to Europe) as its high solar resource largely compensates for the additional cost and electricity losses of long direct-current transmission lines.
- CSP can also produce significant amounts of high-temperature heat for industrial processes, and in particular help meet growing demand for water desalination in arid countries.
- CSP facilities could begin providing competitive solar-only or solar-enhanced gaseous or liquid fuels by 2030. By 2050, CSP could produce enough solar hydrogen to displace 3% of global natural gas consumption, and nearly 3% of the global consumption of liquid fuels.
- Given the arid/semi-arid nature of environments that are well-suited for CSP, a key challenge is accessing the cooling water needed for CSP plants. Dry or hybrid dry/wet cooling can be used in areas with limited water resources.
- The main limitation to the expansion of CSP plants is not the availability of areas suitable for power production, but the distance between these areas and many large consumption centres. Technologies address this challenge through efficient, long-distance electricity transportation.

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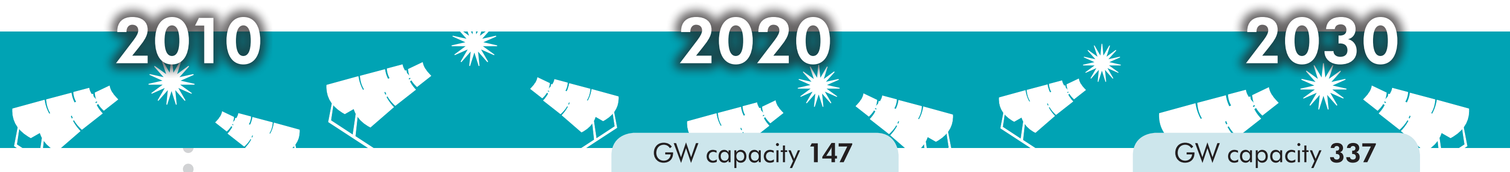


2020: GW capacity **147**
Av. capacity factor **32%**

2030: GW capacity **337**
Av. capacity factor **39%**

CSP roadmap milestones

Governments

- Establish incentives for CSP electricity and heat; lift restrictions on plant size and hybridisation ratios → Adjust incentives to evolving market conditions
- Support mapping global solar resource from on-ground and satellite measures → Establish incentives for solar fuels
- Facilitate grid access for CSP projects
- Increase support to RD&D, establish incentives for innovation

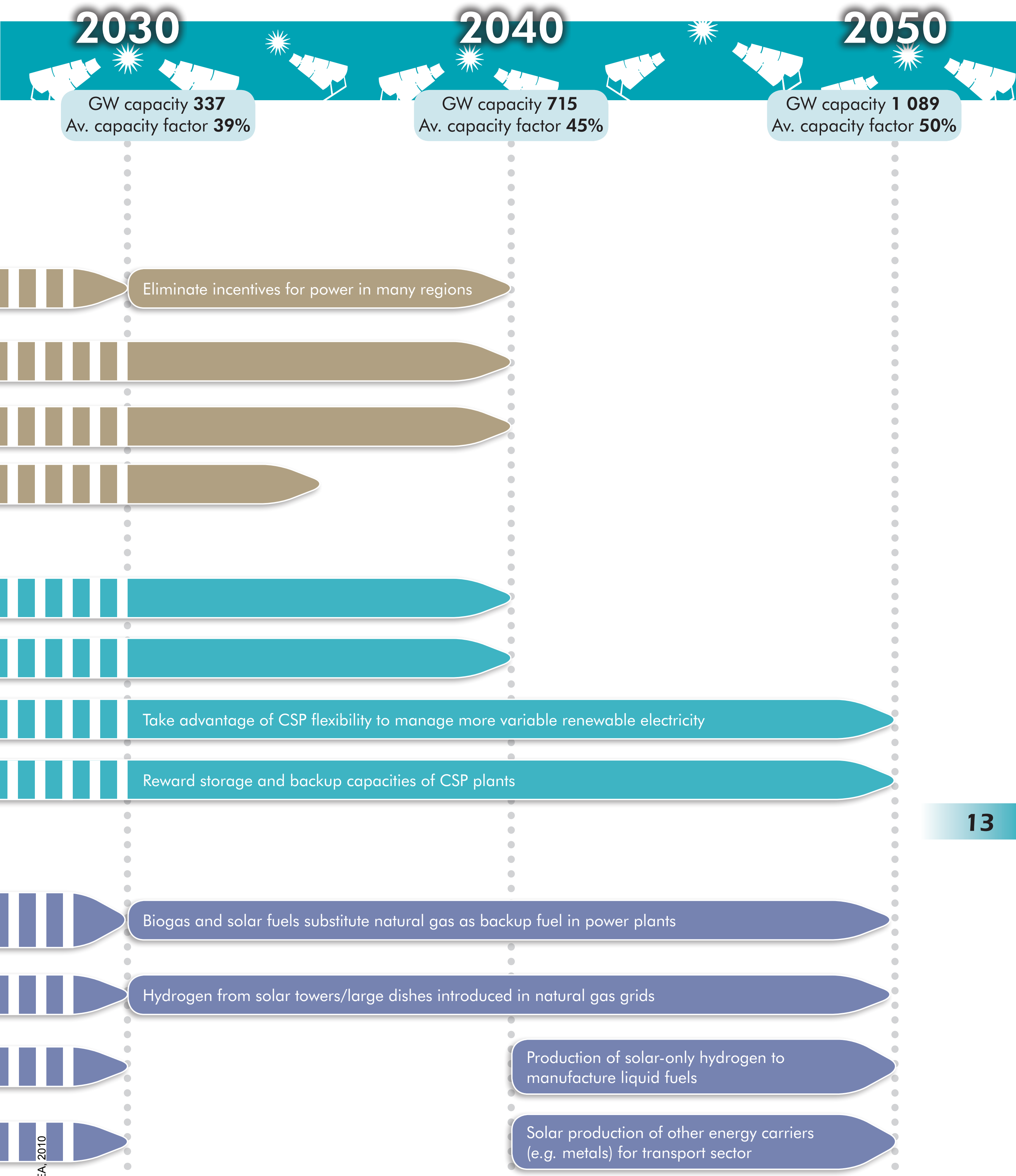
Utilities and grid operators

- Negotiate tariffs for exports/imports of CSP electricity → Build HVDC lines throughout China, India and the United States; Build HVDC lines between exporting and importing countries
- Sign power purchase agreements with independent CSP producers
- Participate in CSP project development

Technology and RD&D

- 1st tower plants with DSG; 1st tower plants with molten salts → DSG in trough plants → All new plants dry-cooled; working temperature 540°C; larger storage capacities
- 1st large-scale LFR → Three-step thermal storage for DSG → Desalination by co-generation in CSP plants
- 1st plant with 100s dishes → Storage and backup for large dishes → 1st tower plants with air receivers and gas turbines
- 1st supercritical CSP plants

DSG: direct steam generation.
LFR: linear fresnel reflectors.
HVDC: high-voltage direct current.

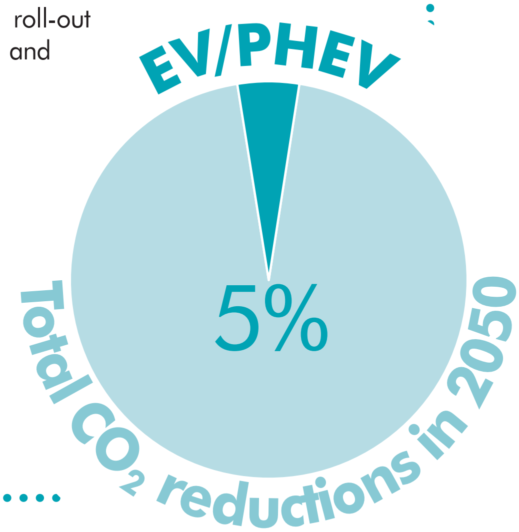

2030
2040
2050
GW capacity **337**
Av. capacity factor **39%**
GW capacity **715**
Av. capacity factor **45%**
GW capacity **1 089**
Av. capacity factor **50%**
Eliminate incentives for power in many regions
Take advantage of CSP flexibility to manage more variable renewable electricity
Reward storage and backup capacities of CSP plants
Biogas and solar fuels substitute natural gas as backup fuel in power plants
Hydrogen from solar towers/large dishes introduced in natural gas grids
Production of solar-only hydrogen to manufacture liquid fuels
Solar production of other energy carriers (e.g. metals) for transport sector

Electric and plug-in hybrid vehicles roadmap

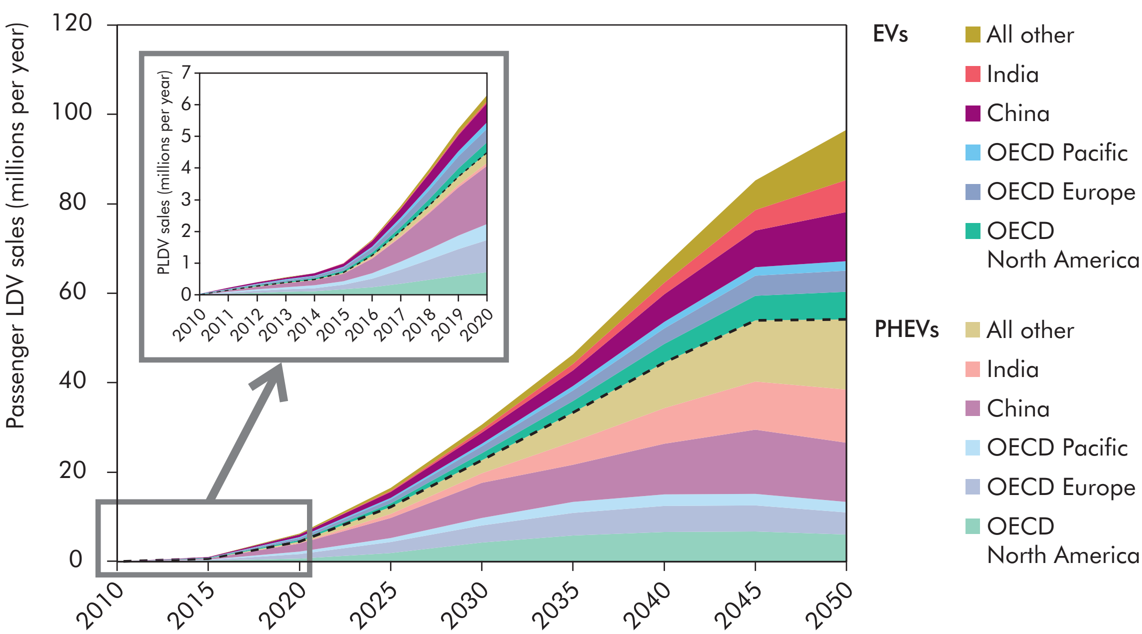
Electric and plug-in hybrid vehicles (EVs/PHEVs are expected to play an important role in achieving a low-CO_2 transport system in BLUE Map, particularly for light-duty vehicles (LDV). A number of manufacturers have announced plans to mass-produce one or more models, and many countries have announced targets for sales by or before 2020. The IEA EV/PHEV roadmap envisions that by 2050, EVs/PHEVs will reach combined sales of about 100 million vehicles per year worldwide, accounting for over half of all new LDV sales.

During the next 5 to 10 years, governments and industry must:

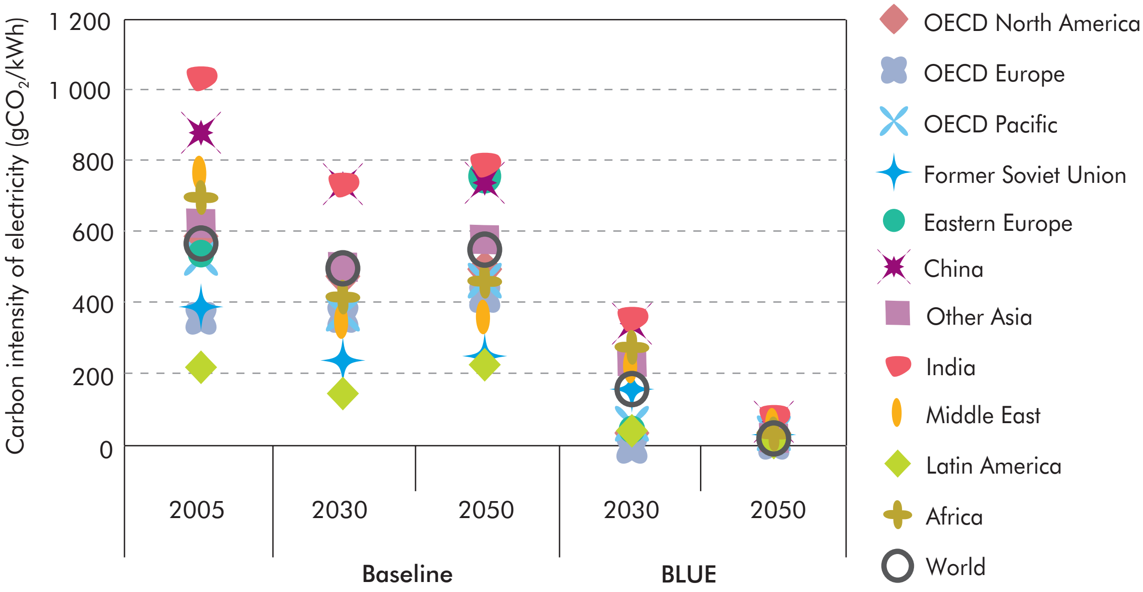
- provide medium- and long-term targets and supporting policies to build confidence for investments in manufacturing capacity and deployment;
- draft national roadmaps, with EV/PHEV infrastructure roll-out strategies, infrastructure priorities and priority areas, timelines and funding, along with a supportive economic and policy context;
- co-ordinate the launch and ramp-up of sales, provision of recharging infrastructure, and electricity supply among national, municipal and regional governments;
- ensure the availability of less carbon-intensive electricity to power plug-in vehicles, and establish appropriate codes and standards for recharging, electricity supply and smart metering;
- improve data on potential markets and consumer behaviour, and increase R&D efforts to reduce costs and develop advanced batteries, including new concepts beyond the current generation of lithium-ion batteries.



EV/PHEV roadmap vision for growth to 2050

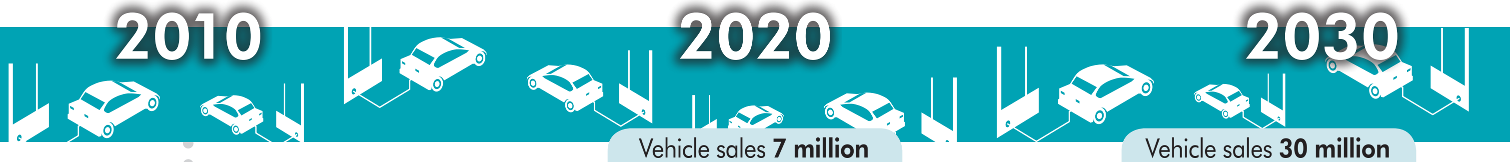


Less carbon-intensive electricity is needed to realise EV/PHEV emissions reductions



Key findings

- Roadmap vision: industry and governments should attain a combined EV/PHEV sales share of at least 50% of LDV sales worldwide by 2050.
- In addition to contributing significant greenhouse-gas emissions reductions, the roadmap's level of EV/PHEV sales will deliver substantial benefits in terms of improved oil security, reduced urban area pollution and noise.
- Policy support is critical, especially in two areas: ensuring vehicles become cost-competitive and providing adequate recharging infrastructure.
- The consumer comes first: wider use of EVs/PHEVs will require an improved understanding of consumer needs and desires, as well as consumer willingness to change vehicle purchase and travel behaviour.
- Performance measurement will be needed: the IEA roadmap contains a set of proposed metrics and targets for key attributes like driving range and battery requirements to ensure that EVs/PHEVs achieve their potential.
- RD&D priorities: research, development and demonstration must continue to reduce battery costs and ensure adequate materials supply. More research is also needed on smart grids and the vehicle-grid interface.
- International collaboration can accelerate deployment: industry and governments need to work together on research programmes, codes and standards, and alignment of vehicle and infrastructure roll-out.



Vehicle sales **7 million**
Global market share **9%**

Vehicle sales **30 million**
Global market share **30%**

EV/PHEV roadmap milestones

Policy framework

2010–2020	2020–2030
Adequate incentives for EV/PHEV purchase and production in line with targets; co-ordination of recharging infrastructure development in key areas	EVs should become commercially viable without significant subsidies; support should continue for widespread expansion of recharching infrastructure

Vehicles/batteries

2010–2020	2020–2030
Low- and medium-volume production, with design optimisations to 2015, then rapidly increase numbers of models offered and average production volumes; battery and other costs decline to target levels	Vehicles become fully commercial, batteries reach all target specifications for cost and durability, including additional cycling tolerance in line with advanced batteries; full recycling systems in place

Codes/standards

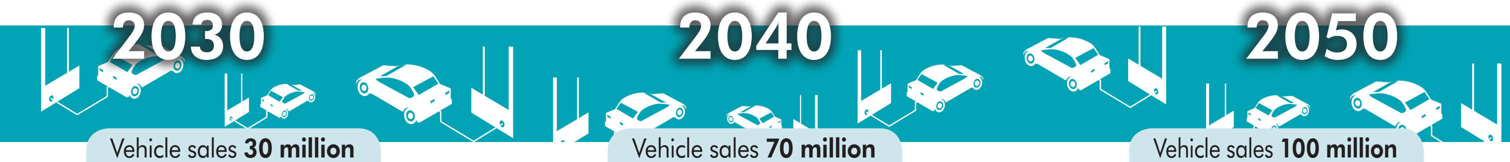
2010–2020	2020–2030
Ensure plugs and charging systems are compatible across major regions, including basic "smart metering" systems for home and public recharging stations; develop protocols for fast recharging	Common systems for vehicle-to-grid electricity sales, fast recharge and/or battery swapping well established

Recharging/electricity infrastructure

2010–2020	2020–2030
Establish home recharging and begin major investments in street/office daytime commercial recharging, including rapid charging where appropriate	Expansion of recharging infrastructure to more areas; greater use of fast recharging; fully established vehicle-to-grid electricity systems

RD&D

2010–2020	2020–2030
Ensure vehicle/battery systems are reliable and safe; achieve near-term technical and cost targets, such as USD 300/kWh battery cost; develop advanced battery concepts and prototypes	Continue RD&D on advanced battery designs moving towards demonstration and deployment as concepts mature; incorporate lessons learned from earlier experiences



2030
Vehicle sales **30 million**
Global market share **30%**

2040
Vehicle sales **70 million**
Global market share **48%**

2050
Vehicle sales **100 million**
Global market share **60%**

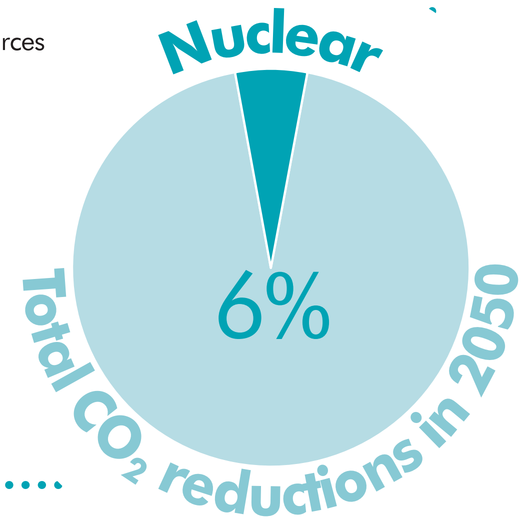
2030–2040	2040–2050
Fast recharging options have achieved lower cost, with batteries well suited; support for widespread implementation of fast recharging as needed to ensure widespread availability	Availability of higher power/energy-dense batteries should position policy makers to encourage remaining segments of light-duty vehicle markets to "go electric", including greater use in larger, longer-distance vehicles
Batteries continue to improve; introduce a new generation of batteries that significantly outperform lithium-ion at a similar cost	EVs achieve superiority to internal combustion engines in most respects, close the gap in driving range
Refine codes and standards as needed; modify to accommodate innovations in batteries, smart grid systems, etc., but minimise the need for reinvestments in existing systems	
Completion of most recharging infrastructure in OECD and other major economies; expand globally as countries establish reliable, low-carbon electricity generation systems	Ongoing recharging infrastructure and generation system expansion and refinement as needed; with ongoing increase in systems and capacity to handle fast charging
Achieve widespread introduction of next generation of battery, full deployment of smart-grid systems and related technologies	Ongoing RD&D as needed; focus on improving battery performance to maximise vehicle driving range

Nuclear energy roadmap

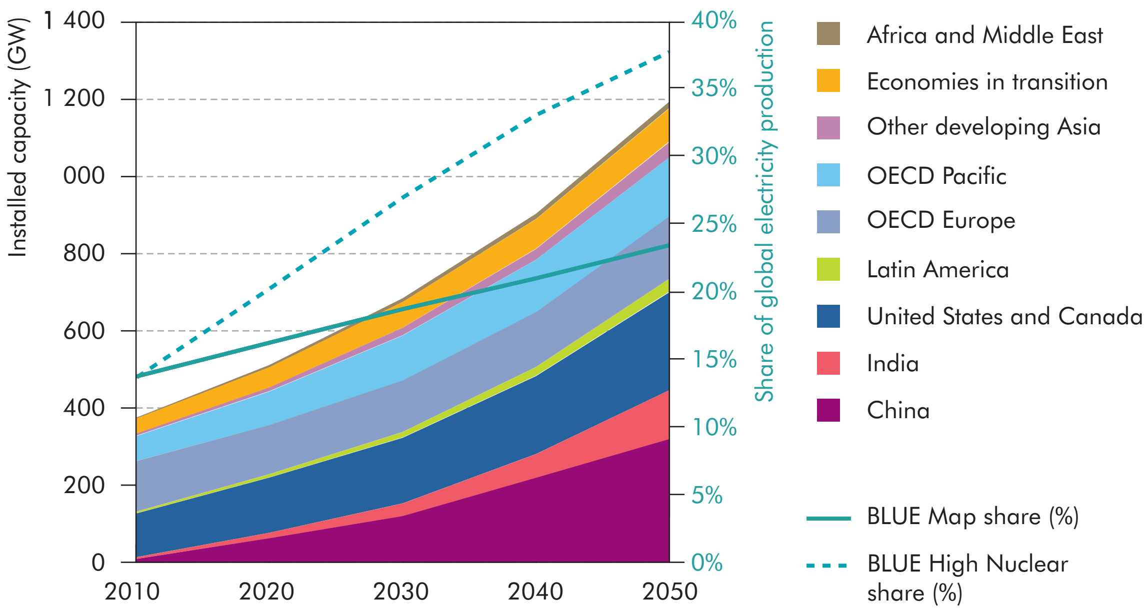
Nuclear power has the capacity to provide large-scale, virtually CO_2-free electricity. The technology is already proven, although new designs hold out the prospect of better levels of performance and reliability, as well as enhanced safety systems. Nuclear power is already in use in 30 countries and provides around 14% of global electricity supply. The share of nuclear energy in countries with operating reactors ranges from less than 2% to more than 75%. Nuclear power has the potential to play a very significant role in the decarbonisation of power generation in many countries.

The next ten years are a critical period for nuclear power development; milestones include:

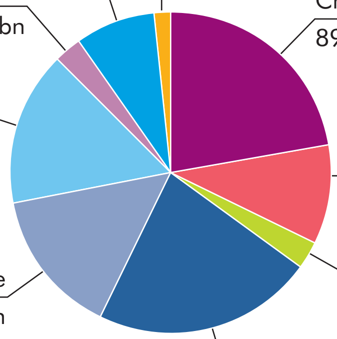
- demonstrate the ability to build the latest nuclear plant designs on time and within budget;
- develop the industrial capacities and skilled human resources to support sustained growth in nuclear capacity;
- establish the required legal frameworks and institutions in countries where these do not yet exist;
- encourage the participation of private sector investors in nuclear power projects;
- make progress in implementing plans for permanent disposal of high-level radioactive wastes;
- enhance public dialogue to inform stakeholders about the role of nuclear in energy strategy;
- expand the supply of nuclear fuel in line with increased nuclear generating capacity.



Nuclear power capacity in the BLUE Map scenario and electricity generation in the BLUE Map and BLUE High Nuclear scenarios



Regional investment needs for nuclear to 2050



Key findings

- This roadmap targets installed nuclear capacity reaching 1 200 GW in 2050, with annual electricity production of nearly 10 000 TWh. This would represent around 24% of electricity generated worldwide, making nuclear the single largest source of electricity.
- The 2050 target for nuclear energy deployment does not require major technological breakthroughs, although further development will help maintain nuclear's competitiveness.
- Political support and public acceptance are key requirements for the implementation of nuclear energy programmes, with a clear and stable commitment to nuclear energy in national energy policy.
- Financing the very large investments needed to build nuclear power plants will be a major challenge in many countries, and in some cases governments will need to take a role in addressing this.
- There is an urgent need to strengthen the nuclear workforce to meet future demands, by investing in education and training.
- Industrial capacities for constructing nuclear power plants will need to increase substantially. Uranium production and fuel cycle capacities will also need to grow.
- The management and disposal of radioactive wastes is an essential component of all nuclear programmes. Progress needs to be made in building and operating facilities for the disposal of high-level wastes.
- The international system of safeguards on sensitive nuclear materials and technologies must be maintained and strengthened where necessary.
- Advanced nuclear technologies, now under development, potentially offer advantages over current technologies. The first of these could be ready for commercial deployment after 2030, although they are not expected to form a large part of nuclear capacity in 2050.

GW added **130**
Share of electricity **16%**

GW added **170**
Share of electricity **19%**

Nuclear roadmap milestones

Policy support

- Provide a clear and stable commitment to nuclear power in energy and environmental policy
- Ensure that the relevant legal and regulatory systems work effectively
- Harmonise regulatory requirements to facilitate the use of standardised designs
- Strengthen international non-proliferation regimes, while providing security of fuel supply
- Ensure that institutions and funding are in place for waste disposal and decommissioning

Technology development and deployment

- Fully establish Generation III+ designs, bringing first-of-a-kind plants on line
- Demonstrate on-time and on-budget completion of further Generation III+ plants
- Implement plans to build and operate geological repositories for waste disposal
- Complete demonstration projects for the most promising Generation IV nuclear plants
- Strengthen RD&D in advanced fuel cycles

Capacity building and industry

- Achieve nuclear construction rates from 2020 around double present levels
- Increase industrial capacities to supply nuclear plant components and systems
- Develop the qualified and skilled human resources needed

Financing

- Establish electricity and carbon markets that support large, long-term investments
- Consider direct government support or guarantees for nuclear investments
- Increase the availability of private sector finance for nuclear plants
- Develop nuclear energy expertise in private sector financial institutions

2030
GW added **170**
Share of electricity **19%**

2040
GW added **220**
Share of electricity **21%**

2050
GW added **290**
Share of electricity **24%**

Develop international legal and institutional frameworks for the wider use of advanced fuel cycles

Build and operate commercial-scale Generation IV nuclear plants

Increase the use of nuclear energy for non-electricity applications such as industrial heat

Continue to increase nuclear construction rates

Develop industrial capacities to support advanced fuel cycles

Strengthen and broaden global supply chains as more countries launch nuclear programmes

Increase uranium production and nuclear fuel cycle capacities to meet rapid demand growth

Establish routine private sector investment in proven nuclear plant designs

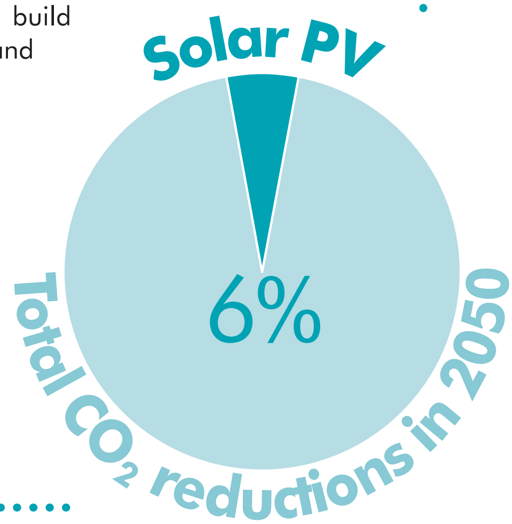
The timescales shown are approximate and will vary from country to country. In particular, countries without an existing nuclear programme will need to take additional capacity and institution building steps that may require more time.

Solar photovoltaic power roadmap

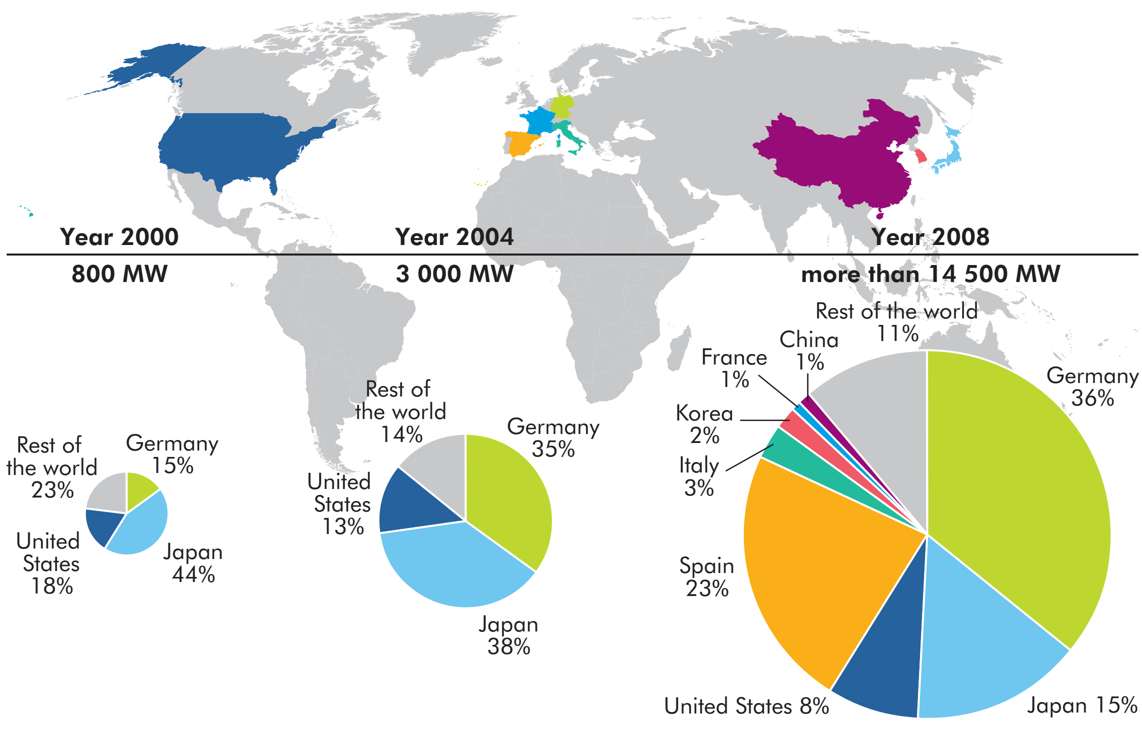
Solar photovoltaic (PV) power is a commercially available and reliable technology directly converting solar energy into electricity. Global PV capacity has been increasing at an average annual rate of more than 40% since 2000 and it has significant potential for long-term growth in nearly all world regions.

This roadmap identifies the critical window of the coming decade for policy action to help bridge the gap to PV competitiveness. During the next 5 to 10 years, governments and industry should:

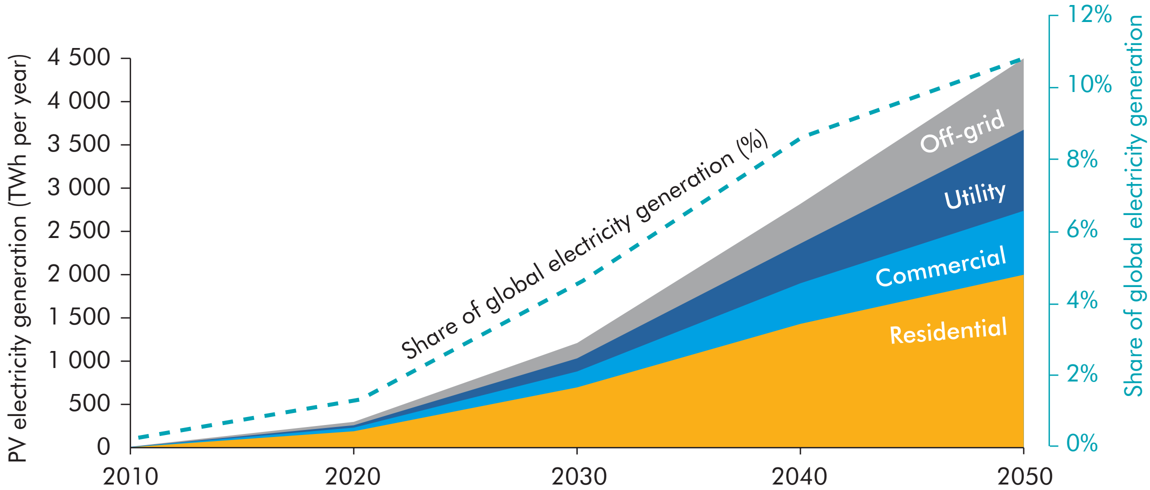
- provide long-term targets and supporting policies to build confidence for investments in manufacturing capacity and deployment of PV systems;
- implement effective and cost-efficient PV incentive schemes that are transitional and decrease over time so as to foster innovation and technological improvement;
- develop and implement appropriate financing schemes, in particular for rural electrification and other applications in developing countries;
- increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term innovations; exchange best practice with developing countries.



Solar PV: installed capacities in leading countries, 2009



Solar PV growth path to 2050



Key findings

- By 2050, PV global cumulative installed capacity could reach 3 000 gigawatts, providing 4 500 TWh per year, *i.e.* around 11% of global electricity production. In addition to avoiding 2.3 gigatonnes (Gt) of CO_2 per year, this level of PV would deliver substantial benefits in terms of the security of energy supply and socio-economic development.
- In the first decade, PV is expected to reduce system and generation costs by more than 50%. PV residential and commercial systems will achieve the first level of grid parity – *i.e.* parity with electricity retail prices – by 2020 in many regions. As grid parity is achieved, the policy framework should evolve towards fostering self-sustained markets, with the progressive phase-out of economic incentives, but maintaining grid access guarantees and sustained R&D support.
- Towards 2030, typical large-scale utility PV system generation costs are expected to decrease to USD 7 to USD 13 cents/kWh. As PV matures into a mainstream technology, grid integration and management and energy storage become key issues.
- The PV industry, grid operators and utilities will need to develop new technologies and strategies to integrate large amounts of PV into flexible, efficient and smart grids.
- Governments and industry must increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while supporting longer-term technology innovations.
- There is a need to expand international collaboration in PV research, development, capacity building and financing to accelerate learning and avoid duplicating efforts.
- Emerging major economies are already investing substantially in PV research, development and deployment; however, more needs to be done to foster rural electrification and capacity building. Multilateral and bilateral aid organisations should expand their efforts to express the value of PV energy in low-carbon economic development.

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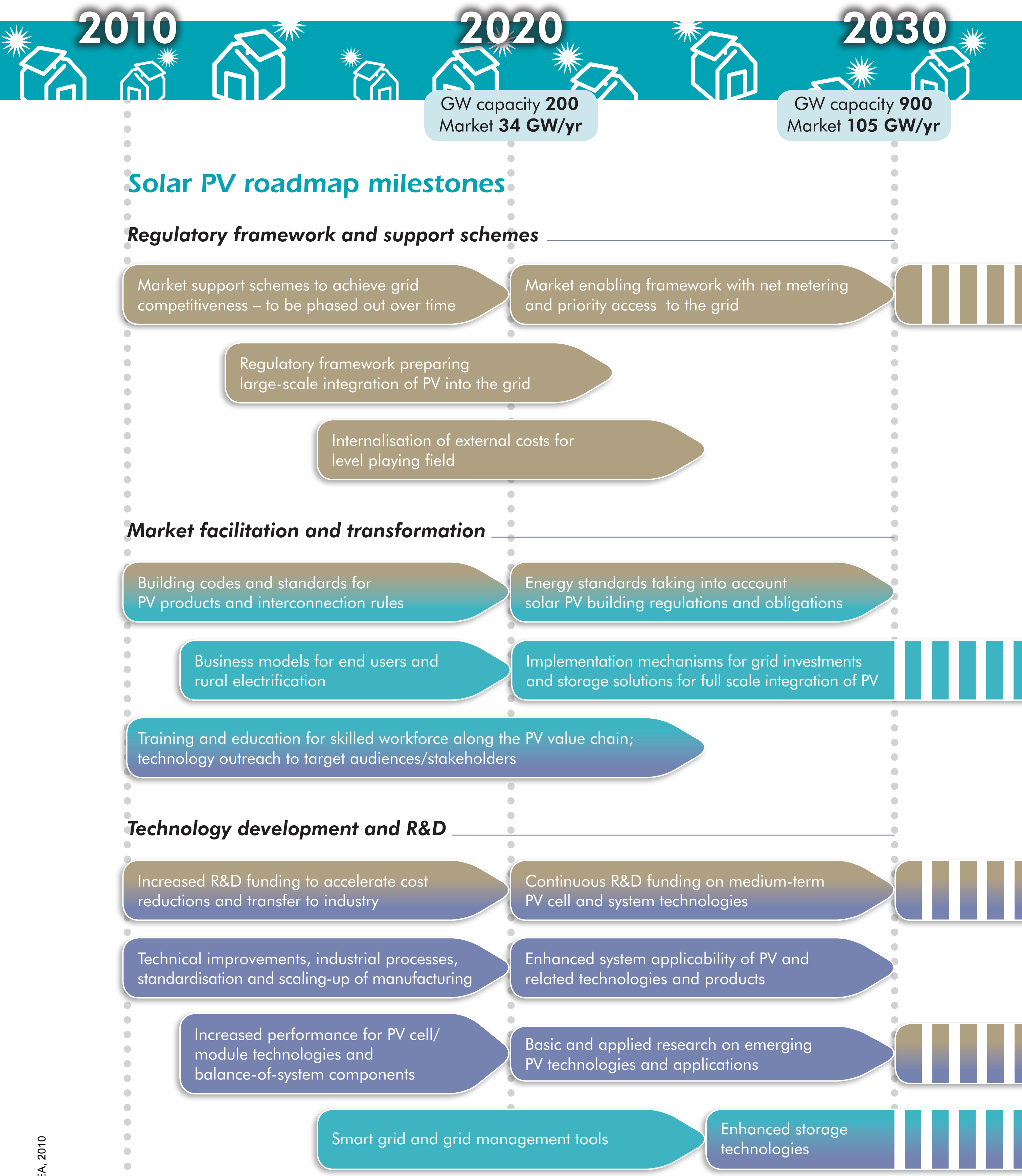
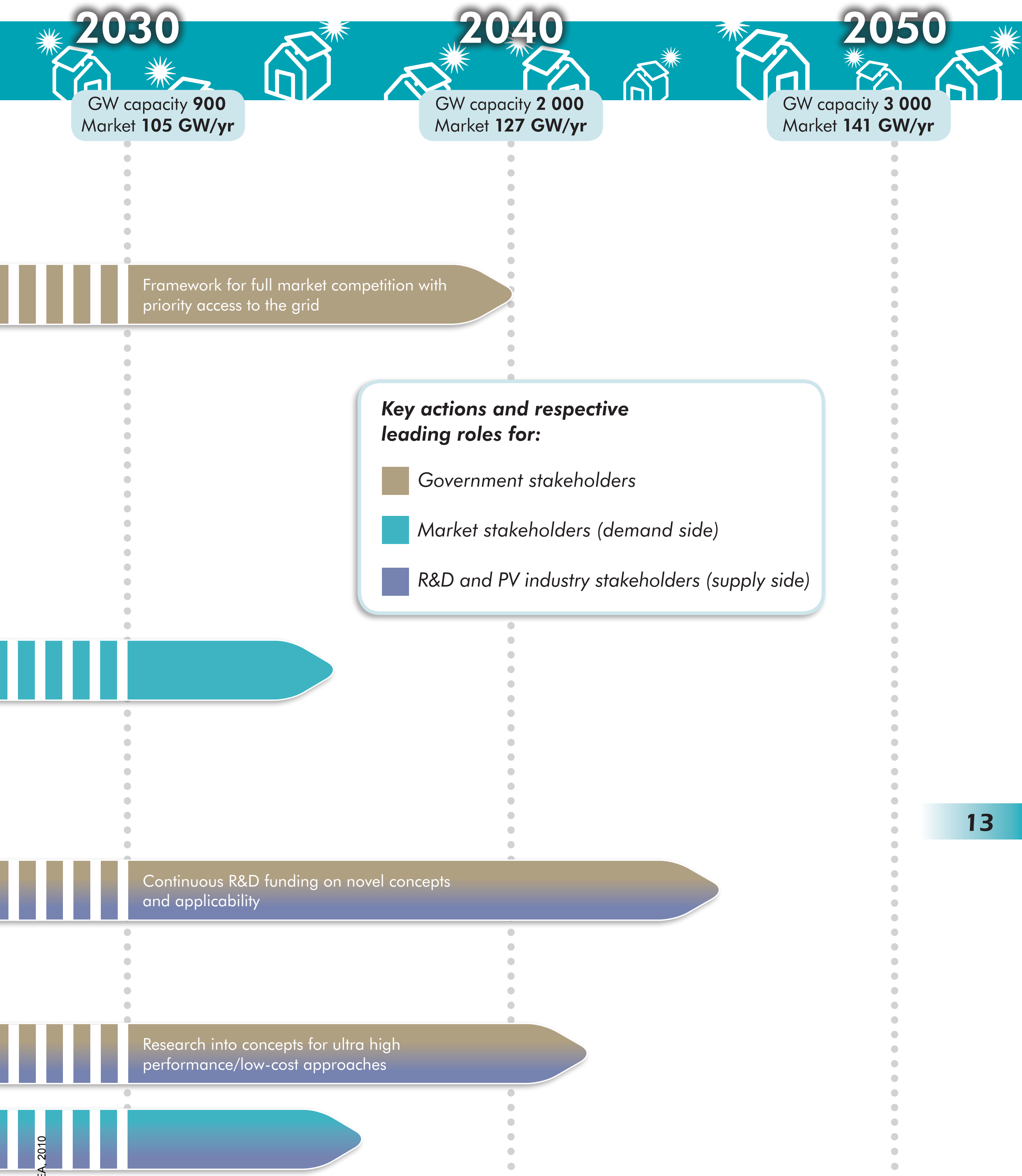

2010
2020
2030
GW capacity 200
Market 34 GW/yr
GW capacity 900
Market 105 GW/yr
Solar PV roadmap milestones
Regulatory framework and support schemes
Market support schemes to achieve grid competitiveness – to be phased out over time
Market enabling framework with net metering and priority access to the grid
Regulatory framework preparing large-scale integration of PV into the grid
Internalisation of external costs for level playing field
Market facilitation and transformation
Building codes and standards for PV products and interconnection rules
Energy standards taking into account solar PV building regulations and obligations
Business models for end users and rural electrification
Implementation mechanisms for grid investments and storage solutions for full scale integration of PV
Training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders
Technology development and R&D
Increased R&D funding to accelerate cost reductions and transfer to industry
Continuous R&D funding on medium-term PV cell and system technologies
Technical improvements, industrial processes, standardisation and scaling-up of manufacturing
Enhanced system applicability of PV and related technologies and products
Increased performance for PV cell/ module technologies and balance-of-system components
Basic and applied research on emerging PV technologies and applications
Smart grid and grid management tools
Enhanced storage technologies

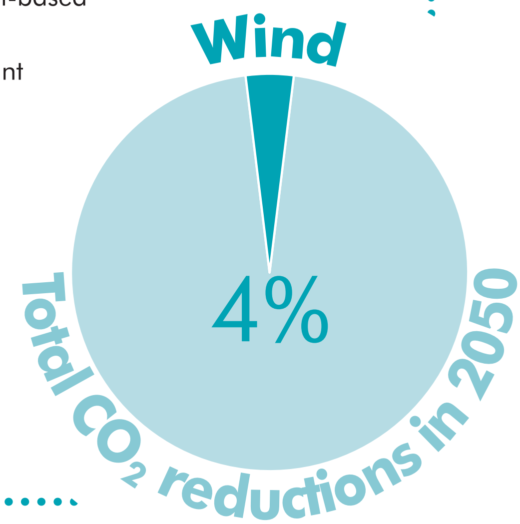

2030
GW capacity 900
Market 105 GW/yr
2040
GW capacity 2 000
Market 127 GW/yr
2050
GW capacity 3 000
Market 141 GW/yr
Framework for full market competition with priority access to the grid
Key actions and respective leading roles for:
Government stakeholders
Market stakeholders (demand side)
R&D and PV industry stakeholders (supply side)
Continuous R&D funding on novel concepts and applicability
Research into concepts for ultra high performance/low-cost approaches

Wind energy roadmap

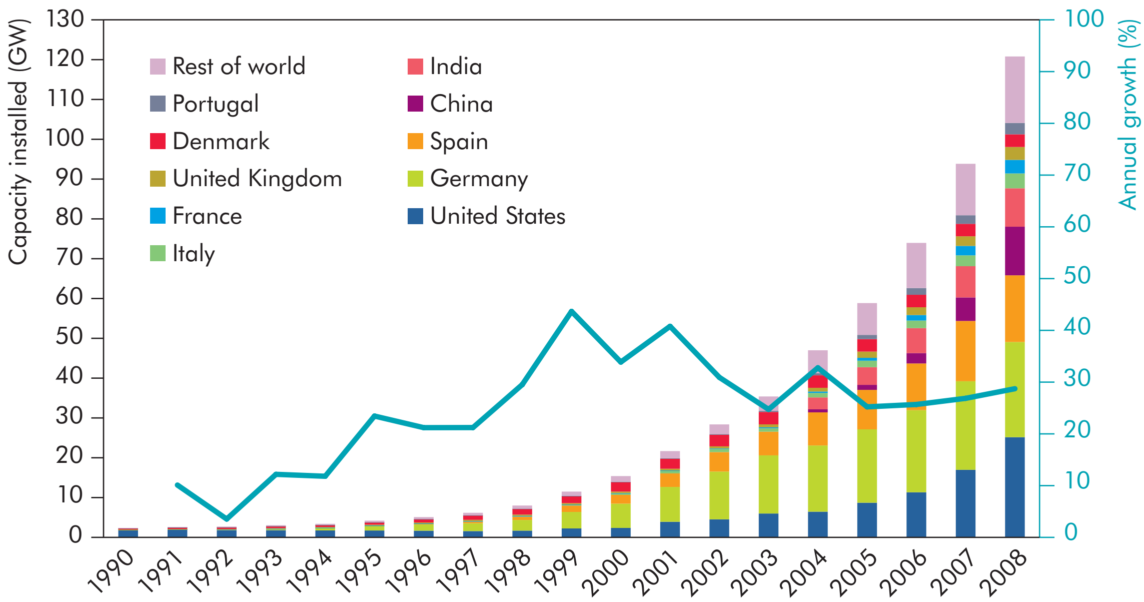
Wind resources are available in nearly every country, and significant cost reductions have made wind energy the fastest growing electricity source worldwide. Wind energy is a sound investment as it reduces energy import dependence with no fuel constraint or price risk, is emissions-free, and has a low environmental impact. The IEA wind energy roadmap contains milestones for continued cost reductions, flexible, targeted incentives, transmission planning, evolved power system operation for reliable integration of wind energy, and social acceptance of infrastructure.

Government and industry over the next ten years should:

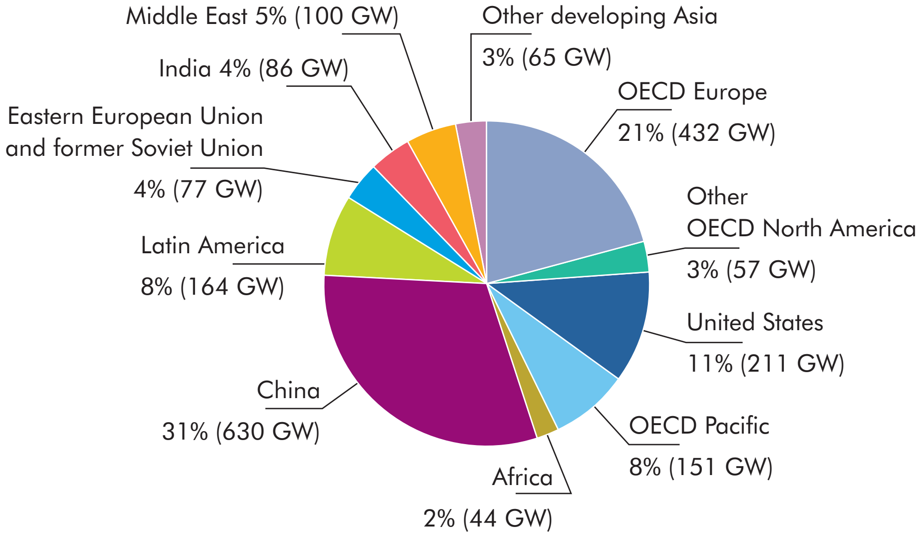
- set long-term targets, supported by predictable market-based mechanisms; pursue cost reductions;
- plan new plants to attract investment, taking into account other power system needs and land/sea usage;
- appoint lead agencies to co-ordinate planning of transmission to resource-rich areas and interconnect power systems; set incentives to build transmission; assess power system flexibility;
- raise public awareness of the benefits of wind power and of the accompanying need for additional transmission infrastructure;
- exchange best practices with developing countries; target development finance bottlenecks; further develop carbon finance options in developing regions.



Wind power has grown rapidly over the last 20 years; several countries have major wind markets today



Regional shares of cumulative wind energy investment by 2050 in the BLUE Map scenario



Key findings

- This roadmap targets 12% of global electricity from wind energy by 2050. 2 000 GW of capacity will annually avoid the emission of 2.8 gigatonnes of CO_2-equivalent.
- Achieving these targets requires investment of some USD 3.2 trillion. 47 GW would need to be installed on average every year for the next 40 years – a 75% increase – amounting to USD 81 billion/yr.
- In 2030, non-OECD economies will produce some 17% of global wind energy, rising to 57% in 2050.
- Wind power can be competitive today where the resource is strong and when the cost of carbon is reflected in markets. Costs per MWh range from USD 70 to USD 130.
- Costs are expected to decrease further as a result of technology development, deployment and economies of scale – by 23% by 2050. Transitional support is needed to encourage deployment until full competition is achieved.
- Offshore costs are at present twice those on land, although the quality of the resource can be 50% higher. This roadmap projects cost reductions of 38% by 2050.
- To reliably achieve high penetrations of wind power, the flexibility of power systems and markets must be enhanced and, eventually, increased. Flexibility is a function of access to flexible generation, storage and demand response, and is enhanced by interconnection, larger and faster power markets, smart grids and forecasting.
- Intensified R&D is particularly needed in the offshore sector to develop a new generation of turbines and sub-surface structures fundamentally designed for the marine environment with minimum operating and maintenance requirement.

2020 — GW capacity: **671** (incl. offshore: **109**)

2030 — GW capacity: **1 024** (incl. offshore: **194**)

Wind roadmap milestones

Policy framework

- Transitional market support mechanisms; long-term deployment targets
- Internalised external energy costs
- Integrated deployment plans; accelerated permitting processes
- Best-practice exchange with developing countries; targeted development financing and CO_2-based mechanisms

Public engagement and environment

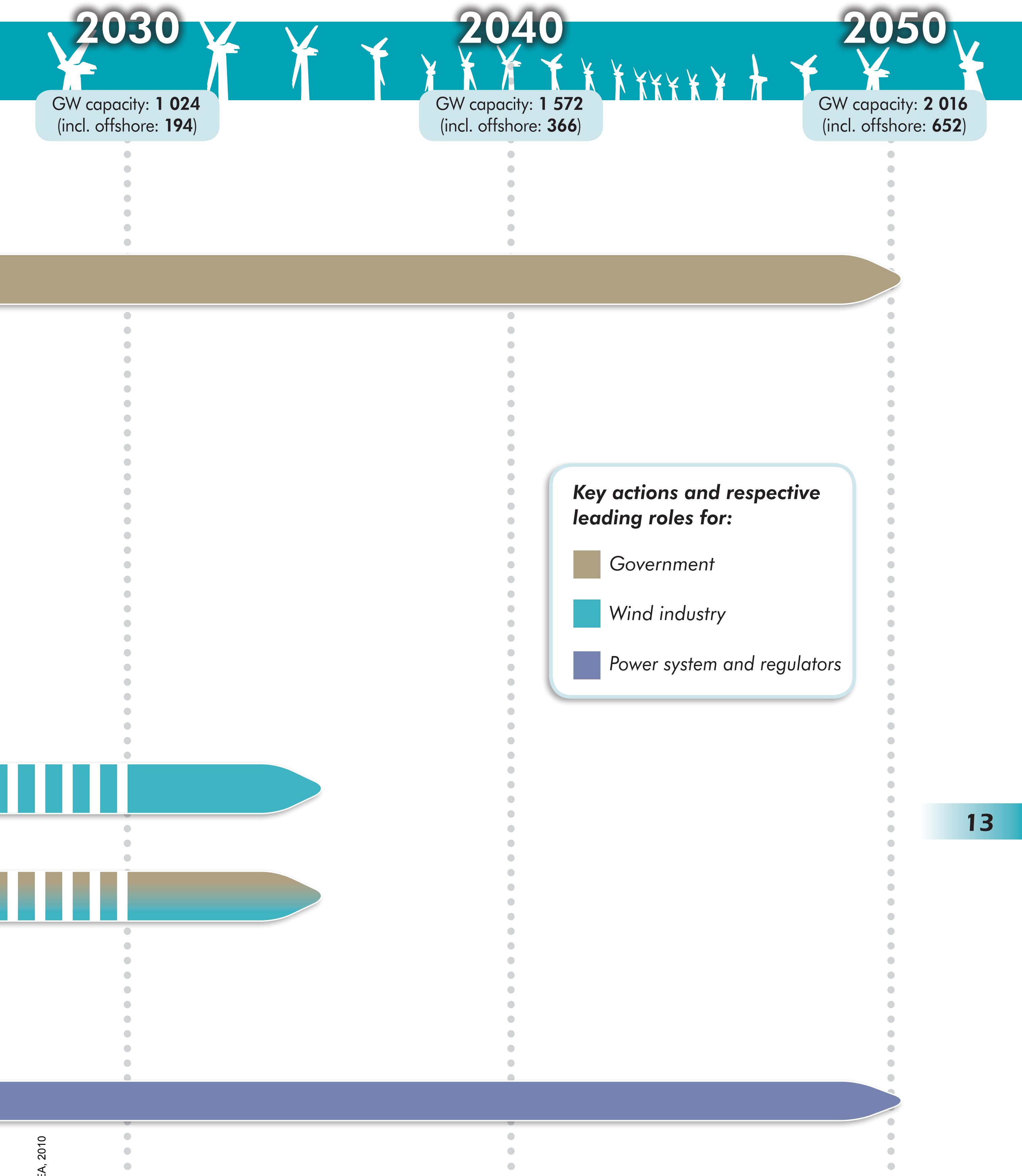
- Raised public awareness of value of wind energy and of the need for stronger transmission systems
- Improved assessment and mitigation methods for socio-environmental impacts

Technology and industry

- Improved resource assessment
- Industry databases of resource, conditions and operating experiences
- Advanced rotors, lighter and stronger materials
- Offshore: cheaper foundations <40m; improved supply chains and installation strategies
- Next generation of dedicated offshore turbines; foundations <200m
- Education and training programmes in OECD and developing countries
- Intensified R&D funding and international collaboration
- Stronger focus on deep offshore

Power system

- Improved forecasting models taken up in system operation
- Integrated transmission planning, incentives to build, equitable grid access
- Continental scale and offshore grid deployment
- Assessment of additional system flexibility needs
- Optimised markets; responsive demand; smarter grids


2030
GW capacity: **1 024**
(incl. offshore: **194**)
2040
GW capacity: **1 572**
(incl. offshore: **366**)
2050
GW capacity: **2 016**
(incl. offshore: **652**)
Key actions and respective leading roles for:
Government
Wind industry
Power system and regulators

Chapter 14 FINANCE

Key findings

- *The BLUE Map scenario requires the investment of USD 46 trillion additional to the investment required in the Baseline scenario from 2010 to 2050. Almost half of these additional investments are needed in the transport sector for advanced vehicle technologies.*
- *The transition to a low-carbon energy system will yield significant fuel cost savings. Undiscounted savings are estimated at USD 112 trillion from 2010 to 2050. Subtracting these fuel savings from the additional investment costs yield total undiscounted net savings of USD 66 trillion. Even at a 10% discount rate, fuel savings in the BLUE Map scenario outweigh the additional incremental investment needed.*
- *There is an urgent need to scale up investment in low-carbon energy technologies. Current investment levels are insufficient to make the necessary transition to a low-carbon energy system. Investment in traditional fossil-based technologies needs to be shifted towards low-carbon energy technologies.*
- *Annual investments in low-carbon energy technologies averaged approximately USD 165 billion over the last three years. To implement the BLUE Map scenario investments in clean technologies will need to reach approximately USD 750 billion per year by 2030, rising to over USD 1.6 trillion per year from 2030 to 2050.*
- *The transition to a low-carbon energy system will offer significant new opportunities for business as a large range of new breakthrough and emerging technologies will need to be developed and widely deployed over the next few decades.*
- *International carbon reduction mechanisms are needed to support the deployment of low-carbon energy technologies in developing countries. These market-based mechanisms should be designed to encourage investments where they are least expensive.*
- *During the demonstration and early deployment of new energy technologies, direct support from governments is likely to be required to reduce the risks of technology development. As new technology gains acceptability, the need for government support should decline.*
- *The involvement of large corporations in technology development will help to facilitate financing as these companies have access to much lower costs of debt and a wider range of investors.*
- *Policy predictability at national and international levels will be important to enable investors to evaluate the risk of policy changes on potential investments, thereby allowing them to consider longer payback periods and allowing lenders to finance a higher portion of the needed investments.*
- *Capital is limited and returns must be sufficient to warrant the risks associated with these investments. Investment in new technologies will require higher returns than investment in traditional technologies. Institutional investors, who hold the largest share of private-sector funding are risk-adverse and will require predictable income streams before they will invest.*

- *Governments and industry should increase public education, raise the awareness of climate change issues among the financial community and promote investment opportunities to new investors.*
- *Greater collaboration with the finance community, and particularly venture capital and private equity investors could help governments more effectively distribute their innovation funding.*

Investment needs

Baseline scenario

In the Baseline scenario, total final energy consumption almost doubles between 2007 and 2050 as the demand for energy-dependent goods, services and leisure activities increases. This implies very high levels of investment on the demand side in energy-consuming devices and processes. It also implies high levels of investment on the supply side in the energy production and supply infrastructure that will be needed to service them.

In the Baseline scenario, total investment[1] is estimated to be USD 270 trillion between 2010 and 2050. Most of this (USD 240 trillion) is accounted for by investments that consumers will make in capital equipment that uses energy, including vehicles, and plants in heavy industry.

In the Baseline scenario, investment needs between 2030 and 2050 are almost double those in the period up to 2030 as the global economy develops and as the demand for cars and other consumer durables rises alongside incomes in emerging and developing countries (Table 14.1). In the BLUE Map scenario, even higher levels of investment are needed between 2030 and 2050 as demand increases for the wider diffusion of low-carbon technologies.

Table 14.1 ▶ ***Average annual investment by sector in the Baseline and BLUE Map scenarios***

	Baseline			BLUE Map		
USD billion	**2010-15**	**2015-30**	**2030-50**	**2010-15**	**2015-30**	**2030-50**
Power generation	210	360	430	270	470	640
Transmission and distribution	170	220	210	270	260	350
Industry	130	150	290	150	170	340
Transport	3 800	4 490	7 220	4 028	4 760	8 080
Total investment (excluding buildings)	**4 310**	**5 210**	**8 150**	**4 720**	**5 660**	**9 400**

Note: Total investments in the buildings sector are not available. Numbers may not add due to rounding. Investments in industry include only cement, aluminium, iron and steel, pulp and paper and chemical and petrochemical sectors.

1. Excluding upstream investments in the production and transportation of coal, oil and gas.

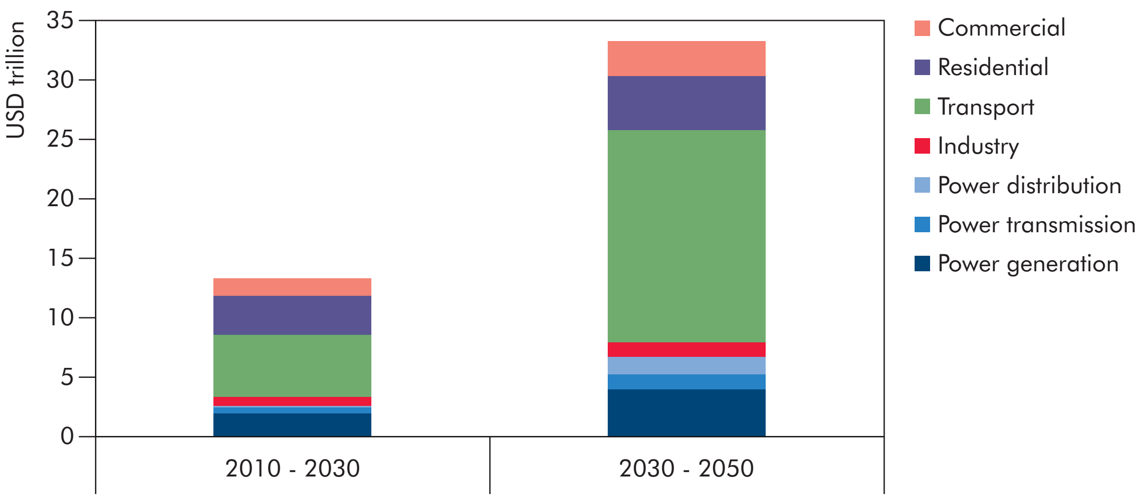
The investment needs in the BLUE Map scenario are 8.6% higher between 2015 and 2030 and 16% higher between 2030 and 2050 than in the Baseline scenario. Transport investment costs rise over time in the Baseline scenario as the sales of vehicles of all types increase, particularly in the developing world.

BLUE Map scenario

The BLUE Map scenario envisages a need for investment USD 46 trillion higher than the Baseline scenario to 2050. Consumers invest in more energy-efficient equipment, buildings, vehicles and industrial plants with carbon capture and storage (CCS), and electricity generators invest in more capital-intensive renewables, nuclear and CCS-equipped plant. Some of these investments are economic even without a carbon dioxide (CO_2) reduction incentive as they yield lifetime fuel cost savings that more than justify the additional investment. But many firms require payback periods of less than 5 years and this creates a major financial barrier to the adoption of energy-efficient technologies with high initial costs and longer payback periods. Additional investment needs are dominated by the transport sector, accounting for 50% of total additional investments, as consumers invest in more expensive advanced vehicle technologies. The buildings sector accounts for 27% of the total investment, power 20%, and industry 4%.

Additional investment needs from 2010 to 2030 are estimated at USD 13 trillion (Figure 14.1), with investments in transport and buildings accounting for the largest shares. USD 33 trillion is required after 2030 for the much more rapid penetration of more advanced vehicle technologies, and for CCS and renewable and nuclear power.

Figure 14.1 ▸ *Additional investments by sector in the BLUE Map scenario*



Note: Additional investments in residential and commercial sectors include cooking, lighting, appliances, space and water heating systems, cooling systems and building shell improvements.

Key point

Most of the additional investment in low-carbon technologies will be required after 2030.

In the power sector, the benefits of greater energy efficiency in the BLUE Map scenario mean that additional investment needs are more modest, while after 2030 the larger share of renewable power generation and increased demand from greater electrification in transport and industry sharply increase the additional investment needed in the power sector in the BLUE Map scenario compared to the Baseline scenario.

Transport

In the Baseline scenario, investment in planes, trucks, buses and passenger light-duty vehicles (LDVs) dominates total transport investments, amounting to 93% of the total USD 230 trillion investment in the transport sector between 2010 and 2050. LDVs alone account for around 60% (USD 139 trillion) of total transport investments (Table 14.2). The scenario envisages about 5 billion LDVs will be sold between 2010 and 2050, rising from 70 million in 2010 to 160 million in 2050, with average annual sales of 120 million LDVs per year. Hybrid vehicles reach about 25% of all sales by 2050. In the Baseline scenario, advanced technology vehicles, including plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs) and fuel cell vehicles (FCVs), account for only a small share of sales worldwide in 2050.

In the BLUE Map scenario, the incremental investment cost across all transport modes through 2050 amounts to USD 23 trillion, 10% higher than the Baseline. This includes USD 13 trillion for LDVs and USD 5 trillion for trucks and buses, with the balance mainly for aircraft and ships. The additional investments are needed for improvements to engines, better aerodynamics, and light weighting of all types of vehicles. The additional cost per vehicle for such improvements, especially in respect to batteries and fuel cell components, is expected to decline over time and with cumulative production.

Table 14.2 ▶ Total investment needs for LDVs

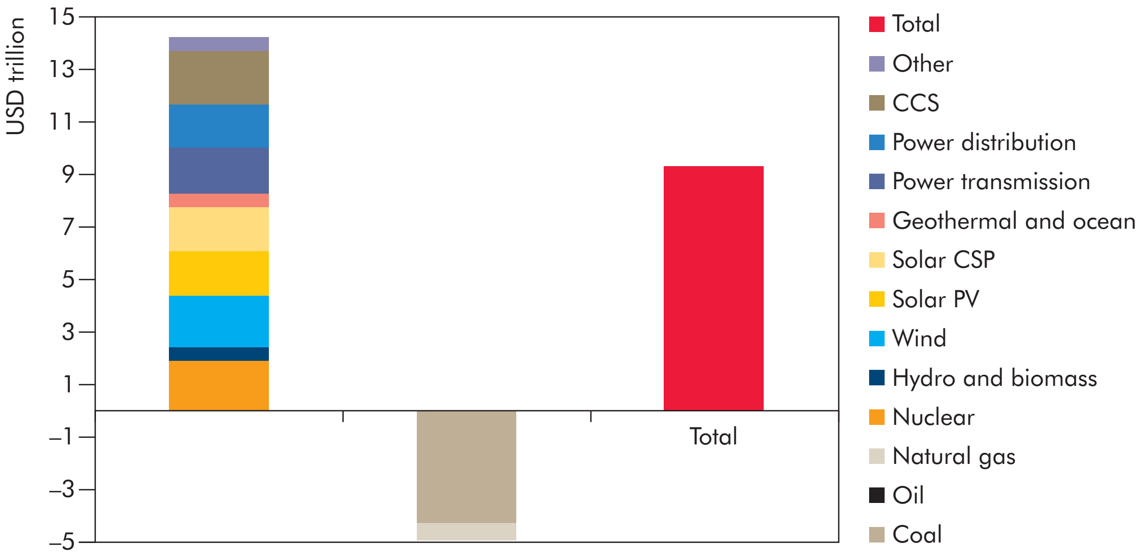
	2010-30		2030-50		2010-50	
USD billion	**Baseline**	**BLUE Map**	**Baseline**	**BLUE Map**	**Baseline**	**BLUE Map**
Conventional vehicles	49 560	39 470	76 020	22 010	125 580	61 090
Hybrids	1 960	7 100	11 740	15 440	13 700	22 540
Plug-ins/EVs	2	7 130	3	49 180	5	56 310
FCVs	0	400	2	11 170	2	11 570
Total	**51 520**	**54 090**	**87 760**	**97 810**	**139 290**	**151 900**

Power sector

In the Baseline scenario, investments in the power sector are estimated to be USD 23.5 trillion between 2010 and 2050. More than half of these investments (USD 15 trillion) will be needed for new power generation capacity, USD 5.8 trillion for maintaining and expanding the electricity distribution network and USD 2.5 trillion for the electricity transmission network. Investments in the conventional technologies of gas, coal, biomass, hydro and nuclear dominate investments in power generation.

In the BLUE Map scenario, energy efficiency reduces electricity demand growth. There is a switch to more capital-intensive renewable, nuclear and CCS-equipped thermal technologies. Additional investment needs in the BLUE Map scenario are estimated at USD 6.0 trillion for power generation, 33% of which is needed from 2010 to 2030 and 67% from 2030 to 2050 (Figure 14.2). Additional investment in the distribution network is estimated at USD 1.6 trillion, while USD 1.7 trillion is needed for transmission systems to connect more remote renewables to the grid. The connection of variable renewables will also require some reinforcing of grids.

Figure 14.2 ▶ *Additional investment needs in the power sector for the BLUE Map scenario compared to the Baseline scenario, 2010-50*



Key point

Additional investment costs needed to decarbonise the power sector are estimated at USD 9.3 trillion.

Buildings

The transition to a more sustainable energy future for the buildings sector will require significant additional investment. Residential, service-sector and public buildings use a wide range of technologies. They are used in the building envelope and its insulation, in space heating and cooling systems, in water heating systems, in lighting, in appliances and consumer products, and in business equipment. The additional initial costs of higher performance building shells, windows, heating and cooling systems, lighting and appliances are often significant, but will come down with deployment, thereby helping to reduce the overall cost of meeting the goals in the BLUE Map scenario.

The buildings sector has a significant number of very attractive energy-efficient and low-carbon technologies that, although they have higher initial costs, are often cheaper on a least life-cycle cost basis than the technologies they replace. Such options can be found in new building shells, lighting, appliances and heating and cooling systems. The modelling takes up these cost-effective options first. Achieving the deeper levels of cut in the BLUE Map scenario requires some much more expensive measures to be taken up, most notably to address the low performance of the existing residential building stock in OECD countries.

The investment is required to ensure that new buildings meet more stringent building codes, to refurbish to a low-energy standard around three-quarters of the existing building stock still standing in 2050 in OECD countries, and for additional investments in heat pumps, solar thermal systems, combined heat and power (CHP) systems, lighting systems and appliances.

The total additional investment in the BLUE Map scenario for the residential and service sectors is estimated to be USD 12.3 trillion, of which USD 7.9 trillion is needed in the residential sector and USD 4.4 trillion in the service sector (Table 14.3).

Table 14.3 ▶ ***Incremental investment needs in the buildings sector for the BLUE Map scenario compared to the Baseline scenario, 2010-50***

	Incremental investment (USD billion)	**Share of total**
Water heating	935	8%
Space heating	566	5%
Cooling and ventilation	2 318	19%
Lighting	231	2%
Appliances and miscellaneous end-uses	2 877	23%
Demolition/early retirement	650	5%
New building shell measures	1 768	14%
Refurbishment of building shell in OECD	2 944	24%
Total	**12 289**	**100%**

The additional investment required in building shells dominates the total additional investment needs in the BLUE Map scenario over and above the Baseline by 2050. Around 60% of this additional investment is needed to refurbish the existing building stock in OECD countries. This additional investment helps to reduce the incremental investment needs for space heating and helps offset some of the cost of shifting to more capital-intensive technology options such as heat pumps, solar thermal and CHP.

In the residential sector, improvements in building shells account for just over half of the incremental investment needs. In the service sector, around 31% of all investment is required for this purpose.

Industry

In the BLUE Map scenario, investment needs by 2050 are estimated to be between USD 2 trillion and USD 2.5 trillion higher than in the Baseline scenario, with most investment being needed in the cement, iron and steel and chemical sectors (Table 14.4). Total additional investments in industry represent 4% of the total investment costs needed across all sectors to halve global CO_2 emissions in the BLUE Map scenario. With the exception of cement, where investment needs in the BLUE Map scenario are more than 50% higher than in the Baseline scenario, investments in the other sectors are estimated to be 10% to 15% higher than in the Baseline scenario.

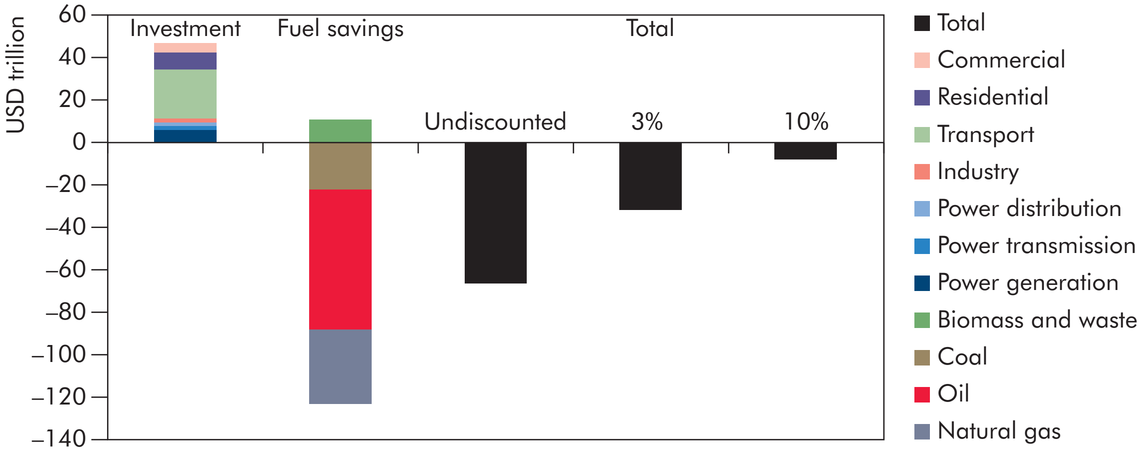
Table 14.4 ▶ **Investment needs in industry in the Baseline and BLUE Map scenarios**

In USD billion	Total investment needs 2010-50 Baseline	Total investment needs 2010-50 BLUE Map	Additional investments
Iron and steel	2 000 – 2 300	2 300 – 2 700	300 – 400
Cement	760 – 970	1 200 – 1 640	440 – 670
Chemicals and petrochemicals	4 100 – 4 700	4 500 – 5 200	400 – 500
Pulp and paper	1 220 – 1 350	1 360 – 1 510	140 – 160
Aluminium	660 – 910	720 – 1 000	60 – 90
Total industry			**2 000 – 2 500**

Fuel savings

The additional investment needs in the BLUE Map scenario will yield significant savings in fossil-fuel consumption, offset by increased bioenergy fuel costs. The total fuel savings in the BLUE scenario compared to the Baseline scenario are around 180 000 Mtoe over the period 2010 to 2050. Calculated using Baseline prices for the Baseline scenario and BLUE prices for the BLUE scenario, the undiscounted value of these fuel savings from 2010-2050 is USD 112 trillion. Subtracting these undiscounted fuel savings from the undiscounted additional investments that will be required, yields a net saving of USD 66 trillion over the period to 2050.[2] Discounting the additional investment needs and the fuel savings these investments generate at a 3% discount rate yields net discounted savings of USD 32 trillion. At a 10% discount rate, net savings are USD 8 trillion (Figure 14.3).

Figure 14.3 ▶ **Additional investment and fuel savings in the BLUE Map scenario compared to Baseline, 2010-50**



Key point

Even using a 10% discount rate, fuel savings in the BLUE Map scenario more than offset additional investment needs.

2. If the fuel savings calculation were based on Baseline fuel prices in both scenarios, which removes the effect of the lower fuel prices under the BLUE scenario, the total fuel savings would decline to USD 78 trillion. The net savings would fall to USD 32 trillion undiscounted, USD 16 trillion based on a 3% discount rate and USD 4 trillion based on a 10% discount rate.

14

Current trends in financing of low-carbon technologies and global energy asset finance

Investments in low-carbon technologies, particularly in the power sector, have increased very significantly since 2001 reaching over USD 173 billion in 2008 from less than USD 11.6 billion in 2001 (Bloomberg New Energy Finance).[3] In 2009, the impacts of the financial crisis and slow-down in economic growth resulted in a 6.6% drop in low-carbon investments (Figure 14.4). The economic stimulus packages and CO_2 targets set by many major economies can be expected in time to result in a rebound in investment flows into low-carbon technologies.

Asset finance remains the most important source of funding for low-carbon technologies accounting for USD 99 billion (60%) of the total funds invested in 2009.[4] Funding from asset finance can be raised either through project finance, on-balance sheet funding in the form of corporate debt or direct equity investment, or through the bond market. Project finance offers an attractive way for companies to fund investments in new generation capacity as the projected cash flow from the project is used to justify the investment rather than the cost being carried on the balance sheet of the project owners.

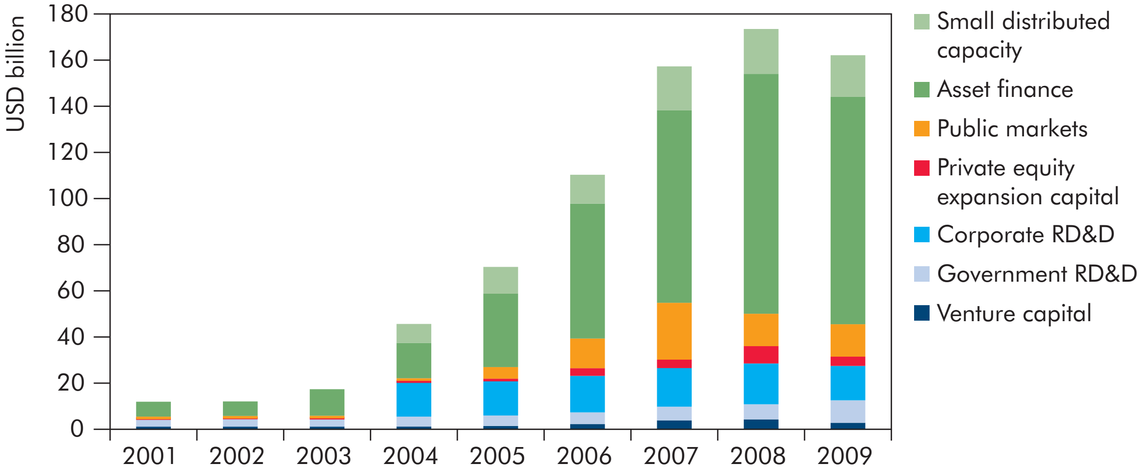
The drop in liquidity caused by the global financial crisis has significantly constrained the ability of project developers to raise funding through project finance. As a result, a much larger share of asset finance has been in the form of on-balance sheet funding. Large corporations with solid balance sheets and strong banking relationships have benefitted from the drop in liquidity driving out many smaller players in the low-carbon energy market. Wind project developers have seen the cost of borrowing rise significantly. This has made many projects unfinanceable. Projects have only been financed on the strength of their developers' corporate balance sheets.

Funding from public markets, which represented an important share of finance in 2006 (12%) and 2007 (16%) saw a significant decline in activity in 2008 as the global financial crisis reduced market appetite for the listing of new companies. Some renewed activity on the public markets was seen during the second half of 2009 with 10 new companies raising USD 3.5 billion via initial public offerings (IPOs) on the market. As confidence returns, a growing share of the funding needs for low-carbon technologies will come from the stock markets through the issuing of new equity.

3. Investments in low-carbon technologies are based on Bloomberg New Energy Finance data which include investments in renewables (including biofuels and small hydropower) and energy efficiency. IEA analysis on additional investment needs in low-carbon technologies also includes investment in transport, electricity networks, nuclear and CCS. Including investments in these other technologies, the current investments in low-carbon technologies are estimated to be approximately USD 200 billion per year.

4. Asset finance excludes amount reinvested in equity.

Figure 14.4 ▶ Investments in low-carbon energy technologies



Note: Asset finance excludes amount reinvested in equity. Estimates for corporate research, development and demonstration (RD&D), and investments in small scale projects are not available for 2001, 2002 and 2003.
Source: Bloomberg New Energy Finance.

Key point

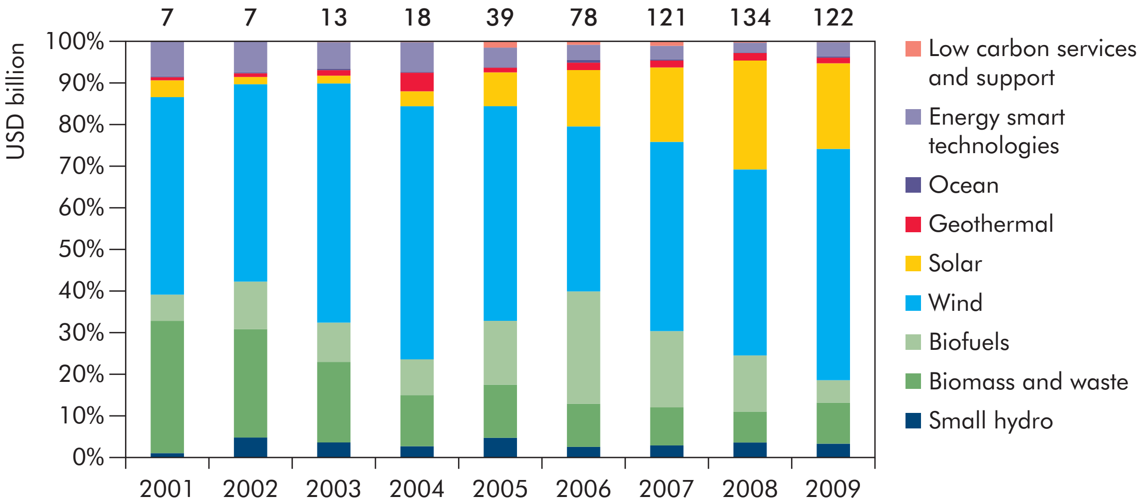
Investment in low-carbon technologies has risen steadily over the last decade, but has dropped back since the start of the financial crisis.

In 2009, low-carbon investment flows from venture capital and private equity amounted to USD 7 billion, a 41% decrease compared to 2008 levels. These funds are particularly important for technology companies in their early stage of development and for manufacturers looking for expansion capital to fund new projects or facilities. Investments in corporate and government RD&D amounted to USD 24 billion in 2008 and 2009.

Investments in wind have accounted for the largest share of total investments in low-carbon technologies, with a share of between 40% and 60% since 2001 (Figure 14.5). Investment in solar energy technologies, which accounted for the second-largest share of total investments (21%) in 2009, has shown the largest increase, rising eightfold from USD 3.2 billion in 2005 to USD 25 billion in 2009. Investment in biomass technologies which accounted for the second-largest share (32%) in 2001 has shown a relatively modest increase compared to wind and solar technologies. The biomass share of total investments in low-carbon technologies has fallen to 10% in 2009. Biofuels, which saw significant growth in activity between 2005 and 2007, showed a decline of 11% in 2008 and 21% in 2009 as lower oil prices and concerns over sustainability of biofuels made investments in biofuels less attractive.

In 2008, an estimated 65 gigawatts (GW) of new renewable power generation, including large hydro, was added globally. This represented a total investment of approximately USD 140 billion. New renewable power generation represented about 40% of the approximately 160 GW of new capacity added in 2008. Investments in renewable power over the next decade will continue to show strong growth, driven by the ambitious renewable energy targets being set by most major economies.

Figure 14.5 ▶ ***Share of investments in low-carbon technologies by technology***



Excludes corporate RD&D, government RD&D and investments in small-scale projects. Figures are not adjusted for reinvested equity.

Source: Bloomberg New Energy Finance.

Key point

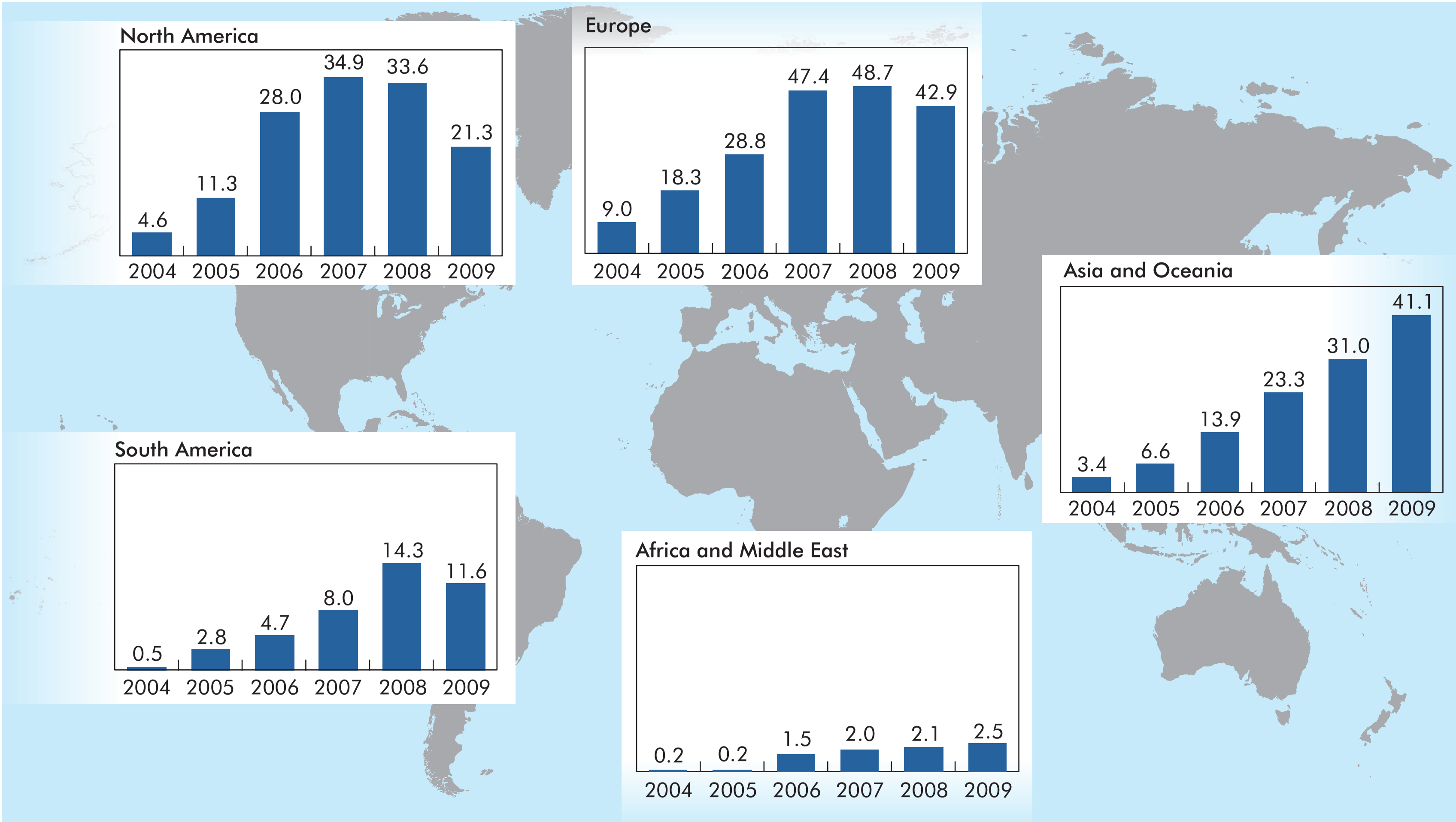
Wind accounts for the largest share of investment in low-carbon technologies.

Regionally, Europe remains the leader in low-carbon energy finance, accounting for 36% of total investments in 2009 (Figure 14.6). North America has steadily seen its share of worldwide low-carbon energy investments decline, falling to 18% in 2009 as other regions have invested more heavily. Investment in Asia, driven primarily by strong growth in China, has seen the largest rise, investing approximately USD 40 billion in 2009, 34% of global low-carbon energy investments. In South America, investments have continued to rise steadily since 2001, reaching USD 12 billion in 2009. The bulk of these investments are attributable to biofuel investments in Brazil.

Current annual investments in the energy sector are estimated at between USD 650 billion and USD 750 billion. The largest share of these investments are in the oil and gas sector, where a survey of the largest 50 oil and gas companies showed investments in 2008 of USD 525 billion (IEA, 2009e). Investments by the largest 25 companies in the electricity and coal mining sectors in 2008 reached USD 143 billion and USD 13 billion, respectively (Table 14.5). In the same year, investments in low-carbon technologies reached just under USD 162 billion.[5]

5. This excludes investments in the transport sector, electricity networks, nuclear and CCS.

Figure 14.6 ▶ **Low-carbon energy investments by region (USD billions)**



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Note: New investment volume adjusted for reinvested equity. Total values include estimates for undisclosed deals.

Sources: Bloomberg New Energy Finance; UNEP SEFI (2009).

Key point

Europe invests most in low-carbon technologies, although growth has been strongest in Asia.

Table 14.5 ▶ Investments by the 25 largest companies in oil and gas, power and coal mining sectors, 2008 (USD billions)

Oil and gas sector	Country	2008	Power sector	Country	2008	Coal sector	Country	2008
PetroChina	China	34.0	E.ON	Germany	23.9	Shenhua Group	China	2.09
Shell	United Kindgom-Netherlands	32.0	GDF Suez	France-Belgium	14.9	Xstrata	United Kingdom-Switzerland	1.20
Petrobras	Brasil	29.1	EDF	France	14.5	China National Coal	China	1.14
Gazprom	Russia	25.6	ENEL	Italy	9.7	BHP Billiton	United Kingdom-Australia	0.94
ExxonMobil	United States	23.9	Iberdrola	Spain	9.7	Anglo American	United Kingdom-South Africa	0.93
Chevron	United States	22.8	TEPCO	Japan	7.5	Teck Cominco	Canada	0.88
BP	United Kingdom	22.0	Kansai Electric	Japan	6.9	Coal India	India	0.86
ENI	Italy	21.4	Florida Power & Light	United States	5.2	Massey Energy	United States	0.74
Total	France	20.5	KEPCO	Korea	5.2	Rio Tinto	United Kingdom-Australia	0.65
ConocoPhilips	United States	19.9	Endesa	Spain	5.1	PT Bumi Resources	Indonesia	0.57
Pemex	Mexico	18.0	Southern	United States	4.5	Arch Coal	United States	0.50
StatoilHydro	Norway	16.9	EDP	Portugal	4.5	SUEK	Russia	0.45
Sinopec	China	15.8	National Grid	United Kingdom	4.3	Consol Energy	United States	0.45
Lukoil	Russia	11.1	RWE	Germany	3.7	Kompania Weglowa	Poland	0.37
Devon Energy Corp	United States	9.4	Dominion Resources	United States	3.5	RWE Power	Germany	0.33
Repsol YPF	Spain-Argentina	9.3	Chubu Electric	Japan	3.4	Peabody Energy	United States	0.27
Rosneft	Russia	8.7	NTPC	India	3.2	PT Adaro Indonesia	Indonesia	0.15
Marathon	United States	7.4	Exelon	United States	3.0	Sasol	South Africa	0.12
EnCana	Canada	7.4	CEZ	Czech	2.5	Banpu	Thailand	0.12
Occidential	United States	6.8	Eletrobras	Brasil	2.1	Drummond	United States	n.a
Canadian Natural Resources	Canada	6.4	Scottish Southern	United Kingdom	1.7	Kuzbassrazrezugol	Russia	n.a
Apache	United States	5.9	Fortum Oyj	Finland	1.6	Detong Coal Mining	China	n.a
Anadarko	United States	5.3	Yangtze Power	China	1.4	Shanxi Coking Coal	China	n.a
Talisman	Canada	5.2	CLP Holdings	Hong Kong	0.8	Mitsubishi Development	Japan	n.a
CNOOC	China	5.1	Pacific Corp	United States	na	PT Kideco Jaya Agur	Indonesia	n.a
Total		**390.0**	**Total**		**142.9**	**Total**		**12.76**

Sources: Thomson Reuters database and IEA (2009e).

Between 2010 and 2020, an estimated USD 300 billion to USD 400 billion per year of additional investments will be required to deliver the BLUE Map scenario outcomes compared to the Baseline scenario. Much of this will be funding through asset finance. The scaling up of investments in low-carbon technologies from 2004 to 2007 will need to continue at a similar rate over the next decade to achieve this. A growing share of the investment currently seen in the energy sector will need to flow into low-carbon technologies. In the power sector, investment flows into renewable power generation is showing an encouraging trend, with investment in renewable power generation surpassing flows into fossil-fueled generation for the first time in 2008.

A growing share of the funding for low-carbon energy technologies will need to be financed by the private sector. Smaller, more innovative companies backed by venture capital and private equity markets are likely to continue to play an important role in the development of low-carbon technologies. Scaling up and deploying these technologies will require large investment flows which will need to be funded by large corporations. Large corporations will finance these investments through a mix of internally generated cash flow and project finance and by issuing debt and equity on international financial markets. In March 2009, USD 95.4 billion was deployed in clean energy investment (Bloomberg New Energy Finance). Of this, USD 51.1 billion was managed in core clean energy funds which had more than 50% of their investments in low-carbon energy companies or projects. An additional USD 10.3 billion was held by energy and infrastructure funds with at least 10% of assets held in renewable energy. Another USD 33.9 billion was managed by environmental and climate change funds in which investments in low-carbon energy represented an important share of the total holdings.

Current trends in low-carbon energy investment are encouraging, but investments over the next 20 years will need to be scaled up by a factor of almost five to reach USD 750 billion per year if the investment needs in the BLUE Map scenario are to be met. Incentives for green growth in economic stimulus packages should help to support investments in the short term. A transition to a low-carbon economy over the medium and long term will be dependent on establishing a clear policy framework which will provide the necessary incentives for investment in these technologies.

International financing mechanisms

Financing technology deployment in non-OECD countries

Many of the least-cost opportunities for deploying some of the leading low-carbon energy technologies, particularly renewable energies, are in non-OECD countries. Much of the additional investment needed to achieve the transition to low-carbon technologies will need to be deployed in countries where only very limited carbon policies currently exist. Funds will need to be transferred from developed to developing countries to overcome financial barriers related to technology diffusion. Current financing flows to developing countries need to be scaled up sharply.

International carbon reduction mechanisms such as the Clean Development Mechanism (CDM) will need to play an important role. In general, CDM is best suited for financing large investments in the power and industry sectors. Investments in the transport and the buildings sectors which will need to be made by billions of small households are not well suited to CDM given the high transaction costs and much smaller individual investment requirements for these sectors.

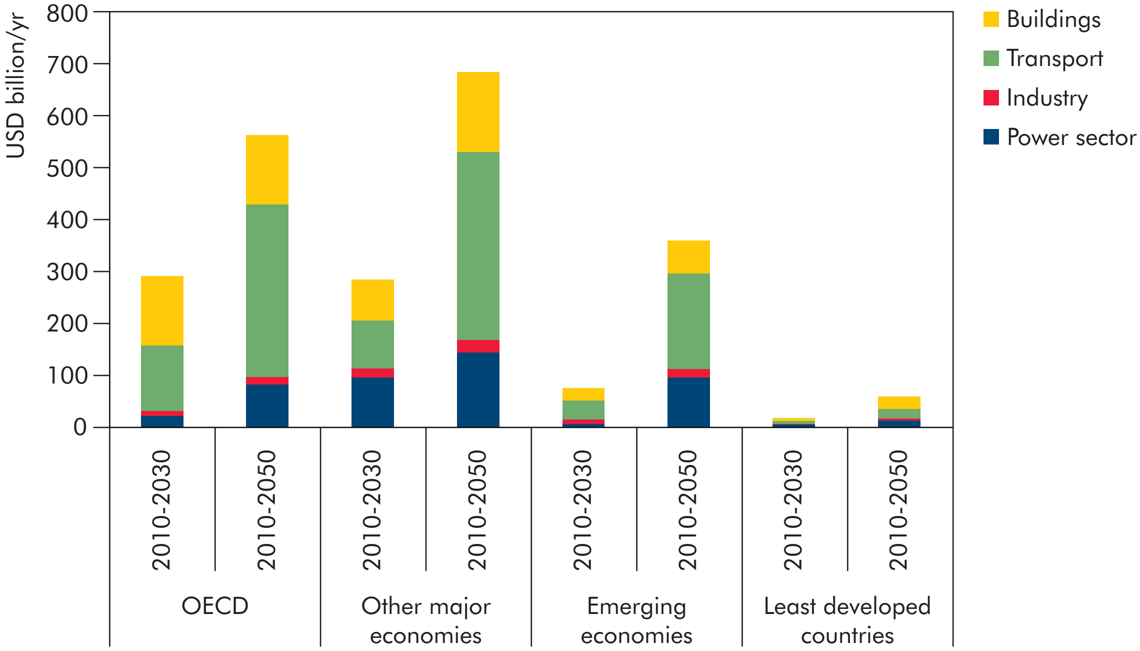
The most appropriate sources of funding for a given country will depend on its stage of economic development. Market-based mechanisms such as the CDM combined with in-country finance should be the main funding mechanisms for a group of the richest non-OECD countries (other major economies), such as China and Russia (Table 14.6). At the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2009 (COP-15), China stated that it would not seek direct financial assistance. In emerging countries, where development aid is needed to improve access to energy, market-based mechanisms and in-country finance may need to be supplemented by additional funding from developed countries. Investment in least developed countries will most probably need to be directly funded by developed countries as these countries are unable to secure financing because of their low credit ratings.

Table 14.6 ► ***Possible funding mechanisms for meeting the additional cost of energy technology transition***

	Gross domestic product per capita USD (purchasing power parity)	Funding mechanisms
OECD	>15 000	In-country self-finance
Other major economies	>5 000	In-country self-finance International carbon reduction crediting mechanisms
Emerging economies	>3 000 and <5000	In-country self-finance International carbon reduction crediting mechanism Funding from developed countries
Least developed countries	<3 000	Funding from developed countries

The largest share of the additional investment between the Baseline and the BLUE Map scenarios to 2030 is in OECD countries, with an average annual incremental investment from 2010 to 2030 of USD 291 billion (Figure 14.7). Incremental investment needs from other major economies between 2030 and 2050 is the largest of the four groupings. Investment levels in emerging economies from 2030 to 2050 is over half those of the OECD countries. Emerging economies will require additional support to reach these levels. Investment needs for least developed countries account for the smallest share at 3% from 2010 to 2050. Other major economies account for the largest share of investment needs over the 2010 to 2050 period, with incremental investment needs of USD 480 billion per year. In comparison, additional investments in OECD countries are USD 425 billion per year from 2010 to 2050.

Figure 14.7 ▶ Additional investment needs in the BLUE Map scenario compared to the Baseline scenario by region and sector



Key point

Although OECD countries will account for the largest share of investments from 2010 to 2030, most of the additional investment from 2030 to 2050 will need to occur in non-OECD countries.

Bilateral and multilateral climate funds

Bilateral and multilateral climate funds offer an important source of finance for low-carbon technologies in developing countries (Table 14.7). These funds cover both mitigation and adaptation costs. Much of the multilateral funding is under the management of the World Bank, which has approximately USD 9.5 billion of funds to distribute for climate change mitigation and adaptation from 2008 to 2012. A number of countries have also committed funds to support investments in developing countries. Japan has made the largest commitment with USD 15 billion being available under the Hatoyama Initiative.

International funds could play a variety of roles as part of a post-2012 agreement. A number of options are under consideration. Future international institutional funding for climate purposes is likely to be significantly larger than it is currently. Existing institutions will need to adapt to handle the larger flow of funds and the different purposes to which they may be put. The extent to which international funding will continue to be delivered by the existing institutions in the future, or whether there may be additional bodies, is the subject of ongoing negotiations.

Table 14.7 ▶ Multilateral and bilateral funding for low-carbon technologies

	Fund	Total amount USD millions
Multilateral initiatives		
	Climate Investment Funds	6 100 (A+M*)
	Clean Technology Fund	4 700
	Strategic Climate Fund	1 400
International Finance Corporation	Sustainable Energy and Water	2 000
GEF 4 (including land-use change and forestry)		1 400
Asian Development Bank	Climate Change Fund	40
	Clean Energy Financing Partnership Facility	90
	Poverty and Environment Fund	3.6
European Investment Bank	Multilateral Carbon Credit Fund (with EBRD)	275.5
Subtotal		*9 910*
Bilateral initiatives		
Japan	Hatoyama Initiative	15 000 (A+M)
Netherlands	Development Co-operation	725
Australia	International Forest Carbon Initiative	132 (M)
United Kingdom	Environmental Transformation Fund - International Window	1 182 (A+M)
Norway	Climate Forest Initiative	2250
Germany	International Climate Initiative	764 (M)
European Commission	Global Climate Change Alliance	76 (M)
Spain	Millennium Development Goals Achievement Fund	92 (M)
Subtotal		*20 220*
Total		**30 130**

Note: List of funds is not exhaustive and focuses on funding for mitigation. The funds are multi-year commitments.
*A+M = adaptation and mitigation; A = adaptation; M = mitigation.
Sources: World Bank (2009a) and UNFCCC (2008).

Box 14.1 ▶ New funding commitments in the Copenhagen Accord

As part of the Copenhagen Accord agreed at COP-15, developed countries agreed collectively to commit around USD 30 billion over the period 2010 to 2012 "to enable and support enhanced action on mitigation, including substantial finance to reduce emissions from deforestation and forest degradation (REDD-plus), adaptation, technology development and transfer and capacity-building" (UNFCCC, 2009).

Developed countries have agreed to increase this support to USD 100 billion per year by 2020. As this figure includes financial support for adaptation and REDD-plus, the values are in line with estimates for the additional investment needed in emerging economies and least developed countries for mitigation shown in Figure 14.7. The Accord also outlines the creation of a Copenhagen Green Climate Fund to be the operating entity of the financial mechanisms of the Convention and calls for the establishment of a Technology Mechanism to accelerate technology development and transfer in support of action on adaptation and mitigation. The terms for the creation of these two new mechanisms are currently unclear and will depend on continued negotiations. It is also unclear whether or not these new bodies are intended as a replacement of, or supplement to the Global Environment Fund.

Carbon markets and finance

The Kyoto Protocol established a series of flexibility measures which enable countries to meet their targets by co-operating on emissions reductions across national borders. It also established the principle of the use of carbon sinks, such as certain forestry and land-use activities, to soak up emissions.

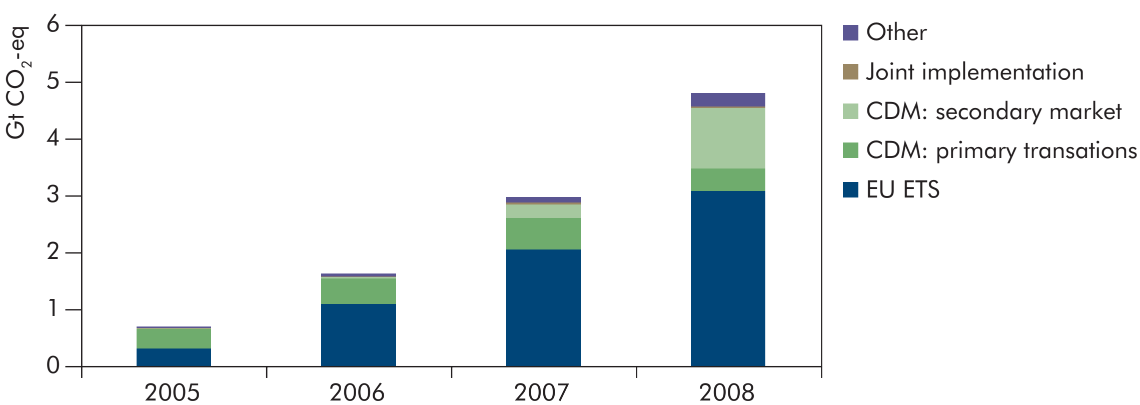
Three emissions market mechanisms were introduced to assist countries in meeting their emission targets in a flexible, cost-effective way:

- International emissions trading which allows country-to-country market transactions.
- The Joint Implementation (JI) of greenhouse-gas mitigation projects between developed countries.
- The CDM for joint projects by developed countries in developing countries.

The Kyoto Protocol also created the infrastructure needed for these international market mechanisms, such as registries and an international transaction log. Subsequently, countries and regions started building their own emissions trading systems. Among the early movers were Denmark and the United Kingdom. The most important milestone was the launch of the European Union Emissions Trading System (EU-ETS) in 2005, still the world's largest system for trading greenhouse gases, which stimulated the development of further trading programmes. In addition, voluntary markets emerged, driven by retail or consumer considerations.

The global carbon market has steadily expanded since 2004. Between 2005 and 2008, the volume of trading increased by a factor of almost 7 and the financial value transacted by a factor of more than 11. Despite turmoil in the financial markets, the financial value of the global carbon market doubled to USD 126 billion in 2008, with a 61% increase in the volume of trading compared to 2007 (World Bank, 2009b) (Figure 14.8 and Table 14.8).

Figure 14.8 ▶ The development of the carbon market



Source: World Bank (2009b).

Key point

The EU-ETS accounts for the largest share of trade in the carbon markets.

14

Table 14.8 ▶ The carbon market (USD billions)

	2005	2006	2007	2008
EU Emissions Trading Scheme	7.9	24.4	49.1	91.9
CDM: primary transactions	2.4	5.8	7.4	6.5
CDM: secondary market	0.2	0.4	5.5	26.3
Joint implementation	0.1	0.1	0.5	0.3
Other	0.3	0.4	0.6	1.3
Total transactions	**10.9**	**31.2**	**63.0**	**126.3**

Note: "Other" includes transactions on the voluntary market, the Chicago Climate Exchange, in the New South Wales and US Regional Greenhouse Gas Initiative (RGGI) systems, and (as of 2008) also of assigned amount units (AAUs).
Source: World Bank (2009b).

The EU-ETS accounts for approximately USD 92 billion of trading through the transaction of allowances and derivatives for compliance, risk management, arbitrage, raising cash and profit-taking purposes. The second-largest segment of the carbon market is the CDM secondary market for Certified Emission Reductions (CERs). This is a financial market with spot, futures and options transactions in excess of USD 26 billion. This secondary CDM market has grown fastest in recent years, with an almost fivefold increase in both value and volume in 2008 compared to 2007.

For the first time since the start of the international carbon market, transactions financing CDM projects fell by 30% by volume and 12% by value in 2008. JI projects also experienced a severe drop. This was the result of difficulties in obtaining financing for climate-friendly projects during the financial crisis, of regulatory delays and of uncertainty surrounding the future of the market under the new global climate change agreement that had been expected to be agreed in Copenhagen in December 2009.

The emergence of these markets at multiple levels, each with their own drivers and prices, demonstrates that carbon markets are likely to have an important role to play in achieving significant greenhouse-gas emissions reductions. Two types of carbon market have emerged:

- Markets induced by cap-and-trade regimes, such as the Kyoto Protocol or the EU ETS. In these markets, transactions are allowance-based.
- Markets induced by the projects implemented under the JI and CDM. In these markets, transactions are project-based.

Allowance-based markets

New emissions trading systems are developing or being proposed in several regions and countries. While some have already defined rules, others have not yet finalised their detailed approach. Lessons are being learned from the early years of existing schemes.

The EU-ETS currently covers the 27 EU member states and about 40% of the total EU greenhouse-gas emissions. In December 2008, the European Council and the European Parliament endorsed an agreement on climate change and energy, which implements a political commitment by the European Union to reduce its greenhouse-gas emissions by 20% by 2020 compared to 1990 levels.[6] The EU-ETS will play a pivotal role in achieving this target as the 2020 cap for ETS installations is 21% below the actual level of 2005 emissions.[7]

Several other trading systems are being developed, including in countries that are not Parties to the Kyoto Protocol. In the United States, the first regional scheme, the RGGI in the north-eastern states, began on 1 January 2009. Others are in discussion, such as the Western States Climate Action Initiative. On 26 June 2009, the House of Representatives passed an American Clean Energy and Security Act. If passed by the Senate, this would create a cap-and-trade programme covering 85% of US greenhouse-gas emissions, including in the power, industry, transport, commercial and residential sectors. The targets are set against 2005 emission levels at a 3% reduction by 2012, 17% by 2020, 42% by 2030 and 83% by 2050.

In New Zealand, the government announced an emissions trading system (the NZ ETS) in September 2007 which aimed to have all the major greenhouse-gas emitting sectors included in the scheme by 2013. The scheme envisaged the unlimited use of Kyoto Protocol project credits. The NZ ETS, which currently only covers the forestry sector, started on 1 January 2008. The new government that came into place in 2008 established a committee to review the NZ ETS. A revised law was passed in November 2009.

Since 2008 the Australian government has been working on plans to establish an emissions trading scheme (the so-called "Carbon Pollution Reduction Scheme [CPRS]") as a key mechanism to transition Australia to a low greenhouse-gas emission future. The proposal includes broad coverage of greenhouse-gas emissions and sectors, covering around 75% of Australian greenhouse-gas emissions, a mix of direct and upstream point of obligation and assistance to help households and business adjust. The emission threshold for direct obligations under the scheme would apply to entities with facilities which have direct emissions of 25 000 tCO_2 equivalent per year or more. If enacted, existing trading systems like the New South Wales Greenhouse Gas Reduction Scheme would be replaced by this more comprehensive system. The House of Representatives passed the CPRS Bill 2010 (and associated Bills) in February 2010, however further consideration of the legislation has been deferred and the scheme will not now be implemented until at least 2013.

The government of Canada is committed to reducing Canada's total greenhouse-gas emissions by 17% from 2006 levels by 2020 and by 60% to 70% by 2050. The creation of a carbon market is part of the government's commitment to reduce emissions. In June 2009, the Canadian government published new guidelines for Canada's Offset System for Greenhouse Gases. The domestic offset system is an important step in the creation of a carbon market in Canada, establishing tradable credits for greenhouse-gas reductions and encouraging cost-effective domestic emissions reductions in areas such as forestry and agriculture that will not be covered by planned federal regulations. Under the proposed regulations, firms will have several options to meet their compliance obligations. These include domestic offset credits and emissions trading as an important component of the

6. A 30% reduction target is proposed if others adopt equally ambitious mitigation objectives.
7. For a detailed description and analysis of the EU-ETS first phase, see Ellerman, Convery and de Perthuis (2010).

government's market-driven approach to reducing greenhouse-gas emissions. The Canadian government has indicated that it will continue to monitor United States developments to ensure harmonised rules.

In September 2008, Japan unveiled an outline of a greenhouse-gas ETS, which was launched on a trial basis in October 2008. Initially, the system is voluntary and Japanese companies are allowed to set their own emissions reduction targets. In addition to allowance trading, companies will be able to use CDM credits, national offset credits and credits from Japan's voluntary emissions trading scheme. In September 2009, the Japanese Prime Minister committed to mobilise all available policy tools including a domestic emissions trading mechanism.

Project-based markets

The Kyoto Protocol established two project-based mechanisms, the CDM and JI. JI had a much slower start than the CDM as the CDM allowed CERs to accrue from projects from 2000 onwards. This created a good deal of interest, particularly after the entry into force of the Kyoto Protocol in 2005.

The CDM has successfully used market mechanisms to identify cost-effective emissions reductions. It has also raised awareness in developing countries. Between 2004 and 2007, CDM projects grew by a factor of more than 8 in terms of volume, and almost 27 times in terms of financial value. In 2008, the World Bank reported that the CDM had initiated transactions for 389 Mt CO_2 equivalent. The secondary CDM markets covered transactions worth an additional 1 072 Mt CO_2. Together these transactions were worth a total of USD 32.8 billion. In February 2010, the United Nations Environment Programme Risø CDM/JI Pipeline indicated that a total of 4 926 CDM projects were under consideration, covering a wide range of categories and industries. Only 41% of these projects had been registered by the CDM Executive Board; most (55%) were still at the validation stage. Of the registered projects only 26% had been issued with CERs. The very large increase in CDM projects over recent years appears to have intensified problems in the registration of projects and the issuing of CERs.

Of all the projects currently submitted,[8] more than 79% are in the field of renewable energy. These are expected to receive over a third of the CERs up to 2012. Projects to reduce hydrofluorocarbons, perfluorcarbons and nitrous oxides are expected to secure almost 29% of the cumulative 2012 CERs, although they account for only 2.3% of the projects. Categories like fuel switching, afforestation and reforestation or transport are only marginally involved. Most projects (76%) are located in Asia and the Pacific region. These are expected to receive 80% of the cumulative CERs up to 2012, delivering emissions savings of 2.1 Gt CO_2-eq. China and India have the largest number of projects. China would host 36% of the currently submitted projects, equivalent to 54% of the expected CERs up to 2012, accounting for emissions savings of 1.4 Gt CO_2-eq. India also has a large share of the submitted projects (28%), but these projects are expected to attract only about 15% of the expected CERs up to 2012, achieving emissions reductions of 0.4 Gt CO_2-eq. Least developed countries only have 1% of the submitted projects,

8. Withdrawn or rejected projects are not counted.

accounting for 1% of the expected cumulative CERs up to 2012, and emissions savings of 0.03 Gt CO_2-eq.

The outlook for carbon finance

The economic downturn and the consequent drop in CO_2 emissions have lowered carbon price expectations in the short term. The uncertain outcome of COP-15 has also reduced confidence in the longer-term prospects for carbon trading. Uncertainties around the timing of any potential cap-and-trade legislation in the United States are an additional negative factor. Even so, global carbon markets have continued to expand. This suggests that carbon finance has gained a momentum of its own, with strong incentives for interested stakeholders.

Carbon markets have shown that they can drive significant emissions reductions worldwide. The development of domestic and regional trading systems has created carbon prices that have already played an important role in supporting investment in abatement measures. But the levels of investment driven by the carbon market to date are insufficient to meet ambitious climate policy goals. To pave the way for an expansion of the carbon market, scaled-up market mechanisms are needed that can cost-effectively support larger-scale emissions reductions in developing countries.[9]

The Copenhagen Accord provides little guidance on the likely use of market mechanisms after 2012. The Accord only states that various approaches will be pursued to enhance cost-effectiveness and promote mitigation action, including the use of markets. This statement keeps the door open both for existing market mechanisms such as the CDM as well as for new market mechanisms. The lack of a clear signal to the carbon market may, at least in the short term, have a negative impact on the role of carbon finance in incentivising lower-greenhouse gas developments. The outcome of COP-15 has also created uncertainty around the precise role of the UNFCCC in delivering any new climate change architecture, adding to uncertainty over the continuation of the CDM and JI mechanisms beyond 2012 at least in their current forms.

Even so, one of the most concrete outcomes of the Copenhagen negotiations was a decision achieved at the meeting of the Parties to the Kyoto Protocol on its fifth session (CMP5) on the enhancement of CDM processes, aimed at improving the future functioning of the CDM. This decision includes requirements to strengthen transparency, to improve the timeliness of the registration and issuance processes, to develop modalities and procedures for standardised baselines and guidance on how to account for national environmental policies, and to tackle issues related to the regional distribution of projects.

From an economic perspective, progressive evolution in the carbon market is welcome insofar as it meets expectations on the demand and supply sides, and reflects the environmental imperatives and political realities of global mitigation. Preliminary estimates show that the potential supply of emissions reduction credits could be much larger than demand, depending on how quickly sectors and countries establish sectoral objectives and achieve mitigation.[10] Discussions in several

9. For an overview of these proposed mechanisms see IEA (2009c), www.oecd.org/env/cc/sectoral.
10. For a detailed discussion see IEA (2009d), www.oecd.org/env/cc/sectoral.

countries suggest that there may be hard limits on the demand side. If so, scaled-up mechanisms will need to be designed carefully in order to avoid a low-carbon price and possible carbon lock-ins that would make it more difficult or expensive to achieve deep reductions in later years. Introduction of price floors in carbon markets could be a possible solution to ensuring that carbon prices are sufficiently high to attract investments in low-carbon technologies. To make best use of carbon finance in any post-2012 climate architecture, market-based instruments should be combined with targeted policy measures that are able to ensure that the support for mitigation in developing countries helps them meet their development goals.[11]

Financing options for an energy technology revolution

A number of other approaches can be adopted to fund low-carbon energy technologies including direct government finance and private-sector finance. As the largest share of funding will come from the private sector, governments need a better understanding of how these markets operate so that they can design appropriate regulation and policy measures to attract that funding.

Different funding approaches will work best at different stages of technology development (Figure 14.9). Government funding is most relevant for early-stage technology development, while private finance tends to focus on later-stage technology deployment and commercialisation. The size of the different investment requirements for the different stages of technology development is roughly captured by area represented in the pyramid.[12]

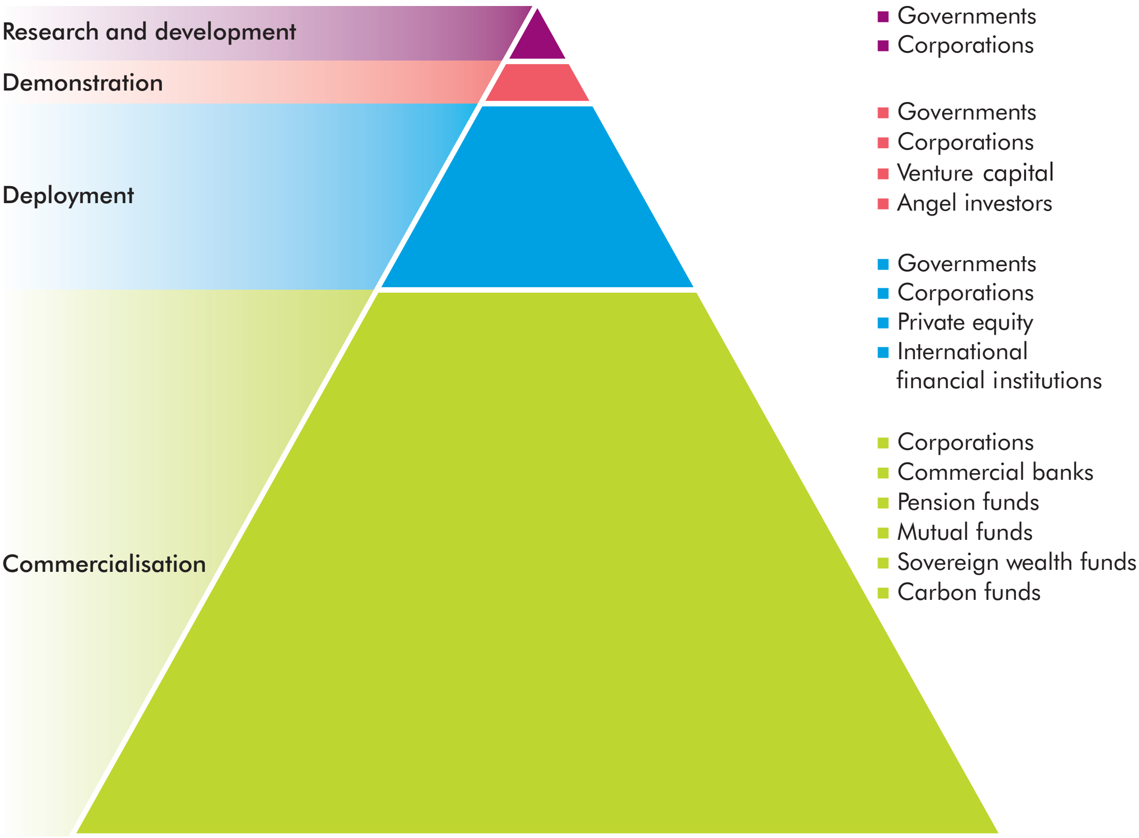
Private-sector finance

Private-sector finance can come through company cash flow generation, equity finance and debt finance. Debt finance includes a wide range of options including bank loans, bonds, project finance and supplier credits. Project finance is particularly attractive as a means of financing new power generation as debt investors lend to a single-purpose entity whose only asset is the new plant. Developers can thereby raise larger quantities of debt without impacting on the company's debt to equity ratios. And lenders get their loans repaid once the project is operational. Equity finance raises money for company activities in exchange for ownership interest in the company. Equity financing is more expensive than debt financing for corporations as the associated risks, and therefore the required returns, are higher for equity than for debt.

An important share of the investment in low-carbon energy technologies will come from large corporations. They will fund these investments from the internal cash flow from their operations and from debt and equity raised in the capital markets.

11. For a discussion of this approach see Baron and Buchner (2009). For an application of the approach in the energy sector see IEA (2009b).
12. The actual share of investments needed at each stage of technology development differs significantly from one technology to another, but in general investment needs rise as technology moves from R&D to demonstration, to deployment, to commercialisation.

Figure 14.9 ▶ Funding options for different stages of technology development



Key point

Investment needs rise significantly as technologies move along the innovation chain.

Box 14.2 ▶ Debt financing options

Companies can raise money from a variety of debt (loan) instruments to finance their operations. Financial institutions agree to lending money to a company in exchange for a promise to repay the capital plus interest. The cost of the debt to the company is the interest charged on the loan, the level of which will in part reflect the level of risk that the debt will not be repaid.

***Senior debt**: is debt which has priority for repayment over unsecured or subordinated debt. Banks provide finance to companies to fund operations.*

***Mezzanine or subordinate debt**: is debt which will be repaid after senior debt has been repaid if a company is unable to fully service its liabilities. Subordinated debt is more expensive than senior debt because the risk of default is higher. It is used when the level of senior debt available has been surpassed. The cost of a mezzanine loan is less than issuing equity to finance investments and therefore offers higher rate of returns for a project.*

***Project finance**: money is borrowed to fund a specific project with repayment due from project revenues only once the project is operational. The amount of debt available is linked to the projected future revenues of the project.*

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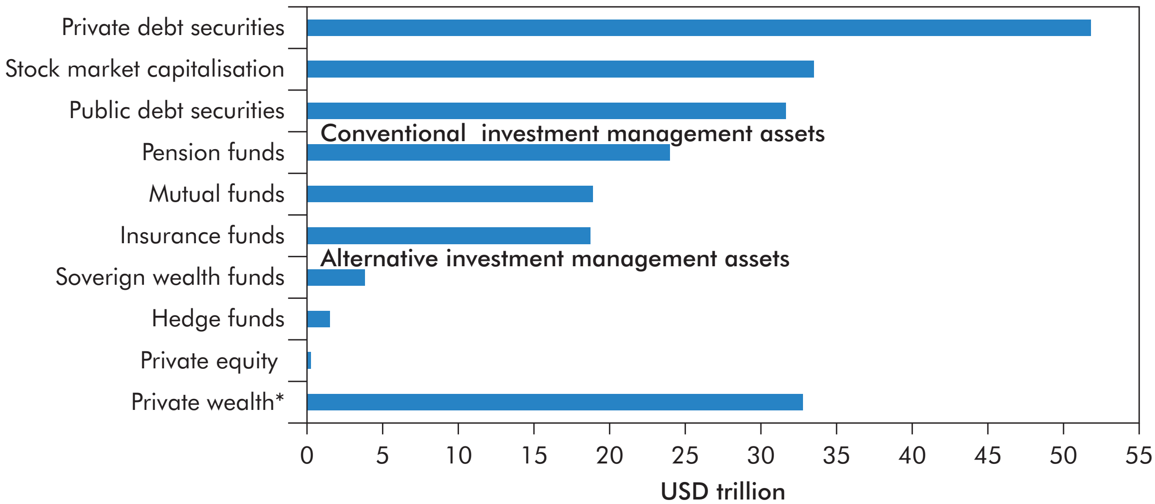
Smaller corporations often have a leading role to play in developing and bringing new technologies to market, but lack the financial muscle to deploy and commercialise their developments. For this they need the support of larger corporations which have greater access to affordable financing for the scale of investments needed. Smaller firms may seek to form partnerships with large established energy companies to help them deploy their new technologies. Governments should also design and implement policies aimed at helping small- and mid-size companies gain access to affordable financing.

The borrowing capacity of the energy market is potentially very large. For example, the current market capitalisation of the global electricity generation market is estimated at USD 1.5 trillion to USD 2 trillion. If this is leveraged by a factor of two or three, a not unreasonable assumption given the relative financial stability of utilities, a total of USD 3 trillion to USD 6 trillion could potentially be raised by utilities to fund investments. Companies will only support investments in low-carbon technologies if sufficient returns from these investments seem likely to be realised.

Global fund management industry

In 2008, the global fund management industry had approximately USD 90 trillion of assets under management (Figure 14.10). The largest share of these funds comes from the United States (approximately USD 30 trillion), followed by the United Kingdom (USD 8 trillion). Conventional funds, including pension, mutual and insurance funds, accounted for about two-thirds of the assets under management. Alternative funds, dominated by private wealth assets, sovereign wealth funds (SWFs), private equity funds and hedge funds, make up the remaining USD 30 trillion. A further USD 33 trillion of private wealth is available, about one-third of which is incorporated in conventional investment management. Different types of investors have different risk and return profiles (Box 14.3).

Figure 14.10 ▶ Global assets, 2008



Note: Approximately one-third of private wealth is invested in pension and mutual funds.
Source: IFSL (2009).

Key point

Conventional funds account for about two-thirds of the assets under management.

Box 14.3 ▶ Investment profiles for different classes of equity investor

Equity investments are direct investments made by investors in exchange for a share of the ownership in a company or project. Different types of equity investors can be classified according to the level of risk they are willing to take and the types of investments in companies they finance. Investments in early-stage companies are inherently more risky with most failing to reach deployment. In these circumstances, extremely high returns are required. In contrast, investments in mature companies are less risky, but also offer significantly lower returns.

Classifying investors by reference to their appetite for risk, from the highest risk takers to the most risk-adverse, investors can be seen to fall into 8 main types:

***Angel investors** are individuals who provide capital for business start-ups, usually in exchange for a stake in the company. Their investment horizon is usually 5 to 7 years. They seek very high returns of at least 10 times their initial investment over its lifetime. Angel investors invest their own capital.*

***Venture capital funds** are raised from a wide range of sources with high risk appetite, and are generally used to finance new technology development. Their focus is on early-stage company development and funds are provided in exchange for equity in the company. The investment horizon ranges from 4 to 7 years. There is a high risk of failure, so venture capital funds seek internal rates of return (IRR) of 50% to 500%.*

***Private equity funds** are raised from a wide range of sources with medium risk appetite. They are used to finance more mature technology, demonstrator companies or under-performing companies. Their investment horizon is shorter, typically 3 to 5 years. They seek a relatively high IRR of 25 to 50%.*

***Mutual funds** are professionally managed collective investment schemes that pool money from different shareholders for investments in a variety of instruments similar to those of pension funds. They have a medium to low risk appetite and seek IRRs of around 15%.*

***Sovereign wealth funds** are state-owned investment funds from countries with large foreign reserve surpluses. These funds invest in a wide range of financial assets aimed at increasing the return on their excess foreign reserves. Investment horizons are medium to long term. Their risk appetite is medium to low. They seek IRRs of around 15%.*

***Infrastructure funds** are raised from institutional investors and pension funds to invest in essential assets with long life spans such as electricity networks, power plants, highways and rail systems. These investments generally provide low-risk, stable cash flows. Investment horizons are medium term from 7 to 10 years. Such funds seek IRRs of 10% to 15%.*

***Insurance funds** represent insurance premiums paid and are invested by insurance institutions in order to meet the liability at maturity. The majority of these funds are from long-term insurance policies. They have a low risk appetite and seek IRRs of approximately 10%.*

***Pension funds** are pooled assets from contributions to pension plans. Investments are made in a wide range of instruments including public equity via stock markets, corporate and government bonds, real estate, and other assets such as infrastructure and commodities which can generate a stable income stream. They have a low risk appetite and seek IRRs of approximately 10%.*

The transition to a low-carbon economy will depend on significant funding being made available by the private sector. The global fund management industry will need to contribute a significant share of this funding. Investments by the industry into low-carbon technologies were USD 162 billion in 2009, about 20% of the total investment of USD 650 billion to USD 750 billion in the energy sector. Current financial flows from the global fund management industry into low-carbon technologies are relatively small, but there is growing interest among institutional investors to move a larger share of their portfolios into this area. This could be achieved either by investing directly in clean technology companies or through investments in large companies which have significant investments in these companies.

Pension funds account for the largest share (39%) of conventional investment management assets (Table 14.9). These are pooled assets from contributions to pension plans that are used to finance pension plan benefits. Mutual funds are professionally managed collective investment schemes that pool money from different shareholders for investment in a variety of financial instruments. Insurance assets represent insurance premiums paid to insurance companies.

Given the large sums managed by insurance companies, pension and mutual funds, a growing share of future investments in low-carbon technologies will need to be funded by these institutional investors if the funding needed to transition to a low-carbon energy sector is to be secured.

Table 14.9 ▶ **Conventional investment assets, 2007**

USD bn	Pension funds*	Insurance assets	Mutual funds	Total conventional	% share
United States	15 255	6 120	9 601	30 976	50
United Kingdom	2 658	2 576	505	5 739	9
Japan	787	2 555	575	3 917	6
France	144	2 007	1 591	3 742	6
Germany	109	1 692	238	2 039	3
Netherlands	810	444	77	1 331	2
Switzerland	404	356	135	895	1
Other	3 833	2 960	6 195	12 988	21
Total	**24 000**	**18 709**	**18 917**	**61 626**	**100**

Note: Figures are for domestically sourced funds regardless of where they are managed.
* IFSL estimates based on OECD and Watson Wyatt data.
Source: IFSL (2009).

Conventional funds are best suited to finance projects which are mature and can show a stable income stream. Funds which look for higher returns are better suited to the earlier-stage financing of technology companies. Many funds are not currently set up to invest in alternative energy assets. More education is needed to promote the advantages of clean energy investments to fund trustees both from an investment viewpoint as well as from sustainability. Pension and mutual funds can influence the direction of investments made by companies they own. They should also therefore be encouraged to commit more of their funds to sustainable investment.

Private wealth

In 2007, there were just over 10 million high net-worth individuals (defined as those with over USD 1 million of assets) and over 100 000 ultra high net-worth individuals (defined as those with over USD 30 million of assets). Together, these individuals had total assets under management of USD 15 trillion (Merrill Lynch Capgemini, 2008). These investors make up approximately 17% of the fund management industry. In a 2008 survey by Merrill Lynch Cap Gemini, 12% of high net-worth investors and 14% of ultra high net-worth investors said they allocated part of their portfolio to green technologies and alternative energy sources.

A number of the wealthiest, including Bill Gates and George Soros, have already committed to helping support investments in low-carbon technologies. Some have set up special foundations to support a wide range of philanthropic activities including support for mitigating climate change. The Energy Foundation, a partnership of major donors including some of the largest foundations, provides support to institutions for advancing new energy technologies. Greater collaboration with, and directed promotion of low-carbon technologies to ultra high net-worth individuals could help to spur additional funding. These investors also have significant influence over pension fund managers and trustees.

Sovereign wealth funds

Countries with large foreign reserve surpluses, particularly those in Asian and oil-producing countries, aim to increase the return on their excess reserves by managing their foreign reserves more actively under special SWFs. More than 60% of the funding of SWFs comes from the export of oil and gas. Funding from the export of non-commodity goods, especially in China, Singapore and Hong Kong also makes up a large portion of SWFs.

Current assets under management by SWFs are estimated at USD 3.8 trillion. As funds under management grow, SWFs are looking at new areas for investment. Low-carbon energy technologies can offer these funds an attractive natural hedge to their oil and gas assets. The medium- to long-term investment horizon of SWFs fits well with the investment characteristics of most low-carbon technologies.

Table 14.10 ▶ Largest ten sovereign wealth funds by assets under management, October 2009

Country	Fund name	Assets USD billion	Origin of funds
UAE - Abu Dhabi	Abu Dhabi Investment Authority	627	Oil
Norway	Government Pension Fund – Global	445	Oil
Saudi Arabia	SAMA Foreign Holdings	431	Oil
China	SAFE Investment Co.	347	Non-commodity
China	China Investment Corp.	289	Non-commodity
Singapore	Government of Singapore Investment Corp.	248	Non-commodity
Kuwait	Kuwait Investment Authority	203	Oil
Russia	National Welfare Fund	179	Oil
China	National Social Security Fund	147	Non-commodity
Hong Kong	Hong Kong Monetary Authority Inv. Portfolio	140	Non-commodity
Total oil and gas related		**2 246**	
Total other		**1 566**	
TOTAL		**3 812**	

Source: WFI (2010).

14

Public finance mechanisms

Public finance mechanisms of various kinds have been used to successfully promote investments in the development and deployment of energy efficiency and renewable energy technologies (Table 14.11). These mechanisms help to overcome market barriers by enabling governments to share risks with the private sector and can help bridge funding gaps which occur along the technology innovation chain. Public financing mechanisms can help to leverage commercial financing by a factor of 5 to 15 (UNEP SEFI, 2008).

Table 14.11 ▶ **Examples of public finance mechanisms used to support investments in clean technologies**

Mechanisms	Description
Credit lines	to local commercial financial institutions (CFI) for proving both senior and mezzanine debt to projects
Guarantees	to share with local CFIs the commercial credit risks of lending to projects and companies
Debt financing	of projects by entities other than CFIs
Private equity (PE) funds	investing risk capital in companies and projects
Venture capital (VC) funds	investing risk capital in technology innovations
Carbon finance	facilities that monetise the advanced sale of emissions reductions to finance project investment costs
Grants and contingent grants	to share project development costs
Loan softening programmes	to mobilise domestic sources of capital
Inducement prices	to mobilise domestic sources of capital
Technical assistance	to build the capacity of all actors along the financing chain

Source: UNEP SEFI (2008).

Public or government funding will be particularly important to support early technology development and demonstration where high technology risks limit the availability of investment capital from the private sector. Direct investments by governments in venture capital and private equity funds could help to more efficiently distribute innovation funding. Venture capital investments are usually around USD 5 million to USD 10 million in size. Private equity transactions are usually larger than USD 50 million to USD 100 million. Government funding may also be warranted for project development where the investment is too small to attract private investors owing to the high transaction costs linked to each individual investment.

The development of "green banks" or specialty banks for the financing of low-carbon energy technologies is an option that is being discussed in a number of countries. These special-purpose financing institutions would provide loans to support the early-stage development of clean energy companies. Initial capitalisation for these banks would come from government funds.

Export credit agencies (ECAs)

Since 2000, ECAs have supported annually on average more than USD 80 billion of investment, either through loans or loan guarantees. Within this total, support for medium- and long-term projects with repayment terms of 5 years or more amounted to USD 30 billion per year. Projects in the energy generation and distribution sectors represented on average 10% of these medium- and long-term projects. Financing from ECAs could play an important role in the future funding of low-carbon technologies, particularly in countries where credit is tight or where domestic banks are unwilling to finance new technologies.

ECAs offer credit insurance or guarantees or act as direct lenders to importers on behalf of governments. In doing so, they facilitate the export of capital goods and related services, in particular in sectors such as infrastructure, transport, manufacturing, energy production or distribution facilities. Since 2008, they have been helping to fill an important funding gap created by the current credit crisis which has sharply reduced the funding available for investments in low-carbon technologies.

Almost all exporting countries have at least one ECA, which plays a counter-cyclical role especially during moments of financial crisis when private market export financing becomes a scarce resource. ECAs have the capacity to extend medium- and long-term insurance or financing. Financial terms and conditions are regulated internationally, primarily through the Arrangement on Officially Supported Export Credits (AOSEC) (OECD, 2009).

The OECD has also offered a forum in which environmental guidelines relating to ECAs underwriting projects in sensitive sectors or sensitive areas have been agreed and implemented. Specific financial terms and conditions have been agreed for the involvement of ECAs in the support of projects in nuclear (Sector Understanding on Export Credits for Nuclear Projects [NSU]) and renewable energies and the water sector (Sector Understanding on Export Credits for Renewable Energies and Water Projects [RSU]). The RSU and NSU include repayment terms of up to 18 years and more flexible repayment schedules, together with a revised fixed interest rate regime for longer-term loans.

The RSU is designed to support renewable energy sources such as solar, wind, biomass and hydropower in preference to traditional energy projects using fossil fuels, for which stricter financial terms and conditions apply. The OECD is reviewing the RSU to broaden its scope to include climate change mitigation projects including those involving improvements in energy efficiency.

Individual underwriting decisions as well as portfolio management strategies remain in the hands of each ECA or its guardian authorities. With their financial capacity to support large capital-intensive transactions, ECAs can influence other credit providers. Within the limits of internationally agreed disciplines, any government or ECA can decide to facilitate the export of certain goods or services deemed to be more environmentally-friendly, or be more generous to low-carbon projects by offering more favourable terms.

Risk and returns

Of the USD 46 trillion in total additional investments needed to transform the energy sector, an estimated USD 20 trillion will need to be financed by large corporations and the international financial markets. Projects seeking to secure this investment capital will need to compete in the market place with other private and public competitors for capital. Similarly, within corporations, projects will need to compete with each other for limited corporate capital.

Cost of debt and equity

A company's cost of debt is its cost of borrowing money to fund investments. This reflects a risk premium based on an assessment of the likelihood that the company will default on its loan. This assessment will depend on a number of factors including the company's current debt level, its projected income stream and cash flow, and its relationship and reputation with the commercial banks. New lenders who do not have established banking relationships generally find it more difficult to raise finance than established lenders with good long-term repayment records. In times of low liquidity such as those that have existed since late 2008, large corporations often benefit from greater access to capital.

A firm's cost of equity is the minimum return on investments which shareholders require. In general, it is more expensive for a firm to raise equity finance than debt finance as the risk associated with holding shares in a company is greater than that of holding debt in a company.[13]

Risk versus return

When evaluating the future returns of a given project, investors and corporations judge the value of future income streams from the project by estimating its future revenues and cost streams. A discount rate is applied to the projected income based on the perceived risk of the project or the probability that the estimated income streams will fail to materialise. The higher the perceived risk of a project, the higher the discount rate applied. A risky project needs to be able to project higher profitability if it is to be competitive with lower-risk projects against which it may be competing for capital.

Governments generally apply a lower discount rate than private companies since governments can borrow more cheaply than companies. In addition, investments in the private sector generally require a much higher return than investments made by governments. Relatively low societal discount rates of around 3% are often used to analyse investment choices by governments. In the private sector, discount rates closer to 10% to 15% (or higher for particularly risky investments) are often applied to reflect private-sector costs and required returns.

13. In the case of a firm's liquidation, a company's debt holders are repaid first and any remaining assets after the repayment of all debt is then divided among its shareholders.

A number of factors will be considered by investors when considering projects in the power generation sector (Table 14.12). These will affect the risks associated with the successful completion of projects, and their costs and benefits in operation. The overall level of risk will affect the discount rate applied, and hence investors' assessments of the current value of the likely returns on their investment.

Table 14.12 ▶ Factors affecting perceived risk for various power generation projects

	Fuel price risk	Permitting and licensing	Grid connection	Construction time	Public acceptance	Rate structure (assuming no feed-in tariffs)	CO_2	Technology
Onshore wind	None	Medium	High	Medium	High	Medium-high	None	Medium
Offshore wind	None	Medium	High	High	Medium-high	Medium-high	None	High
Photovoltaic	None	Low-medium	Medium	Low	Low	Low	None	High
Concentrating solar power	None	Low-medium	Medium	Medium	Low	Low	None	High
Nuclear	Low	Medium-high	Low	Very high	High	Medium	None	Medium
Natural gas combined cycle	High	Low	Low	Low	Low	Low	Medium	Low
Coal-fired	Medium-high	Low-medium	Low	Low	Medium	Low	High	Low
Fossil with carbon capture and storage	High	Medium-high	Low	Medium	Medium-high	Low	Low	High
Biomass	High	Low	Low	Medium	Low	Low	None	Medium
Geothermal	None	Low-medium	Medium-high	High	Low	Medium	None	Medium-high
Small hydro	None	Low	Medium	Low	Medium	Low	None	Low
Large hydro	None	High	Low	High	High	Low	None	Low

Note: Country risk is also important, but a factor that affects all technologies.
Source: IEA analysis based on discussions with various financial institutions.

Reflecting these risks, different technologies are observed to be subject to different discount rates (Table 14.13).

Table 14.13 ▶ Observed discount rates by project type

Offshore wind	12-15%
Onshore wind	10-12%
Photovoltaic	10-12%
Concentrating solar power	10-15%
Geothermal	10-12%
Nuclear	10%
Large hydro	8-10%
Small hydro	8-10%
Natural gas combined cycle	7-8%
Coal-fired plants	7-8%

Source: IEA analysis based on discussions with various financial institutions.

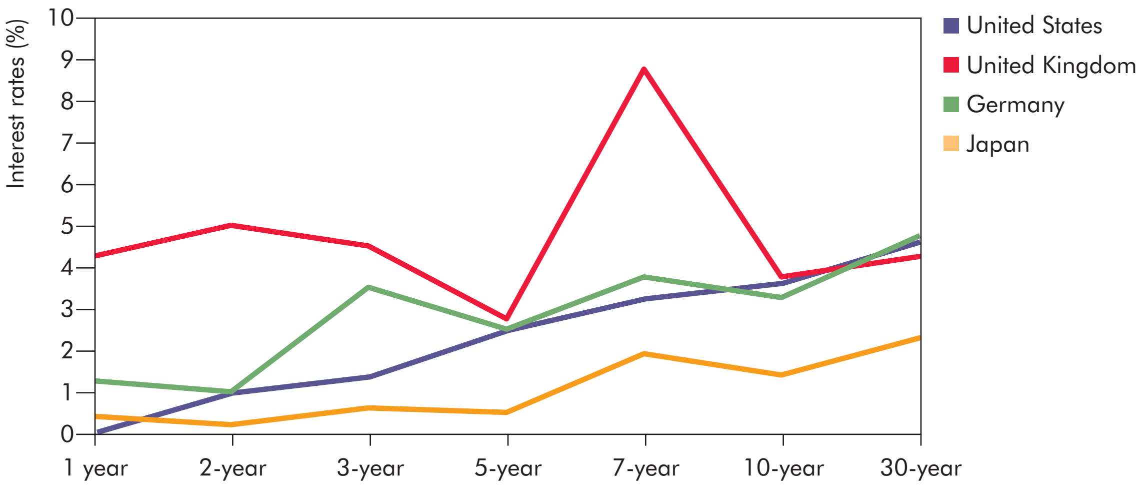
Fossil-fired technologies are already well proven. They also have shorter construction times and lower capital costs. As a result, they are subject to significantly lower discount rates than renewable power generation technologies other than hydro. Fossil-fired technology projects therefore find it easier to attract capital investment than renewable projects. As the power market evolves and more renewable technologies enter the market, the cost of these technologies should fall and confidence should rise in their performance. Discount rates for renewable technologies should therefore fall over time. And the discount rates for fossil-fired technologies, particularly those based on coal combustion without CCS, can be expected to rise to reflect the higher cost of CO_2 emissions.

Required returns

For a project to attract funding it must exceed a company's cost of capital which is the cost to the company of raising debt or equity funding. The cost of debt can be calculated from the cost of government bonds plus a default premium. Interest rates on government bonds depend on the length of the period over which the loan is taken (Figure 14.11). The cost of equity is the cost of the risk-free rate (government bond) plus a premium for the expected risk.

The IRR of renewable energy projects needs to be higher than 10% to justify the higher risks associated with these investments. Given the large amounts of capital needed to finance the transition to low-carbon technologies, returns will need to be high enough to attract limited capital to these investments. Governments have at their disposal a range of policy and financial instruments, including loan guarantees, feed-in-tariffs, co-financing and tax credits, which they can deploy to help reduce the level of perceived risk for low-carbon generation projects.

Figure 14.11 ▶ Interest rates on government bonds (at 6 April)



Source: Bloomberg database.

Key point

The cost of debt and required returns varies across different countries.

Policy needs

A long-term integrated policy framework is needed

Many of the most promising low-carbon technologies currently have higher initial costs than their fossil fuel competitors. Research, development, demonstration and deployment (RDD&D) is needed to lower these costs. A stable global carbon price will probably need to form the cornerstone of any successful policy in the longer term, but will not be sufficient by itself. It will need to be complemented by an integrated framework of other policies and measures. To be most effective, technology support policies need to evolve as a technology matures from the research stage to full commercialisation (see Chapter 12).

In parallel, governments need to address regulatory frameworks, such as planning and permitting systems, that create barriers to new low-carbon technologies. Public acceptance barriers also need to be overcome, for example through educating the public on the benefits of low-carbon technologies.

The development of a low-carbon economy will depend heavily on business. Many new businesses will be developed and old ones transformed. Regulation and market conditions will need to ensure that businesses and investors along the entire spectrum from RDD&D to commercialisation can secure high enough returns to justify the risk of the technology underperforming or failing at any step. The time required to develop and deploy many of the technologies needed for the energy technology transition is generally much longer than the investment horizon of most businesses and investors.

Policy predictability will be important. Policy uncertainty raises investor risk. Governments need to minimise this risk so that investors can be confident of policy stability over a longer payback period and consequently be prepared to finance a larger proportion of the needed investments. Current carbon prices are not sufficiently high or stable enough to attract the scale of the investment that is needed in new technologies. For investors, a higher and more certain carbon price would help to remove uncertainty from the carbon markets and make investment more attractive.

Many investors have already recognised the importance of climate change and a number of different initiatives such as the Institutional Investors Group on Climate Change (IIGCC), the Investor Network on Climate Risk (INCR) and the UNEP Financial Initiative have been created to promote the importance of climate change within the investment community. These initiatives are encouraging, but more active engagement between governments, industry and the financial community is needed.

Venture capital and private equity markets could help governments more effectively to distribute innovation funding. Many national governments have extensive R&D programmes for low-carbon technologies, but these technologies often fail to make the transition from the laboratory to commercialisation. Greater collaboration between government R&D institutions and the financial community can help to advance the commercialisation of these technologies. The United States Entrepreneur in Residence programme is a good example of collaboration between government and venture capital experts working together to commercialise technologies that have been developed at national laboratories.

As new technologies move from demonstration to deployment, partnerships with large incumbent energy companies will help to raise the necessary levels of funding required for firms to scale up. In the current tight financial markets, access to affordable capital may determine whether a firm will succeed or fail. The ability of governments to fund the needed energy technology transition will be limited. Governments will need to develop coherent strategies to determine which areas of R&D they should fund, and which can be left to the private sector. Some funding will also be needed for the demonstration of capital-intensive technologies such as CCS.

Governments and industry should increase public education and raise awareness of climate change issues in the financial community. They should promote low-carbon investment opportunities to the public and private pension funds as well as to SWFs and help educate them on the strategic rationale for investment in low-carbon technologies. Many funds today are not currently set up to invest in the types of financial instruments most commonly used to fund investments in low-carbon technologies. For example, many funds can only invest in the public equity market and are not able to make direct investments or invest in the sort of debt instruments which represent the majority of current funding for low-carbon technologies.[14]

A number of different tax measures, including modified capital gains taxes, tax credits, tax exemptions or lower rates of tax for reinvestment in low-carbon technologies could help stimulate investment. In the United States, the tax credit scheme for low-carbon technologies has been the most effective instrument to increase financial flows to the sector. It has allowed many financial institutions with large tax liabilities to make large equity investments in projects at significantly lower required returns. Some of these have been funded at rates of return even as low as 5% to 6% as a result.

Market structure

The decarbonisation of the power sector will require additional investments of USD 9.3 trillion from 2010 to 2050, a 40% increase compared to the Baseline scenario. Securing such a high level of additional investments will be challenging in any market, but it will be particularly so in competitive power markets where generation has been unbundled from distribution and supply. In such markets, investment timeframes are generally very short compared to the time that is needed to plan, permit, build and start to operate a new renewable or nuclear energy plant. In contrast, vertically integrated power utilities can assume relatively lower levels of risk as they can virtually guarantee their ability to sell the power they generate through their own distribution networks.

The experience of competitive power markets has shown that investors' decisions are based on the shorter investment timeframes that favour new investment in

14. Additional information can be found in the summary of the workshop on Financing the energy technology revolution hosted by HSBC on 13 May 2009 in London (IEA, 2009a).

Natural gas combined cycle plants or coal plants with lower capital investments and shorter payback periods, rather than in renewable energy projects. As a result, competitive power markets are less amenable to the investments in nuclear and renewable power that will be essential in decarbonising electricity generation. Many doubt whether the current competitive market structures will be able to deliver a decarbonised power market in the timeframe needed to combat climate change.

Financing renewables

Achieving the BLUE Map scenario will require investments in renewable power generation to be half of all investments in power generation over the next 40 years. An estimated USD 12 trillion will be required for investments in renewable power generation to reach 5 700 GW of installed capacity by 2050, a fourfold increase compared to current levels (nearly fourteenfold excluding hydro). A switch from traditional power generation technologies to a greater share of renewables will significantly increase the financing needs of utilities since renewable power has higher upfront capital costs. Many renewable energy technologies require either incentives to attract investment or mechanisms to value the CO_2 and other environmental benefits they offer.

A number of other factors may particularly impede the financing of renewable energy projects. These may be inherent in the type of technology in question, or may vary according to project location. For example:

- A higher proportion of the cost of a renewable project is often incurred upfront than is the case with conventional, fuel-based technologies.
- Some renewable energy resources, such as wind and concentrating solar power, may be located far from demand centres. This increases the cost of interconnection. The allocation of grid connection costs is an important factor in investment decisions.
- Permitting can be a lengthy process, particularly if a project requires multiple agency approval, in some cases at local, regional and national levels of government. Projects may be delayed, and costs increased, by issues such as unforeseen public opposition or local environmental concerns.
- Perceived policy risk, driven by the possibility of negative or arbitrary changes over time in the policy environment for renewable energy technologies, can undermine investor confidence, in turn pushing up the required risk premium on investments.

Renewable energy industries are also relatively immature. Supply chain bottlenecks may lead to higher costs.

Financing renewables in developing countries

Development finance institutions (DFIs), both bilateral and multilateral, provide funding to foster the deployment of renewable energy in developing countries through project-based investments and technical assistance, typically related to capacity building.

Multilateral development banks (MDBs) are an important source of financing for joint development efforts and often offer long-term funding which may not be available in the local financial markets. Financing facilities can be designed on a case-by-case basis to support differing needs. The role of MDBs has increased since the financial crisis in providing direct lending or financial guarantees. For example in 2009, the International Finance Corporation (IFC) invested USD 720 billion in renewable energy and USD 310 billion in energy efficiency projects, which leveraged more than an additional USD 6.1 billion in investment from other sources (World Bank, 2009a). Bilateral development banks are also an important source of development finance. The German state-owned KfW Entwicklungsbank, for example, invested USD 340 million in renewable energy projects in developing economies in 2008.

DFIs are beginning to integrate public finance mechanisms into their development assistance programmes with a view to leveraging commercial investment in low-carbon energy technologies, including renewables, in developing countries. This involves loan guarantees, loan softening programmes to incentivise commercial finance institutions in developing countries to extend loans for renewable energy applications, and technical assistance grants to enhance the capacity of the main market players, for example through staff training and the development of technical standards.

Carefully designed support policy frameworks are essential if asset finance is to be used efficiently. Alongside policy support, barriers to deployment need to be identified and addressed. For example, the risk of failing to find a buyer for the electricity generated by a project can be a serious impediment to investment. Even in cases where power purchase agreements have been signed, government or DFI support may still be required to insure the credit-worthiness of the purchaser of the electricity. In some countries, assurances from the government may not be enough to meet the concerns of the investment community, for example if there is political instability or if market conditions are changing quickly, *e.g.* as a result of rapid inflation or deflation. Carbon-delivery guarantees such as those proposed in the World Bank's Carbon Partnership Facility, or carbon insurance using public finance but also open to the private insurance industry, could help share the operational risks relating to renewable energy projects.

Actions that should be considered by governments to facilitate investments in renewables include:

- Establishing long-term targets for renewable energy deployment which include short-term milestones.

- Implementing support mechanisms that provide sufficient incentives to investors and ensuring that they are transparent, stable and predicable in the longer term.

- Developing effective systems to internalise the external costs of all forms of electricity production into market prices for electricity.

- Supporting investment in new grid infrastructure to facilitate the rapid connection of new renewable capacity.

Financing carbon capture and storage

CCS deployment will require additional investment between now and 2050 in the region of USD 2.5 trillion to USD 3 trillion. This is roughly 6% of the total low-carbon technology investment that is needed to achieve the outcomes implicit in the BLUE Map scenario in 2050. Of this total, the additional investment associated with carbon capture plant will be almost USD 1.3 trillion. Carbon transport infrastructure will require an estimated USD 0.5 trillion to USD 1 trillion. And carbon storage will require an additional USD 0.1 trillion to USD 0.7 trillion through to 2050. The next ten years are critical, with 100 projects required by 2020 (IEA, 2009f). This will entail an average annual additional investment of USD 5 billion to USD 6.5 billion to 2020, of which USD 3.5 billion to USD 4 billion will be required in OECD countries and USD 1.5 billion to USD 2.5 billion will be required in non-OECD countries. Currently, around USD 17 billion to USD 20 billion has been committed by governments for the deployment of CCS, well short of what is needed to get on track for the outcomes envisaged in the BLUE Map scenario.

The large-scale global deployment of CCS and other carbon mitigation technologies will be dependent on a widespread, technology-neutral, funding mechanism being in place which puts a stable cost on the emission of CO_2. Current measures are insufficient to put a price on CO_2 that will justify the additional cost of CCS. This gap will need to be significantly narrowed if CCS is to be widely implemented.

CCS technology is large scale. As a result, the investment risk associated with CCS is particularly large. It is also vulnerable to fluctuations in carbon incentives. Government support is likely to be important for the large-scale demonstration and deployment of CCS, to provide the investment security that currently does not exist in the carbon market for investments of this size.

To support investments in CCS, governments will need:

- To identify, announce and promote early demonstration project partnerships with industry.
- To provide capital and operational funding sufficient to bridge the commercial funding gap for early CCS demonstration. This may include capital grants, feed-in tariffs, carbon price guarantees, and other mechanisms (Table 14.14).
- To take action to moderate the investment risk associated with early demonstration projects. This may include project-specific agreements, long-term liability indemnification, loan guarantees, and other mechanisms.
- To implement funding mechanisms sufficient to drive the commercial deployment of CCS in the medium to long term. This may include cap-and-trade arrangements, carbon taxation, CCS mandates, emission performance standards, and other mechanisms.

In addition to these domestic actions, OECD countries will need to support the development of CCS in non-OECD countries. This will require OECD countries to contribute to the funding and support of early demonstration projects in these regions. It will also require OECD countries to work with non-OECD countries to ensure that current and future CO_2 reduction mechanisms applicable to developing countries such as the CDM are strengthened and extended to support the deployment of CCS. Enhancement and expansion of existing multilateral and bilateral financial mechanisms, for example the World Bank and the Asian Development Bank, should also be considered.

Table 14.14 ▶ Funding options to bridge the commercial gap for early CCS demonstration

Capital grants	Governments would make capital available to project developers to assist in the development of CCS projects. Some governments have already made capital financing available for CCS from general budgets, from specific budgets such as economic recovery packages, and from bonus credits hypothecated from ETSs.
Feed-in tariffs	Governments would implement new, or expand current, feed-in tariff programmes to include CCS. In a number of countries feed-in tariffs already exist for renewable energy. These should be extended to include CCS.
Price guarantees	Governments would set up a "contract for differences" with CCS operators in which the government would agree to supplement the market price for CO_2 reductions up to an agreed level that is sufficient to operate a CCS plant commercially. The contract could also include a provision whereby if the market price for CO_2 exceeds the agreed level, payments would be reversed.

Financing nuclear power

An estimated USD 4.0 trillion will need to be invested in new nuclear capacity to reach a total capacity of 1 200 GW by 2050. With the average nuclear plant taking at least 5 to 7 years to build and costing approximately USD 3 billion to USD 5 billion per plant, the financing of nuclear projects presents challenges quite different from those inherent in the financing of most other types of power plant (NEA, 2009).[15] The risks associated with construction delays and cost-overruns are particularly important in financing nuclear plant. Only large hydro plants entail similarly long construction times and extremely high investment costs.

Most nuclear plants under construction today have strong government involvement through government-controlled enterprises, through loan guarantees or as government-sponsored and financed projects. Few utilities have the financial muscle to develop a new nuclear power plant on their balance sheet. It is unlikely that nuclear projects will proceed on a 100% privately financed basis.

Nuclear power plants are exposed to the following factors relevant to their financing:

- High capital costs. They are also technically complex, increasing the risk during construction and operation.
- Long construction periods. This, coupled with their high capital requirements, means that they are particularly susceptible to electricity market uncertainties in the timescales in which they are expected to recoup investments or repay loans.

15. The cost and construction time for nuclear plants varies widely, with much lower costs and construction times seen in Asia than in Europe and North America.

- Political and social controversy.
- The need for clear solutions and financing schemes for radioactive waste management and decommissioning.
- The need to operate at high load factors.

Future nuclear investments will probably need to be financed either as consortium investments between a number of utilities or by government-controlled enterprises such as Electricité de France or Korea Electric Power Corporation (KEPCO). Government loan guarantees are likely to be an important factor in the successful financing of new nuclear projects. ECAs could also help fill some of the financing gap by offering preferred credit conditions for funding nuclear investments, *e.g.* under the AOSEC. ECAs have not yet had a big impact on nuclear financing.

To finance a nuclear project in partnership with one or two other companies, a company would need to have a market capitalisation of at least USD 10 billion. It would need a capitalisation of at least USD 25 billion if it was to be able to finance a project on its own. Worldwide, 15 utilities have a market capitalisation above USD 25 billion. Around 50 have a market capitalisation more than USD 10 billion.

The Finnish approach to the financing of new nuclear plant, in which a consortium of large electricity users has funded the Areva plant now under construction, may become a more common model for the financing of both nuclear and other types of generation capacity. Consortium investing enables companies to diversify their power generation capacity and technology dependence. As the risk of shortages in power generation capacity rises in many regions, electricity distribution companies are likely to increase their investments in power generation capacity to ensure a secure and forecastable cost of electricity.

To reach the levels of nuclear power envisaged in the BLUE Map scenario would require an estimated 20 to 30 nuclear projects to be constructed every year from now until 2050. This is equal to an average annual financing need of approximately USD 80 billion to USD 120 billion.

The financing of new nuclear plant may be easier in Europe than in the United States given the much larger size of European utilities compared to their United States counterparts. Europe has 10 utilities with a market capitalisation above USD 25 billion. The United States has only two. New nuclear power in the United States will be heavily reliant on government loan guarantees. The United States has already committed USD 16 billion in loan guarantees for new nuclear plants. This would cover the construction cost of about three plants. Much more funding will be needed to cover the expected construction of 10 to 13 plants in the United States within the next 20 years.[16] In China, the government's involvement in the power and banking sectors will facilitate financing for new nuclear build. Market structure is particularly important for funding nuclear projects. Regulated electricity markets with vertically integrated utilities are better set up for funding nuclear than competitive electricity markets with merchant utilities.

16. The 2011 United States budget proposes a tripling of the loan guarantee programme to USD 54 billion.

Governments that wish to see investment in new nuclear will need to consider:

- Providing clear and sustained policy support for the development of nuclear power, by setting out the case for a nuclear component in energy supply as part of a long-term national energy strategy.
- Working with electric utilities, financial companies and other potential investors, and the nuclear industry from an early stage to address concerns that may prevent nuclear investment.
- Establishing an efficient and effective regulatory system which provides adequate opportunities for public involvement in the decision-making process, while also providing potential investors with the certainty they require to plan investment. A one-step licensing process with pre-approval of standardised designs offers clear benefits.
- Ensuring that electricity market regulation does not disadvantage nuclear. Longer-term contracts may be necessary to provide certainty for investors.
- Enabling measures that will allow nuclear power to benefit from carbon prices.
- Providing government loan guarantees to support some of the construction risk linked to the long build time for nuclear.

Financing low-carbon transport

Transport accounts for the largest share of investment financing in both the Baseline and the BLUE Map scenarios. At more than USD 250 trillion between 2010 and 2050 in the BLUE Map scenario, this is about 10% higher than the expected USD 230 trillion in the Baseline scenario. Vehicles will become more expensive in the BLUE Map scenario and this increment will need additional financing.

The vast majority of LDV purchases are currently made by consumers who finance these purchases through local banks or through the car companies themselves. In the Baseline scenario, the demand for such financing will rise roughly with the rate of growth in car ownership. This has grown quickly, especially in countries such as China and India. As consumers gain wealth and shift to more expensive cars, this results in the demand for capital rising even faster than the growth in car ownership.

There will also be a need in the BLUE Map scenario for the financing of major investments in new products and infrastructure. This will include the development of a recharging infrastructure for EVs and the construction of battery manufacturing plants. These developments will each require the investment of several trillion dollars between 2010 and 2050. While this will be paid for indirectly through consumer vehicle and electricity purchases, the often quite risky upfront investments will need to be funded from other sources.

The financing of low-carbon transport investment will be influenced by the following factors:

- Relatively high transaction costs are involved in many individual buyers making many individual investments in LDVs.

- Most low-carbon vehicles are currently significantly more expensive than conventional technologies and cost more than most consumers are willing to pay.
- The development and deployment of low-carbon vehicles will require large capital outlays by car manufacturers, potentially ahead of market demand.
- Very large infrastructure investments will need to be made to create, rather than respond to, clear market demand.
- The current technology for EVs may still require significant improvements in terms of range and costs before these vehicles can move beyond niche markets.

To facilitate investment in low-carbon transport, governments may need to consider:

- Direct support for the deployment of low-carbon vehicles to reduce risks and incentivise the market.
- Support for the financing of PHEVs and EVs by encouraging public utilities or car manufacturers to lease car batteries to consumers, thereby reducing upfront costs.
- Government loan guarantees to help reduce financing risks for capital expansion to develop new product lines and infrastructure.
- The development of green banks to provide preferential lending conditions to consumers for low-carbon vehicles.
- Direct investment in infrastructure networks, where appropriate in collaboration with private investors.

Chapter 15 ACCELERATING THE DIFFUSION OF LOW-CARBON TECHNOLOGIES IN EMERGING ECONOMIES

Key findings

- *If global carbon dioxide (CO_2) emissions are to be halved by 2050, non-OECD countries as well as OECD countries will have to reduce their emissions below current levels. Non-OECD countries' economies will be growing very rapidly in this period. To cut their emissions, they will need to deploy existing and new low-carbon technologies on a very significant scale.*

- *Lessons can be learned from the largest emerging economies such as China, India, Brazil, Russia and South Africa. These countries are already ramping up their deployment of key low-carbon technologies and rapidly improving their capability to develop cleaner energy technologies.*

- *The exposure of markets and firms in emerging economies to low-carbon technologies being developed elsewhere can play an important role in the development and diffusion of those technologies. This can be achieved through the acquisition of licences, the purchase of production equipment, joint ventures, cross-border mergers and acquisitions, and training.*

- *Strong domestic policies that stimulate investments in clean energy, whether driven by standards and regulations or market mechanisms, are crucial. The successful absorption of foreign technology will also depend on other factors such as the country's governance and business climate, and on infrastructure and skill capacities.*

- *Clear intellectual property rights (IPR) frameworks, within which firms can develop legal agreements that will enable access to new technologies, are also important. Fast tracking the patent approval of low-carbon technologies, licence of right (LOR) systems, the use of private and/or publicly facilitated patent pools, and frameworks for sharing intellectual property (IP) within collaborative RD&D may all have a part to play in strengthening the effectiveness of IP regimes in supporting technology diffusion.*

- *Current levels of financing for the diffusion of low-carbon technologies in non-OECD countries are insufficient to support the transition to the low carbon energy system envisaged in the BLUE Map scenario. An additional USD 400 billion a year between 2010 and 2030, rising to over USD 1 trillion a year from 2030 to 2050, will need to be invested in clean technologies in non-OECD countries.*

- *Both private and public investment will be needed to achieve this level of diffusion. Non-OECD governments need to structure their public finance mechanisms in ways to channel private-sector investment decisions towards low-carbon projects. Limited public funding can make a significant contribution to leveraging investment through the private sector.*

- *Indigenous innovation capabilities can play an important part in supporting the development and diffusion of low-carbon technologies in emerging economies. Governments should set clear research, development and demonstration (RD&D) and technological priorities, and take steps to develop the technological capability needed to achieve them.*
- *Although OECD countries still have the edge in respect of a number of cutting-edge energy technologies, some emerging economies, especially China, are rapidly improving their capability to innovate, particularly in niche areas.*

Introduction

Achieving the outcomes envisaged in the BLUE Map scenario will require both the wide-scale diffusion of existing low-carbon technologies and RD&D in new, more efficient, energy-related technologies. This chapter focuses particularly on the acceleration and scale-up of such developments in non-OECD countries, especially in the largest emerging economies (Box 15.1). The objective of this chapter is to better understand the international technology flows, the barriers to technology adoption and dissemination, and the strategies to enhance low-carbon technology development and diffusion in these countries, highlighting the essential role played by domestic policies.

Box 15.1 Developing countries and emerging economies: a changing definition

A number of terms have been used to describe non-OECD countries.

***"Developing countries"** is a general term used to describe countries with levels of material well-being lower than those of developed countries and of countries in transition.[1] The term is often used as a counterpart to "industrialised countries". There is no single internationally recognised definition of industrialised or developed countries. Levels of development may vary widely within the group of so-called developing countries, some of which have relatively high average standards of living. Organisations such as the World Bank and the United Nations apply numeric definitions based on gross national income per capita to classify economies as being low-income, middle-income or high-income. Some organisations break down the group of non-OECD countries to identify smaller groupings, for example of least developed countries (LDCs), or least economically developed countries (LEDCs) or "emerging economies". Within the United Nations Framework Convention on Climate Change (UNFCCC), developing countries are defined as the major developing countries as well as LDCs which are not included in Annex I of the Convention.*

1. Countries in transition is a term used to describe countries which are developed but not yet for the most part in the OECD.

Box 15.1 ▶ **Developing countries and emerging economies: a changing definition** (continued)

*The term **"emerging economies"** first appeared in the early 1980s to identify middle-income emerging markets where foreign financial institutions were allowed to buy securities (Hoskisson et al., 2005). The term **BRIC** was coined by the investment bank Goldman Sachs in 2001 as an acronym for the four largest emerging markets (Brazil, Russia, India and China). New acronyms have come forward to broaden the list of largest emerging economies, such as **BRICS** (BRIC plus South Africa) and **BRIICS** (BRICS plus Indonesia). These countries do not traditionally share a common agenda in global negotiations on access to clean energy technologies, although they are all technically members of the 130 member-strong G-77 and China group within the United Nations (UN) negotiation framework.[2] At the 15th Conference of the Parties to the UNFCCC in Copenhagen (COP-15), a new informal group, referred to as BASIC (Brazil, South Africa, India and China), emerged as an influential force in the negotiations.*

The term emerging economies is used in this chapter to refer to BRICS-like countries (i.e. *Brazil, Russia, India, China and South Africa) that have economies large enough to influence the global economy more widely. These countries will have to play an increasingly important role in low-carbon technology development and diffusion in the future.*

Although the following analysis focuses primarily on the largest emerging economies, there is a need to broaden technology development and diffusion in all developing countries. The less advanced developing countries face priorities and challenges that are very different from those of the rapidly emerging economies. Even so, the approaches that are needed to help rapidly emerging countries play a part in reducing greenhouse-gas emissions are also likely to be of relevance in helping to set a low-carbon transition trajectory for less advanced developing countries to follow (Box 15.2).

Box 15.2 ▶ **An urgent priority: low-carbon development in the least developed countries**

The poorest developing countries are not only pursuing economic growth and social progress. They also have to adapt to the effects of climate change. Anything that slows down their development will exacerbate the effects of climate change on them. Co-ordinated and well-considered assistance needs to be provided to help them engage in reducing their own carbon emissions.

The emerging economies are increasing their exposure to new technologies through trade and foreign direct investment (FDI). These routes are unlikely to be as productive for less advanced developing countries that have generally lower levels of FDI and trade and relatively limited technological capabilities. For these countries, a more promising strategy would be to focus on facilitating and supporting access to existing clean energy technologies while in parallel strengthening domestic firms' productive and technological capabilities. Such strategies can be reinforced by enhancing the linkages between official development assistance (ODA) and FDI.

2. See:www.g77.org/

Box 15.2 ▶ An urgent priority: low-carbon development in the least developed countries (continued)

Less advanced developing countries can secure financial support for their mitigation efforts through a number of routes. These include the bilateral and multilateral climate funds described in more detail in Chapter 14, and funds under the UNFCCC such as the Global Environment Facility (GEF) Trust Fund and the Special Climate Change Fund (SCCF). Carbon finance mechanisms also have a part to play.

A number of studies have tried to assess the sustainable energy development needs and priorities of the less advanced developing countries and the energy technologies which would most suitably help to meet those needs.[3] A number of programmes are assisting these countries with the preparation and implementation of low-carbon emission plans and strategies. This includes support for UNFCCC activities such as the drawing-up of Technology Needs Assessments[4] and Nationally Appropriate Mitigation Actions, and for establishing low-carbon growth or development plans, and low-carbon technology roadmaps.[5]

Background

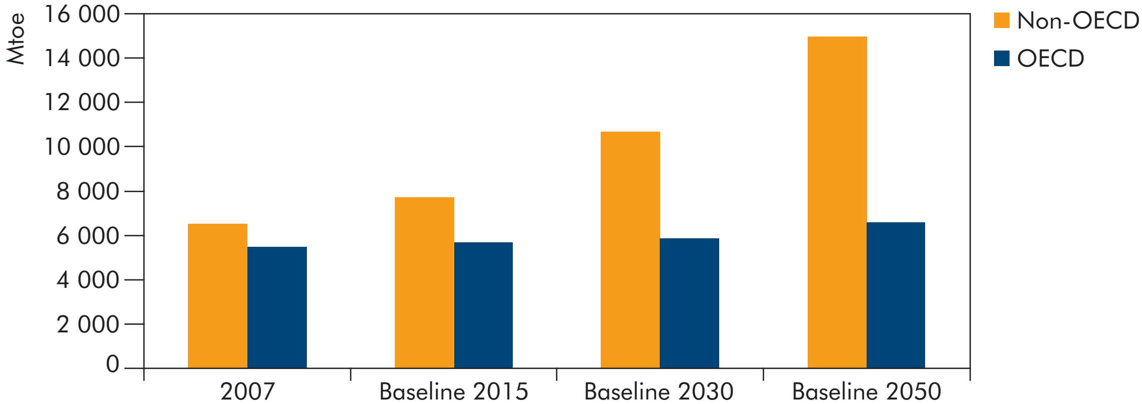
Non-OECD countries' contribution to CO_2 emissions reduction in the Baseline and BLUE Map scenarios

Between 2007 and 2050, energy demand in non-OECD countries accounts for 89% of the increase in world energy demand in the Baseline scenario (Figure 15.1). By 2050, non-OECD countries' total emissions of energy-related CO_2 amount to 42 gigatonnes (Gt) a year, an increase of over 160% over 2007 levels. As a result of improvements in energy efficiency, CO_2 emissions per unit of GDP decline by 52% in the Baseline scenario.

The demand for energy services for mobility, heating, cooling and for specific electricity uses such as lighting or information technologies, is closely linked to economic growth. For emerging and developing economies, the challenge is to continue economic growth without locking in high emissions. For rapidly emerging economies such as China, India, Brazil and South Africa which have experienced rapid growth in fossil fuel use in recent years and are projected to continue to do so in the Baseline scenario, the decarbonising of energy systems will be particularly important.

3. For example the "Second synthesis report on technology needs identified by Parties not included in Annex I to the Convention" prepared by the UNFCCC (2009).
4. A list of all Country Technology Needs Assessment Reports compiled so far is available at: ncsp.undp.org/tna-country-list.
5. Additional information on ongoing activities in this area can be found at: en.openei.org/wiki/CLEAN; and ncsp.undp.org/.

Figure 15.1 ▶ OECD and non-OECD primary energy demand in the Baseline scenario

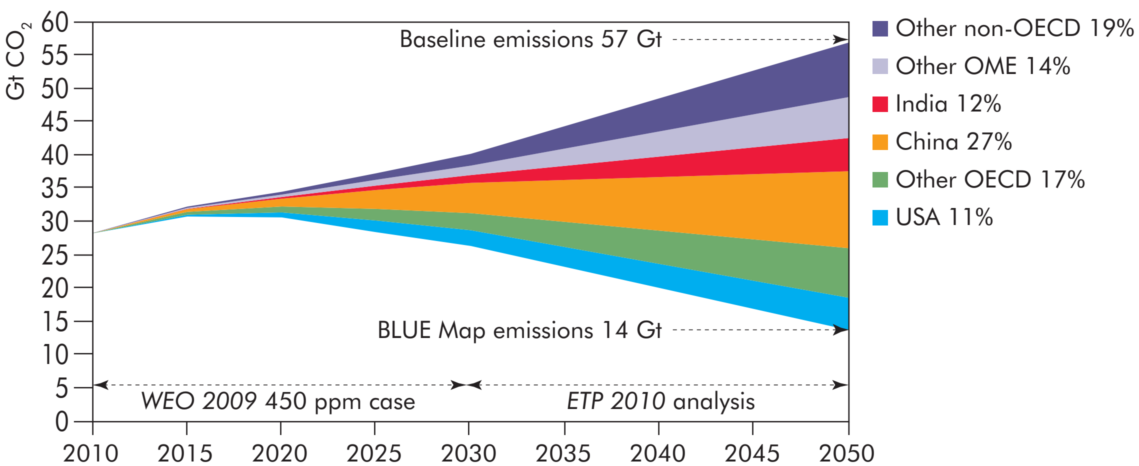


Key point

Primary energy demand in non-OECD countries is projected to increase much faster than in OECD countries in the Baseline scenario.

Non-OECD countries make the biggest contribution to CO_2 abatement in the BLUE Map scenario (Figure 15.2). Within the non-OECD countries, a group of countries referred to collectively as other major economies (OME), which includes Brazil, China, Russia and South Africa, accounts for most of the savings by 2050. China alone makes about 27% of the total savings from the Baseline emission levels in 2050.

Figure 15.2 ▶ World energy-related CO_2 emission abatement by region



Key point

In the BLUE Map scenario, emerging economies contribute the majority of the reductions in energy-related CO_2 emissions by 2050.

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To achieve the outcomes envisaged in the BLUE Map scenario, global energy-related CO_2 emissions must be reduced from the 29 Gt CO_2 emitted in 2007, to 14 Gt CO_2 by 2050. Non-OECD countries currently already emit 16 Gt CO_2. Even if OECD countries were to be able to reduce their emissions from 13 Gt CO_2 to zero by 2050, non-OECD countries would need to reduce their current emission levels by 2 Gt. This is a 12.5% reduction from today's levels.

In practice, it is very unlikely that OECD countries will be able to become entirely carbon-neutral within this timeframe. So non-OECD countries will need to achieve much more than a 12.5% reduction from current emission levels. Achieving this, without producing additional emissions as a result of their expected very significant increases in economic growth, is an enormous challenge.

Investment needs in emerging economies in the BLUE Map scenario

Achieving significant overall CO_2 emissions reduction against the backdrop of a very significant growth expected in energy use will require enormous investment in both existing and new technology.

To attain the outcomes envisaged in the BLUE Map scenario, most of the additional investment between 2010 and 2050 is needed in non-OECD countries, where many of the least-cost opportunities for deploying low-carbon technologies present themselves. Average incremental investment in non-OECD countries between 2010 and 2050 amounts to USD 1.5 trillion a year, 73% more than the investment required in OECD countries. Non-OECD countries also account for the largest share of the additional investments needed by 2030, equivalent to an average of just under USD 400 billion a year, about 35% more the investment needs in OECD countries.

Investment levels in non-OECD countries rise threefold from 2030 to 2050. The additional investment needed in the OMEs will be the largest of all groups of non-OECD countries, at an average of just under USD 700 billion a year, equivalent to about 62% of all non-OECD incremental investment needs between 2030 and 2050. As described in Chapter 14, at least 53% of these investments are needed in the transport sector for alternative vehicle technologies.

There is considerable scope for deploying low-carbon technologies in emerging economies. Investment in these areas will be crucial to achieving the emissions reduction objectives of the BLUE Map scenario (Table 15.1). The shares of investment required in China and India highlight the importance of these countries in this regard.

Table 15.1 ▶ ***Examples of incremental investment costs for selected low-carbon technologies in non-OECD countries in 2010-50 in the BLUE Map scenario (USD billions)***

	Carbon capture and storage	Electric and plug-in hybrid electric passenger light duty vehicles
Non-OECD	447	6 085
China	185	2 670
India	68	1 425

Sources: Compiled from IEA (2009a and 2009b).

Diffusion of low-carbon technologies in emerging economies

Non-OECD countries have traditionally been assumed to access new technologies as a result of technology transfer from industrialised countries to non-industrialised countries (Box 15.3). This reflects the assumption that technological knowledge generally flows from countries with a higher technological capacity to countries with a lower one. Recently, more attention has been given to the concept of technology diffusion, a process which reflects the increasing two-way flow of technologies among and between OECD and non-OECD countries, and of the role of emerging economies as strong manufacturing bases and export markets in their own right.

Box 15.3 ▶ Technology transfer: history and initiatives

The Intergovernmental Panel on Climate Change (IPCC) defines technology transfer as the broad set of processes that govern the flows of knowledge, experience and equipment among different stakeholders (IPCC, 2000). Technology transfer encompasses the technology hardware (physical devices, equipment and infrastructure), the "software" aspects (knowledge and processes, also referred to as know-how), and the "orgware" (institutional frameworks and regulation) that underpin it (IIASA, 2009). Private firms, governments, financial institutions, non-governmental organisations (NGOs), community groups, international institutions, research organisations, consultants and individual consumers all have a part to play, each having their own motivations, interests and negotiating power.

Most technology transfer occurs within the private market through voluntary transactions between firms or across country boundaries within multinational corporations. Access to foreign technology can also be gained outside normal market mechanisms, for example through imitation or reverse engineering. Technology transfer may also be led by governments through such programmes as ODA, or may be achieved through education, return migration and training (Maskus, 2004).

The UNFCCC and the Kyoto Protocol have specific provisions which recognise the need to encourage international technology transfer. These include financial mechanisms such as specialised funds and market-based initiatives. At COP-15 in Copenhagen, the Parties to the UNFCCC prepared a draft decision to expand international collaboration at all levels in the technology development cycle. This envisaged establishing a new technology mechanism that would promote and channel finance to national and collaborative technology initiatives, catalysing the development and use of technology roadmaps or action plans, and enhancing co-operation between national, regional and international technology centres and institutions. This decision has not been adopted. Additional initiatives outside the UN framework have also emphasised technology transfer, such as the G8+5 process (involving the G8 member countries[6] plus Brazil, China, India, Mexico and South Africa), the Asia-Pacific Partnership on Clean Development and Climate (APP), the Major Economies Forum on Energy and Climate (MEF), and a number of bilateral partnerships.

6. The G8 countries are the United States, Russia, the United Kingdom, France, Germany, Japan, Italy and Canada.

Technology moves between countries in a variety of ways, depending on the type of technology, its stage of maturity, and the recipient country's capacity to absorb, apply and adapt it. The speed and effectiveness of technology diffusion will depend on such issues as whether the technology is under patent or trade secret protection or is in the public domain; whether the technology is a mature technology that can be relatively easily absorbed or a cutting-edge technology that involves extensive know-how and tacit skills for effective implementation; and whether the technology is already commercialised or requires further development through, for example, R&D collaboration. Insofar as emerging economies want to stimulate or steer technology diffusion beyond the level that markets would achieve on their own, they need to devise their own strategies and priorities by assessing the technology pathways available to them and adapting or designing suitable policies.

This chapter provides an overview of technology flows related to low-carbon technology diffusion. The analysis is subject to a number of important limitations that have to be taken into account. More work needs to be done to improve analysis of the trends in low-carbon technology diffusion (Box 15.4).

Box 15.4 ▶ Tracing international technology flows: precision of the data and the need for more certainty

Measuring international technology flows is complex. It often focuses on hardware diffusion, as the diffusion of software elements such as education and training are much more complicated to identify and assess.

This chapter uses data on patents, trade flows and international financial flows to draw some general conclusions about the diffusion of low-carbon technologies at global level. These data should be used with caution because:

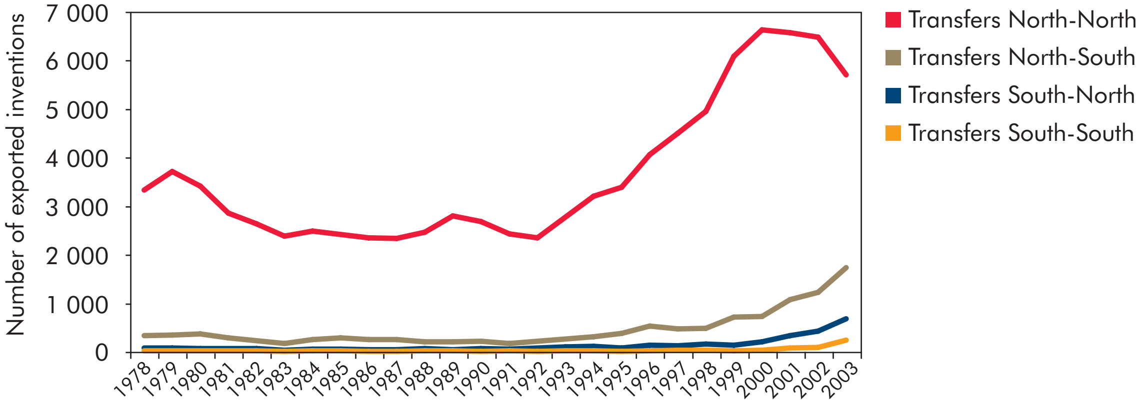
- *Data on patents can be a misleading measure of technology diffusion in the absence of information on national patent laws and the extent to which patents are actually exploited. Patents are only one of the means of protecting innovation, and certain types of innovation are less suited to patenting than others. Although they are changing quickly, developing countries have less of a history of filing patents.*
- *Commodity classifications for low-carbon technologies are insufficiently granular to provide a robust basis for the measurement of trade transfer flows.*
- *Reliable data on international finance are particularly difficult to identify. This is due to inconsistencies and/or incomplete reporting by OECD countries of financial support, limited and incomplete information on multilateral development banks (MDBs) and other non-UNFCCC funds, lack of primary data on financial flows under the Kyoto Protocol's clean development mechanism (CDM), and uncertainties regarding estimates of private financing for the deployment and diffusion of low-carbon technologies. For example, sectoral data on FDI inflows are only available periodically from the United Nations Conference on Trade and Development (UNCTAD) and at a level of aggregation that makes it difficult to extract trends in investment in low-carbon technologies.*

Although the data presented in this chapter are useful as indicators of approximate relative magnitudes, data quality clearly needs to be improved.

Low-carbon technology flows

The international technology diffusion of climate-friendly inventions,[7] as measured by the share of inventions that are patented in at least two countries,[8] has historically mostly taken place between OECD countries (Figure 15.3). From 2000 to 2005, 73% of exported inventions have diffused in this way. Exports from OECD countries to emerging economies, although only 22% of the total, are growing rapidly, with China alone attracting about three-quarters of the transfers. Exports from emerging economies to OECD countries account for 4% of all exported inventions and are also growing (Dechezleprêtre *et al.*, 2010).

Figure 15.3 ▶ ***International trends in technology diffusion***



Source: Dechezleprêtre *et al*. (2008).

Key point

In the last decade, the role of non-OECD countries in low-carbon technology diffusion has grown.

The rate of diffusion of low-carbon technologies to emerging economies has increased rapidly. China is the world's largest producer and consumer of solar water heating, accounting for 65% of all installations, and recently became number three in total wind power capacity (The Climate Group, 2009). India ranks fifth in terms of cumulative wind power capacity (REN21, 2009). In Brazil, ethanol accounted for more than 52% of fuel consumption by light-duty vehicles (LDVs) in 2008 (UNEP, 2009). Each of those nations is among the top ten countries in installed renewable energy capacity (Table 15.2). Installed clean energy capacity has increased rapidly in these countries in the last five years, with China growing by 79%, India by 31%, and Brazil by 14% (The Pew Charitable Trusts, 2010).

7. Encompassing wind, solar, geothermal, ocean energy, biomass, waste-to-energy, hydropower, methane destruction, climate-friendly cement, energy conservation in buildings, motor vehicle fuel injection, energy-efficient lighting and CCS.
8. This measure is based on the assumption that a firm only patents an invention when it plans to exploit it commercially.

Table 15.2 ▶ Top 10 countries in renewable energy capacity, 2009

	Renewable energy capacity (GW)
United States	53.4
China	52.5
Germany	36.2
Spain	22.4
India	16.5
Japan	12.9
Rest of EU-27*	12.3
Italy	9.8
France	9.4
Brazil	9.1

*This comprises 22 countries: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia and Sweden.

Source: The Pew Charitable Trusts (2010).

Emerging economies have in a number of cases acquired production capabilities through the integration of local producers into global value chains often co-ordinated by firms based in OECD countries. This has enabled emerging economies rapidly to specialise in several clean energy technologies and to export to both OECD and non-OECD countries (Box 15.5). China is the largest exporter of wind turbine towers, of static converters that change solar energy into electricity, of solar batteries for energy storage in off-grid photovoltaic systems, and of the concentrators used to intensify solar power in solar energy systems (WTO, 2009).

Box 15.5 ▶ Examples of South-South technology transfer

The two major Chinese manufacturers of heavy electric machinery, Shanghai Electric and Dongfang Electric, have received orders from India for large-scale supercritical coal-fired power plants. Dongfang Turbine has secured an order for the main machinery for a natural gas combined cycle (NGCC) power plant in Belarus (Ueno, 2009). Shanghai Power Corporation's overseas sales account for 45% of the company's total revenue, up from 13% in 2006. A majority of the increase comes from the export of supercritical and sub-supercritical technologies to developing countries (Tan and Gang, 2009).

Brazil's state-controlled oil company, Petrobras, has secured contracts for ethanol imports and technology access with a range of African countries, including Senegal, Nigeria, Mozambique and Angola. Nigeria will acquire technical expertise alongside its ethanol imports, so that it can start implementing its 10% ethanol blend policy even before local ethanol manufacturers come on stream. Brazil is also investing USD 100 million in the construction of an ethanol plant in Angola (GRAIN, 2007).

Some companies based in emerging economies are currently recognised as global industry leaders in specific low-carbon technologies. The world's best-selling developer and manufacturer of on-road electric cars is an Indian venture, the Reva

Electric Car Company. It has successfully penetrated a number of national markets, including in high-income countries (World Bank, 2009a). Beijing Jike Energy New Technology Development Co. has developed geothermal heat pumps (GHP) based on US ground-gas technologies. It is now an industry leader and holds patents for its ground-coupling pipe optimisation and burial technology, and for the software it has developed for ground-gas GHP systems design (The Climate Group, 2009).

In some cases, emerging economies' growth in low-carbon technology expertise, such as solar PV expansion in China and the notable success of Brazil in biofuels, has resulted from strong domestic policies aimed at strengthening indigenous technology development. More often, access to technology has been facilitated through the acquisition of licences from multinational firms. For example, one of China's largest wind technology manufacturers, Goldwind, initially acquired access to wind technology by purchasing licences from German wind turbine maker Vensys.[9] China has also acquired licences to produce boilers, turbines, and generators for supercritical and ultra-supercritical coal-fired power plants. In other cases, technology has diffused through joint ventures. For example, BP Solar's joint venture with Tata Group has driven solar PV activity in India. Toyota's joint venture with China's leading car manufacturer Sichuan FAW has resulted in the production of the Prius hybrid car in China. And a number of joint-venture efforts between Japanese and Indian companies have enabled the production in India of high-efficiency, low-emission coal technologies.[10] Access to low-carbon technologies has also been facilitated by the purchase of production equipment or through the strategic acquisition of firms based in OECD countries (Box 15.6). Although technology may not be the primary driver in many of these purchases, technology diffusion is often a consequence. The establishment of R&D centres in developed countries by firms from non-OECD countries also enables diffusion. For example, the Indian wind turbine manufacturer Suzlon has expanded its R&D facilities in several countries in Europe, and engaged into collaborative R&D (Ueno, 2009; Barton, 2007; Lewis, 2007; MEF, 2009).

Box 15.6 ▶ Acquisition of foreign technologies through merger and acquisition

The Indian wind turbine manufacture Suzlon, founded in the 1990s and now the world's fifth-largest turbine manufacturer, operates in 20 countries around the world. It supplies turbines to projects in Asia, North and South America and Europe. A key part of the company's strategy has been to acquire majority shares in European technology companies. Following the purchase of rotor-blade designer AE-Rotor Techniek in 2000, in 2006 Suzlon became the largest net buyer of companies abroad through the acquisition of Belgian gearbox manufacturer Hansen International for USD 565 million (UNEP, 2007). Suzlon has subsequently sold more than half of its previous 61% stake in Hansen, in large part to pay for the acquisition of the German-based company RePower, one of the leading manufacturers of onshore and offshore wind turbines, which was completed in 2009 (Cleantech Group, 2009). Before acquiring RePower, Suzlon entered into a joint venture with the company to fund a joint Renewable Energy Technology Centre in Germany.

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9. Goldwind also acquired a 70% stake in Vensys and its subsidiary companies.

10. For example, L&T-MHI Boilers Private Ltd./L&T Turbine Generators Private Ltd., covering supercritical boiler and turbine technologies, and Toshiba JSW Turbines & Generator Private Ltd., covering 500 MW to 1 000 MW supercritical steam turbines and generators.

The three major channels through which technologies spread internationally are international trade, FDI and licensing (Maskus, 2004). All have increased substantially in recent decades, especially in developing countries. The choice of channels depends on the technology being diffused and on the characteristics of the countries and firms involved in the process. Some emerging countries have adopted a strategy of technology acquisition strongly based on licensing. For instance, China has encouraged joint ventures, as opposed to FDI, to maximise technology access by local firms. This strategy is likely to work only for countries with sufficient market power, and carries the risk of transferring sub-standard technologies.

Uncertainties about the policy environment in non-OECD countries may lead multinationals to use licensing as a substitute for FDI. Factors such as the level of intellectual property protection may impact multinationals' willingness to license the technology for fear of it being copied by domestic firms, but it may also depend on the level of development, the market structure and the imitation capability in the host country. For example, there is evidence that fears about the copying of technologies have contributed to companies' reluctance to diffuse clean coal combustion technologies to China (Vallentin and Liu, 2005).

Trade flows

The trading of low-carbon capital and intermediate high-tech goods and services across borders carries some potential for supporting positive technology diffusion between countries.

Statistics on world trade in this field are very imprecise.[11] Even so, data from the United Nations Commodity Trade Statistics Database (UN COMTRADE) can be used to illustrate recent trends in renewable energy technologies in BRIC countries (Table 15.3). The data show that all BRIC countries increased both imports and exports of a range of renewable energy products and associated goods in 2005-08, and that some of them are switching from being importers to net exporters of these technologies.[12] Comparison of the 2005 and 2008 data shows a shift from a negative value of USD 11.5 billion to a positive value of almost USD 4.2 billion in three years (Table 15.3). The bulk of this change is attributable to China, as it managed to change its balance by more than USD 18 billion, to reach a positive value of USD 8.5 billion. Imports of renewable energy technologies to China increased by 56% from 2005 to 2008, while exports increased by 337%, reaching USD 37.2 billion in 2008.

India showed the largest increase in renewable energy technology exports among BRIC countries. Imports into India increased by 172% between 2005 and 2008, amounting to USD 2.8 billion in 2008, while exports increased by 494%, reaching

11. This is because the sector or commodity classification systems do not have stand-alone customs codes for all low-carbon technologies, and because a number of "dual-use" categories include both environmental and non-environmental products.

12. This analysis focuses mainly on products and components used for wind, solar (both PV and solar thermal) and hydro. It excludes biofuels and geothermal.

USD 3 billion in 2008. Data for Brazil and Russia show the opposite trend to that of China and India. Brazil more than doubled its imports of renewable energy technologies, while exports only increased by 57%, resulting in net imports to the value of USD 1.1 billion in 2008. Russia had the sharpest increase of imports among BRIC countries, from USD 1.2 billion in 2005 to USD 4.4 billion in 2008, while exports doubled to reach nearly USD 1 billion in 2008.

Table 15.3 ▶ Net exports* in BRIC countries related to renewable energy technologies (USD billion)

	2005	2008	2008/2005 change
Brazil	–0.35	–1.12	–0.77
Russia	–0.71	–3.46	–2.74
India	–0.50	0.31	0.81
China	–9.92	8.45	18.37
BRIC totals	–11.49	4.18	15.66

*Exports minus imports.

Source: Based on UN Comtrade database (2009).

International financial flows of low-carbon energy technologies

Several types of international financial flow support technology diffusion. The main categories of financing include private flows, official flows through bilateral and multilateral ODA, and flows under the UNFCCC and the Kyoto Protocol through the CDM and the funds administered by the GEF. There are a number of different sources of data and information on these flows. For example, data on FDI enable the tracking of aggregated and occasionally sector-level flows from one country to another, and provide information on broad financial trends.[13] Many studies have attempted to estimate investment and financial flows to address climate change, and have provided indications of the support available for mitigation technologies (UNFCCC, 2007, 2008 and 2009; Corfee-Morlot, Guay and Larsen, 2009). The analysis provided below builds on these studies but specifically focuses on low-carbon energy technologies.

13. Analysis from Corfee-Morlot, Guay and Larsen (2009) highlights a number of limitations to the use of FDI data, as not all investments result in new production. In particular: funds moved from parent firms to their foreign affiliates do not represent the actual use of funds; most mergers and acquisitions do not add new production; net data may hide real investment trends; and the increasing role of offshore financial centres blurs the final destinations of investment. Furthermore, while it is possible to measure the amount of FDI, it is no guarantee that the quantity of FDI investments is in proportion to the amount of knowledge acquired by the recipient country.

Private flows

Global private investment for clean energy technologies is a small share of total private investment, but is growing quickly. In 2008, for the first time investment in new renewable energy power generation capacity, including large hydro, was greater than investment in fossil fuel generation (UNEP, 2009). Global private investments in energy efficiency and renewable energy increased from USD 33.2 billion to USD 155 billion between 2004 and 2008, with wind, solar and biofuels attracting most investment. Together, these three sectors accounted for 86% of new investment in 2008 (UNEP, 2008 and 2009).

Private investment in clean energy in non-OECD countries has also grown rapidly, from USD 1.8 billion in 2004 to USD 36.6 billion in 2008. In 2008, China led investment in Asia with USD 15.6 billion of new investment, mostly in new wind projects and in some biomass plant. New investment activity in India grew by 12% from 2007 to USD 3.7 billion in 2008, with the largest portion of new investment going to the wind sector. Total financial investment in Brazil was USD 10.8 billion in 2008, an increase of 76% over 2007, with ethanol representing 70% of new renewable investment in the country (UNEP, 2009). With clean energy investments up more than 50% in 2009, China for the first time accounted for more investment in clean energy than any other country, pushing the United States into second place (The Pew Charitable Trusts, 2010). Developing countries' share of all new global financial investments in clean energy increased from 13% in 2004 to 31% in 2008. This is still well below the level that is needed to be on a path to achieve climate stabilisation.

Foreign Direct Investment (FDI)

FDI represents the largest source of private climate-related investment, especially in OECD countries, but also in those non-OECD countries where relatively strong enabling conditions exist for investment. For LDCs, official development assistance may be more important than FDI as a source of financing. The UNFCCC (2007) estimates that ODA funds represent less than 1% of investment globally, but account for 6% of investment in LDCs.

FDI inflows to developing economies are estimated to have reached USD 517 billion in 2008. The four BRIC countries are among the top five investment destinations for FDI.[14] BRIC countries have the benefit of large local markets that are growing quickly, and in many cases relatively cheap labour. India benefits particularly from the presence of competent suppliers and skills and talent, and Brazil is frequently mentioned for its incentives (UNCTAD, 2009a and 2009b). In 2005, FDI investment in CO_2 mitigation projects was about USD 12 billion in OECD countries and almost USD 7 billion in non-OECD countries (UNFCCC, 2008).

FDI flows are very important to developing countries in sectors such as mining, manufacturing, electricity, gas and water, and transport, storage and communications. In 2007, FDI accounted for 12.6% of total gross fixed capital

14. Based on UNCTAD's "World Investment Prospect Survey 2009-2011" which estimates favourite investment destinations being China, the United States, India, Brazil and the Russian Federation (in that order).

formation in electricity, gas and water in developing countries, three times the amount invested through multilateral and bilateral aid programmes (Table 15.4). It is not, however, possible to distinguish from these data the investments that result in lower CO_2 emissions from those that may increase them.

Table 15.4 ▶ Sources of investment in gross fixed capital formation in non-OECD countries, 2000

Sectors	FDI flows %	International borrowing %	Bilateral ODA %	Multilateral ODA %	Domestic* %	Total GFCF** USD billion
All sectors	10.2	3.8	0.7	0.4	85.0	1 654
Agriculture, hunting, forest, fishing	1.7	0.2	0.8	0.5	96.9	68
Mining and quarrying	17.8	0.0	0.4	0.1	81.8	69
Manufacturing	15.3	0.5	0.1	0.0	84.1	443
Electricity, gas and water supply	12.6	5.8	0.6	3.3	77.7	67
Transport, storage and communications	8.9	1.5	1.7	1.4	86.4	248

* Because some FDI are partially financed from local host country sources, the distinction between international and domestic sources is not entirely accurate.
** The investment in new physical assets during a given year is reported in the national accounts of countries as gross fixed capital formation (GFCF).
Source: Brewer (2009).

Official flows

Bilateral official development assistance

Bilateral ODA is monitored by the OECD Development Assistance Committee's Creditor Reporting System (DAC-CRS).[15] Under the OECD system, ODA is defined as financial support that has as its main objective the promotion of the economic development and welfare of developing countries. Recent analysis shows that bilateral ODA in the period 2003 to 2007 showed large net increases, and averaged about USD 105 billion a year (Corfee-Morlot, Guay and Larsen, 2009).

Data from the OECD DAC-CRS show that bilateral ODA in 2008 for eight low-carbon technologies[16] amounted to USD 1.2 billion, with hydro accounting for about a third of the total, and China receiving around 9% of the flows (Table 15.5). It is assumed that ODA covers only the incremental cost of those investments.

15. The Development Assistance Committee (DAC), in which bilateral donors work together to co-ordinate development co-operation, is made up of 23 OECD members (22 countries and the European Commission).
16. Power generation/renewable sources; nuclear power plants; hydro-electric power plants; geothermal energy; solar energy; wind power; ocean power; and biomass.

Table 15.5 ▶ Bilateral ODA expenditure to developing countries and a selection of emerging economies in 2008 for eight low-carbon technologies (USD million)

	Power	Nuclear	Hydro	Geothermal	Solar	Wind	Ocean	Biomass	Total
Brazil	0.91	1.76	0.06	0	0.36	0	0	0.13	3.22
China	28.83	24.44	43.63	0	8.67	2.36	0	1.62	109.55
India	3.68	0.03	19.92	0	1.14	0	0	0.02	24.79
South Africa	0.43	0.18	0.1	0	0	0.29	0	0.05	1.05
Developing countries	158.5	379.94	399.64	30.76	30	175.6	0.01	17.39	1 191.84

Source: Based on OECD DAC-CRS database (2009).

Although funding from bilateral ODA in support of climate-friendly technologies is growing, it is becoming increasingly difficult to build support for international finance assistance and for subsidising technology diffusion to nations such as China and India which hold substantial capital reserves and whose sovereign wealth funds and firms are buying US and EU firms. Investment in some sectors, *e.g.* biofuel production, may be easier to secure than in others, such as steel, where emerging economy-based producers are in direct competition with OECD steel industries, or cement, where emerging economies often have more modern kilns and run cleaner technology than developed countries. ODA should still play a role in emerging economies to demonstrate technology to scale, to create policy frameworks and to build capacity.

Export credits

Governments often promote exports of private technology by making available export credits which provide guarantees against potential risks. Long-term export credits to developing countries are provisionally estimated at USD 31.2 billion on average annually between 2002 and 2008, of which some USD 2.9 billion annually on average went to the energy sector (Corfee-Morlot, Guay and Larsen, 2009). Low-carbon energy technologies including nuclear, hydro, geothermal, solar, wind, tidal and biomass accounted for only a small share of this support, representing just over USD 534 million on average a year, *i.e.* about one-sixth of total export credits in the energy sector.

Multilateral official development assistance

MDBs and UN bodies are observers and not members of the DAC. Reporting to the OECD/DAC on multilateral ODA only takes place on a voluntary basis. As a result, multilateral ODA information is largely absent from the OECD/DAC-CRS database and multilateral ODA expenditure in 2008 for low-carbon technologies appears to amount to only USD 0.3 billion (Table 15.6). This is almost certainly a significant underestimate of total multilateral low-carbon investments.

Table 15.6 ▶ Multilateral ODA expenditure to developing countries and to a selection of emerging economies in 2008 for eight low-carbon technologies* (USD million)

	Power	Nuclear	Hydro	Geothermal	Solar	Wind	Ocean	Biomass	Total
Brazil	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.18	0.18
China	0.23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.23
India	10.3	N/A	N/A	0.17	N/A	N/A	N/A	1.27	11.74
South Africa	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Developing countries	99.69	78.21	39.32	0.17	23.83	2.55	N/A	12.56	256.33

* See footnote 16.
Note: N/A refers to data that are not available.
Source: Based on OECD DAC-CRS database (2009).

The World Bank estimates that investments in clean energy and energy efficiency activities in developing countries by MDBs have increased significantly in recent years, reaching an average of USD 4.1 billion annually for the years 2006-07 from an annual average of USD 2.2 billion between 2000 and 2005 (World Bank, 2006). This excludes the Climate Investment Funds (Box 15.7). The World Bank group alone is estimated to have committed USD 2.9 billion to low-carbon projects or programmes in 2008 (World Bank, 2009b). On the assumption that the World Bank accounts for about 70% of total MDB concessional financing (OECD, 2007), the total investment by MDBs might be expected to be of the order of USD 4.1 billion.

Box 15.7 ▶ Climate Investment Funds (CIFs)

In late 2008, the MDBs together with developed and developing countries created the Climate Investment Funds (CIFs) to which donor countries have pledged funding over three years amounting to USD 6.1 billion. The CIFs include two new trust funds. One of these, the Clean Technology Fund (CTF), focuses on scaling up investments to support the demonstration, deployment and diffusion of low-carbon technology projects in developing countries. The CTF offers highly concessionary financing, with interest rates of 0.25% and 0.75% for 20 and 40 years. But CTF lending is conditional on co-finance from a blend of grant financing and other bilateral and multilateral development lending. The main areas of focus of the CTF are the power sector (renewable energy and highly efficient technologies), the transport sector (efficiency and modal shifts), and energy efficiency (in buildings, industry and agriculture). By December 2009, clean investment plans had been submitted to the CTF by nine countries with a total proposed CTF financing of USD 2.95 billion. Given the size of the fund, this initiative could mean significant new sources for promoting technology diffusion in developing countries. The other CIF trust fund, the Strategic Climate Fund, is broader and more flexible in scope and will include adaptation as well as mitigation activities. Additional information can be found at: www.climateinvestmentfunds.org/cif/

Flows under the UNFCCC and the Kyoto Protocol

The most important mechanisms supporting technology diffusion to developing countries under the UNFCCC and the Kyoto Protocol are the CDM and the funds administered by the GEF, the financial mechanism of the UNFCCC.

Analysis of project design documents suggests that 36% of CDM projects claim to involve some form of technology transfer (Sers and Haites, 2008). These projects account for 59% of the annual emissions reduction claimed by all CDM projects. Further analysis has shown that 279 out of the 644 CDM projects registered up to May 2007 involve transfers of greenhouse-gas mitigation technologies (Dechezleprêtre, Glachant and Ménière, 2008). Very few of these projects involve the transfer of equipment alone. Most also include the transfer of knowledge and operating skills. Wind power projects often involve technology transfer. Projects in areas such as electricity production from biomass or energy efficiency measures in industry rely mainly on domestic technologies.

Under the CDM, host governments can stipulate that projects contain some level of technology transfer as a condition for national approval. China does this. Other countries do not. So the share of projects claiming elements of technology transfer varies considerably. China also requires that the ownership of a foreign party in any CDM project shall not exceed 49%. As a result, the owner of a CDM project can only be a Chinese-owned enterprise or a joint venture in which the Chinese partner holds the majority stake. This measure represents a clear disincentive for foreign high-tech firms to enter the market by engaging in CDM activities. The project-specific nature of the CDM also limits the extent to which it can promote cumulative technological learning.

There is as yet no agreed method for assessing the investment flows generated by the CDM. It is therefore not possible to determine the proportion of CDM investment that flows to developing countries from OECD countries. Different methodologies for assessing this result in very different estimates. Depending on the methodology used for measuring financial flows, estimates of the level of annual financing generated from the CDM could range between USD 6.5 billion and USD 33 billion.[17]

Experience with both the GEF and the CDM has shown that limited public funding can make significant contribution to leveraging investment through the private sector. The GEF has been in operation since 1991. Between 1991 and 2008 it provided just over USD 2.4 billion in grants to projects related to climate change and leveraged on average about seven times more investment capital through co-financing.[18] Most of the GEF resources have been allocated to renewable energy, energy efficiency, low-carbon technologies and sustainable transport projects. Capacity-building is a part of all projects. Funding of GEF climate change projects averaged about USD 163 million a year between 2003 and 2006.

17. These figures are based on recent estimations of the size of the CDM market by the World Bank (2008).
18. The financing leveraged by the GEF for mitigation projects has averaged USD 1.15 billion per year and amounted to USD 1.5 billion in 2007 (UNFCCC, 2009). For additional information, see GEF project database, available at: gefonline.org/home.cfm

Summary of international financial flows for diffusion of low-carbon technologies

Investment in low-carbon technologies in developing countries is estimated to be between USD 56 billion and USD 83 billion a year (Table 15.7). These investment flows fall well short of the levels of investment that are needed in the deployment of low-carbon energy technologies in developing countries if the ambitions of the BLUE Map scenario are to be achieved.

Table 15.7 ▶ ***Financing for diffusion of low-carbon technologies in developing countries by financing source***

Source of financing	Estimated annual investment (USD billion)
Private flows	
Private investment	43.6
Official flows	
Multilateral ODA	4.1
Bilateral ODA	1.2
Export credit agencies	0.5
Flows under the UNFCCC	
GEF	0.2
CDM	6.5 – 33
Total	**56.1 – 82.6**

Sources: Compiled from UNFCCC (2008); UNEP (2009); Corfee-Morlot, Guay and Larsen (2009) and OECD DAC-CRS database (2009).

In the BLUE Map scenario, additional investments in clean technologies in non-OECD countries are approximately USD 400 billion a year between 2010 and 2030, rising to over USD 1 trillion a year from 2030 to 2050. Most of this funding will have to be mobilised through the private sector. Although estimates of the private financing for deployment and diffusion of low-carbon technologies are very uncertain, it is estimated that between 89% and 93% of current financing comes from the private sector. Non-OECD governments need to take account of the importance of the private sector's involvement in technology diffusion when setting their domestic policies, and will need to seek to stimulate investment in appropriate technologies by encouraging private-sector investment in low-carbon projects where they can.

Private-sector investment decisions are directly influenced by the conditions in the country in which firms are considering investing. They will take account of a wide range of factors, including the size and competitiveness of the market, available labour skills and costs, physical and telecommunication infrastructures, the availability of financial services, political and economic stability and the transparency of local governance structures (Maskus, Saggi and Puttitatnun, 2005). Some of these factors are largely outside the direct control of national policy. But governments can influence a range of conditions which will attract private-sector investments in clean technologies, for instance through regulatory, infrastructure and skills improvements. The challenge for governments is to set political goals in ways which acknowledge and take advantage of business behaviours and interests.

Enhancing technology diffusion

Emerging economies have adopted a range of policy measures to stimulate investment in clean energy (Table 15.8).

Strong domestic policy frameworks in countries such as Brazil, India and China have enabled the relative strength of these nations' clean energy sectors. China has some of the world's most ambitious renewable energy targets, calling for 30 gigawatts (GW) from wind and from biomass energy by 2020. Brazil offers priority loans for renewable power projects and has ambitious targets for ethanol and biodiesel. India provides a preferential tax rate of 15% (compared with the standard rate of 30%) to renewable energy projects. India also supports wind power with provincial feed-in tariffs, while biomass and mini-hydro are supported by accelerated depreciation mechanisms (The Pew Charitable Trusts, 2010).

Table 15.8 ▶ ***National clean energy policies implemented in emerging economies***

Countries	Renewable energy standard	Clean energy tax incentives	Auto efficiency standards	Feed-in tariffs	Government procurement	Green bonds
Brazil	✓	✓	✓	✓		✓
China	✓	✓	✓	✓		✓
India		✓	✓		✓	✓
South Africa				✓		

Source: Based on The Pew Charitable Trusts (2010).

The successful absorption of new technology by developing countries also depends on a number of factors, such as the country's governance and the business climate, its overall macroeconomic stability, the availability of financing, the enabling infrastructure and the capacity of the industrial base to exploit innovation (Table 15.9). Governments can influence many of these factors and can put in place specific measures to support investment in particular technologies.

Table 15.9 ▶ *Enabling environments for technology diffusion, examples of implementation measures and main actors involved*

Enabling environments	Examples of implementation measures	Key actors	Examples of technology-specific measures
Macroeconomic policy framework	Stable macroeconomic conditions; energy sector reforms; removal of subsidies for conventional energy products; eliminate barriers to trade and FDI; creation of incentives such as tax preferences and export credit programmes	Governments, MDBs, financial institutions, World Trade Organization	Provide reliable, long-term incentives, *e.g.* well adapted feed-in tariffs for wind generation or renewable electricity standards that provide market pull for solar energy
Institutional and regulatory frameworks	Stable legal system; strong measures to defeat corruption; transparent policies; policies driving decarbonisation; elimination of conflicting regulation; framework for trading intellectual assets and acceptable level of IPRs; enforcement mechanisms; participatory approaches for involvement of local stakeholders	Governments, MDBs, NGOs, local stakeholders	Develop comprehensive legislative and regulatory frameworks for CCS that address, among other things, long-term storage and provide clarification on long-term liability
Financial instruments	Finance mechanisms able to leverage investments (*e.g.* carbon market); forms of risk mitigation and risk sharing; access to finance	Governments, firms, financial institutions, MDBs, consultants	Create financing programmes that use buildings as collateral in order to increase access to capital for energy efficiency projects in the building sector
Infrastructure	Supporting infrastructure (*e.g.* grid access for renewable energy producers)	Governments, firms, financial institutions, MDBs	Upgrade transmission networks using best-available cable technologies to address complexity of integrating large amounts of marine energy into the electricity grid
Human and institutional capacity	Train local firms and develop capacity; train workforce and government officials; increase technology literacy; promote exchange programmes; business exchanges; capacity-building activities	Governments, MDBs, NGOs, firms, research organisations, international organisations, the media	Set up green job programmes to train necessary personnel on operations and maintenance for wind energy projects

The legal, institutional and economic realities of emerging economies can sometimes raise additional barriers to the diffusion of low-carbon technology. For example, investors will give a higher weight to sovereignty risk in emerging economies than in OECD markets. This increases the cost of investment in emerging economies. The weak institutional track records, protective banking systems and risk-averse lending structures of some emerging economies also increase the difficulty to having access to capital and liquidity. High investment costs and incompatible prices, subsidies and tariffs also create significant economic and market barriers (Box 15.8).

Box 15.8 ▶ Barriers to trade in low-carbon energy technologies

Trade barriers on imports can hinder technology diffusion by raising the domestic price of low-carbon technologies. The removal of such barriers is important for developing countries. China, Hong Kong (China), Mexico, Singapore and Thailand are among the top ten exporters of renewable energy technologies and, therefore, have significant export interest in trade liberalisation in the sector (WTO, 2009). EU tariffs of as much as 57% on compact fluorescent lamps (CFL) imported from China have led to a significant decline in Chinese CFL exports to the European Union (Brewer, 2009).

Biofuels experience significant tariffs. Tariffs on ethanol and on some biodiesel feedstocks, including import and export duties on Brazilian ethanol, amounted to USD 6 billion in 2006. OECD countries' subsidies to domestic biofuel producers reached USD 11 billion in 2006. As a result, investments are not being made where technology is the most cost-effective (IMF, 2008). In Egypt, the average tariffs on PV panels are 32%, ten times the 3% tariff imposed in OECD countries (World Bank, 2008).

Eliminating tariff and non-tariff barriers on clean energy technologies could increase their traded volume by an average of 14% in 18 developing countries that emit high levels of greenhouse gases (World Bank, 2009a). Barriers to trade in services also have negative impacts, since the deployment of many clean energy technologies requires a wide range of consulting, engineering or construction services. An opportunity to liberalise trade in some climate-friendly goods and services currently exists at the multilateral level within the context of the Doha Round.

Beyond such economic and market factors, other factors likely to hold back technology diffusion include a lack of information on the technical performance of often complex technologies, inefficient networking, and inadequate systems and tools for research.

The role of IPRs in technology diffusion is a matter of debate. Some commentators, usually from developed countries, argue that stronger IPR regimes encourage investment in innovation and the diffusion of low-carbon technologies, and particularly of technology-intensive goods. Others, often from developing countries, argue that IPRs slow the rate at which their firms can produce low-carbon technologies and prevent firms from producing at the cutting edge of technology. In response, there have been calls for more flexible approaches, such as joint ownership, the creation of patent pools and patent commons[19] for low-carbon technologies.

Publicly facilitated patent pools have a long history. To protect the public good, governments have created collective rights organisations which have mandated the licensing of patents at established fee levels, created and managed public patent pools, directly purchased enabling technology patents and placed them in the public domain, and even created mergers between firms. Private institutions or industry-led consortia have also organised private patent pools, including small contract-based patent pools, large industry-wide patent pools, and technology standard-setting patent pools. Sewing machines, aircraft, movie projectors, videos, radios and many other technologies have been widely diffused through the use of

19. For example, Eco-Patent Commons is an effort co-ordinated by the World Business Council for Sustainable Development (WBCSD) that puts environmentally beneficial patented technologies in the public domain without royalty.

patent pools. Private and/or publicly facilitated patent pools are being explored in the software, biotechnology and health care industries. Similar approaches may help accelerate technology diffusion in energy technologies, for instance through technology-specific or sector-specific patent pools.

Recently some countries have been entering into bilateral negotiations to explore frameworks for sharing intellectual property (IP) within collaborative RD&D programmes for climate-friendly technologies. For example, the United Kingdom and China are developing an agreement to help decide where IP rights should lie in joint work between UK and Chinese businesses and research organisations. Lack of clarity on allocating IP rights is known to be a barrier to collaborative RD&D. It is possible that experience gained through these bilateral discussions, drawing upon practical experience and working models in other RD&D fields, could present a basis for broader agreements on IP sharing as a means to facilitate stronger collaborative RD&D.

Some practical policy solutions have been proposed for streamlining IPRs. The United Kingdom, Australia, the United States and Japan have all put in place arrangements to fast track patent approvals for low-carbon technologies. An internationally co-ordinated approach to the fast tracking of patents could also be facilitated through the World Intellectual Property Organisation. Separately, some governments are providing financial and capacity-building support to IP applicants and technology developers. Licence of right (LOR) systems provide an incentive to patent holders to make patent licences available to anyone requesting such a licence, with adequate remuneration agreed upon between the patentee and the party seeking a non-exclusive licence, or, in the absence of such an agreement, established by the patent office or a court. The incentive is usually in the form of a reduced patenting fee.

Countries need to implement IPR legislation that reflects their particular circumstances, including their stage of industrial and technological development, and their goals, infrastructure and international relationships. But all countries need clear rules concerning the ownership of patents and the boundary and scope of the national protection and enforcement mechanisms, since they need to provide the frameworks within which firms can develop legal agreements that will enable access to new technologies.

Box 15.9 ▶ Rationale for intellectual property rights

The nature of a given innovation will determine what type of intellectual property it is, and the rights that the creator can claim over it. The most common categories of IP include patents, trademarks, design rights and copyright. A single innovation may encompass a number of different types of IP. Patents provide protection against the copying of innovations, thereby protecting the innovator's investment in the innovation. IPRs provide the necessary commercial and legal protection while enabling the creation or invention to become public. Public disclosure in turn fosters competition. IPRs also protect consumer interests, insofar as the presence of a genuine trademark on the goods helps assure consumers that they are receiving the original article, not a copy that may be of lesser quality. The enforcement of IPRs plays a crucial role in sustaining the effectiveness of IP laws. Without effective enforcement in the form of such penalties as injunctions, damages or the destruction of counterfeit goods, IP laws are likely to have little effect in promoting innovation.

Even where affordable access to patents is possible, in some cases this is not enough to enable developing countries' firms to begin producing these technologies. The lack of practical experience gained in the development phase of a technology can also act as an obstacle to diffusion. Tacit knowledge and other related knowledge such as trade secrets are often not patented but may be essential to the effective implementation of a technology (Ockwell *et al*., 2009).

If countries are to benefit from technology diffusion, they need to be able to adapt the technology, to develop and deploy it within the specific country context, to replicate it, to enhance it, and eventually to innovate it so as to create a new product. Evidence suggests that the lack of human capacity to undertake such technology absorption is a much greater barrier to technology adoption in developing countries than in developed countries (Worrell *et al.*, 2000). Government policies need to treat the diffusion and development of low-carbon technologies as sides of the same coin. Countries that innovate are more likely to benefit from innovation coming from abroad. As low-carbon technological capabilities build up in non-OECD countries, this will facilitate both the diffusion of existing low-carbon technologies within developing countries and the adoption, adaptation and development of low-carbon technologies that fit with the priorities of developing countries.

Skills and knowledge can be developed by investing in the country's institutions responsible for creating, storing and transferring knowledge, such as universities, RD&D centres and training institutes, as well as networks. In addition, bilateral or multilateral international collaboration on RD&D can play an important role in fostering knowledge-sharing and developing capacity, particularly when it involves private-sector participation. Different kinds of absorptive capacity may be required for technologies at different stages of development (Ockwell *et al.*, 2007). The absorption of technologies at an early stage of development is likely to require the development and deployment of competences in related technologies as well as commercialisation skills.

Strengthening low-carbon technological capacity in emerging economies

Although developing countries need rapidly to introduce low-carbon technologies, most of the innovation is highly concentrated in developed countries. Japan, the United States and Germany are responsible for about 60% of all filed patented inventions in thirteen climate change mitigation technologies[20] between 2000 and 2005. Japan alone accounts for 37% of the world's inventions on average, and is responsible for over 50% of the world's inventions in electric and hybrid vehicle technologies, and in waste-to-energy and lighting technologies (Dechezleprêtre *et al*., 2010).

20. See footnote 7.

Between 1997 and 2003, the share of climate-friendly inventions patented by emerging countries grew at an average annual rate of 18%. Emerging economies accounted for 16.3% of patented climate-friendly technologies in 2003 (Dechezleprêtre *et al.,* 2008). China and Russia were respectively the fourth- and sixth-largest inventors between 2000 and 2005, with strong positions in particular fields such as geothermal (China) and cement (China and Russia). Brazil also figures among the top eleven countries (Table 15.10).

Table 15.10 ▶ *Averages of the share of world climate innovations for selected countries, 2000-05*

	World rank	Average percentage of world's climate inventions	Most important energy technology classes (decreasing order)
Japan	1	37.1%	All technologies
United States	2	11.8%	Biomass, insulation, solar
Germany	3	10.0%	Wind, solar, geothermal
China	4	8.1%	Cement, geothermal, solar
Russia	6	2.8%	Cement, hydro, wind
Brazil	11	1.2%	Biomass, hydro, marine
Chinese Taipei	21		Ocean, lighting
India	27		Cement

Source: Based on Dechezleprêtre *et al*. (2010).

Other patent-landscaping exercises show similar patterns. The joint share of the BRICS countries in world patents in renewable energies and CCS is just under 3%,[21] and just over 2% in the field of energy efficiency in buildings (Walz *et al.,* 2008). BRIICS countries accounted for only 6.5% of global renewable energy technology patents in 2005, while the European Union accounted for 36.7%, the United States for 20.2% and Japan for 19.8%. In the patenting of automobile equipment for reducing car emissions, BRIICS share was just 0.7% (OECD, 2008).

A strong upward trend in patent activity has emerged recently in non-OECD countries, especially in China[22] and to a lesser extent in India. BRIIC countries are narrowing the gap relative to OECD countries, with annual renewable energy technology patenting growth rates more than twice those of the European Union and the United States. Roughly 0.7% of BRIIC country patents were filed in the renewable energy field from 2003 to 2005, compared with less than 0.3% in the United States (World Bank, 2009a).

21. China and Russia have the largest shares among BRICS countries in these fields, followed by India and South Africa.
22. More detailed analysis suggests that most patents originating from China are filed by foreign subsidiaries. Over 85% of patents in many of China's core high-tech economic sectors are owned by companies in developed countries (Liu, 2007).

Much of the growing success of emerging economies, especially in China and India, in building up their innovation capabilities is a result of a combination of increased exposure to international technology through trade and FDI flows, and strong investment in national skills development. This has been made possible by exceptional economic growth and capital accumulation. In addition, some emerging economies have traded access to foreign technology for access to their national markets. For example, foreign manufacturers have a higher chance of being considered in public tenders in China if they set up R&D centres in the country. Several emerging economies have also established ambitious R&D policies and identified low-carbon R&D priorities (Table 15.11).

Table 15.11 ▶ R&D priorities, policies and expenditure for clean energy in BRICS countries

Countries	Low-carbon R&D priorities and spending	R&D policies
Brazil	Biomass (mainly ethanol production) is the leading focus for R&D. Particular R&D emphasis is on the breeding of new sugar cane varieties for ethanol production, ethanol production from cellulosic biomass and sugar cane gasification to produce energy with gas turbines. Hydropower, solar electricity and wind energy are also high priorities for R&D. Federal government spending on energy R&D was 3.1% of all federal R&D in 2006 (USD 140.5 million out of USD 4.5 billion). Brazil's estimated public RD&D expenditures on bioenergy in 2008 amount to USD 62.8 million.	The Science Technology and Innovation Action Plan 2007-2010 aims to increase aggregate state and federal expenditures in R&D, from 1.02% of GDP in 2006 to 1.5% of GDP by 2010, and to promote an increase in overall R&D investment. The Plan relies on federal resources of the order of USD 22 billion. Recent efforts have sought to foster R&D investment by private firms through tax incentives, grants, business incubation and support to venture capital. An Innovation Law signed in 2004 provides incentives for building and strengthening partnerships between universities, research institutes and private companies, but there have been some concerns about the effectiveness of this law in creating public-private partnerships.
Russia	R&D top-priority themes include the efficiency of energy production (conversion of primary energy), the development of smaller hydroelectric plants and the modernisation of the transport infrastructure. The efficiency of heating supply is also a priority. Russia's estimated public RD&D expenditures in energy efficiency in buildings in 2009 amount to USD 22.6 million, while estimated expenditures in energy efficiency in industry for the same period amount to USD 23.4 million.	Russia's R&D expenditure per capita is among the highest of the BRICS countries, with the bulk of R&D funding made by the government. However, total R&D expenditures remain far below those of most OECD countries in terms of a percentage of GDP. The public R&D system is highly fragmented in terms of funding and steering mechanisms, and Russia's innovation performance remains modest. Recent policy reforms have included the creation of special economic zones in some formerly closed science cities, specialising in issues such as nuclear physics, advanced materials and nanotechnology. Tax breaks and other incentives are designed to attract private investments. The Russian government has taken control of the formerly autonomous Russian Academy of Sciences, and is expected to restructure it with the objective of enhancing the coherence of Russia's innovation system.

Table 15.11 ▶ R&D priorities, policies and expenditure for clean energy in BRICS countries (continued)

Countries	Low-carbon R&D priorities and spending	R&D policies
India	The priority subjects are wind energy, smaller efficient vehicles, solar, and the utilisation of biomass, with an emphasis on jatropha and other domestically grown non-edible feedstocks for biodiesel. R&D into decentralised, domestic renewable energy sources is also a priority. India's estimated average public RD&D expenditures on solar energy in 2007-2008 amount to USD 20.6 million, and estimated expenditures on bioenergy for the same period amount to USD 10.5 million.	R&D spending has remained at about 0.8% of GDP since 1990, with the central government representing the principal source of financial support. The Eleventh Five-Year Plan establishes a target of overall spending on science and technology of 2% of GDP, of which R&D spending constitutes one component. In 2007, the Ministry of New and Renewable Energy proposed total renewable energy RD&D funding of USD 0.32 billion over the period 2007-12, a very significant increase over the USD 15.5 million in the previous Five-Year Plan.
China	Capacity-building priorities include coal gasification, coal-to-hydrogen, wind power, solar thermal energy, PV and EVs. Solar PV cells and solar water heaters have a particularly high priority. Research emphasis is also on water power, fuel-cells, geothermal energy and wave power. Major importance is also attached to energy-saving technologies, particularly in buildings, and to the transport sector (particularly in the area of electric vehicles). China's estimated public RD&D expenditures in solar energy in 2006 amount to USD 29.3 million, and estimated expenditures in wind energy in 2006 amount to USD 11.7 million.	In recent years, China has significantly increased its total R&D spending to a level of 1.5% of GDP, or roughly USD 40 billion. This is a level similar to that of many Western countries, but still behind the world leading R&D investors such as the United States and Japan. China's National Medium- and Long-Term Programme for Science and Technology Development, issued in 2006, sets a global R&D spending target of 2.5% of GDP by 2020, and calls for an increased reliance on indigenous technologies. The Chinese government has started to take a less direct role on R&D management, and has encouraged research institutes and universities to capitalise on the value of their R&D products and to engage in commercial activity. Private enterprises have taken on an increasing role in R&D.
South Africa	Capacity-building priorities include coal gasification and coal-to-synfuels, leading to good preconditions for the future application of CCS. There is increasing interest in synthetic biofuels, mini-hydroelectric schemes, and commercial and domestic solar water heaters. An Energy Efficiency Strategy has been approved, and efficiency in both commercial and residential buildings has been included as a priority. Gross expenditure on energy R&D in 2005 was USD 96 million.	The National R&D Strategy of 2002 highlights a commercialisation gap between the R&D and business sectors and the need to develop improved technology transfer mechanisms. Energy research, development and innovation is a strategic focus area of the National R&D Strategy. The aim is to address the challenge of developing a sustainable base for national energy research. In recent years, the government has adopted the 2008 Intellectual Property Rights Act and the Technology Innovation Agency Act to bridge universities and companies, and promote technology transfer and commercialisation. Emphasis has been placed in the formation of innovation hubs and the creation of incubators.

Sources: Compiled from Walz *et al.* (2008); IEA (2009c) and OECD (2005).

It is difficult to assess emerging economies' innovation capabilities and the rate at which they are catching up with OECD countries. Emerging economies, especially China, have strengthened their positions markedly, but OECD countries are still producing more energy-related innovation, concentrating on major cutting-edge technologies. The concentration of clean energy patent ownership in OECD-based companies indicates that the diffusion of low-carbon technologies into emerging and developing economies will have an important part to play in enabling those countries to make their expected contribution to the BLUE Map scenario outcomes. But the speed of diffusion of these technologies will be as much influenced by policies and measures in emerging economies, and by their ability to exploit technology innovation, as by OECD countries.

The way forward

No single policy change will reduce barriers and accelerate the diffusion of low-carbon technologies into emerging economies. Integrated strategies will have to be built which are technology- and country-specific and which reflect the stage of technology maturity, the characteristics of the countries seeking to absorb the technology, and the stakeholders involved.

A number of practical policies and measures to enable diffusion could be implemented by emerging economies today.

Technologies that are already competitive are accessible to emerging economies through a number of commercial channels. Broader adoption of these technologies requires that emerging economies:

- Adopt transparent, stable and long-term national policies that provide a strong market incentive and support for low-carbon technologies, for instance driven by performance standards or policy targets and regulations.
- Encourage higher value-added FDI and domestic private investments towards clean energy technologies. This requires a low level of restriction on FDI, and putting in place a business-enabling environment and a good investment climate for attracting private-sector investments, for instance through regulatory, infrastructure and skills improvement.
- Invest abroad, for instance through FDI and mergers and acquisitions, in order to acquire technology and enter new markets. Market openness and the elimination of barriers to trade should be promoted in both directions. The creation of overseas R&D centres might also be an option to develop channels to acquire knowledge and learning.
- Provide clear IPR management regimes, through IPR protection laws and effective enforcement. At the same time, the role of patent pools and licensing backed by public support could be further explored.
- Improve the capability of domestic firms to conduct effective negotiations with technology holders, based on a clear understanding of the technology concerned.

For technologies that are technically proven but which require large-scale demonstration, or technologies that are close to competitive today, emerging economies should:

- Identify common areas of interest for joint international collaborative R&D efforts with OECD and other non-OECD countries. International partnerships provide opportunities for demonstrating the viability of a relevant technology to scale, fostering knowledge sharing, and raising public acceptance, and may build on existing bilateral or regional co-operative experiences, such as the Innovation China-United Kingdom (ICUK) model or the Asia-Pacific Partnership.

- Implement policies and regulations that encourage localisation of corporate R&D activities focusing on innovative technologies into their territories, for example through the provision of fiscal or financial incentives to companies that invest in R&D.

- Provide a framework for IPRs that encourages innovation, within which agreements can be structured. In creating IPR regimes, emerging economies should also consider the needs of their own research institutions and industry to commercialise domestic innovation.

- Promote local innovative capabilities in both basic and applied research. A major challenge for emerging economies is to strengthen their academic institutions by recruiting adequate staff and providing them with adequate resources. Such capacity-building can also be achieved through encouraging closer university-industry collaboration, for example by inviting senior managers of domestic and foreign firms to participate in the governing boards of academic institutions, and by establishing science parks and business incubators.

- Provide incentives to enterprises, including small and medium-sized firms, to buy or license technologies. In developing such policies, issues related to access to finance should involve the banking sector.

Chapter 16 TECHNOLOGY CHOICES AND BEHAVIOUR

Key findings

- *Reaching the full greenhouse-gas mitigation potential of energy-efficient and low-carbon energy technologies will depend to a significant extent on influencing consumers' technology choices and behaviour.*

- *To date, measures to encourage the adoption of low-carbon technologies have focused primarily on technological and economic barriers while relatively little attention has been paid to the influence of social and behavioural factors.*

- *An improved understanding of the human dimensions of energy consumption, particularly in the residential and commercial sectors and in personal transport, will help policy makers to catalyse and amplify technology-based energy savings.*

- *A small but growing set of energy efficiency policies and programmes are successfully addressing important aspects of consumer behaviour by integrating insights from social and behavioural research. Successful programmes use strategies that target, inform, motivate and empower energy consumers.*

- *To facilitate greater residential energy efficiency, governments and utilities should design programmes based on improved research on behavioural aspects of energy consumption, and provide clear information on energy use through greater use of in-home feedback devices, home energy reports, Internet tools and labels.*

- *Successful low-carbon transport strategies will need to be informed by behavioural research into the economic and non-economic drivers that shape transportation-related decisions and practices. More research is needed to understand people's choice of transport mode, vehicle technology, distance travelled and driving practices.*

- *Subsidies and financing programmes that counterbalance higher initial vehicle costs are needed to support the development of sustainable markets for new transport technologies. Vehicle efficiency strategies should identify and address potential rebound effects, whereby drivers travel farther due to fuel cost savings.*

- *Policies to promote the uptake of low-carbon personal vehicles should be supplemented by the development and promotion of safe, reliable and convenient alternatives to personal transportation, including mass transit and information and communications technology alternatives.*

- *Eco-driving practices, including reductions in excessive vehicle acceleration and driving speeds, smoothing traffic flows and reducing congestion, should be adopted as a part of driver training and educational efforts.*

Introduction

The energy technology revolution identified by the BLUE Map scenario requires the rapid and widespread adoption of a wide range of existing and new energy technologies throughout the energy system. This will depend not only on influencing traditional energy markets, but also to a large extent on influencing the decisions that are regularly made by people in respect of many millions of relatively small investments in household and personal vehicle technologies. To be successful, policies and programmes to advance household energy efficiency and promote low-carbon vehicles and renewable energy will need to be informed by a better understanding of the marketing, informational and behavioural aspects that underpin those decisions. This chapter looks more closely at the question of consumers' propensity to adopt new technologies, with particular focus on energy efficiency in buildings and low-carbon personal vehicles.[1]

Energy efficiency can potentially make the largest contribution to reducing energy use and carbon dioxide (CO_2) emissions over the period to 2050. Historically, improvements in energy efficiency have been one of the most important drivers of reductions in energy intensity. Without the energy efficiency gains achieved in OECD countries over the last 35 years, current energy use would be 63% higher than it is. Although energy efficiency improvements are expected to continue to reduce energy intensity in the future, the size and speed of such savings will depend on several behavioural factors including patterns of technology adoption, maintenance and use. Consumer choices lie at the heart of the well-known gap between potential and actual levels of energy efficiency. These choices often reflect a significant disconnect between consumer attitudes and behaviours.[2] To address this, policy makers need a better understanding of the dimensions of consumer behaviour and energy use.

Transportation patterns and technology choices also require a balanced approach that recognises both the human and technological dimensions of energy consumption. From vehicle choices to decisions about amounts and modes of travel, human behaviour significantly influences levels of energy demand in the transportation sector. Transportation policies that reflect people's behaviour can enable better vehicle choices, help induce modal shifts from less efficient to more efficient modes of travel, encourage constraint in the number of vehicle kilometres (km) travelled, and help reshape driving habits in ways that will reduce fuel consumption and carbon emissions.

The potential contribution of behaviour

Recent research efforts have attempted to quantify the potential for behaviour-related energy savings and to characterise the nature of the behavioural changes that might contribute to these savings in the residential and personal transportation sectors (Dietz, Gardner and Gilligan *et al.,* 2009; Laitner, Knight, McKinney *et al.,* 2009; Gardner and Stern, 2008). These studies suggest a potential for behaviour-related energy and greenhouse-gas savings in the range of 20% to 30%.[3]

1. There are also important consumer preferences related to the use of renewable energy, particularly in households.
2. A recent Gallup Poll conducted in the United States indicated that 78% of respondents believed that they ought to be spending thousands of dollars to improve the energy efficiency of their homes. A separate Gallup Poll found that less than 2% of people reported making energy efficiency investments in their homes. www.gallup.com/poll/127220/Americans-Prioritize-Energy-Environment-First-Time.aspx
3. The BLUE Map scenario does not identify what proportion of the energy savings compared to the Baseline scenario results specifically from behavioural changes.

There is evidence that, for maximum impact, policy interventions need to be tuned specifically to the behavioural changes they are seeking to achieve (Dietz *et al.*, 2009). To improve home weatherisation and the upgrading of heating and cooling equipment, for example, a combination of strong financial incentives and programme designs that take behaviour into account is likely to be most effective. To encourage a switch to more efficient vehicles and non-heating and cooling home equipment, measures such as improved rating/labelling systems, the provision of reliable information to households and retailers, financial incentives for households and/or vendors, and strong social marketing are likely to play a more important role. To secure changes in equipment maintenance and adjustment decisions and in daily use behaviours, a combination of mass-media messages, household- and behaviour-specific information, and communication through individuals' social networks and communities is likely to prove most effective.

Around 22% of household energy use in the United States could potentially be saved if people were to adopt cost-effective energy conservation and efficiency behaviours (Laitner, Knight, McKinney *et al.*, 2009). More than half of the potential energy savings could be achieved through low-cost or no-cost behavioural changes, rather than requiring more complex investment decisions (Table 16.1).

Table 16.1 ▶ *Potential impact of behaviour on United States household energy use*

Category of actions	Potential savings (EJ)	Percentage of total
Low-cost/no-cost	5.2	57%
Smart investment decision	3.9	43%
Total energy savings	9.1 ± 2.6	22% of household energy

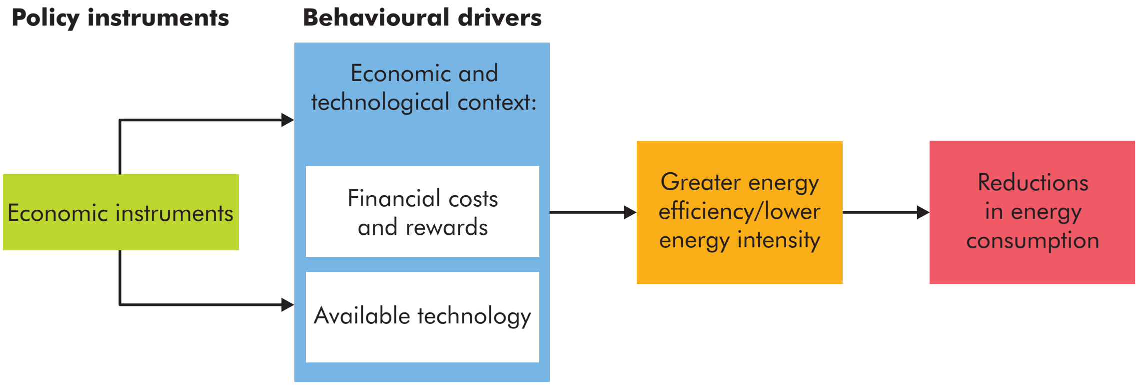
Source: Laitner, Knight, McKinney *et al.*, (2009).

There is also evidence that, faced with shortfalls in electricity supplies, a number of countries and communities have been able very rapidly and deeply to reduce electricity consumption to avoid blackouts (IEA, 2005). Brazil, for example, was able to cut electricity demand by 20% when faced with a severe drought in 2001. A more recent crisis in Juneau, Alaska provided the impetus for electricity savings of 30% in just six weeks. After the crisis was resolved, the city's consumption remained 10% lower than the previous year (Meier, 2009). These examples clearly show that significant energy savings can be achieved quickly through behavioural change, at least on a temporary basis. The need is to devise programmes and policies that can make such behaviours, and the savings that result from them, permanent.

Social and behavioural frameworks

Most current approaches to the analysis of energy consumption are framed by reference to a techno-economic model in which consumption levels are driven by the availability of technologies and economic conditions that either encourage or impede their adoption (Stern, 1986). This approach assumes that energy efficiencies and reductions in energy consumption are achieved by making new technologies available at the right price, and promoting them to consumers on the basis of their rational economic benefits (Figure 16.1). Energy consumption and technology changes are then assumed to result from a set of rational economic calculations involving the price of energy, the cost of technologies, and the level of disposable income. On this basis, the model inevitably tends to favour solutions that lean heavily on the introduction of carefully crafted economic incentives and disincentives (Archer, Pettigrew, Costanza *et al.,* 1987). Consumers are assumed to be logical decision makers who will take steps to alter their behaviour in a rational manner when confronted with rising energy prices or more resource-efficient products to increase their net benefit. Unfortunately, these assumptions have not been proven to apply in practice (Parnell and Popovic Larsen, 2005).

Figure 16.1 ▶ *The techno-economic model of energy efficiency*



Source: Stern (2002).

Key point

The traditional techno-economic model does not take into account important human behavioural aspects.

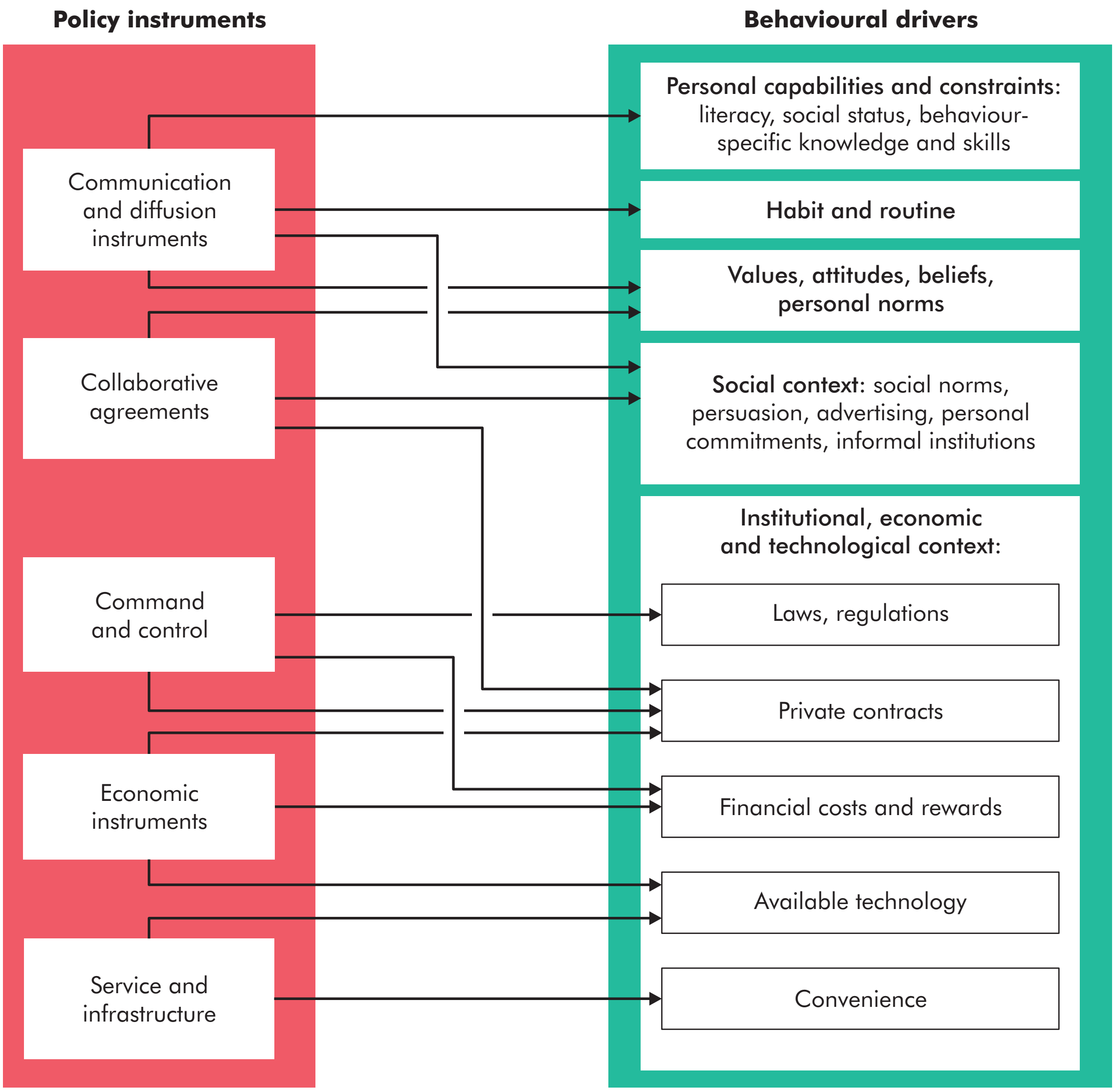
The weakest aspect of this model is the assumption that individuals are economically rational actors. This is apparently not necessarily the case. For example, even when information on the costs and performance of technologies is available, people do not consider it in their cost calculations when deciding whether to purchase a residential solar unit (Archer, Pettigrew, Costanza *et al.*, 1987). Even the most financially skilled consumers do not necessarily use payback calculations as part of their vehicle purchase decision making (Turrentine and Kurani, 2007). A number of other studies have also observed flaws in the rationality of the decision-making process of individuals (NRC, 2002; Feldman, 1987; Stern and Aronson, 1984).

In practice, consumers do not consider expenditure on energy and energy-using equipment as investments. Rather, they are influenced by a variety of non-economic variables including structural and institutional factors, cultural values and norms, individual beliefs and attitudes and interpersonal dynamics. Recognising this complex array of the social, cultural and psychological factors that shape consumer behaviour is likely to result in more effective programmes, policies and forecasts (Laitner, DeCanio and Peters, 2001).

Extensions and alternatives to the techno-economic model

If policies are to influence energy consumption more effectively, they need to reflect a more complex understanding of the many factors that shape or drive individual behaviours (Stern, 2002). Such policies will reflect not only the influence of financial costs and rewards and the availability of technology choices, but also the importance of personal capabilities, habits, values, norms and social and institutional contexts (Figure 16.2).

Figure 16.2 ▶ Policy instruments and behavioural drivers



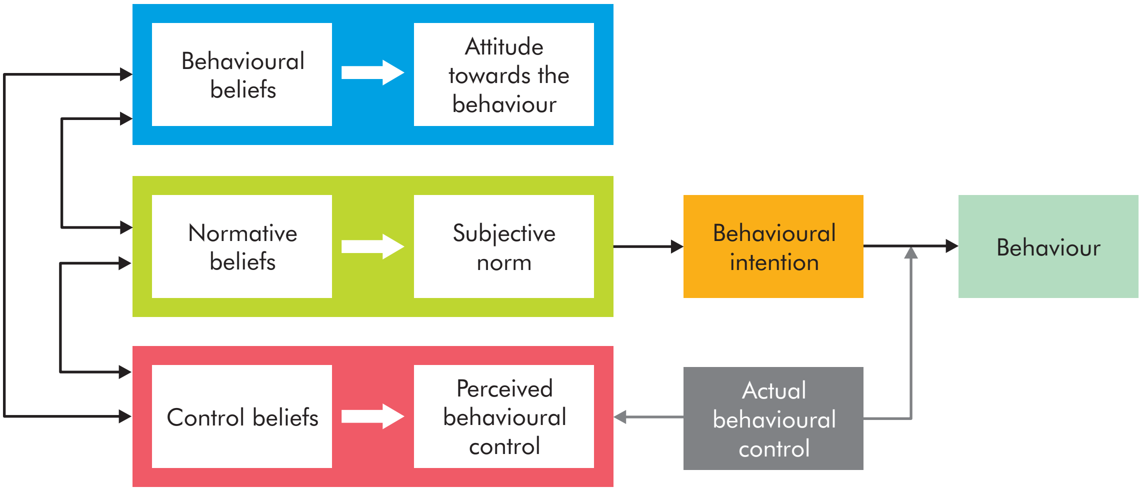
Source: Stern (2002).

Key point

A diverse set of behavioural factors must be considered in designing programmes and policies aimed at improving the adoption of energy efficiency and low-carbon technologies.

For instance, psychological models focus on a narrowly defined set of variables that shape individual behaviour including beliefs, intentions, sense of self-efficacy and subjective norms. The theory of planned behaviour suggests that conscious, choice-making behaviours result from a process in which people weigh the advantages and disadvantages of potential actions based on existing values and norms (not simply economics). As shown in Figure 16.3, these types of decision are determined by the person's own attitudes or opinions about the behaviour, other people's opinions about the behaviour and perceived behavioural control (Ajzen, 1988). This theory suggests that people carry out their intended behaviours in the absence of insurmountable barriers. The approach has been employed to better understand vehicle choice and the relationship between consumer attitudes and technology adoption.

Figure 16.3 ▶ Theory of planned behaviour



Source: Ajzen (2006).

Key point

Models exist that provide an effective means of determining the psychological factors that shape energy technology adoption and use.

Another approach focuses on understanding the factors that shape habitual, or routine, behaviours. Such behaviours are typically performed without full conscious reasoning at the moment they are carried out. As many as 95% of household energy behaviours, such as the routine use of appliances or lighting, are habitual rather than the result of conscious, planned decisions (Wagenaar, 1992). For policy purposes, it can be helpful to distinguish between infrequent energy behaviours such as installing compact fluorescent light bulbs (CFLs) or properly inflating tyres and frequent behaviours such as slower highway driving or the air drying of laundry (Figure 16.4). These are distinguished from consumer behaviours, such as the infrequent and higher-cost investment in more energy-efficient appliances, devices and products.

Figure 16.4 ▶ ***Household behaviours associated with energy consumption, efficiency and conservation***

Frequency of action

Cost	***Infrequent***	***Frequent***
Low-cost / no cost	Energy stocktaking behaviour Install CFLs Pull fridge away from wall Inflate tyres adequately Install weather stripping	Habitual behaviours and lifestyles Slower highway driving Slower acceleration Air dry laundry Turn off computer and other devices
Higher cost / investment	Consumer behaviour New EE windows New EE appliances Additional insulation New EE car New EE AC or furnace	

Source: Laitner, Ehrhardt-Martinez and McKinney (2009).

Key point

Important distinctions between different types of energy-related behaviours must be considered in energy efficiency programme design.

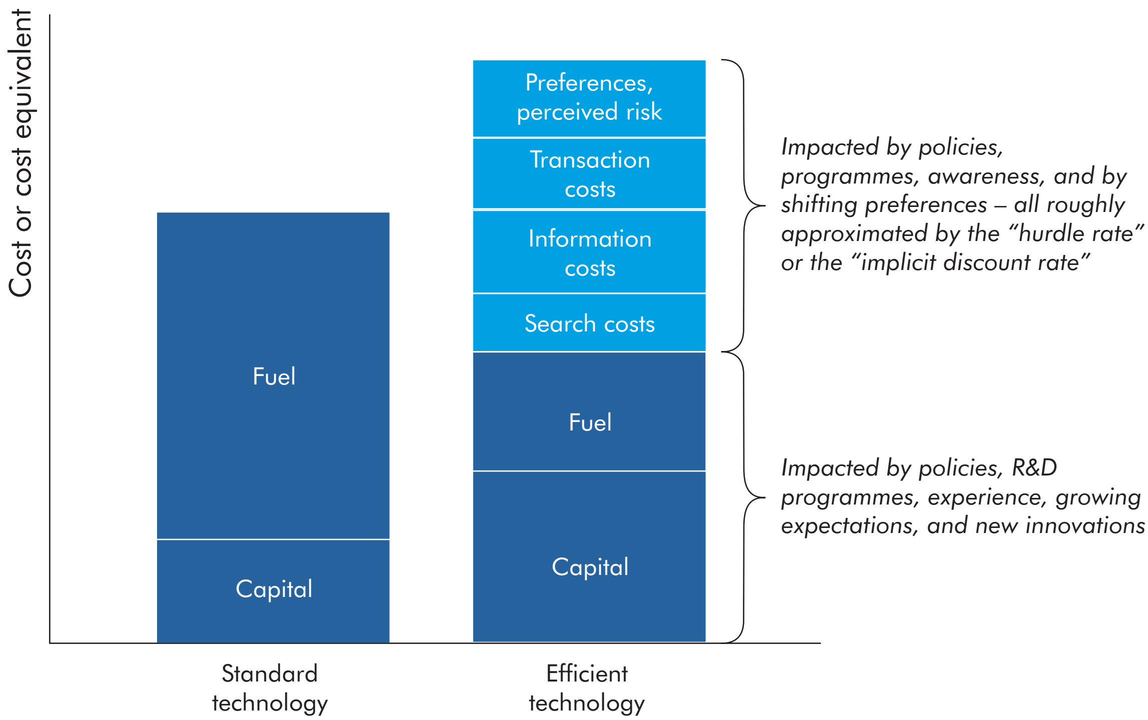
Using frameworks such as these to better understand energy-related behaviours can help to provide a basis for more effective programme and policy designs that take appropriate account of social, cultural and psychological factors.

Consumer adoption of energy-efficient technologies in households

In the BLUE Map scenario, end-use energy efficiency accounts for more than one-third of CO_2 emissions reductions by 2050. To achieve these savings, a higher rate of energy efficiency improvement must be achieved than will occur on the basis of current policies in the Baseline scenario. The BLUE Map scenario envisages this being achieved through the adoption of more efficient appliances and lighting, improved building shells, and the expanded use of heat pumps and solar heating technologies. These changes are unlikely to occur without a broad range of consumer-focused initiatives to overcome barriers to technology adoption. These initiatives include standards and other regulations, labelling schemes, information campaigns and energy audits.

If policies are to successfully catalyse and expand the adoption of new, energy-efficient technologies, they must effectively help households to overcome a range of barriers to their adoption. Among the factors that influence household decisions to adopt new technologies are the time and inconvenience associated with searching for a better product, collecting and assessing information, and completing the transaction. Consumer perceptions of the potential risks associated with the shift to more efficient technologies may also impede their adoption. Policies can make energy-efficient technologies more attractive to would-be adopters (Figure 16.5).

Figure 16.5 ▶ ***Impact of policies on different costs relating to technology choices***



Source: Laitner (2009).

Key point

Policies and programmes must identify and address the hidden costs associated with energy-efficient technology adoption.

Overcoming the costs and risks associated with new technologies is an important step towards increasing technology adoption; however emerging social science research suggests that it is unlikely to be sufficient and that other factors play equally important roles. This research highlights the emergence of successful consumer-focused programmes and policies that target, inform, motivate and empower energy users.

Targeting people and behaviours. The would-be adopters of more energy-efficient technologies present a diverse range of attitudes, interests, values, motivations and resources. Successful community-based social marketing recognises that multiple internal and external barriers may hinder widespread public participation in any form of sustainable behaviour. These barriers will be different for different individuals (McKenzie-Mohr and Smith, 1999). In addition, encouraging people to adopt specific behaviours, such as installing CFLs, using low-flow shower heads or buying energy-efficient washing machines, requires the development of a range of customised tools. Survey research methods can help to identify the barriers faced by different types of individuals, households, organisations and businesses in adopting different behaviours. Promotional programmes and policies which are informed by such research are better able to remove or work around structural, social, personal and psychological barriers and to achieve desired outcomes. The success of targeting programmes is well documented in the healthcare field and is gaining increased attention among researchers and practitioners concerned with energy efficiency (Abrahamse, Steg, Vlek *et al.*, 2005; Backhaus and Heiskanen, 2009; Breukers, Heiskanen and Mourik *et al.*, 2009).

Informing people about energy technologies and programmes. People need information about energy-efficient technology options if they are to be able to make informed decisions. Many OECD countries have implemented labelling schemes for appliances, and electronic and other products to help inform consumer purchase decisions. These labelling schemes are of variable effectiveness. If designed correctly, energy labels can provide useful information to consumers and influence their purchase decisions (Thorne and Egan, 2002). European Union (EU) labelling schemes have achieved significant outcomes in terms of consumer awareness, market impacts and energy savings, although the effectiveness of the United States Energy Guide Label has been questioned as consumer comprehension has been found to be low (Thorne and Egan, 2002).

Giving people access to information about their domestic energy consumption patterns may also be important in reducing energy demand and encouraging the more efficient use of energy. For most people, the only measure they get of their energy consumption is the bill that they receive at the end of the month or quarter. This information comes far too late to be useful in influencing behaviour, except in the widest sense. And while energy bills often report the total amount of electricity consumed and the costs incurred, they do not typically identify the end uses with highest demand or suggest how individual consumers can change their energy demand or increase energy efficiency to reduce energy costs. Energy bills are insufficient to provide the level of detailed and timely feedback that consumers need if they are to manage their own energy consumption more effectively.

This problem has been recognised for many years. Kempton and Montgomery (1982) illustrated the paradox of consumption without meaningful information in the following way:

> [Imagine a grocery] *store without prices on individual items, which presented only one total bill at the cash register. In such a store, the shopper would have to estimate item price by weight or packaging, by experimenting with different purchasing patterns, or by using consumer bulletins based on average purchases.*

Recent research indicates that providing energy consumers with targeted information about their specific energy consumption practices can result in residential energy savings of between 5% and 15% (Ehrhardt-Martinez, Donnelly, Laitner *et al.*, 2010; EPRI, 2009; and Darby, 2006).

Consumers can also benefit from improved information about government programmes, incentives and resources. A recent comparison of federal programmes in the United States suggests that good information and ensuring that programmes are designed for the convenience of consumers are critical to programme success and the achievement of energy savings (Stern, Gardner, Vandenbergh *et al.,* 2010).

Motivating the use of new technologies through social norms, networks, goals, commitments and other incentives. Consumers are often reluctant to replace appliances that are still functioning. Just as economic incentives have had some success in helping people overcome financial barriers, other types of incentives and motivation can encourage people to replace outdated or inefficient equipment before the end of its natural life. The use of social norms, networks, goals and commitments can help achieve this objective. For example, in making decisions, people often look to their peers. This is something that governments can exploit by using communication and guidance to seek to create a critical mass in support of a policy or technological change (Griskevicius, Cialdini and Goldstein, 2008; Schultz, Nalan, Cialdini *et al.,* 2007; and Nolan, Schultz, Cialdini *et al.,* 2008).

Encouraging people to set personal goals or commitments can also increase energy efficiency (McKenzie-Mohr and Smith, 1999). For example:

- In California, home assessors were asked to seek a verbal energy efficiency commitment from householders. Three to four times as many people who had made such a commitment retrofitted energy efficiency measures in their homes as those who had not made such a commitment.
- In another study, homeowners were mailed a pamphlet on energy conservation. One group received a shower flow restrictor along with the pamphlet while the other did not. Homes that received the shower flow restrictor were more likely to engage in the other conservation actions mentioned in the pamphlet such as reducing the temperature on their water heaters.

Empowering individuals by removing financial and non-financial barriers. Consumers often lack the financial resources, incentives or time and ability to make energy-efficient choices.

Consumers can have difficulty securing the funds they need to cover the up-front investment costs associated with costly building retrofits or the purchase of energy-efficient equipment that is more expensive than less efficient models. Some energy efficiency programmes are successfully using different strategies such as on-bill financing (Consumer Energy Alliance, 2009) and green mortgages (HUD, 2009; Prior, 2009) to address this issue.

Structural barriers such as the principal-agent barrier and the home ownership transfer barrier can also impede the adoption of energy-efficient technologies.

The principal-agent barrier occurs when one party makes investment decisions and a different party carries the cost of those decisions (ACEEE, 2007; IEA, 2007). This type of barrier has important implications for technology adoption in new home construction markets, commercial building leasing markets and rental housing markets. In new homes, builders often make technology decisions that shape the subsequent, potentially very long-term, energy use of homebuyers. Similarly, in the commercial building sector and rental housing market, building owners often decide on energy-related technologies that determine tenant energy bills.

In the residential sector, the home ownership transfer barrier may present an even larger impediment to investments in energy efficiency. Home owners may be reluctant to invest in costly energy efficiency improvements if they are unlikely to remain in the house long enough to recoup the benefits of these investments. A number of policy strategies have been suggested to overcome this, including innovative financing, utility on-bill financing, loans tied to property taxes and energy-efficient mortgages. Another approach would require energy efficiency upgrades at the point of sale or major renovation (McKinsey, 2009).

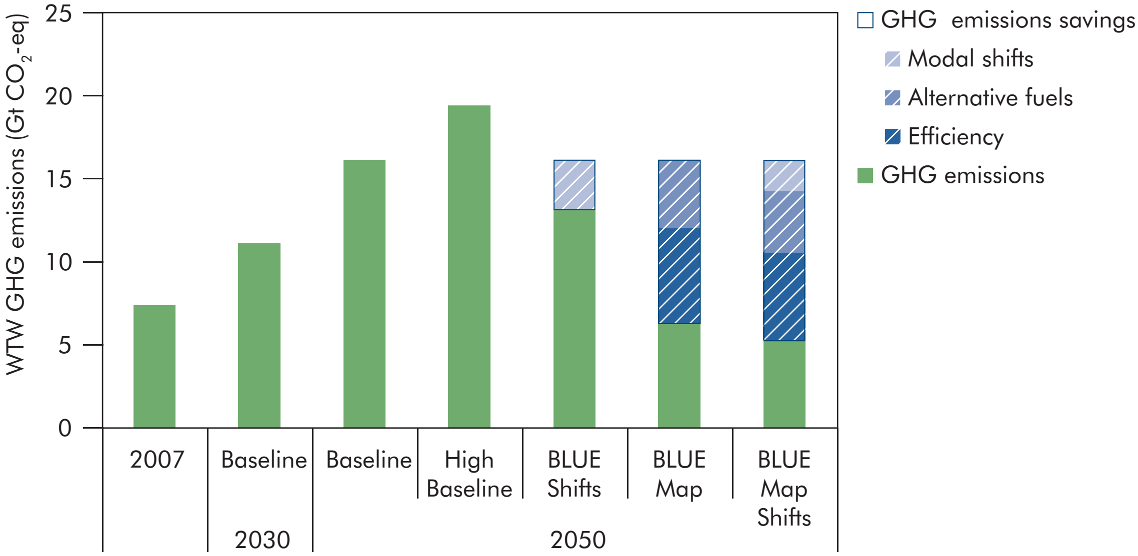
Research from the fields of behavioural economics, sociology, psychology and anthropology has identified systematic biases in consumer decision making that are likely to impede the timely adoption of energy-efficient technologies (Stern, 1985; Lutzenhiser, 1992 and 1993). Households tend to use different mental accounting systems for different kinds of expenditure such as recurring gas and electricity costs, appliance purchases and financial investments (Prelec and Loewenstein, 1998). As a result, households tend to be relatively indifferent to information about returns on investment in energy efficiency. Policies and programmes can correct for some of these biases by structuring choices in more thoughtful ways so as to improve the likelihood that people will make better choices (Thaler and Sunstein, 2008).

Consumer adoption of low-carbon transportation

Light-duty vehicles (LDVs) accounted for about 45% of global transport energy use in 2007. The outcomes in the BLUE Map scenarios depend on significant energy savings and emissions reductions being achieved in the transport sector. For example, in the BLUE Map/Shifts scenario, CO_2 emissions from transport in 2050 could be reduced to as much as 40% below 2005 levels or by 70%, equivalent to a saving of 10 gigatonnes (Gt) of CO_2, compared to the Baseline scenario (IEA, 2009).

Achieving these reductions would require strong policies to encourage the development and implementation of alternative vehicles and fuels and to encourage consumers and businesses to take them up. Much of the projected saving arises from changes in behaviour associated with the adoption of more energy-efficient, including electric, vehicles and with a shift to less carbon-intensive modes of travel (Figure 16.6). In addition, policies will be needed to discourage potential increases in vehicle-kilometres travelled and to encourage more efficient driving behaviours.

Figure 16.6 ▶ Transport greenhouse-gas reductions by scenario and source of reduction



Note: WTW is well-to-wheel, GHG is greenhouse gas.
Source: IEA Mobility Model database.

Key point

Transport greenhouse-gas reductions come from a mix of modal shift, efficiency improvements and alternative fuels, all of which depend on behavioural changes.

Purchase and adoption of more efficient light-duty vehicles

The global number of passenger LDVs increased from roughly 500 million to 800 million in the 15 years from 1990 to 2005, and is projected in the Baseline scenario to reach two billion by 2050. The greenhouse-gas emissions implications of this large and growing demand for LDVs have resulted in increased attention being paid to a variety of new vehicle technologies that hold the promise of substantial improvements in vehicle fuel economy. As discussed in Chapter 7, the pathway to significant greenhouse-gas emissions reductions in LDVs will require the comprehensive adoption of a portfolio of new vehicle technologies.

The transition to low-carbon transportation will rely heavily on consumers' vehicle choices and their adoption of new driving practices. Vehicle choices will determine which new vehicle technologies will be adopted, how quickly they are adopted, and the level of emissions that will result. Making a rapid transition towards greater fuel efficiency and the use of advanced, alternative fuel vehicle technologies will require programmes and policies that address the social and behavioural factors that influence personal vehicle choices. Drivers may also need to adapt to shorter driving ranges, to learn new refuelling procedures, and to adopt new driving practices associated with acceleration and handling.

Incremental improvements in fuel economy have so far been accomplished through the introduction of more efficient vehicles without major changes in attributes such as their size, weight and power. Even so, vehicle choices still involve a trade-off between fuel economy on the one hand and power, size and weight on the other. These choices have been factored into the Baseline and BLUE Map scenarios, both of which assume some future increase in vehicle size, weight and power, for example through increasing sales of sport-utility vehicles (SUVs) in many countries. In the BLUE Shifts scenario, these characteristics are held roughly constant into the future for OECD countries and evolve more slowly than in the Baseline scenario in other countries, maximising the fuel economy benefits of new technologies. This would require significant changes in vehicle choice trends.

More significant changes in consumer behaviours will be needed to accelerate the transition to advanced technology vehicles. Whether the shift is to electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs) or fuel cell vehicles (FCVs), consumers will be faced with significant changes in vehicle attributes. For example, many of these new vehicles are likely to have a much shorter driving range before they need refuelling as well as longer refuelling or recharging times than today's vehicles. Fuel availability may also be reduced, at least during a transition period.

Many consumers do not pay significant attention to fuel economy when making vehicle purchase decisions.[4] Individuals who express an interest in fuel economy appear to be interested not only in private cost savings but also in communicating a symbolic statement that they view resource conservation or thrift as an important value (Turrentine and Kurani, 2007).

In OECD countries outside the United States, consumers appear to be more sensitive to fuel prices. Some research on elasticities suggests that a 10% increase in fuel prices is likely to result in a 4% increase in fuel efficiency, a 7% decline in fuel demand, a 2% decline in average annual driving distance, and a 1% decline in the overall car stock in the long term (OECD, 2003). Both the EU and Japan have achieved improvements in new vehicle fuel economy while the United States has not (Schipper, 2008). Regardless of the location, however, the main response to increasing fuel prices is an improvement in fuel economy rather than a decrease in car travel (International Transport Forum, 2008).

Even though many consumers face real difficulties in assessing fuel economy benefits, research on consumer choice and vehicle purchase decisions suggests that vehicle labelling can play a useful role in steering people towards choosing more fuel-efficient vehicles. For example, the emission profiles of eco-labelled passenger vehicles have been found to be a significant influencer of consumer purchase decisions in Maine (Noblet, Teisl and Rubin, 2006). Although the labels did not change consumers' vehicle class preferences, they did shape their choices within specified vehicle classes. Such labelling programmes are likely to benefit from educational activities that inform people that vehicles vary significantly in their environmental characteristics and dispel the myth that existing regulations have addressed emissions (Teisl, Rubin and Noblet, 2008). Labelling programmes could further benefit from new Internet tools; Internet sites are increasingly the preferred

4. Some recent research (CBO, 2008) suggests that fuel prices are having a small impact on vehicle-kilometres travelled and vehicle choice in the United States. The study examined the scope and intensity of consumers' responses to the upward trend in gasoline prices that began in 2003. According to the study, freeway motorists travelling in areas where rail transit was a viable substitute reduced the number of freeway trips by 0.7% for every 50 cent increase in the price of gasoline. Similarly, the market share of light trucks relative to all new passenger vehicles began to decline in 2004.

medium for providing consumers with access to vehicle information as well as enabling them to make meaningful comparisons before they even make the trip to a showroom.[5]

Concerns about fuel economy and the environment have also resulted in a growing demand for hybrid vehicles. The shift to PHEVs and EVs will represent an even more significant technological move for consumers. Many questions remain about consumer perceptions and preferences and how they are likely to affect the speed and scale of adoption of these new and very different vehicle technologies. Consumer polling indicates that once consumers are made aware of PHEV technology, as many as 49% of United States consumers become interested in it.[6] Similarly, in a study of United States car buyers, 26% said that they would pay a USD 4 000 premium for a PHEV (OPC, 2006).

A preliminary assessment of drivers' perceptions has found that consumer concerns regarding EVs centre on the range and maximum speed of the vehicle, although many drivers expressed a desire to have one (Kurani, Heffner and Turrentine, 2007). United States-based research suggests that there is likely to be widespread interest in PHEVs, but that EVs may be more attractive to people in specific target markets. Successful target markets are likely to include (Turrentine, 1996):

- taxi services in high density urban areas;
- middle-class buyers in high density urban areas in rapidly developing countries;
- residents of gated communities, resorts, retirement towns and new cities;
- urban EV markets in medium density cities of developed economies;
- neighbourhood EVs for multi-vehicle households;
- low-cost, low-range "neighbourhood" EVs for multi-vehicle households;
- "instant" rental cars and car sharing programmes.

Social research suggests that the overall efficiency of the global vehicle stock could be significantly increased by taking consumer preferences, values and perspectives into consideration. People's choices about vehicle size and market class seem to be primarily governed by the expected use of the vehicle. But within those classes, vehicle choices can be shaped through the thoughtful design and widespread use of vehicle fuel economy labels as well as the implementation of other programmes and policies designed to inform, motivate and empower consumers. One example is fuel economy or CO_2-based vehicle taxation, that can be linked to the fuel economy rating of each vehicle.

Reducing driving rebound effects

Increased energy efficiency can play an important role in lowering the energy consumption and carbon emissions associated with each kilometre travelled. Such improvements tend to make driving cheaper. This may encourage drivers to travel further or more often, so that improvements in fuel economy are offset

5. See, e.g., www.fueleconomy.gov.

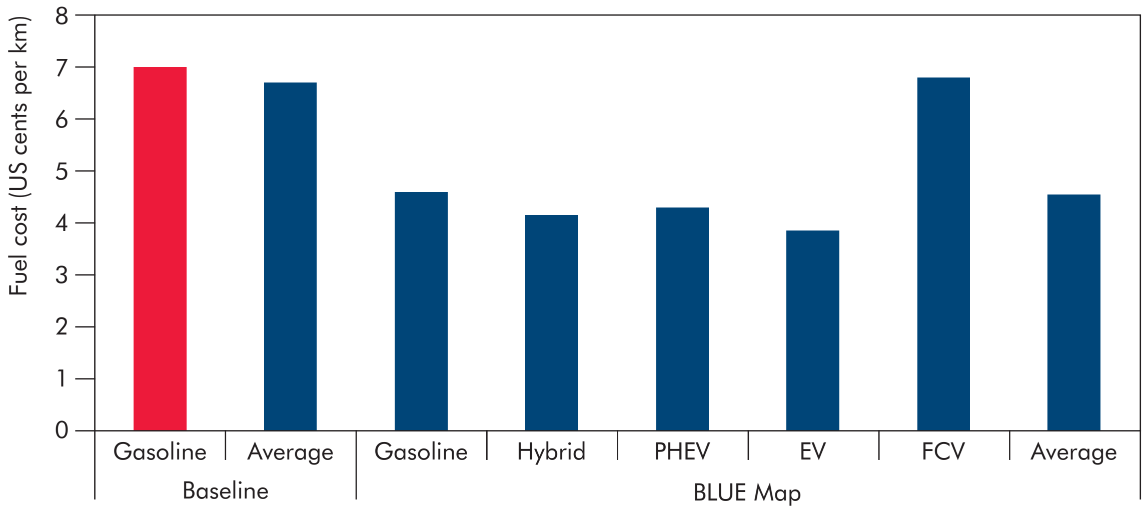
6. When consumers were told that they would have to pay more for the PHEVs than they do for conventional vehicles, interest fell but was still substantial (Synovate Motoresearch, 2006).

by additional travel. This phenomenon is commonly known as the rebound or takeback effect (Schipper, 2000). The rebound effect indicates that travellers are sensitive to travel-related price signals. When the cost of a trip is high, people are less likely to take a trip, but when costs are low, people travel more or further. Such effects should be addressed through policies that help reduce their impact.[7] Residual rebound effects should be factored into savings estimates.

A substantial body of research on travel-related rebound effects[8] indicates that around 10% to 30% of efficiency-related savings are offset by associated increases in travel demands, *i.e.* that a 10% reduction in fuel costs results in a 1% to 3% increase in driving. This is consistent with recent reviews of elasticities that find similar relationships for reductions in driving as fuel costs rise (UKERC, 2007; Goodwin, Dargay and Hanly, 2004). Vehicle travel elasticities are typically estimated to be higher for the long run than the short run, and higher in Europe than in the United States. This may be due to the existence of a wider range of travel options in Europe than in the United States.

In the Baseline scenario, the average LDV has a fuel cost of around US 6.5 cents per km of driving in 2050 (Figure 16.7). Many of the technologies and vehicle types that feature prominently in the BLUE Map scenario have a much lower driving cost. Overall the average fuel cost in the BLUE Map scenario in 2050 is about US 4.5 cents per km, about a 33% reduction in cost compared to the Baseline average. With a 20% rebound effect, this would trigger a 6% to 7% increase in driving, with a similar increase in fuel use and CO_2 emissions, all else being equal.

Figure 16.7 ▶ Fuel cost per kilometre by vehicle technology, 2050



Source: IEA Mobility Model database.

Key point

Reductions in fuel costs per kilometre of driving could result in increases in overall travel distances which would partially offset the efficiency-related energy savings.

7. It is important to note that in none of the reported cases has the rebound effect exceeded efficiency gains and even in those instances where rebound has occurred, efficiency gains have been substantial. The concern here is with reducing the rebound effect through appropriate policies.

8. The majority of studies on travel-related rebound have been conducted in the United States, with a few in Europe.

On the basis of past trends, it appears that the rebound effects associated with vehicle efficiency improvements and new technology vehicles in the future are likely to be relatively small. Even these relatively small rebound effects could be prevented by an increase in fuel taxes of 33%, to offset the efficiency-induced reduction in driving cost and the rebound effect. Other approaches include increasing the opportunities for non-vehicle travel or reshaping the structure of vehicle-related travel costs. Of particular interest are approaches that shift some of the fixed costs of vehicle ownership such as battery costs or insurance to a payment linked to the distance driven. This type of approach could both accelerate the adoption of new car technologies by lowering the up-front cost and limit the impact of rebound effects by increasing the cost per kilometre travelled.

Modal shifts

As described in Chapter 7 and in more detail in IEA (2009), the BLUE Shifts scenario reduces both LDV and air travel worldwide in 2050 by 25% relative to the Baseline scenario. This is achieved by a combination of shifting some trips to bus and rail transit and some to non-motorised modes such as walking and cycling, together with the elimination of some travel as a result of land use changes leading to fewer and shorter trips. This would avoid some of the shift towards car and air travel that happens in the Baseline scenario.

Reducing the rate of travel shift towards car and air travel will be challenging as countries get richer. Especially in OECD countries where cars already dominate travel choices, achieving the objectives of the BLUE Shifts scenario will require important changes in the way people plan and execute their daily travel. An important part of achieving the BLUE Shifts scenario is to develop urban and intercity transport systems that make it easier and more convenient to travel by efficient public modes. These changes would encourage some behavioural change to occur as a matter of course. People are unlikely to change their travel patterns much if doing so involves reduced convenience or comfort, or increased travel time. Creating cities that are convenient and safe to move around in without private vehicles is critical to the successful achievement of the outcomes envisaged in the BLUE Shifts scenario.

Efforts to change the modal mix of travel will depend on changes in urban and regional land use, and on creating more opportunities to people to reach destinations by walking or taking mass transit. This can be achieved through denser development patterns, more mixed use development, and improving the infrastructure for walking, cycling and transit. In the developing world, new bus rapid transit systems offer the possibility of efficient, high speed travel at low cost and represent an important opportunity for creating liveable cities that avoid becoming overly car-oriented. Creating an infrastructure that is friendly to pedestrians and cyclists will also be important in all parts of the world. Many cities currently lack pavements on many or most streets, and few have an extensive system of cycle lanes. Such infrastructure also has important benefits for safety, particularly in large developing cities where pedestrians and motor vehicles are typically not well separated at present. For intercity travel, encouraging investment in comfortable coach systems and in intercity rail systems can play an important role in reducing private vehicle travel.

Even with strong investments in public transit and non-motorised modes, there will continue to be strong incentives for people to rely on cars. This is because after a vehicle is purchased, the marginal cost per trip of using the car is low. Driving is often a very convenient, comfortable mode of transport, involving relatively little walking or exposure to the elements. Walking and cycling trips are by nature relatively short and good pavements, bus shelters, bike lanes and lighting need to be available to ensure safety, security and comfort. To encourage use of transit modes, services must be frequent, high speed, safe, and generally of high quality, and access points must be located close to dwellings.

Measures to discourage car travel may be necessary to complement the provision of high quality alternative modes. Such measures can include limiting parking spaces or increasing parking costs, implementing high fuel taxes, or implementing road pricing systems which require payment for crossing into urban areas or per kilometre of travel on specific autoroutes. The advent of electronic pricing systems has increased the viability of road pricing schemes. Car-sharing schemes can also provide car access when needed while reducing the overall reliance on cars by making the car trip the exception rather than the rule (IEA, 2009).

The continued development and adoption of new information and communications technologies (ICT) can reduce the need for travel by allowing people to communicate and work effectively without the need to travel long distances for meetings or the daily commute to their workplace. Through the use of e-commerce, teleconferencing and teleworking, people and companies increasingly have a choice as to how they conduct their business interactions and these choices have important energy implications (Laitner and Ehrhardt-Martinez, 2008; Laitner, Ehrhardt-Martinez and McKinney *et al.*, 2009). In the United States alone, estimates indicate 3.9 million households had at least one telecommuter in 2006 (CEA, 2007). Current rates of telecommuting could double over a 10-year period. This would result in a saving of 588 million tonnes of greenhouse-gas emissions (Fuhr and Pociask, 2007). In order to maximise potential energy savings, programmes and policies need to support and encourage businesses to adopt ICT alternatives to transportation.

The use of a combination of measures including robust investments in alternative modes and some measures to discourage driving, can help shift travel patterns significantly. They might be able to cut average car travel by 25% in 2050 or earlier. In the BLUE Shifts scenario, this results in a 20% reduction both in energy use and in CO_2 emissions (IEA, 2009). More research is needed to better understand the policy interventions that will be needed to achieve specific changes in travel patterns.

Eco-driving via feedback and programmes

Energy and CO_2 emissions can also be reduced through interventions aimed at changing driving behaviour, such as reductions in excessive vehicle acceleration and driving speeds, smoothing traffic flows and reducing congestion. Eco-driving represents a set of changes in driving habits that can be learned through training and information guides, including through real-time information being provided by the vehicle to its driver. An increasing number of eco-driving initiatives are integrating and applying high-tech monitoring and feedback devices that provide dynamic, real-time feedback to drivers. Early programme results suggest that fuel economy savings range between 5% and 15% with some of the best results for individual drivers resulting in fuel economy improvements of 20% to 50% (International Transport Forum, 2008).

A recent United States eco-driving programme involving real-time driver feedback achieved fuel savings of 10% to 20% without significant increases in travel time (Barth and Boriboonsomsin, 2009). The percentage saving was found to be dependent on the congestion level with the largest savings being achieved in severe traffic congestion. In Belgium, a four hour course on fuel-efficient driving achieved average fuel savings of 5.8% although with large differences between individuals (Beusen, Heisakanen, Mourik *et al.,* 2009). These figures may underestimate the potential savings available more widely, as the drivers participating in this study had already made significant efforts to reduce their fuel consumption. Another study (ECMT/IEA, 2005) estimated that average energy savings from widespread eco-driving interventions across OECD regions could probably save approximately 5% of fuel on an ongoing basis. A small number of OECD countries currently run national eco-driving campaigns. Participants have achieved an immediate reduction of CO_2 emissions of around 10% (OECD Observer, 2008).

Since running eco-driving courses is relatively inexpensive, and the lifetime fuel savings per person can be very high, the cost-effectiveness of eco-driving is generally considered to be excellent. Fitting real-time information systems such as fuel economy computers in cars is also highly cost-effective, and provides an important reminder to drivers of the value of eco-driving on a daily basis.

Policy implications

Simply making energy efficiency and low-carbon transport options available and economically attractive is unlikely to bring about the rate and degree of change that is needed to mitigate climate change. Efforts to reduce energy consumption and CO_2 emissions must actively involve the people, businesses, organisations and institutions who consume energy. People-centred approaches that integrate and apply social and behavioural insights can provide the means for accelerating energy savings and closing the gap between actual and potential energy efficiencies and CO_2 reductions.

For these reasons, policy makers should take account of social and behavioural perspectives in the development of all relevant energy-related programmes and policies. This will include targeting and tailoring energy efficiency programmes so as to better inform, motivate and empower consumers to change household energy consumption practices. It will also necessitate the development of new, innovative transportation policies that are based on a more comprehensive understanding of vehicle and mode choices, decisions about vehicle-kilometres travelled and the more widespread adoption of eco-driving practices.

To better integrate behavioural issues into policy making, there is a need for more research to develop a better understanding of the energy-saving potential of social and behavioural initiatives. Economists and policy makers should develop and use enhanced models and frameworks that recognise and incorporate social and behavioural aspects relating to energy consumption. New approaches should complement and extend the purely techno-economic model as a means of understanding, explaining and forecasting energy consumption patterns. Energy programmes and policies should be developed employing a portfolio of energy saving measures that recognise the social and behavioural dynamics of energy consumption.

To facilitate greater residential energy efficiency, governments and utilities need to identify differences in energy consumption practices across different segments of the population, identify barriers to change, and develop tailored programmes. Additional research should be performed to identify the behaviours that can most readily be influenced by policy measures and interventions. Utilities should provide households with in-home feedback devices and associated programmes to help people become better energy managers. Home energy labels should be developed and required for all residential buildings. Utilities should also provide consumers with regular home energy reports so that households have timely information about their energy consumption that is easy to read and understand. This should also provide them with appropriate benchmarks against which they can assess their current energy consumption. Internet-based tools should be developed to help consumers easily and effectively compare the energy implications of appliances and electronics.

To improve the effectiveness of low-carbon transportation options, additional research is needed to investigate existing vehicle choice preferences, how they are changing, and the ways in which preferences vary across different population segments. Policy makers also need to develop a better understanding of the ways in which consumers are likely to respond to new vehicle technologies; this should include investigating the ways in which the principles of behavioural economics might be applied to help shape vehicle choice patterns. Governments also need to investigate the rebound effect to determine the degree to which it offsets efficiency-related savings, to determine where, when and why it occurs and to identify those who are most susceptible to the effects of rebound. The outputs of this research should be used to help determine the policy options that might be most effective in reducing rebound.

In addition, vehicle-specific programmes and policies need to be supported with more comprehensive efforts to look at a more efficient transport system. This includes determining the degree to which smart land use policies have been effective in shaping transportation behaviours and how that effect varies across different population segments. It also involves developing safe, reliable, convenient alternatives to personal transportation, and encouraging drivers to break out of well-established car habits by removing barriers to change. Vehicle manufacturers also should provide greater use of in-car feedback devices which can help consumers become better energy managers. Eco-driving efforts can supplement these strategies, and should be included as a part of drivers' training classes.

Chapter 17 ENVIRONMENTAL CO-IMPACTS OF EMERGING ENERGY TECHNOLOGIES

Key findings

- *Low-carbon technologies often also reduce air pollution and deliver other energy-related environmental benefits. Careful assessment is needed to leverage potential co-benefits and to ensure that any negative co-impacts are understood, quantified and, where possible, mitigated.*

- *The fitting of CCS to an ultra-supercritical (USC) coal plant would reduce net efficiency by around 6 to 12 percentage points. CCS would increase water demand due to the carbon dioxide (CO_2) capture process and the extraction of additional coal. The construction of new pipeline networks for CO_2 transport needs to be carefully managed in order to avoid adverse impacts on ecosystems.*

- *Natural gas combined cycle (NGCC) power plants emit a quarter of the nitrogen oxides (NO_X), sulphur dioxide (SO_2) and particulate matter (PM) of a USC coal plant. They consume one-third as much water and use half as much land. Natural gas combustion does not produce significant amounts of solid or liquid waste, eliminating the need for holding ponds or other means of waste disposal. Methane emissions that frequently occur along the natural gas supply chain can partially offset the CO_2-reduction benefits of NGCC relative to coal power.*

- *Nuclear power plants emit no health-damaging air pollutants or greenhouse gases during electricity generation. Nuclear power plants withdraw and consume more water than coal per unit of electricity generated. Waste volumes relative to coal plants are small, but nuclear waste requires particularly careful handling and very long-term secure storage.*

- *Concentrating solar power (CSP) installations produce no harmful air pollutants or greenhouse gases during operation. Concentrating solar power plants with wet cooling systems consume more water than coal plants per unit of energy produced. Water consumption can be reduced by about 90% by using dry-cooling technology, but with higher upfront costs and an efficiency penalty of 1% to 5%.*

- *Solar photovoltaic (PV) and wind power are essentially zero-emissions technologies during electricity generation. They provide significant health and environmental benefits relative to coal power. Photovoltaic and wind consume almost no water in normal operation. Wind farms can have negative impacts in relation to their physical presence and noise levels.*

- *The air pollution resulting from biofuel production and combustion depends on the feedstock, harvesting and processing methods, and combustion control technology applied. Where biofuels need to be irrigated, their water consumption is significantly higher than that of any other fuel source. It is important to consider the activities displaced when assessing the net greenhouse gas consequences of land clearing for biofuel production.*
- *Electric vehicles (EVs) and hydrogen fuel-cell vehicles (HFCVs) deliver net reductions in NO_X emissions compared with gasoline-powered vehicles even when they use coal-based electricity. They will need to use electricity generated from low-carbon technologies if they are to be able to play their full role in mitigating CO_2 emissions. EVs and HFCVs that rely on water-intensive forms of electricity generation use similar or higher volumes of water in their fuel production as conventional gasoline vehicles.*
- *Further study is recommended to refine the estimates in this assessment, and to make them more readily applicable at a regional, national and local level.*

Introduction

Objective and scope

Many of the technologies deployed to reduce CO_2 emissions will also have wider economic, social and environmental impacts ("co-impacts"). These may be positive or negative. In some cases, a particular set of actions may have both positive and negative co-impacts.

This chapter reviews some of the wider impacts of specific low-carbon technologies. It sets out an analysis of related considerations that policy makers may wish to take into account in deciding whether or not, or how best, to enable the broader deployment of low-carbon energy technology options. Many of these impacts will be setting-specific. Policy makers will need to undertake their own analyses to assess the impacts and magnitudes of specific technologies in different settings.

This chapter focuses primarily on environmental and health-related co-impacts.[1] Special attention is given to the following issues that, particularly in developing countries, may raise more immediate political and social concerns than CO_2 mitigation:

1. Impacts related to employment, energy security, building corrosion, accident risks, manufacturing and construction are generally outside the scope of this assessment. Construction-related environmental co-impacts result from all power plants, but differences between technologies are generally negligible compared with impacts from other stages of the power-generation life cycle.

- air quality and related impacts on human health;
- water quality and availability; and
- land use and related impacts on food availability and price stability.

This chapter provides a technology-specific review of these impacts in respect of the emerging alternatives for power production and vehicle propulsion that are expected to be more widely deployed in the BLUE Map scenario. Further analysis would be needed to produce a more detailed assessment of other technologies envisaged to come to fruition before 2050 in this scenario.

Co-impacts in context

The cost of some co-impacts will be reflected in the price of the products or services that give rise to them. For example, the wider growth of biomass for energy purposes may put pressure on the availability of arable land. This will reflect itself in the market rate for land and hence the cost of biomass. But it will also reflect itself in the price of food, and have an impact possibly much more widely than on just those who benefit from the use of biomass in fuel production.

In cases where the production or consumption of goods and services such as energy, creates costs or benefits that are not reflected in the prices charged for the goods and services being provided, these co-impacts are known as externalities (Khemani and Shapiro, 1993). The consequences of these co-impacts may be borne by individuals or groups who are not responsible for their occurrence and who do not benefit from the activities that cause them. For example, pollutants emitted during the combustion of fossil fuels may degrade air quality and adversely affect the health of nearby populations. In the absence of some means of bringing the external costs to bear on the users of the product or service, there is a risk that consumers will be indifferent to the negative external co-impacts they create.

Several major studies have attempted to value the co-impacts associated with various energy technologies (Box 17.1). A study financed by the European Union estimated that if external costs in the form of damage to the environment and health, excluding those associated with climate change, were taken into account, the cost of electricity produced from coal would double, and the cost of electricity produced from natural gas would increase by 30% (ExternE, 2001). The external costs of energy production and use in the United States in 2005, excluding those associated with climate change, were estimated at USD 120 billion, largely attributable to the human health consequences of the air pollution associated with electricity generation and motor vehicle transportation (NAS, 2009).[2]

Not all co-impacts are negative. Many low-carbon energy technologies, for example renewable energy, energy efficiency and cleaner fossil fuel technologies, offer cleaner alternatives that also eliminate or significantly reduce other forms of conventional pollution.

2. Valuations of human life and the environment often raise economic, philosophical and ethical questions. There is room for further research and discussion on the best ways to account for these issues in the energy sector.

Box 17.1 ▶ Major studies assessing the co-impacts of energy technologies

Electricity generation

• *External costs of Energy (ExternE)*

For more than 15 years beginning in 1991, 50 research teams in more than 20 countries worked under the auspices of the European Commission to estimate and value the socio-environmental impacts associated with energy conversion. The ultimate objective of this work was to identify ways in which energy prices could better reflect the total economic, social and environmental costs of energy conversion, including policy instruments that could best achieve that end.

www.externe.info.

• *New Energy Externalities Development for Sustainability (NEEDS)*

The NEEDS project, supported by the Directorate General for Research of the European Commission, refined and further developed the externalities methodology already set up in ExternE through an attempt to design, implement and test an analytical framework to assess the long-term sustainability of energy technology options and policies. The ultimate objective of NEEDS was to evaluate the full (i.e. direct and external) costs and benefits of energy policies and of future energy systems, both at the level of individual countries and for the EU as a whole. NEEDS was completed in March 2009.

www.needs-project.org.

• *Renewable Energy Costs and Benefits for Society (RECaBS)*

The RECaBS project was initiated by the IEA's Implementing Agreement on Renewable Energy Technology Deployment. The primary objective of the RECaBS project was to estimate the costs and benefits of electricity from renewable energy sources compared with conventional technologies in a fully documented and transparent way. The main output from the project, completed in October 2007, is a web-based Interactive Energy Calculator, which enables cost-benefit analyses to be undertaken for specific energy technologies.

recabs.iea-retd.org

Passenger vehicle energy sources

• *The Greenhouse gases, Regulated Emissions and Energy use in Transportation model (GREET)*

To evaluate the full energy and emission impacts of advanced vehicle technologies and new transportation fuels, the fuel cycle from well-to-wheel (WTW) and the vehicle cycle from material recovery to vehicle disposal need to be considered. Sponsored by the United States Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Argonne National Laboratory has developed the GREET Model that allows researchers and analysts to evaluate various vehicle and fuel combinations on a full life-cycle basis.

www.transportation.anl.gov/modeling_simulation/GREET/index.html

It is important to take proper account of co-impacts in considering investments in emerging low-carbon energy technologies. Emerging technologies often require larger upfront investments or give rise to larger operating costs than more mature technologies. Where they produce positive co-benefits, these can in some cases help to narrow projected cost gaps. Where emerging technologies create negative co-impacts, the careful identification and estimation of such impacts and costs may help lead to more sustainable policies and investments.[3]

Sulphur dioxide, NO_X, PM and other air pollutants are harmful to human health and the environment.[4] Air pollution is a particularly serious threat to public health in urban areas across the developing world. Many measures to reduce CO_2 emissions also have an impact on air quality. Improving energy efficiency or switching to cleaner, renewable forms of electricity production can reduce both greenhouse-gas emissions and air pollution, thereby leading to co-benefits for human health and the environment.

In the European Union (EU), China, India and the European part of Russia, more than 3.3 billion life-years were lost in 2005 due to $PM_{2.5}$ (PM with a diameter of 2.5 micrometres or less) exposure alone (Table 17.1). The 2030 Baseline scenario estimates the loss of life-years rising by about 70% to 5.7 billion. The 2030 BLUE Map scenario results in more than 1.2 billion life-years saved relative to the Baseline scenario.

Table 17.1 ▶ ***Estimated life-years (in millions) lost due to exposure to $PM_{2.5}$ emissions***

		ETP Baseline scenario		ETP BLUE Map scenario	
Country or region	**2005**	**2020**	**2030**	**2020**	**2030**
China	2 233	2 903	2 897	2 707	2 340
India	865	1 637	2 647	1 522	2 044
Russia*	47	45	47	43	41
European Union	206	122	117	118	111

* European part only.

Note: The Baseline scenario figures in the table are taken from the Reference scenario in WEO 2009. The BLUE Map scenario figures are assumed to be the same as the WEO 2009 450 PPM scenario.

Sources: IEA (2009); IIASA (2009).

Impact areas

The analysis in this chapter reviews three broad impact areas:

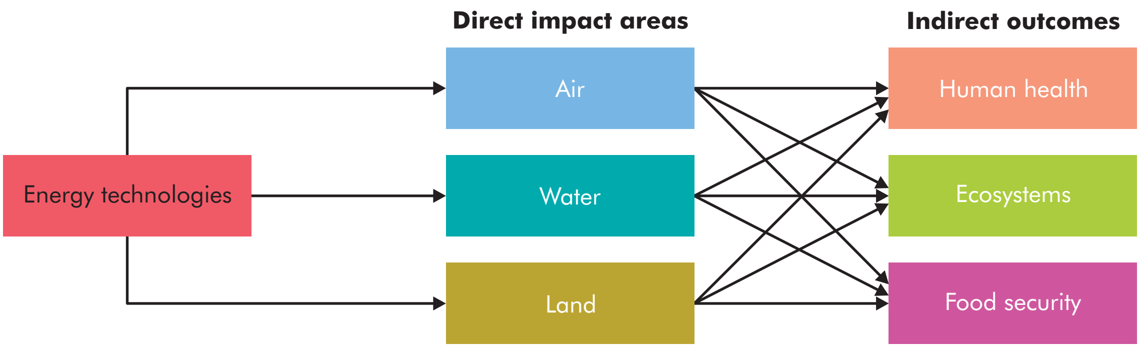
- air impacts: impact on the emission of major pollutants;

3. It is important also to consider local political, economic and environmental circumstances when weighing the significance of co-impacts.
4. A number of studies indicate these pollutants also have an impact on climate change.

- water impacts: impact on consumption and contamination rates; and
- land impacts: impact on area requirements, surface transformation and the displacement of other uses.

The indirect consequences of these impacts, for example on human health, are often of more interest to policy makers than the direct impacts themselves (Figure 17.1). Indirect outcomes will often depend on local circumstances. For example, the costs associated with air pollution will depend on the quantity, type, location and duration of emissions, as well as the size, geographical distribution and health sensitivity of the population. Given such variability, co-impacts are most effectively assessed and evaluated at national, regional and/or local levels.

Figure 17.1 ▶ Energy use has indirect effects on human health and the environment



Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

Energy technologies often affect the environment and, in turn, influence outcomes that are highly relevant to policy makers.

Co-impacts in the electricity sector

Technologies assessed

This section assesses the co-impacts of nine supply-side energy technologies in the electricity sector:[5]

- Coal: ultra-supercritical coal combustion (USC). USC is used as a reference baseline for the evaluation of the co-benefits/costs of other technologies;
- Coal: biomass co-combustion (BCC);
- Coal: ultra-supercritical efficiency with post-combustion CCS;

5. These technologies are expected to be commercially available by 2025. Performance levels and air pollution emission rates are based on reference cases in the NEEDS project. Estimates for water and land co-impacts are based on other studies comparing similar technologies with varying performance levels. Thermal energy technologies are assumed to use wet-cooling systems.

- Coal: integrated gasification combined cycle (IGCC);
- Natural gas: NGCC;
- Nuclear: generation III;
- Solar: CSP;
- Solar: PV; and
- Wind.

Energy efficiency technologies in buildings also play an important role in the BLUE Map scenario, delivering a significant proportion of total CO_2 reductions by 2050. Energy efficiency can provide environmental co-benefits larger than those that are achievable with even the cleanest forms of electricity production, and often at a lower cost (Box 17.2).

Box 17.2 ▶ Energy efficiency in buildings

Energy efficiency technologies for buildings play an important role in achieving the outcomes implicit in the BLUE Map scenario. Energy efficiency, by reducing electricity consumption, frees up existing supplies for other uses and reduces the need for additional generation capacity. Energy efficiency measures are not themselves free of co-impacts, however. These co-impacts, for example those associated with the production of insulation materials, need to be properly factored into any thorough cost-benefit analysis of energy efficiency options.

Energy use in buildings currently accounts for nearly 40% of the world's total final energy consumption. IEA analysis illustrates how CO_2 emissions can be reduced significantly by applying best available technologies (BATs) to building envelopes and in heating, ventilation and air-conditioning systems, lighting and appliances. Existing buildings can often be retrofitted with improved technologies such as heat pumps, combined heat and power (CHP) and solar heating systems. Energy-efficient new buildings can reduce heating demand by as much as a factor of ten compared to the average buildings being constructed today. The additional costs are often comparatively small, and many efficiency technologies generate a return on investment within several years or less due to savings on electricity bills. The achievement of significant early CO_2 reductions will be critically dependent on retrofitting, given the low turnover rate of existing building stocks.

In addition to offering a low-cost or even cost-saving alternative for CO_2 mitigation, energy-efficient technologies in buildings provide many other benefits associated with lower levels of energy consumption. Positive co-impacts include reduced health-threatening air pollution, lower levels of fresh water consumption and contamination, and a smaller footprint on arable land and wildlife habitats from electricity generation.

Although some energy-efficient technologies carry direct negative environmental impacts, the overall effects are usually small compared to the impacts of generating additional electricity. It is important however, for example, to avoid overly "tight" building designs that trap unhealthy indoor air pollutants, and to minimise the manufacturing and demolition wastes associated with new construction.

Baseline case: USC coal combustion

Coal technology will continue to be the world's most widely deployed means of power generation in the near future. It continues to fill new capacity needs at a high rate, making up approximately one-third of power generation capacity under construction worldwide (IEA, 2008a).

For the purposes of establishing a baseline against which to evaluate the co-impacts of other generation technologies, the analysis starts from the characteristics of a high-performance USC coal power plant.[6]

Air impacts

The coal combustion process emits a number of air pollutants with well-documented impacts on human health and the environment, including SO_2, NO_X, PM, mercury, carbon monoxide, lead, arsenic, ammonia and other toxic substances. SO_2, NO_X and PM form the primary focus in this assessment.

SO_2 is linked with a number of adverse effects on the respiratory system; is the leading cause of acid rain, which can damage forests, lakes and buildings; and contributes to the formation of lung-damaging PM. NO_X contributes to the formation of ground-level ozone, which can trigger or exacerbate respiratory illnesses; contributes to the formation of lung-damaging PM; causes acid rain; and can lead to eutrophication of coastal estuaries. PM exposure can cause chronic bronchitis, aggravated asthma and premature death in people with heart and lung disease. PM deposition can change the nutrient balance in soils and bodies of water, and PM suspended in the air is a major cause of reduced visibility in many parts of the world.

Emissions of most air pollutants can be largely controlled with proven technologies, and control standards are expected to tighten over time in developed countries. However, many plants being built or planned, particularly in developing countries, omit available high-level emission controls to reduce construction costs.

In a year, the well-controlled USC coal baseline plant, assuming a 75% capacity factor, would emit an estimated 2 066 tonnes of SO_2, 2 862 tonnes of NO_X and 261 tonnes of PM.

Water impacts

A typical 600 MW coal-fired power plant with open-loop cooling withdraws more than 48 million litres of water an hour to run its cooling system at full operating capacity (US DOE, 2006). Only a small percentage, around 1 million litres per hour, of this water is consumed, but some is lost to the atmosphere through

6. Based on USC hard-coal reference case in the NEEDS project. Peak net capacity: 600 MW; net energy conversion efficiency: 45%; PM control rate: 99% (7.3^{E-5} tonnes/mWh including life-cycle emissions); NO_X control rate: 70% (8.0^{E-4} tonnes/mWh including life-cycle emissions); SO_2 control rate: 93% (5.8^{E-4} tonnes/mWh including life-cycle emissions); fuel source: hard coal with sulphur content of 0.9%.

evaporation before being returned to source. An open-loop system can negatively impact ecosystems when heated water is returned to a cooler natural source. This impact can be mitigated by using closed-loop systems, but net water consumption typically increases in such systems due to higher evaporation rates during the cooling process. The use of dry-cooling or air-cooling systems can substantially reduce water consumption in coal power stations, but this approach gives rise to additional fixed and operating costs and has not been widely adopted.

Coal combustion results in large volumes of solid and liquid waste, including fly ash, slag and sludge. Fly ash has economic value as a low-cost additive to concrete, although this can absorb only a relatively small amount of the total fly ash produced each year from coal combustion. Coal sludge contains toxic chemicals and must be stored in secure containment ponds. These waste ponds often exceed 1 billion litres in volume. Advanced control technologies are necessary to prevent acidification and the contamination of nearby water supplies due to nitrates, sulphates and other chemicals in process wastewater. Ineffective storage can result in local contamination from toxic substances such as the arsenic and mercury present in the coal waste.

Coal mining often uses water in large quantities for dust-suppression, land-reclamation and coal-washing, depending on site-specific mining conditions, methods and regulations. Water requirements can range from 40 to 400 litres per tonne of coal mined (US DOE, 2006). In some cases, additional water is used to transport coal to power plants by pipeline in the form of coal-water slurry.

Land impacts

As with all centralised forms of electricity production, coal plants require land. But the footprint of a coal-fired plant is only a very small proportion of the total amount of land that is needed to support its operation. Coal mining and waste disposal use much larger areas of land, depending on the mining method employed and the extent to which land is restored once mining is concluded. Surface mining, in which earth overlying the coal deposits is removed, often destroys large areas of vegetation, damages ecosystems and leaves behind barren soil or rock. Soil at waste sites can become contaminated and typically remains so, well beyond a coal plant's operational lifetime.

Biomass co-combustion

Biomass co-combustion technology encompasses a range of systems that integrate biomass combustion with the burning of fossil fuels to generate heat or electricity. Modern plants can achieve 20% co-firing, and some smaller coal-fired power stations have targets to increase the proportion of biomass co-firing to 50% or higher (Cremers, 2009). The appeal of BCC is generally tied to a reduction in CO_2 emissions per unit of output compared to 100% coal combustion.

17

For the purposes of this evaluation, a large-scale power plant with specifications similar to those of the USC baseline is assumed to burn 80% coal and 20% perennial grasses and wood-based forestry products.

Air impacts

Co-combustion with both wood and perennial grasses such as switchgrass would lead to a slight reduction in SO_2 emissions relative to the USC baseline due to the lower sulphur content of biomass compared with coal. Without additional controls, PM emissions may increase with wood co-combustion. With the use of affordable pre-combustion and control technologies, the co-combustion of switchgrass, wood and most other biomass materials can yield modest reductions of SO_2, NO_X and PM per unit of electricity produced in large-scale systems.

Biomass harvesting can have a negative impact with regard to air emissions if feedstocks are transported over long distances. The long-distance shipping of wood residues and energy crops is not widespread, but may become more common if local supplies are unable to meet the growing demands of large power plants in certain areas. In most cases, the processes required to prepare biomass for co-combustion result in less air pollution than coal mining.

Water impacts

Co-combustion using 20% biomass could reduce water consumption and pollution during the power generation process compared to a coal-fired plant. Although fast-growing energy crops such as switchgrass require little or no irrigation in most climates, more water may be used in the cultivation and harvesting of other types of biomass. The use of biomass waste products such as sawdust and forestry residues is likely to consume less water than would be consumed for coal mining.

Land impacts

Biomass potentially competes with agriculture for arable land. Government polices need to be formulated carefully in order not to incentivise food crop displacement or forest clearing and not to divert non-waste wood away from use in staple wood-based products.

Biomass co-combustion power plants need a reliable supply of biomass. This is a potential constraint to the wider deployment of biomass in power generation. An acute or sustained supply shortage in biomass supplies may result in switching to less efficient or unsustainably harvested biomass feedstocks. This would negate many of the environmental benefits of using biomass for energy production. A surge in demand for woody biomass could also trigger price spikes in products that compete for forest-based resources.

Policy measures need to ensure that responsible and sustainable land management and harvesting practices are employed to minimise the environmental impacts of the cultivation of short-rotation forest plantations and perennial grasses such as switchgrass on surrounding habitats. In some cases, native energy crops can benefit the soil by reducing erosion, improving nutrient retention and filtering out water impurities. With proper harvesting methods such as limiting cut-back during a single harvest, switchgrass can also provide protective habitat for wildlife.

Other considerations

Building codes and worldwide concrete standards generally prohibit the use of fly ash containing materials other than those derived from coal. So fly ash from a BCC plant cannot be used as a concrete additive in the way that fly ash from a coal-only plant can. The feasibility and timing of any revision to building codes to change this position are uncertain.

Carbon capture and storage

Carbon capture and storage technologies can be integrated with a variety of CO_2-emitting processes, although large commercial-scale CCS has not yet been applied to a coal-fired power plant. This evaluation assumes that post-combustion CCS is fitted to an USC plant and captures 90% of CO_2 emissions.[7] Plant size, performance and other emission controls are comparable to the USC coal baseline.

There is an efficiency penalty of 6 to 12 percentage points associated with the additional energy required to capture, compress and transport CO_2 into storage (IEA, 2008b). For the USC baseline, this would translate to a reduction in net efficiency of 13% to 27%. This efficiency penalty would result in additional resource requirements, including proportionally greater amounts of coal, as well as larger volumes of limestone, ammonia and other substances used in pollutant control systems.

Air impacts

Carbon capture systems remove residual amounts of acid gases in addition to CO_2, including SO_2, during power generation. But other air emission rates per unit of output would increase with the use of CCS. Smog-forming NO_X emissions would increase by approximately 20% to 30% (NEEDS, 2009; Rubin, 2004). Ammonia emissions would also increase as a result of chemical reactions in the capture process (IPCC, 2005). A more detailed analysis is required to determine the net human health and environmental outcomes that would be associated with a decrease in SO_2 emissions together with an increase in one or more other pollutants.

Coal mining and transport are the primary pre-generation activities influenced by CCS. The additional coal required per unit of net power generated necessitates more intensive mining operations, and increases related air pollutant emissions accordingly. Emission levels depend heavily on the method of mining, and the mode and distance of coal transport.

Water impacts

Coal-fired plants with CCS use more water than those without CCS due both to the energy penalty and to the use of water in the carbon capture process (US DOE, 2009). Compared to the USC coal baseline, the addition of CCS is

7. The environmental co-impacts may be different for other carbon capture methods such as pre-combustion and oxyfuel.

estimated approximately to double withdrawals and to increase consumption by one-third or more (ANWC, 2009; Hannegan and EPRI, 2009; US DOE, 2009). However, some of the additional water consumption may be offset by the water that is recovered in dehydrating the CO_2 stream.

The additional mining undertaken to supply the coal requirements for CCS also uses more water. Given wide differences in water use between different mines, projects need to be analysed on a case-by-case basis to determine the specific additional water needs created by the application of CCS in power generation.

Land impacts

Carbon capture and storage increases land use for additional mining. Land use impacts during the electricity generation process are minimal, if the land required for CO_2 transport and storage is excluded. The large-scale development of a CCS network will make demands on land use, but with proper planning and execution impacts on food crops and ecosystems should be largely avoidable, as should any potential impact on ecosystems from the crossing and compartmentalisation of habitats.[8]

Integrated gasification combined cycle

One of the main advantages of IGCC relative to USC is that it enables a cleaner and less energy-intensive carbon capture process. This section reviews IGCC without carbon capture to highlight how it otherwise differs from the USC coal baseline with respect to environmental co-impacts.[9]

Air impacts

Integrated gasification combined cycle offers some environmental benefits relative to USC, including lower emission levels of most major air pollutants. SO_2 emissions are reduced prior to combustion when acid gases and other contaminants are removed from the syngas. SO_2 emissions are controlled typically at a rate of 95% or higher. The gasification process also enables more efficient control of PM emissions due to the gasifier's high operating pressures. NO_X emissions are also generally lower under well-controlled conditions. Emissions of most other hazardous air pollutants from IGCC plants are comparable to, or lower than, the USC baseline.

Water impacts

Integrated gasification combined cycle with wet-cooling technology consumes approximately one-third less water than pulverised coal technology. Lower water consumption is due primarily to the gas turbine's minimal cooling water requirements. This is offset only partially by the additional water required for the gasification process.

8. There are uncertainties related to the permanence of geologic CO_2 storage and, related to this, the possibility that sequestered CO_2 may leach into and contaminate nearby water supplies. Water contamination is considered to be avoidable with proper site selection and management..

9. While higher efficiencies may be achieved in the long term, the net efficiency for IGCC in this case is assumed to be 45%.

USC requires advanced control and treatment technologies to prevent acidification or contamination of nearby water supplies due to nitrates, sulphates and other chemicals in process wastewater. These systems are even more important in an IGCC plant, which in some ways more closely resembles a chemical plant than a coal-combustion plant.

Integrated gasification combined cycle requires similar amounts of coal as USC and, therefore, results in similar levels of mining-related emissions and water consumption except where coal is transported by pipeline as coal-water slurry. This approach is more economically attractive for the direct feed-in to IGCC plants, but requires relatively large volumes of water.

Land impacts

Land-use issues for IGCC technology are similar to those of the USC baseline. The volume of the ash, slag and slurry by-products is roughly the same as that related to USC technology given equivalent levels of combustion efficiency.

Other considerations

Integrated gasification combined cycle produces large quantities of sulphur and sulphuric acid from the gasification process. These relatively pure forms of sulphur can often be sold for other industrial and chemical uses such as fertiliser production.

Natural gas combined cycle

Natural gas currently accounts for the largest share of electricity capacity under construction in OECD countries, and is heavily relied upon as a fuel for electricity generation in many parts of the world. NGCC power plants use natural gas to power one or more gas turbines and excess heat is used to power one or more steam turbines.

Air impacts

Natural gas combined cycle emits only about 25% as much NO_X, SO_2 and PM as USC per unit of electricity generated, including upstream emissions from extraction-related activities and transport. Roughly half the NO_X emissions originate from the operating power plant, with the rest emitted along the fuel supply chain. Most SO_2 emissions occur during gas production. SO_2 emissions from an NGCC power plant are low, except where an unusually high-sulphur mix of natural gas is used.

Water impacts

Natural gas combined cycle plant operation, including natural gas production and transport, consumes roughly one-third as much water as a coal plant at around 200-300 litres per hour for a 400 MW plant operating at full capacity. Most of this water is used in the cooling phase of NGCC plant operation, with relatively little used in natural gas extraction or transport.

Some water pollution can occur during natural gas distribution, if oils used during the production process are released into the environment. The potential for water contamination may increase as the practice of hydraulic fracturing, used to access unconventional natural gas resources in shale rock and coal beds, becomes more widespread. With proper environmental oversight, these impacts are relatively small. The only waste stream from the power plant itself is a small amount of spent catalyst generated every one to five years from the selective catalytic reduction system used to control NO_X emissions (Spath and Mann, 2000).

Land impacts

Natural gas combined cycle plant operation, including onshore natural gas extraction and pipeline transport, uses roughly half as much land as the USC baseline.[10] The majority of this land is used for drilling sites and for pipeline networks for transport. An NGCC plant uses a relatively small amount of land, particularly due to the smaller area needed for on-site fuel storage and emission-control equipment (Fthenakis and Kim, 2009). NGCC does not produce significant amounts of solid or liquid waste, eliminating the need for holding ponds or other means of waste disposal.

Other considerations

Natural gas combined cycle technology is often viewed as a low-carbon alternative to coal-fired power plants, on average emitting half as much CO_2 per unit of electricity output. But natural gas is largely composed of methane, which is a greenhouse gas with a warming effect roughly 20 times stronger than CO_2, although with a much shorter atmospheric lifetime. Significant amounts of methane are often emitted by way of leaks in the natural gas extraction and supply chain. These emissions have the potential to reduce markedly the climate change benefits of NGCC over USC.

Nuclear: Generation III

Nuclear power generation has been in commercial use for more than 50 years. Most new plants commissioned up to 2020 are likely to be based on relatively new third-generation designs which offer improved safety, lower costs and smaller amounts of radioactive waste per unit of electricity generated than previous generations of nuclear power technology.

Air impacts

One of the primary advantages of nuclear power technology is that it emits virtually no NO_X, SO_2, PM, or greenhouse gases in the electricity production process. Some air pollutants are emitted as a result of electricity production for uranium mining and milling, but these emission levels are less than those associated with coal mining, processing and transport.

10. Land use associated with the natural gas fuel cycle may be considerably higher for a particular NGCC plant if a large proportion of its fuel is delivered via pipeline over a long distance.

Water impacts

Nuclear power plants typically withdraw and consume more water than coal plants per unit of electricity produced (US DOE, 2006). A 1 000 megawatt nuclear plant operating at full capacity typically consumes roughly one to two million litres of water per hour (US DOE, 2006). This demand for water can cause problems for inland nuclear plants in the event of sustained heat waves or droughts. In the case of coastal plants, sea water can be used for cooling, eliminating the need for freshwater consumption. In both cases, a proportion of the water withdrawn for cooling evaporates, and the rest is usually returned to its original source. Large volumes of effluent water that have been heated just a few degrees can adversely affect aquatic ecosystems.[11]

Underground and open-pit uranium mining can have negative effects with respect to water consumption and contamination. Much smaller volumes of fuel are needed for nuclear power than for coal combustion, but large amounts of ore must be mined to extract sufficient quantities of the type of uranium that is suitable for power generation.

A less invasive alternative to conventional mining for uranium extraction, known as *in situ* leaching (ISL), involves injecting alkaline or acidic liquids underground to separate out and recover uranium. This technique eliminates the need to physically mine land to recover the ore. It was used for 28% of the world's uranium production in 2008 (WNA, 2008). It is generally considered to be less environmentally harmful than conventional mining, but it still requires soil and groundwater restoration. Not all uranium deposits are suitable for ISL.

Once mined, natural uranium must be milled, enriched and fabricated into fuel rods before being used in a power plant. These processes require both water and energy. Emissions are largely dependent on the energy profile of the electricity source.

Land impacts

Nuclear plants have a relatively small footprint. Land requirements are broadly similar to that of a USC plant, but much smaller if the space needed for the mining and storage of fuel is taken into account. Waste volumes relative to coal plants are very small, but the radioactivity of nuclear waste requires careful handling procedures and secure stand-off areas. High-level radioactive waste needs to be stored securely for thousands of years. Uranium mining can have negative impacts on surface vegetation and long-term land productivity depending on the site and mining methods employed.

Other considerations

High-level radioactive waste from nuclear power generation requires cooling as the process of natural radioactive decay continues to generate heat, typically for a period of several decades. There is consensus among international experts

11. Discharged cooling water does not contain unsafe levels of radiation under normal operating conditions.

that deep geological disposal provides an appropriate and safe technological route for the final disposal of high-level waste. However, no geological repository for spent fuel or high-level waste has yet been built, primarily because of public concern over safety and the consequent socio-political issues associated with the siting of repositories. As an interim strategy, spent fuel is currently stored in either spent-fuel pools or dry-cask storage on site. There is a need for continued scientific and technical work on specific storage sites, and to increase technical confidence through the further reduction of uncertainties.

Nuclear power suffers from negative perceptions, particularly around risk, which limit its public acceptability in some countries. The impacts of a major nuclear power accident on human health could be enormous, resulting in potentially thousands of premature deaths over a very wide geographical area. But the probability of such an occurrence, given effective plant management and control, is very low. Such low-risk, high-impact issues are not factored into this assessment.

As a result of higher nuclear power production in the BLUE Map scenario, uranium consumption will amount to about 5.6 million tonnes between 2010 and 2050, 70% higher than in the Baseline scenario. This exceeds current estimated conventional uranium resources of about 5.4 million tonnes, although so-called unconventional resources in phosphate rocks could amount to an additional 22 million tonnes (NEA, 2008). Increased uranium demand should result in more exploration, which may lead to the discovery of additional conventional resources. In the longer term, the commercial deployment of advanced nuclear reactor and fuel cycle systems may enable greater amounts of energy to be obtained from each tonne of uranium.

Solar: concentrating solar power

Concentrating solar power concentrates heat from solar radiation to produce electricity indirectly using conventional steam turbines or other power cycles.

Air impacts

Concentrating solar power generation produces no harmful air pollutants, other than from basic plant operations such as mirror-cleaning. These emissions are negligible compared to the USC coal baseline. CSP plants are sometimes coupled with natural gas plant as a backup power source so that the combined plant can generate continuously, even at night. The overall level of emissions of a CSP plant will, therefore, depend on the specific backup technology and the levels of its use.

Water impacts

The wet-cooling systems of most existing CSP plant configurations require larger volumes of water than coal power per unit of electricity output (US DOE, 2007). An exception is the parabolic dish-engine system, which uses heat from solar energy to power a heat cycle engine and generate electricity without the need for steam turbines. Such parabolic dish systems are best suited for small-scale power production due to their relatively high costs.

Most CSP plants are sited in sun-rich areas, some of which are water-scarce. So many new CSP projects are exploring dry-cooling technologies, which reduce water consumption by about 90%, but have higher upfront costs and impose an efficiency penalty of 1% to 5% (World Bank, 2009). In dry coastal areas, CSP can provide combined power generation and desalination, using seawater to cool the power cycle and the waste heat to convert seawater into freshwater.

Land impacts

Concentrating solar power produces very little solid or liquid waste. CSP plants use more land than USC plants, but the difference is small when the land used for coal mining is taken into account (Fthenakis and Kim, 2009). Linear Fresnel collectors offer the most efficient use of land among existing CSP technologies. Attractive sites for CSP are often unsuitable for agricultural use and are in relatively isolated areas with low population densities. But siting plants in remote natural habitats such as deserts with rare species of plant and animal life may amplify the negative impacts of CSP operations on local ecosystems. Ecological recovery times in arid settings also tend to be longer than in wet environments.

Solar: photovoltaic power

Photovoltaic displays many of the characteristics of CSP in terms of environmental co-impacts, but uses much less water than CSP with wet-cooling.

Air impacts

Photovoltaic is an essentially zero-emissions technology during the electricity generation process, providing potentially significant health and environmental benefits relative to the USC baseline. Some emissions associated with PV occur during the manufacturing and installation of plant components.

In addition to conventional materials such as steel, cement and aluminium used to construct all power plants, PV technologies require specialty materials such as crystalline silicon for conventional solar panels and tellurium or cadmium for thin-film technologies. Mining and processing these materials consumes energy which, depending on the means of production, can be a source of air pollution. But these emissions are insignificant compared to the cumulative life-cycle air pollution levels associated with a coal plant (Fthenakis, Kim and Alsema, 2008).

Water impacts

Photovoltaic energy conversion does not require turbine technology, circumventing the need for water- or air-based cooling systems. This gives PV an advantage over coal, nuclear and CSP in water-scarce regions. As with CSP, relatively small volumes of water are required for PV plant operations and upkeep, primarily to clean the solar panels. Water issues associated with the one-time mining and processing of solar specialty materials for a given plant are negligible when compared with those of coal, which carry on over the lifetime of a plant.

Land impacts

Land impacts for large-scale PV power plants are similar to CSP in that prime sites are unlikely to compete with other human uses, but may disrupt sensitive desert ecosystems. Mining and processing specialty materials for PV components consumes energy, transforms land and can generate toxic waste by-products, but the associated impacts are small compared to the USC baseline.

Unlike CSP and most other thermal energy technologies, PV technology is modular and can be readily used in micro-installations to power rural communities or individual homes. Mounting PV on existing buildings creates no additional land footprint.

Other considerations

Advanced thin-film PV technologies require specialty materials such as tellurium, selenium and cadmium that are relatively rare, highly concentrated in a few regions and in some cases are produced only as by-products of other major commodities. Rapidly increasing demand for these materials in the future could result in supply bottlenecks.

Wind

From a health and environmental perspective, the co-impacts of onshore and offshore technologies vary to some extent in nature, but not significantly in magnitude.

Air impacts

Wind power produces no emissions other than those minimal levels incurred in the manufacture and production of turbines and towers. This feature provides a significant benefit relative to coal, eliminating negative emission-related impacts on human health, ecosystems and climate.

Water impacts

Wind power requires no water for normal operation and generates no water waste or contaminants. Wind power's ability to generate electricity without consuming water gives it a considerable advantage over most energy options in water-scarce regions where ample wind resources are available.

Land impacts

A large onshore wind farm requires considerably more space than the USC baseline. A wind farm's relatively large footprint is driven by the need for adequate spacing between turbine blades. Most of the land between the tower bases can be used for other purposes such as agriculture or grazing. Offshore wind installations bypass the need for land altogether, with the exception of any additional transmission lines that must be built, although they can create competition for sea space, e.g. in relation to shipping, fishing or recreational use.

Other considerations

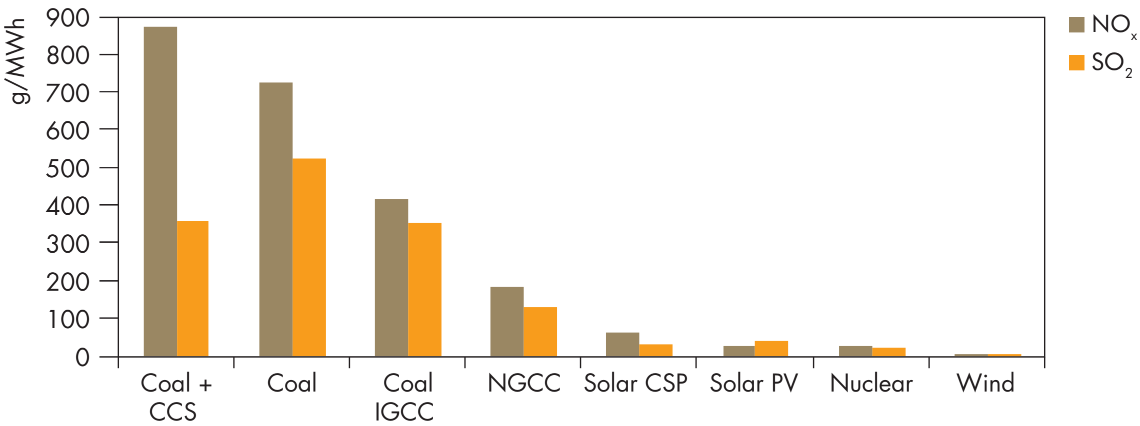
Wind farms can have negative co-impacts in relation to their physical presence, noise levels and visual impact. If not carefully located, large wind turbines can interfere with the flight paths of birds and bats. The noise and vibration created during the installation and operation of offshore wind turbines can drive away aquatic animal species. Wind turbines may also obstruct landscape views both on and offshore. While these cumulative impacts are generally accepted to be much less significant than the health and environmental impacts of a USC plant, they create important barriers to the wider deployment of wind power in certain areas.

Quantitative results from the electricity sector

Air pollution: NO_x and SO_2

With respect to NO_x and SO_2 emissions, solar, wind and nuclear technologies offer the highest co-benefits relative to the USC baseline. NGCC and, to a more limited extent, IGCC, also emit less than USC (Figure 17.2).

Figure 17.2 ▶ *NO_x and SO_2 emissions from energy technologies in the electricity sector*



Note: Estimate for BCC not available; wind estimate is based on offshore technology.

Source: NEEDS Project life-cycle estimates for the year 2025.

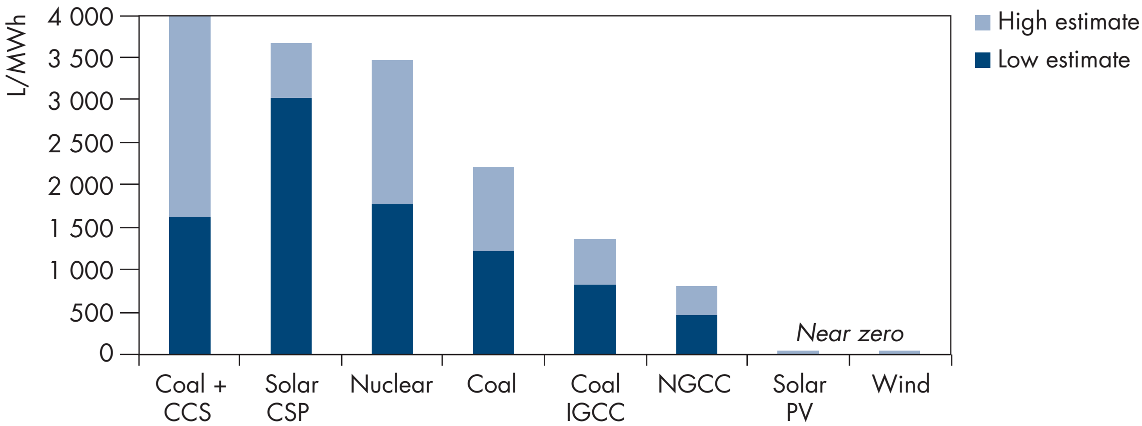
Key point

A number of low-carbon energy technologies such as nuclear, wind, solar and NGCC also emit relatively low levels of health-damaging air pollutants.

Water consumption

In terms of water demand, wind and solar PV offer the greatest co-benefits relative to coal, using virtually no water in power generation (Figure 17.3). All forms of coal-based power production, along with nuclear and CSP, require large volumes of water. NGCC falls in between other thermal technologies and PV/wind. Dry cooling significantly reduces the water use normally associated with thermal energy technologies, but lower efficiencies and higher installation costs have prevented dry cooling from becoming widely deployed.

Figure 17.3 ▶ ***Water demands of energy technologies in the electricity sector***



Notes: Coal estimates reflect a range of sub- and supercritical plant configurations. Estimate for BCC not available.
Sources: US DOE (2006); US DOE (2009); Hannegan and EPRI (2009).

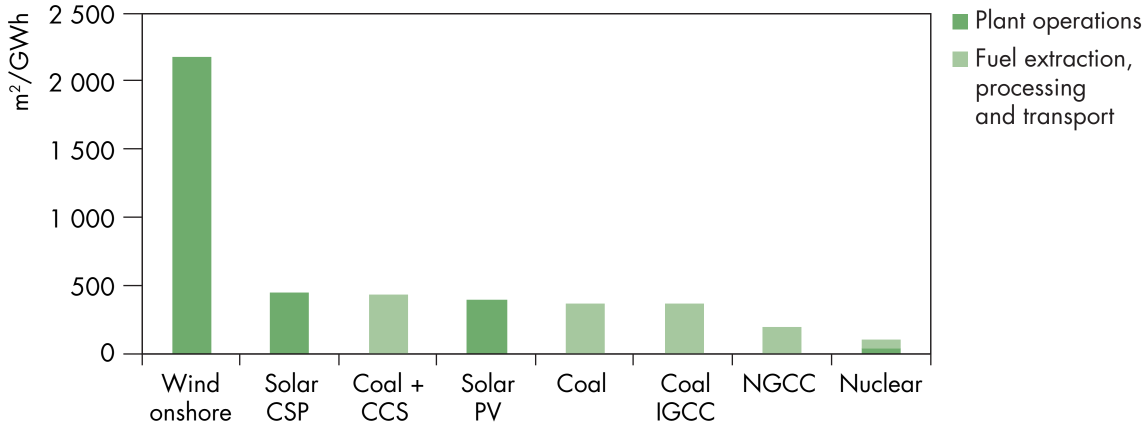
Key point

Solar PV and wind power can dramatically reduce water use in the power sector.

Land use

Onshore wind power requires more land than other power technologies per unit of electricity produced (Figure 17.4). Most of this land remains available for secondary uses such as agriculture or grazing. Solar power plants occupy relatively large areas of land relative to fossil fuel combustion plants, but the gap is significantly narrowed when fuel extraction, processing and transport of fossil fuels are taken into account. Nuclear power requires the smallest land area per unit of electricity generated over a typical plant lifetime, but this simplified estimate does not reflect the long time horizon necessary (of the order of thousands of years) for the full land reclamation of nuclear waste disposal sites.

Figure 17.4 ▶ **Direct land use from energy technologies in the electricity sector**



Note: Land use estimates do not account for time of occupation or recovery. Most land occupied by onshore wind farms remains available for secondary uses. Solar PV does not occupy additional land when fitted to buildings.

Source: Fthenakis and Kim (2009).[12]

Key point

Natural gas and nuclear power have a relatively small land footprint compared to coal.

Overall results relative to the coal baseline

Different electricity generation technologies have different environmental co-impacts on air, water and land (Table 17.2). Green shading indicates positive co-impacts are likely relative to the USC baseline; yellow indicates high levels of uncertainty or variability relative to the USC baseline; orange indicates negative co-impacts are likely relative to the USC baseline; and grey indicates minimal or no impacts relative to the USC baseline.

Relative to the USC coal baseline, other advanced coal and nuclear technologies offer lower-carbon baseload power alternatives with a mix of positive and negative environmental co-impacts. Some life-cycle impacts vary significantly depending on the mining, processing, transport and waste disposal methods employed. NGCC emits less air pollution, consumes less water, and has less negative co-impacts during the fuel extraction process than USC coal. Renewable technologies, while generally more expensive, can provide even greater CO_2 reductions, as well as a range of environmental benefits to air, water and land.

12. Estimates reflect median values where a wide range of estimates was available. The coal estimate reflects a range of sub-critical and supercritical plant configurations, as well as a range of surface and underground mining methods. Land use for coal + CCS is assumed to be 20% greater than the extraction, processing and transport portion of conventional coal, and may not adequately reflect additional impacts related to CO_2 transport and storage. IGCC estimate for land use is assumed to be the same as the coal baseline. Estimate for BCC not available.

Table 17.2 ▶ **Energy technology co-impacts in the electricity sector relative to a USC coal baseline**

Energy technologies	Life-cycle impacts* (Pre- and post-generation)			Power generation impacts			CO_2 emissions (t/mWh)**
	Air	Water	Land	Air	Water	Land	
Coal: USC	*Baseline technology for relative assessments below*						0.777
Coal: Biomass***	Positive	Positive	Variable / uncertain	Variable / uncertain	Minimal	Minimal	0.622
Coal: CCS	Negative	Negative	Negative	Variable / uncertain	Negative	Minimal	0.142
Coal: IGCC	Minimal	Variable / uncertain	Minimal	Positive	Positive	Minimal	0.708
NGCC	Positive	Positive	Positive	Positive	Positive	Positive	0.403
Nuclear	Positive	Variable / uncertain	Variable / uncertain	Positive	Negative	Positive	0.005
Solar: CSP	Positive	Positive	Positive	Positive	Negative	Minimal	0.017
Solar: PV	Positive	Positive	Positive	Positive	Positive	Minimal	0.009
Wind	Positive	Positive	Positive	Positive	Positive	Variable / uncertain	0.002

* Includes co-impacts from fuel extraction, processing and transport. Does not include co-impacts from plant construction or manufacturing.

** Based on NEEDS life-cycle estimates for year 2025. Does not include non-CO_2 greenhouse gases such as methane.

*** Assumes biomass is sustainably harvested and carbon-neutral.

Transport co-impacts: passenger light-duty vehicles

Transport creates a range of co-impacts including greenhouse-gas emissions and air, water and noise pollution (Box 17.3). The following analysis reviews the environmental co-impacts associated with a variety of existing and emerging passenger light-duty vehicle (LDV) and fuel technologies.

Box 17.3 ▶ Noise pollution

Most modes of transportation produce noise. Noise levels can be measured, but perceptions of discomfort are more subjective. Even at equivalent noise levels, people are most annoyed by air transport, followed by road transport, and least by rail transport (Griefahn, Marks and Robens, 2006).

Noise reduction is high on the agenda of vehicle manufacturers, but current trends differ across transportation sub-sectors:

- *For aircraft, noise levels and fuel consumption can go in opposite directions. For example, a move to efficient open-rotor designs would increase noise.*
- *For cars, the emergence of low-rolling-resistance tyres and near-silent electric propulsion systems offer the potential for significantly quieter vehicles and less energy use. A minimum level of noise may need to be generated by EVs to avoid increases in vehicle-pedestrian accidents.*
- *Train technologies are becoming generally quieter. Improving energy efficiency in most cases helps reduce noise levels.*

Technologies assessed

This analysis looks at a range of co-impacts for five vehicle and fuel technologies in the passenger LDV sector:

- Gasoline: conventional internal combustion engine (ICE). Due to its extensive use and familiarity in most regions of the world, the gasoline ICE is used as a reference baseline for the evaluation of the co-benefits/costs of other technologies;
- Diesel;
- Biofuels;
- EVs; and
- HFCVs.

All of these technologies play a major role in the BLUE Map scenario.

Air impacts

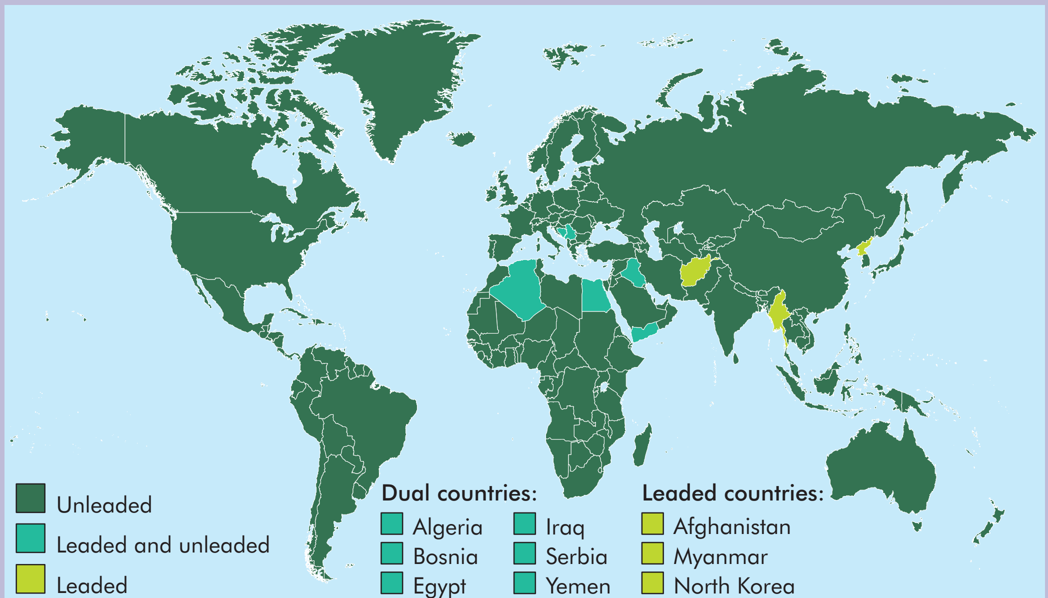
All LDVs powered by an ICE emit a number of air pollutants with well-established links to human health problems and environmental degradation. Major air pollutants that have been subject to regulation include carbon monoxide (CO), NO_X, SO_2, PM, hydrocarbons (HC) and volatile organic compounds (VOCs). Most countries have effectively implemented stringent regulations to eliminate lead pollution (Box 17.4).

Ground-level ozone is formed partly as a result of vehicle emissions by chemical reactions in the atmosphere involving primary pollutants such as NO_X and HCs. Ozone has a range of negative effects on human health and plant life. A number of other toxic pollutants and carcinogens such as benzene are also emitted from gasoline-powered automobiles.

Box 17.4 ▶ Lead emissions from gasoline

Lead has been used in gasoline motor fuels for many decades as an octane enhancer. Lead causes neurological damage in humans, with children being particularly vulnerable. Efforts to begin phasing out lead began in the United States in the 1970s, with the introduction of exhaust gas catalytic converters. According to UNEP and the Partnership for Clean Fuels and Vehicles (PCFV), gasoline is now completely lead-free almost everywhere in the world (Figure 17.5). The elimination of lead from fuel has also accelerated the use of catalytic converters, which generally reduce emissions of other pollutants such as NO_X, CO and HC.

Figure 17.5 ▶ Leaded petrol phase-out: global status March 2010



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Source: UNEP and PCFV.

In OECD countries, vehicle emission standards have been steadily tightened since the 1970s, with the emergence of new technologies enabling better control of the combustion process and the post-combustion treatment of exhaust gases. Electronic engine controls and real-time performance sensors have enabled better regulation and brought about significant reductions in many of the most harmful air pollutants around the world.

Carbon monoxide, HC, NO_X and PM are now regulated in most countries where car ownership is widespread, following procedures defined locally or adapted from standards developed in other countries. Standards are regularly tightened to encourage continuous improvement of engine and exhaust post-treatment technologies. Even so, it took nearly 30 years (from 1975 to 2005) for regulated pollutants to return to the global emission volumes of 1975 when the first regulations were implemented.[13]

Emission levels for several major vehicle pollutants for different vehicle fuel technologies are shown in Table 17.3. Advanced gasoline and diesel technologies offer across-the-board improvements in emission levels over older cars that still make up the vast majority of the global fleet. Most diesel-powered vehicles on the road today emit substantially higher amounts of PM and NO_X than conventional gasoline vehicles. However, advances in efficiency and control technologies have narrowed this gap and, with progressively tightening fuel and emission standards, diesel engines in OECD countries are expected to perform broadly as well as gasoline engines in the future with respect to air pollutant emissions per kilometre travelled.

Table 17.3 ▶ *Lifetime emissions from different light-duty vehicle technologies*

Fuel technology	Fuel consumption	GHGs (tCO_2-eq)		NO_X (t)		SO_X (kg)		PM (t)	
	(Lge/100km)	WTT	TTW	WTT	TTW	WTT	TTW	WTT	TTW
2010 Global avg gasoline vehicle (Euro 2)	8.5	6.1	34.8	2E-03	84.9	2.4	12.8	1E-04	3.6
2010 Global avg diesel vehicle (Euro 2)	6.7	3.7	27.4	1E-03	121.5	1.7	804.0	7E-05	15.0
2010 New gasoline vehicle (Euro 5)	6.2	4.5	25.3	1E-03	9.0	1.8	9.3	8E-05	0.8
2010 Advanced diesel vehicle (Euro 5)	5.8	3.2	24.1	8E-04	27.0	1.5	43.5	6E-05	0.8
2010 Hybrid vehicle (Euro 5)	4.5	3.2	18.4	9E-04	9.0	1.3	6.8	6E-05	0.8
2010 EV - coal electricity	2.2	25.1	0	3E-02	0	18.7	0	2E-03	0
2010 EV - NG electricity	2.2	13.0	0	6E-03	0	4.7	0	4E-04	0
2020 HFCV - coal electricity	5.4	60.8	0	6E-02	0	45.2	0	6E-03	0
2020 HFCV - NG reforming	5.4	28.8	0	2E-02	0	11.3	0	9E-04	0

Note: Numbers expressed as XE-0X are in scientific notation (*e.g.*, 2E-03 equals 0.002). Vehicles are assumed to travel 15 000 km per year during a 10-year lifetime. Lge denotes litres of gasoline-equivalent; WTT denotes "well-to-tank"; TTW denotes "tank-to-wheel". An EV powered exclusively by nuclear, solar, or wind, rather than coal-based electricity, would achieve near-zero well-to-wheel (WTW) emissions.

Sources: IEA Mobility Model; Delucchi (2003); Bauer *et al.* (2008).

13. Estimate based on IEA Mobility Model.

The use of biofuels can have varying co-impacts on pollution emission levels. Blending ethanol into gasoline generally lowers CO, HC and PM emissions although at some blend levels, evaporative HC emissions can increase. Biodiesel blends result in lower PM, CO and HC emissions compared to petroleum diesel. For both ethanol and biodiesel, changes in NO_X emissions are generally minor and can go up or down depending on conditions and engine calibration.

Upstream emissions from biofuel production depend on the type of feedstock used, associated changes in land use, harvesting and refinement methods, transport distances, and the combustion control technologies applied. For example, the production of sugar cane-based biofuel produces levels of CO, NO_X and PM higher than corn ethanol or conventional gasoline over the course of its life-cycle if straw burning is used to harvest the sugar cane (Hess *et al.*, 2009). Recognising this, in Brazil, where most of the world's sugar cane for biofuels is produced, a 2007 "Agro-environmental Protocol" established jointly by government and the sugar cane industry aims to phase out most burning by 2017.[14]

Zero-emission vehicles powered by electricity or hydrogen fuel cells are likely to appear in significant numbers before 2050. Such vehicles give rise to pollution only indirectly through the production of the electricity or hydrogen that they use. Conventional emission standards will, therefore, be effectively redundant for such vehicles, although they will still need to be kept in place for the relatively small proportion of conventional ICE vehicles projected by the BLUE Map scenario in 2050.

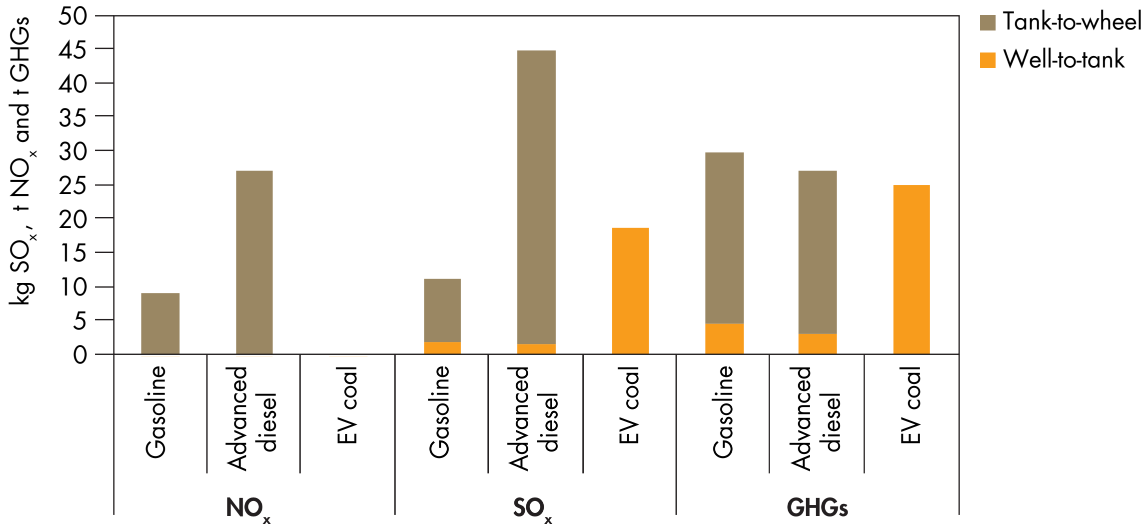
Figure 17.6 shows that the wider deployment of EVs will deliver significant NO_X reductions relative to gasoline and diesel technology even with electricity generated from USC coal, but only modest greenhouse-gas reductions. EVs will need to be powered by low-carbon electricity technologies if they are to play the important role in mitigating CO_2 envisaged for them in the BLUE Map scenario. The electrification of vehicle fleets will also bring about a shift in the location of emission sources, as the air pollution associated with passenger vehicles moves away from densely populated urban areas to more rural areas where large power plants tend to be located.

Most OECD countries give three to ten years' notice of the implementation of new regulations in order to allow equipment manufacturers to adapt vehicle manufacturing processes and scale up new technologies before they become mandatory in new vehicles. Long-term emission standards around the world are expected to tighten and converge by 2020, or soon thereafter (Figure 17.7). As a result, the environmental gap between different technologies and regions is expected to narrow significantly.

Over time, the impact of tighter standards in some regions will be at least partially offset by significant growth in the number of kilometres travelled. In fast-growing urban areas, especially where vehicle emission standards are still not stringent or enforcement is weak, air quality issues related to vehicle emissions will continue to be a matter of concern. In the Baseline scenario, EVs, PHEVs and HFCVs do not penetrate vehicle markets significantly in any country before 2050, and so do not contribute to improving urban air quality. Even in the BLUE Map scenario, they only reach significant shares of the vehicle stock between 2025 and 2030. Reductions in pollutant emissions over the next 15 years will need to continue to come primarily from cleaner fuels and tighter emissions standards for ICE vehicles.

14. *Protocolo Agroambiental*: http://www.saopaulo.sp.gov.br/spnoticias/lenoticia.php?id=87950.

Figure 17.6 ▶ **Lifetime emissions from a gasoline, diesel and electric vehicle**



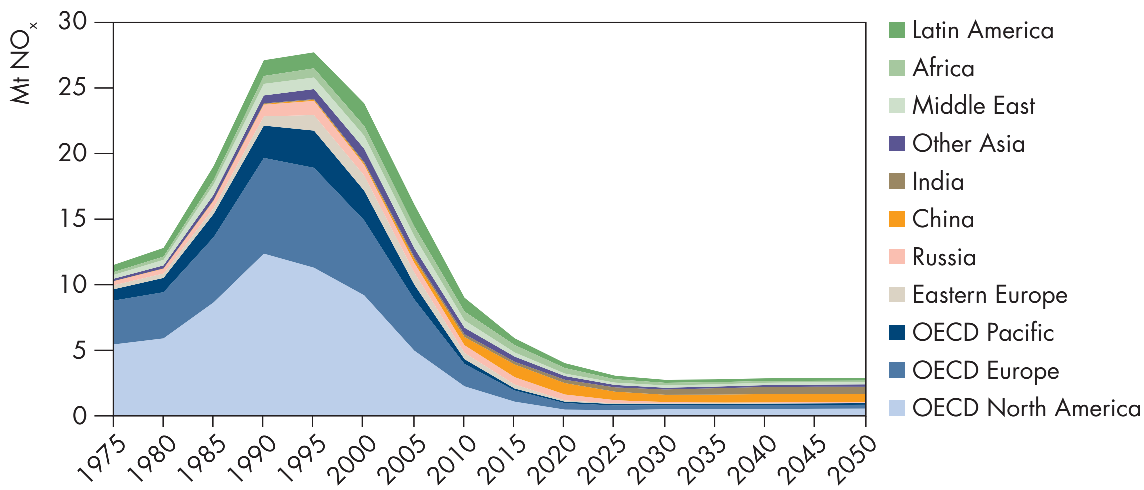
Note: The Figure reflects a 2010 new gasoline-powered vehicle (Euro 5 standards) and EV technology powered with electricity from a coal USC power plant. Vehicle lifetime assumes 15 000 km/year for ten years. An EV powered exclusively by nuclear, solar, or wind, rather than coal-based electricity, would achieve near-zero WTW emissions.

Source: IEA Mobility Model and NEEDS project.

Key point

EVs can deliver significant reductions in NO_x, but will need to be powered by low-carbon electricity technologies if they are to have an important role in mitigating CO_2 emissions.

Figure 17.7 ▶ **Historical and projected NO_x emissions from passenger vehicles**



Key point

Projected NO_x emissions illustrate the expected convergence of vehicle emission standards throughout the world.

Water impacts

Water plays a critical role in the transportation sector, where it is used in large quantities in the exploration and extraction of petroleum and in the refinement processes used to create gasoline and diesel fuels.

Waterways are negatively impacted by the pollution that occurs during oil extraction and refining and from oil and gas spills during fuel transport. Each year, between three and 7.2 billion litres of crude oil, roughly half of which is intended for use in vehicle fuels, are unintentionally released into the environment, including waterways. Biofuels can also damage aquatic ecosystems, not only from spills but also more commonly where fertiliser runoff from biofuel crops contributes to eutrophication and oxygen depletion in bodies of water.

The production of electricity for EVs and diesel consumes roughly similar amounts of water as the production of conventional gasoline (Figure 17.8). Actual water consumption will vary according to the resource extraction methods and fuel refining processes used. This is particularly the case with biofuels. The need to irrigate biofuel crops is the primary cause of water consumption associated with ethanol and biodiesel production using conventional feedstocks such as sugar cane, corn, rapeseed and soybeans. Gasoline blended with 85% ethanol (E85) produced from irrigated corn is estimated to consume 10 to 25 times the amount of water used to produce conventional gasoline and approximately 14 times more than E85 made with non-irrigated corn.

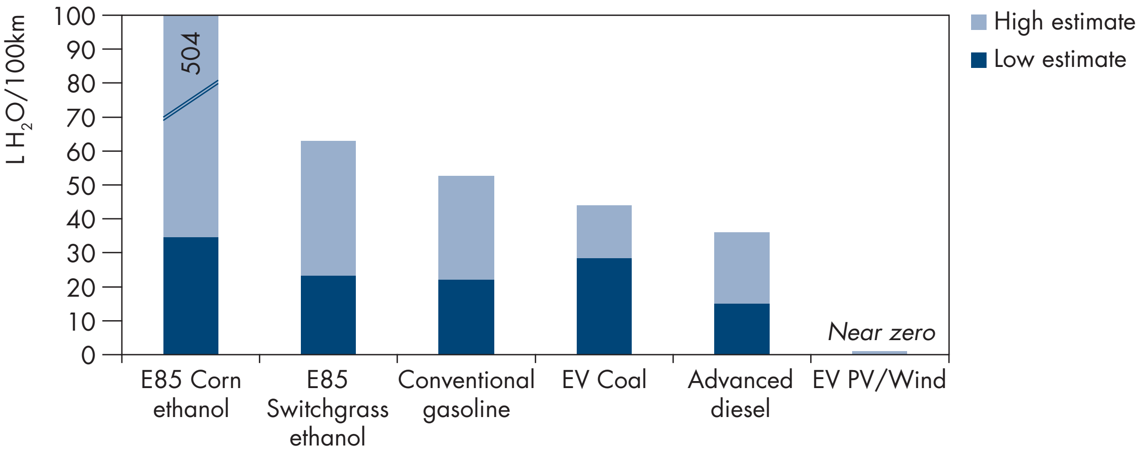
Different biofuel crops require different levels of irrigation. Switchgrass, for example, requires less water than most biofuel feedstocks, delivers energy more efficiently, and can be grown in areas less likely to compete for land with food crops. The use of agricultural waste products as feedstocks can also minimise water consumption.

Location is important in determining the irrigation needs of a given crop. It is estimated that producing one litre of ethanol from sugar cane requires nearly 3 500 litres of irrigation water in India and 2 400 in China, compared to just 90 litres in Brazil (de Fraiture, Giordano and Liao, 2007). National biofuel mandates and growing demand for fuels to power rapidly growing vehicle fleets in China and India could prove a troublesome combination in water-scarce regions unless significant advancements are made in second-generation biofuel technology.

Electric vehicles powered by wind- or PV-generated electricity would use essentially no water during their entire fuel life-cycle. EVs powered by coal-fired electricity use similar amounts of water as conventional gasoline-powered vehicles due to the high volumes of water consumed during coal mining, processing and combustion.

Hydrogen production is an energy-intensive process. The associated water requirements would depend on the mix of electricity used. Hydrogen fuel production for HFCVs, if powered by water-intensive sources of electricity, has been estimated to consume three times as much water as the production of conventional gasoline sufficient to power a vehicle the same distance (King and Webber, 2008).

Figure 17.8 ▶ Water consumption associated with passenger vehicle fuels



Sources: US DOE (2006); Wu *et al.* (2009).

Key point

The production of biofuels can use significantly more water than the production of gasoline, if irrigation is needed. Some forms of electricity generation use significantly less.

Land impacts

Petroleum-based fuels and biofuels can have a number of negative impacts on land. Petroleum products, including gasoline and diesel fuels, contain toxic substances that contaminate soils and damage plant life if spilled or leaked into the environment. Some biofuel crops cause acidification of soils and biodiversity loss, particularly when forest clearing is involved. But some energy crops such as switchgrass may replenish and restore soils when grown and harvested sustainably.

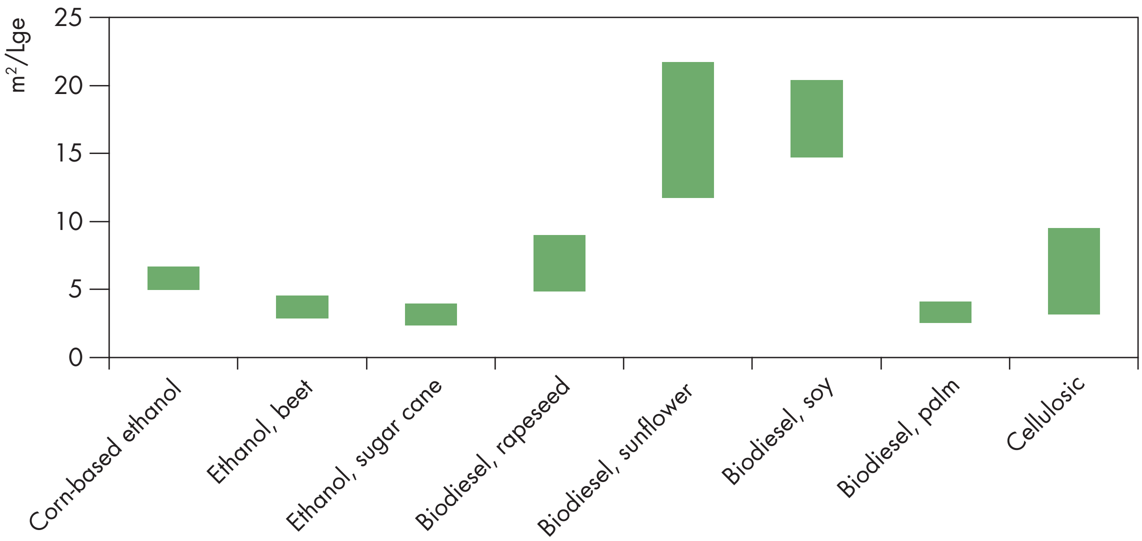
Many scientists and policy experts have at least partially attributed rising food prices during 2007-2008 to the displacement of food crops in favour of biofuel production, spurred by renewable fuel mandates and government subsidies. It is unclear to what extent the higher prices can be attributed to biofuel production, as other factors such as historically high oil prices may also have played a role in driving up prices. But it is clear that biofuels are significantly more land-intensive than other fuel technologies and that they sometimes compete for a relatively limited stock of arable land.

Approximately 2% of global cropland is currently used to grow fuel crops (UNEP, 2009). Most of the world's biofuel production today is derived from food crops, with 90% of this production taking place in the United States, Brazil and the EU (UNEP, 2009). There is a possibility that government biofuel targets in these regions, as well as in large, rapidly growing countries such as China and India, may strain food supplies.

Soybeans and sunflowers are particularly land-intensive crops for producing biodiesel, requiring several times more land than palm oil or rapeseed per litre of gasoline-equivalent produced (Figure 17.9). Similarly, corn uses more land than sugar cane or beet to produce an equivalent amount of bioethanol, as measured in litres of gasoline-equivalent.

Land area alone does not provide a complete picture of the environmental impacts of biofuels. Such impacts will also depend for example on the type of land that is given over to biofuel production. Irreparable ecosystem damage and net increases in greenhouse-gas emissions can occur where thick forests or carbon-rich peat lands are cleared for the purpose of planting energy crops.

Figure 17.9 ▶ Land-use intensity for different types of biofuels



Note: m^2/Lge denotes metres-squared per litre of gasoline-equivalent.

Sources: Bauer *et al.* (2008); IEA (2004); Küsters (2007); Novozymes (2007); Schmer *et al.* (2008); Tereos (2007).

Key point

Land area requirements for biofuel production depend heavily on the type of feedstock used.

Road transport also uses large areas of land for roads and other infrastructure and encourages urban sprawl. Roads can interfere with animal migration corridors. Road accidents have major health impacts on passengers, pedestrians and others, such as cyclists in urban environments. While these effects are widely acknowledged as important considerations when planning transportation infrastructure, the associated impacts do not vary notably by LDV or fuel technology. In the BLUE Shift scenario, there may be less need for cars overall compared with the Baseline scenario due to increased public transportation and to land-use planning efforts to improve non-motorised vehicle and pedestrian access.

Other considerations

In the BLUE Map scenario, EV sales make up about 33% of vehicle sales by 2050. PHEVs constitute 30% of sales. This results in a cumulative EV/PHEV demand for lithium between 2010 and 2050 that approaches the entire estimated reserve base, even with extensive recycling. If EVs are to eventually dominate LDV markets, additional cost-effective lithium resources must be discovered, less lithium must be used per unit of battery storage, or a suitable type of energy storage system that does not use lithium must be developed. Supply bottlenecks for certain rare earth metals integral to EVs may also occur as the technology becomes more widely deployed.

Recommendations for next steps

As policy makers design and implement more aggressive measures to reduce greenhouse-gas emissions, they will also need to take account of the impact of such measures on non-climate aspects of the environment. Such co-impacts can be both positive and negative. They need to be properly accounted for, evaluated and managed.

Policies such as subsidies, tax incentives, or other favourable treatments can distort markets and produce unintended consequences. Such subsidies or distortions are only generally justified where they are designed explicitly and carefully to correct market failures by internalising externalities, for example by shifting cost burdens to the source of a negative externality.

Today's policy trends suggest that the energy sector's CO_2 emissions will be increasingly constrained in the future. Rationed allowances, taxes, or the direct regulation of greenhouse-gas emissions can already be found in many parts of the world. Such policies seek directly to influence public- and private-sector choices about energy technology and related investments.

To ensure that such measures do not undermine other desirable policy outcomes, policy makers are recommended to:

- identify the co-impacts of energy technologies;
- quantify those co-impacts;
- monetise those co-impacts where possible or prioritise them if monetisation is not feasible; and
- take account of the value of co-impacts in policy decisions.

Identify the co-impacts of energy technologies

Well-founded policies will take proper account of all the most significant economic, social or environmental impacts they give rise to. Economic impacts can often be observed through measurable indicators such as the price of electricity, employment rates and private financial costs. Social and environmental impacts are often less obvious and more difficult to measure.

An effective assessment of the co-impacts of energy technologies requires the involvement of all stakeholders, including government, industry, academia and private citizens who might impact or be impacted by the technology.

Projects supported by the Clean Development Mechanism (CDM) of the United Nation's Framework Convention on Climate Change have not always adequately addressed economic, environmental and social development needs even though these are often a high priority for developing countries. To address this issue, Japan's Ministry of the Environment has launched initiatives based on a co-benefits approach and has taken steps to promote the emphasis of co-benefits through policy and technical dialogue, capacity building, bilateral statements and pilot studies. The co-benefits approach aims to address climate change concerns while also improving local environments and enabling developing countries to achieve their development goals in a more sustainable manner.[15]

Quantify co-impacts

Once an energy technology co-impact has been identified, the next step is to determine the scope and scale of its impact. For air pollution, for example, this involves quantifying the impacts on human health, such as the severity and length of related illnesses or premature deaths and the number of people likely to be affected. Other environmental impacts such as ecosystem damage or building corrosion may also be important factors.

Quantifying such impacts can be highly complex, and results can vary greatly by location depending on many regional and local factors such as population, climate, topography and natural resource profile. The process is further complicated by the need to consider the long-term implications of current decisions and behaviour.

In the United States, a number of states are collaborating with the private sector, researchers, the federal government and environmental groups to advance energy solutions that deliver co-benefits. New York State implemented its *Energy $mart* programme in 1998 to improve energy reliability, reduce energy costs, mitigate health and environmental effects related to energy use and to improve the state economy.[16] The programme is estimated to have reduced participants' energy bills by USD 570 million; created 4 700 jobs, prevented nearly 2 600 of NO_X and 4 700 tonnes of SO_2 emissions; and decreased annual CO_2 emissions by 2 million tonnes (US EPA, 2010).[17]

Monetise co-impacts

Comparing and weighing technologies and their impacts against one another requires that quantified impacts are normalised with a uniform evaluative measure. This is most commonly done in economic terms by placing a monetary value on all identifiable impacts.

Assigning a monetary value to environmental impacts is often challenging, particularly when the asset affected does not have an established market value. The fact that some policy interventions impose costs on future generations further

15. www.env.go.jp/en/earth/ets/icbaghserp081127.pdf
16. www.getenergysmart.org/
17. www.epa.gov/statelocalclimate/state/tracking/index.html

complicates this process. Uncertainty and risks must also be taken into account, but can be managed to the extent that reasonable probabilities can be estimated. Additional difficulties in valuation arise when environmental losses may be irreversible, as in the case of species extinction.

The concept of equity – the fair distribution of costs and benefits – may also play a role in the weighing of results. Policy makers need to determine the extent to which a relatively wide distribution of benefits is more desirable than the distribution of a larger total benefit to a more limited group of beneficiaries.

If impacts cannot be monetised, they should be subject to a priority-setting process that will enable qualitative judgements to be made in the final evaluation of policy options.

In 2007, the Canadian Ministry of Environment launched a programme for air pollution and climate change mitigation intended to leverage co-benefits achievable from co-ordinated action on both issues. The Canadian government estimates that benefits from the reduced risk of death and illness associated with air quality improvements will be over USD 6 billion annually by 2015.[18]

Integrate value of co-impacts into policy decisions

Identifying, quantifying and, ideally, placing a value on the co-impacts of low-carbon energy technologies can play an important role in policy development. While financial considerations will continue to be an important driver for climate and energy policies, strategies designed solely based on achieving the largest greenhouse-gas reductions for the lowest direct cost may in some cases yield sub-optimal or unsustainable outcomes.

Traditional environmental co-impacts, alongside broader political, economic, social and regulatory factors, should be carefully considered by policy makers when developing climate and energy strategies.

18. www.ec.gc.ca/doc/media/m_124/brochure/BR_c1_eng.htm

ANNEXES

Annex A FRAMEWORK ASSUMPTIONS

This annex provides the framework assumptions used in the development of *Energy Technology Perspectives 2010*.

Demographic assumptions

Between now and 2050 world population will grow by more than 32% to 9.1 billion, with Asia and Africa leading the way (UN, 2009a). OECD countries will drop from 18% of the world's population in 2007 to 15% in 2050 (Table A.1).

Table A.1 ▶ Population projections (millions)

	2007	2015	2030	2050
OECD	**1 185**	**1 244**	**1 309**	**1 332**
OECD North America	441	484	537	578
United States	*302*	*333*	*371*	*405*
OECD Europe	543	558	575	575
OECD Pacific	202	202	197	180
Non-OECD	**5 424**	**6 058**	**7 000**	**7 818**
Economies in transition and non-OECD Europe	337	339	331	311
Middle East	193	235	293	353
Africa	958	1 153	1 525	1 999
Latin America	461	503	563	600
China	1 327	1 404	1 471	1 426
India	1 123	1 294	1 485	1 614
Other developing Asia	1 025	1 131	1 332	1 515
World	**6 609**	**7 302**	**8 309**	**9 150**

Sources: IEA (2009a); IEA (2009b); UN (2009a).

Today, about half of the world's population lives in urban areas, the majority in developing countries. The percentage of urban dwellers has increased by 12% since 1975 and is projected to increase to 70% by 2050 (UN, 2009b).

Between 2007 and 2050, Asia's urban population will increase from 1.7 billion to 3.5 billion, Africa's from 0.4 billion to 1.2 billion, and that of Latin America from 0.4 billion to 0.5 billion. As a result of these shifts, developing countries will have more than 80% of the world's urban population in 2050 (UN, 2009b).

Today, the global median age is 28 years. Over the next four decades the world's median age will likely increase by ten years, to 38. The proportion of population 60 years or over is projected to rise from 11% in 2009 to 22% in 2050 (UN, 2009c). This ageing will have important consequences for energy consumption as the lifestyle and needs of older people differ from those of young people.

A

Macroeconomic assumptions

Global GDP is projected to grow by more than three times between 2007 and 2050 to a level of USD 225 trillion per year (Table A.2). In European countries and in Japan it grows by about two-thirds and in North America it more than doubles. The main growth will be outside the OECD.

Table A.2 ▶ GDP projections (% per year, based on purchasing power parity)

	2007-2015	2015-2030	2030-2050
OECD	**1.4**	**1.9**	**1.2**
OECD North America	1.8	2.3	1.4
United States	*1.8*	*2.2*	*1.3*
OECD Europe	1.0	1.8	0.7
OECD Pacific	1.3	1.3	1.7
Non-OECD	**5.7**	**4.1**	**3.4**
Economies in transition and non-OECD Europe	3.3	3.3	3.5
Middle East	4.5	4.0	2.5
Africa	4.7	3.1	3.1
Latin America	3.1	2.5	2.5
China	8.8	4.4	3.8
India	7.0	5.9	3.3
Other developing Asia	3.2	3.5	2.6
World	**3.3**	**3.0**	**2.6**

Sources: Hawksworth (2006); IEA (2009c).

International energy prices

Energy price projections up to 2030 are taken from *World Energy Outlook 2009* (IEA, 2009c). For the period between 2030 and 2050 they have been developed for this study taking account of the long-term oil supply cost curve (IEA, 2008).

Table A.3 ▶ Oil, gas and coal price projections for the Baseline scenarios (in 2008 USD per unit)

	Unit	2008	2030	2050
IEA crude oil imports	Barrel	97	115	120
Natural gas				
United States imports	*MBtu*	8.3	*11.4*	*11.9*
European imports	*MBtu*	*10.3*	*14.0*	*14.7*
Japanese imports	*MBtu*	*12.6*	*15.9*	*16.7*
OECD steam coal imports	Tonne	121	109	115

Note: MBtu is million British thermal units.
Sources: IEA (2009c); IEA analysis.

Table A.4 ▶ **Oil, gas and coal price projections for the BLUE scenarios (in 2008 USD per unit)**

	Unit	2008	2030	2050
IEA crude oil imports	Barrel	97	90	70
Natural gas				
United States imports	*MBtu*	*8.3*	*10.2*	*7.9*
European imports	*MBtu*	*10.3*	*11.0*	*8.6*
Japanese imports	*MBtu*	*12.6*	*12.5*	*9.7*
OECD steam coal imports	Tonne	121	65	58

Note: MBtu is million British thermal units.
Sources: IEA (2009c); IEA analysis.

Methodology

The scenarios have been developed using a combination of four approaches:

- **Global perspective:** the Baseline scenario for 2007 to 2030 is based on the Reference Scenario of the IEA *World Energy Outlook 2009*. This scenario has been further elaborated to include the period 2030 to 2050 using the *Energy Technology Perspectives* (ETP) model. The ETP model of global energy supply and demand has been used to analyse the BLUE scenarios for the period 2007 to 2050.
- **Country/regional perspective:** MARKAL and TIMES models for individual countries and regions have been used to assess the potential for CO_2 emissions reductions in China, OECD Europe and the United States.
- **Sector perspective:** the IEA Secretariat has developed sector models with country- and region-level detail for industry, the residential and commercial sectors, and the transport sector. These spreadsheet models are detailed simulation tools that serve as repositories for information from experts and different models. They also serve as a communication tool between the modelling groups.
- **Technology perspective:** the present and future characteristics of technology options and their potentials have been assessed on the basis of expert information from the IEA Implementing Agreements and other sources.

The primary tool used for the analysis of the BLUE scenarios is the IEA ETP model. This global 15-region model permits the analysis of fuel and technology choices throughout the energy system, from energy extraction through fuel conversion and electricity generation to end-use. The model's detailed representation of technology options includes about 1 000 individual technologies.

The ETP model belongs to the MARKAL family of bottom-up modelling tools (Fishbone and Abilock, 1981). MARKAL has been developed over the past 30 years by the Energy Technology Systems Analysis Programme (ETSAP), one of the IEA Implementing Agreements (ETSAP, 2004). The ETP-MARKAL model uses optimisation to identify least-cost mixes of energy technologies and fuels to meet the demand for energy services, given constraints like the availability of natural resources.

A

Additional analysis has been undertaken for China, India, OECD Europe and the United States. Some regions in the ETP model are large, and cover a range of areas with vastly different energy resource availability and energy demands. In such cases, the use of regionalised country models can add value. For this analysis, the IEA Secretariat co-operated with a number of modelling groups with national and/or regional models. The insights from their models, which are based on the same approach as the ETP model, were used to refine the analysis.

The ETP model has been supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors. These models were developed to assess the effects of policies that do not primarily act on price. These demand-side models explicitly take capital stock turnover into account, and have been used to model the impact of new technologies as they penetrate the market over time.

Investment modelling limitations

The investment analysis presented is inevitably a partial assessment of the investment needs for energy-consuming equipment and, to a lesser extent, of the needs in the upstream energy sector. In the industrial, residential and commercial sectors, only major energy-consuming equipment and devices have been covered, as sufficient data do not exist to accurately project the quantity and price of a wide range of small energy-consuming devices – from telephone chargers in homes to coffee machines in business and industry.

There is a question of what boundary to place on investment costs. For example, for cars, the model uses consumer prices, because energy efficiency improvements apply to a wide range of the car's components, including engines, drive trains, appliances, structural weight, aerodynamics and tyres. For building improvements in the residential and service sectors, however, the model only counts the marginal increase in costs for more energy-efficient homes, because a breakdown of the costs of energy efficiency compared to the fabric or structure of a building would be arbitrary, while including the total construction cost would result in buildings taking up a disproportionate share of investment needs, when their primary role is shelter.

As a result of these issues, and the generally more widely available information on the marginal cost of energy efficiency options, the relative increase or decrease in investment needs in the BLUE scenarios compared to the Baseline scenario should be treated with greater confidence than the absolute level of investment in the Baseline.

Annex B IEA ENERGY TECHNOLOGY COLLABORATION PROGRAMME

IEA Global Energy Technology Network

The IEA provides the framework to accelerate energy technology deployment through multilateral technology initiatives called Implementing Agreements (IAs). Through the IAs, IEA member countries partner with industry and IEA non-member countries to form a cost-effective, global network.

Many Implementing Agreements include participants from IEA non-member countries. China participates in six IAs (buildings, transport, fusion, hydropower and clean fossil fuels), while India participates in three (energy efficiency, clean fossil fuels, fusion). The most recent IEA non-member countries to join IAs include the United Arab Emirates (solar) and Thailand (motor fuels). In addition, the Energy Technology Data Exchange (ETDE) allows access to their extensive database of scientific information to more than 60 non-IEA countries. The Climate Technology Initiative (CTI) engages with IEA non-member countries to share best practice, to build capacity, and to facilitate technology transfer and financing. The Energy Technology Systems Analysis Programme (ETSAP) develops energy modelling software that provides countries with the tools necessary to devise national plans and strategies.

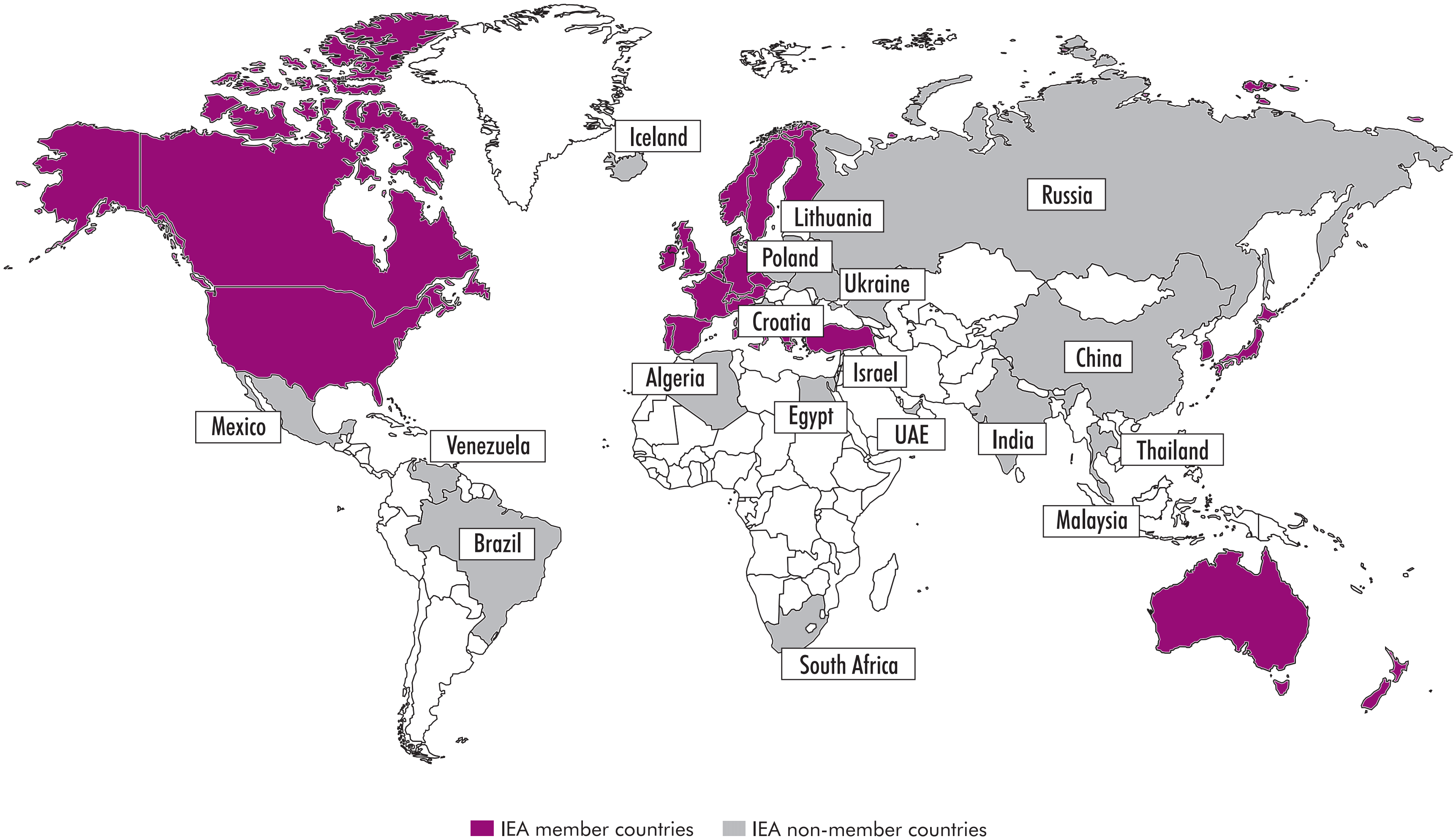
There are currently 50 industrial partners from IEA member countries largely concentrated in multilateral technology initiatives concerning clean fossil fuels and renewables. Six industrial partners to clean fossil fuels IAs are located in key IEA non-member countries: Brazil, China, India, Russia, South Africa and Thailand.

Improving energy efficiency, whether in the buildings and commercial services, electricity, industry or transport sectors, is crucial for the environment and for energy security. Fourteen IAs currently research various aspects of these end-use sectors. One recently created Agreement co-ordinates policies, promote standards and analyse issues related energy efficient electrical equipment.

Clean fossil fuels are at the core of energy demand in the transport and electricity generation sectors and will be for many more years. The work of six IAs focuses on finding ways to make the most of existing resources, while at the same time getting the most from every barrel of oil or tonne of coal while reducing costs and improving efficiency.

Renewable energy technologies provide clean, flexible, stand-alone or grid-connected electricity sources, but they need the correct policy environment and collaboration with industry to facilitate deployment and to further reduce costs. Ten Implementing Agreements research renewable energy technologies.

Figure B.1 ▶ *Countries participating in the IEA global energy technology network*



The boundaries shown on this map do not imply official endorsement or acceptance by the IEA.

IEA Implementing Agreement Portfolios*

		Basic Science	R&D[1]	Demon-stration[2]	Deploy-ment[3]	Information Exchange
Cross-Cutting	Climate Technology Initiative					■
	Energy Technology Data Exchange					■
	Energy Technology Systems Analysis		■			■
End-Use Buildings	Buildings and Community Systems		■	■		■
	District Heating and Cooling		■	■		■
	Efficient Electrical Equipment		■	■		■
	Energy Storage		■	■		■
	Heat Pumping Technologies		■	■		■
Electricity	Electricity Networks		■	■		■
	Demand-Side Management		■	■	■	■
	High-Temperature Superconductivity		■	■		■
Industry	Emissions Reduction in Combustion	■	■	■		■
	Industrial Technologies and Systems		■	■		■
Transport	Advanced Fuel Cells	■	■	■	■	■
	Advanced Motor Fuels	■	■	■		■
	Advanced Transport Materials	■	■	■		■
	Hybrid and Electric Vehicles	■	■	■	■	■
Fossil Fuels	Clean Coal Centre	■	■		■	■
	Clean Coal Sciences	■	■			■
	Enhanced Oil Recovery	■	■			■
	Fluidised Bed Conversion	■	■	■		■
	Greenhouse Gas R&D Programme	■	■	■	■	■
	Multiphase Flow Sciences	■	■	■		■
Fusion	Fusion Environment, Safety and Economy	■	■	■	■	■
	Fusion Materials	■	■	■		■
	Large Tokamaks	■	■	■		■
	Nuclear Technology of Fusion Reactors	■	■	■		■
	Plasma Wall Interaction in TEXTOR	■	■	■		■
	Reversed Field Pinches	■	■	■		■
	Spherical Tori	■	■	■		■
	Stellarator Concept	■	■	■		■
	Tokamaks Poloidal Field Divertors	■	■	■		■
Renewables and Hydrogen	Bioenergy	■	■	■		■
	Deployment				■	■
	Geothermal	■	■	■		■
	Hydrogen	■	■	■		■
	Hydropower	■	■	■		■
	Ocean	■	■	■		■
	Photovoltaics	■	■	■	■	■
	Solar Concentrated	■	■	■	■	■
	Solar Heating and Cooling	■	■	■		■
	Wind	■	■	■		■

* Indicates primary focus, which does not exclude significant activities in other areas.
1. Including modelling and technology assessment.
2. Including research, advice and support of demonstration of the particular technology.
3. Including market introduction and technology transfer.

B

IEA Implementing Agreement energy sectors*

		Supply[1]	Transformation[2]	Demand
Cross-Cutting	Climate Technology Initiative			
	Energy Technology Data Exchange			
	Energy Technology Systems Analysis			
End-Use Buildings	Buildings and Community Systems			
	District Heating and Cooling			
	Efficient Electrical Equipment			
	Energy Storage			
	Heat Pumping Technologies			
Electricity	Electricity Networks			
	Demand-Side Management			
	High-Temperature Superconductivity			
Industry	Emissions Reduction in Combustion			
	Industrial Technologies and Systems			
Transport	Advanced Fuel Cells			
	Advanced Motor Fuels			
	Advanced Transport Materials			
	Hybrid and Electric Vehicles			
Fossil Fuels	Clean Coal Centre			
	Clean Coal Sciences			
	Enhanced Oil Recovery			
	Fluidised Bed Conversion			
	Greenhouse Gas R&D Programme			
	Multiphase Flow Sciences			
Fusion	Fusion Environment, Safety and Economy			
	Fusion Materials			
	Large Tokamaks			
	Nuclear Technology of Fusion Reactors			
	Plasma Wall Interaction in TEXTOR			
	Reversed Field Pinches			
	Spherical Tori			
	Stellarator Concept			
	Tokamaks Poloidal Field Divertors			
Renewables and Hydrogen	Bioenergy			
	Deployment			
	Geothermal			
	Hydrogen			
	Hydropower			
	Ocean			
	Photovoltaics			
	Solar Concentrated			
	Solar Heating and Cooling			
	Wind			

* Indicates primary focus, which does not exclude significant activities in other areas.
1. Including electricity generation and distribution, industrial processes.
2. Including energy consumption and optimisation.

Lastly, nine IAs co-ordinate national and regional fusion programmes, in both IEA member and non-member countries, and share experimental results.

By combining efforts, Implementing Agreement participants save time and resources. Implementing Agreements largely respond to the goals of IEA countries: to enhance energy security, environmental protection and economic growth. The work of the IAs covers the full range of R&D portfolios, working in all aspects of energy – supply, transformation and demand.

Implementing Agreements

End-use

Transport

Advanced Fuel Cells	www.ieafuelcell.com
Advanced Materials for Transportation	www.iea-ia-amt.org
Advanced Motor Fuels	www.iea-amf.vtt.fi
Hybrid and Electric Vehicles	www.ieahev.org

Buildings

Buildings and Community Systems	www.ecbcs.org
District Heating and Cooling	www.iea-dhc.org
Efficient Electrical End-Use Equipment	www.iea-4e.org
Energy Storage	www.energy-storage.org
Heat Pumping Technologies	www.heatpumpcentre.org

Electricity

Demand-Side Management	www.ieadsm.org
Electricity Networks, Analysis and R&D	www.iea-enard.org
High-Temperature Superconductivity	www.superconductivityIEA.org

Industry

Emissions Reduction in Combustion	http://ieacombustion.com
Industrial Energy-Related Technology Systems	www.iea-iets.org

B

Fossil Fuels

Clean Coal Centre	www.iea-coal.org.uk
Clean Coal Sciences	http://iea-ccs.fossil.energy.gov
Enhanced Oil Recovery	http://iea-eor.ptrc.ca/
Fluidised Bed Conversion	www.iea-fbc.org
Greenhouse Gas R&D Programme	www.ieagreen.org.uk

Renewable Energy and Hydrogen

Bioenergy	www.ieabioenergy.com
Geothermal	www.iea-gia.org
Hydrogen	www.ieahia.org
Hydropower	www.ieahydro.org
Ocean Energy Systems	www.iea-oceans.org
Photovoltaic Power System	www.iea-pvps.org
Renewable Energy Technology Deployment	www.iea-retd.org
Solar Heating and Cooling	www.iea-shc.org
SolarPACES	www.solarpaces.org
Wind Turbine Systems	www.ieawind.org

Fusion

Environment, Safety, Economy of Fusion	www.iea.org/techagr
Fusion Materials	www.frascati.enea.it/ifmif
Large Tokamaks	www-jt60.naka.jaea.go.jp/lt
Nuclear Technology of Fusion Reactors	www.iea.org/techagr
Plasma Wall Interaction in TEXTOR	www.iea.org/techagr
Reversed Field Pinches	www.iea.org/techagr
Stellerator-Heliotron Concept	www.iea.org/techagr
Tokamaks with Poloidal Field Divertors	www.aug.ipp.mpg.de/iea-ia

Cross-Cutting Activities

Climate Technology Initiative	www.climatetech.net
Energy Technology Data Exchange	www.etde.org
Energy Technology Systems Analysis Programme	www.etsap.org

To access all links to Implementing Agreement websites, see www.iea.org/techag.

For more information

The free brochure *Frequently Asked Questions* provides a brief overview of the energy technology collaboration programme.

English	www.iea.org/papers/2007/impag_faq.pdf
French	www.iea.org/papers/2008/impag_faqfrench.pdf
Mandarin	www.iea.org/papers/2007/impag_faqchinois.pdf
Portuguese	www.iea.org/papers/2007/impag_faq_port.pdf
Russian	www.iea.org/papers/2007/impag_faqrusse.pdf
Spanish	www.iea.org/papers/2007/impag_faqespagnol.pdf

For highlights of the recent activities of the Implementing Agreements, see the free publication, *Energy Technology Initiatives*.

http://www.iea.org/papers/2010/technology_initiatives.pdf

To learn more about the IEA Committee on Energy Research and Technology (CERT), its working parties and expert groups, consult the IEA website.

www.iea.org/about/stancert.asp

More about the strategy of the CERT can be found in the *CERT Strategic Plan 2007-2011 and Action plan 2009-2011*

www.iea.org/about/docs/CERT_Strategic_Plan.pdf

www.iea.org/about/docs/cert_action_plan.pdf

The free downloadable publication, *Mobilising Energy Technology* describes activities and achievements of the CERT Working Parties and Expert Groups.

www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1514

To review the rules and regulations under which Implementing Agreements operate, see the free brochure, *IEA Framework*.

www.iea.org/Textbase/techno/Framework_text.pdf

To receive regular updates on the activities of the IEA Implementing Agreement and the global technology network, subscribe to the free newsletter, *OPEN Energy Technology Bulletin*.

www.iea.org/impagr/cip/index.htm

Annex C ACRONYMS

This annex provides information on acronyms used throughout this publication.

Acronyms

APEC	Asia-Pacific Economic Co-operation
APP	Asia-Pacific Partnership on Clean Development and Climate
ARRA	American Recovery and Reinvestment Act
ASHP	air-source heat pumps
AST	active solar thermal
BAT	best available technology
BAU	business-as-usual
BCC	biomass co-combustion
BEE	Bureau of Energy Efficiency (India)
BEV	battery electric vehicles
BF	blast furnace
BFBC	bubbling fluidised-bed combustion
BIGCC	biomass-integrated gasification with combined cycle
Bio-SNG	bio-synthetic natural gas
BOF	basic oxygen furnace
BPT	best practical technology
BRIC	Brazil, Russia, India and China
BRICS	BRIC plus South Africa
BRIICS	BRICS plus Indonesia
BTL	biomass-to-liquids
CAFE	Corporate Average Fuel Economy
CCGT	combined cycle gasification turbine
CCRC	Climate Change Research Centre
CCS	carbon capture and storage
CDM	Clean Development Mechanism (under the Kyoto Protocol)
CDQ	coke dry quenching
CEQ	Council on Environmental Quality (United States)
CER	certified emission reduction
CERT	IEA Committee on Energy Research and Technology
CFBC	circulating fluidised-bed combustion
CFI	commercial financial institutions
CFL	compact fluorescent lamps
CHP	combined heat and power
CIF	Climate Investment Fund

CLEEN	Cluster for Energy and the Environment (Finland)
CNG	compressed natural gas
COD	chemical oxygen demand
COG	coke-oven gas
COP	coefficient of performance
COP15	15th Conference of Parties to the United Nations Framework Convention on Climate Change
CPRS	Carbon Pollution Reduction Scheme
CSH	concentrating solar heating
CSLF	Carbon Sequestration Leadership Forum
CSP	concentrating solar power
CSPG	China Southern Power Grid
CTF	Clean Technology Fund (World Bank)
CTL	coal-to-liquid
DFI	development finance institution
DME	demethyl ether
DOE	Department of Energy (United States)
DOI	Department of the Interior (United States)
DOT	Department of Transportation (United States)
DRI	direct reduced iron
EAF	electric arc furnace
EC	European Commission
ECA	export credit agency
EEA	European Economic Area
EERE	Department of Energy's Office of Energy Efficiency and Renewable Energy (United States)
EET	Emerging Energy Technologies Programme (United Kingdom)
EFRC	Energy Frontier Research Centre (United States)
EFTA	European Free Trade Association
EGSE	Experts Group on Science for Energy (IEA)
EIA	Energy Information Administration (United States)
EIT	economies in transition
EOR	enhanced oil recovery
EPA	Environmental Protection Agency (United States)
ES	electricity storage
ESMIG	European Smart Meters Industry Group
ETI	Energy Technologies Institute (United Kingdom)
ETS	Emissions Trading Scheme
EU	European Union
EU ETS	European Union Emissions Trading System
EUP	energy using product

EURIMA	European Mineral Wool Manufacturers Association
EV	electric vehicle
ExternE	External Costs of Energy (research project of the European Commission)
FAME	fatty acid methyl ester
FBC	fluidised bed combustion
FCV	fuel-cell vehicles
FDI	foreign direct investment
FERC	Federal Energy Regulatory Commission (United States)
FP	Framework Programmes for Research and Technology Development
FYP	five-year plan
G2V	grid to vehicle
GCCSI	Global Carbon Capture and Storage Institute
GDP	gross domestic product
GEF	Global Environmental Facility
Gen-III	Generation III
Gen-IV	Generation IV
GFCF	gross fixed capital formation
GHG	greenhouse gas
GHP	geothermal heat pumps
GIS	Geographic Information Systems
GREET	The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model
GSHP	ground-source heat pumps
GTL	gas-to-liquid
HAPs	hazardous air pollutants
HDVC	high voltage direct current
HFCV	hydrogen fuel cell vehicle
HFO	heavy fuel oil
hi NUC	high nuclear scenario
hi REN	high renewables scenario
HSE	Health & Safety Executive (United Kingdom)
HSPF	Heating Seasonal Performance Factor
HSR	high-speed rail
HTS	high temperature superconductor
HVAC	heating, ventilation and air-conditioning
HVC	high-value chemical
HVDC	high-voltage direct current
IA	IEA Implementing Agreement
ICE	internal combustion engine
ICT	information and communications technologies

ICUK	Innovation China-United Kingdom
IEA	International Energy Agency
IEP	integrated energy policy
IGCC	integrated gasification combined cycle
IIGCC	Institutional Investors Group on Climate Change
ILO	International Labour Organization
INCR	Investor Network on Climate Risk
IOE	International Employers Organisation
IOF	industries of the future
IPCC	Intergovernmental Panel on Climate Change
IPO	initial public offering
IPR	intellectual property rights
IRR	internal rates of return
ISL	*in situ* leaching
ISO	International Organisation for Standardisation
ITUC	International Trade Union Confederation
LBNL	Lawrence Berkeley National Laboratory
LCD	liquid crystal display
LDCs	least developed countries
LDV	light-duty vehicle
LEDs	light-emitting diodes
LEDCs	least economically developed countries
LFR	linear Fresnel reflectors
LNG	liquefied natural gas
LOR	licence of right
LPG	liquefied petroleum gas
M&A	mergers and acquisitions
MCFC	molten carbonate fuel cells
MDB	multilateral development bank
MEF	Major Economies Forum on Energy and Climate
MEP	minimum energy performance
MER	market exchange rates
MNRE	Ministry of New and Renewable Energy (India)
MOE	molten oxide electrolysis
MoMo	IEA Mobility Model
MPG	miles per gallon
MTO	methanol to olefin
NAPCC	National Action Plan on Climate Change (India)
NDRC	National Development and Reform Commission (China)
NEA	Nuclear Energy Agency (OECD)
NEC	National Energy Commission (China)

NEDC	New European Duty Cycle
NEEDS	New Energy Externalities Development for Sustainability (research project for the European Commission)
NEP	National Electricity Policy (India)
NEWNE	synchronous grid operation of northern, eastern, western and north-eastern grids (India)
NGCC	natural gas combined cycle
NGO	non-governmental organisation
NGOC	natural gas open-cycle
NMEEE	National Mission on Enhanced Energy Efficiency (India)
NSM	National Solar Mission (India)
NSU	Sector Understanding on Export Credits for Nuclear Projects
NTP	National Tariff Policy (India)
NZEC	Near Zero Emissions Coal project
O&M	operation and maintenance
OCM	oxidative coupling of methane
ODA	official development assistance
OECD	Organisation for Economic Cooperation and Development
OEM	original equipment manufacturer
OHF	open-hearth furnace
OME	other major economies
ORC	Organic Rankine cycle
OSTP	Office of Science and Technology Policy (United States)
OTEC	ocean thermal energy conversion
p.p.	percentage points
PAFC	phosphoric acid fuel cells
PCC	pulverised coal combustion
PCFV	Partnership for Clean Fuels and Vehicles
PE	private equity
PEM	proton exchange membrane
PEMFC	polymer electrolyte fuel cells
PHEV	plug-in hybrid electric vehicles
PPP	purchasing power parity
PV	photovoltaic
R&D	research and development
RD&D	research, development and demonstration
RDD&D	research, development, demonstration and deployment
RECaBS	renewable energy costs and benefits for society
REP	rural electrification policy (India)
RGGI	Regional Greenhouse Gas Initiative (United States)
ROW	rest of the world

RSU	Sector Understanding on Export Credits for Renewable Energies and Water Projects
SA	sectoral agreement
SC	supercritical
SCCF	Special Climate Change Fund
SGCC	State Grid Corporation of China
SNG	synthetic natural gas
SOFC	solid oxide fuel cells
SUV	sport-utility vehicle
SWF	sovereign wealth funds
Synfuel	synthetic fuel
Syngas	synthetic gas
T&D	transmission and distribution
TERI	The Energy and Resources Institute (India)
TPES	total primary energy supply
TTW	tank-to-wheel
ULCOS	ultra-low CO_2 steelmaking
UN	United Nations
UN COMTRADE	United Nations Commodity Trade Statistics Database
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
US AID	United States Agency for International Development
USC	ultra-supercritical
USCSC	ultra-supercritical steam cycle
USD	United States dollar
UT	Union Territories (India)
V2G	vehicle to grid
varRE	variable renewable energy
VC	venture capital
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute
WTT	well-to-tank
WTW	well-to-wheel

Annex D DEFINITIONS, ABBREVIATIONS AND UNITS

This annex provides information on definitions, abbreviations and units used throughout this publication.

Fuel and process definitions[1]

Aquifer
An underground water reservoir. If the water contains large quantities of minerals, it is a saline aquifer.

Arbitrage
Arbitrage is the practice of taking advantage of a price difference between two or more markets.

Asset finance
Asset finance is a secured business loan in which the borrower pledges its assets as collateral.

Biomass
Biological material that can be used as fuel or for industrial production. Includes solid biomass such as wood, plant and animal products, gases and liquids derived from biomass, industrial waste and municipal waste.

Black liquor
A by-product from chemical pulping processes which consists of lignin residue combined with water and the chemicals used for the extraction of the lignin.

Bond market/bonds
Bond is a formal contract to repay borrowed money with interest at fixed intervals.

Brown coal
Sub-bituminous coal and lignite. Sub-bituminous coal is defined as non agglomerating coals with a gross calorific value between 4 165 kcal/kg and 5 700 kcal/kg. Lignite is defined as non-agglomerating coal with a gross calorific value less than 4 165 kcal/kg.

Clean coal technologies (CCT)
Technologies designed to enhance the efficiency and the environmental acceptability of coal extraction, preparation and use.

1. More detailed information can be obtained by consulting the annual IEA publications *Energy Balances of OECD Countries, Energy Balances of Non-OECD Countries, Coal Information, Oil Information, Gas Information* and *Electricity Information*.

Coal
Unless stated otherwise, coal includes all coal: both coal primary products (including hard coal and lignite, or as it is sometimes called, brown coal) and derived fuels (including patent fuel, coke oven coke, gas coke, coke oven gas and blast furnace gas). Peat is also included in this category.

Coal-to-liquid (CTL)
Coal can be converted into liquid fuels using two different approaches: by direct or indirect coal liquefaction (DCL and ICL). The DCL process involves the dissolution of coal in a mixture of solvents, followed by thermal cracking whereby hydrogen is added as a donor solvent. In the ICL process, the first step is the gasification of coal to produce a synthetic gas, which is then converted in a second step to a liquid fuel through Fischer-Tropsch or methanol synthesis.

Coking coal
Hard coal of a quality that allows the production of coke suitable to support a blast furnace charge.

Coke oven coke
The solid product obtained from the carbonisation of coal, principally coking coal, at high temperature. Semi-coke, the solid product obtained from the carbonisation of coal at low temperatures, is also included, along with coke and semi-coke.

Corporate debt
Corporate debt is the liabilities held by a company used to fund investments.

Derivatives
Derivatives are generally used as an instrument to hedge risk, but can also be used for speculative purposes.

Direct equity investment
Direct equity investments refer to the acquisition of equity (or shares) in a company.

Electricity production
The total amount of electricity generated by a power plant. It includes own-use electricity, as well as transmission and distribution losses.

Energy intensity
A measure of total primary energy use per unit of gross domestic product.

Enhanced oil recovery (EOR)
Also known as tertiary oil recovery, it follows primary recovery (oil produced by the natural pressure in the reservoir) and secondary recovery (using water injection). Various EOR technologies exist, such as steam injection, hydrocarbon injection, underground combustion and CO_2 flooding.

Fischer-Tropsch (FT) synthesis
Catalytic production process for the production of synthetic fuels. Natural gas, coal and biomass feedstocks can be used.

Fuel cell
A device that can be used to convert hydrogen or natural gas into electricity. Various types exist that can be operated at temperatures ranging from 80°C to 1 000°C. Their efficiency ranges from 40% to 60%. For the time being, their application is

limited to niche markets and demonstration projects due to their high cost and the immature status of the technology, but their use is growing fast.

Futures
Futures are tradable financial contracts.

Gas
Includes natural gas (both associated and non-associated, but excludes natural gas liquids) and gas-works gas.

Gas-to-liquids (GTL)
The production of synthetic crude from natural gas using a Fischer-Tropsch process.

Hard coal
Coal of gross calorific value greater than 5 700 kcal/kg on an ash-free but moist basis and with a mean random reflectance of vitrinite of at least 0.6. Hard coal is further disaggregated into coking coal and steam coal.

Heat
In IEA energy statistics, heat refers to heat produced for sale only. Most heat included in this category comes from the combustion of fuels, although some small amounts are produced from geothermal sources, electrically powered heat pumps and boilers.

Heavy petroleum products
Heavy petroleum products including heavy fuel oil.

Hedge funds
A hedge fund is an investment fund opened to a limited range of investors. These funds aggressively manage a portfolio of investments that use advanced investment strategies such as leveraged, long, short and derivative positions with the goal of generating high returns.

Hydro
The energy content of the electricity produced in hydropower plants assuming 100% efficiency.

Integrated gasification combined-cycle (IGCC)
A technology in which a solid or liquid fuel (coal, heavy oil or biomass) is gasified, followed by use for electricity generation in a combined-cycle power plant. It is widely considered a promising electricity generation technology, due to its potential to achieve high efficiencies and low emissions.

Light petroleum products
Light petroleum products include liquefied petroleum gas, naphtha and gasoline.

Liquefied natural gas (LNG)
Natural gas that has been liquefied by reducing its temperature to -162°C at atmospheric pressure. In this way, the space requirements for storage and transport are reduced by a factor of over 600.

Liquidity
Liquidity is the ability to sell assets without significant movement in the price and with minimum loss of value.

Low-carbon energy technologies
Lower CO_2 emissions, higher-efficiency energy technologies from all sectors (buildings, industry, power and transport) that are being pursued in an effort to mitigate climate change.

Markets
Markets are structures which allow buyers and sellers to exchange any type of goods, services and information.

Middle distillates
Middle distillates include jet fuel, diesel and heating oil.

Nuclear
Nuclear refers to the primary heat equivalent of the electricity produced by a nuclear plant with an assumed average thermal efficiency of 33%.

Oil
Oil includes crude oil, natural gas liquids, refinery feedstocks and additives, other hydrocarbons and other petroleum products (such as refinery gas, ethane, liquefied petroleum gas, aviation gasoline, motor gasoline, jet fuel, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, paraffin waxes and petroleum coke).

On-balance sheet funding
On-balance sheet funding is debt and equity issued by a company which appears on the company's balance sheet to fund investments.

Options
Options are instruments that convey the rights, but not the obligation to engage in a future transaction on an underlying security or in a future contract.

Other renewables
Includes geothermal, solar, wind, tide/wave/ocean energy for electricity generation. The direct use of geothermal and solar heat is also included in this category.

Private equity
Private equity is money invested in companies that are not publicly traded on a stock exchange or invested as part of buyouts of publicly traded companies in order to make them private companies.

Project finance
Project finance is the financing of long-term infrastructure, industrial projects and public services, based upon a non-recourse or limited recourse financial structure where project debt and equity used to finance the project are paid back from the cashflow generated by the project.

Renewables
Energy resources, where energy is derived from natural processes that are replenished constantly. They include geothermal, solar, wind, tide/wave/ocean, hydropower, biomass and biofuels.

Purchasing power parity (PPP)
The rate of currency conversion that equalises the purchasing power of different currencies. It makes allowance for the differences in price levels and spending patterns between different countries.

Spot
Spot price is the price that is quoted for immediate settlement of a transaction.

Steam coal
All other hard coal that is not classified as coking coal. Also included are recovered slurries, middlings and other low-grade coal products not further classified by type. Coal of this quality is also commonly known as thermal coal.

Synthetic fuels
Synthetic fuel or synfuel is any liquid fuel obtained from coal, natural gas or biomass. The best known process is the Fischer-Tropsch synthesis. An intermediate step in the production of synthetic fuel is often syngas, a mixture of carbon monoxide and hydrogen produced from coal which is sometimes directly used as an industrial fuel.

Technology transfer
The term "technology transfer" has two definitions. The first definition is the process of converting scientific findings from research laboratories into useful products by the private sector. The second definition is used more in economic development literature and involves cross-border transmission of technology from one country to another.

Traditional biomass
Refers mainly to non-commercial biomass use.

Transactions
Transaction is a condition under a contract between a buyer and seller to exchange an asset for payment.

Total final consumption (TFC)
The sum of consumption by the different end-use sectors. Total final consumption is broken down into energy demand in the following sectors: industry, transport, other (includes agriculture, residential, commercial and public services) and non-energy uses. Industry includes manufacturing, construction and mining industries. In final consumption, petrochemical feedstocks appear under industry use. Other non-energy uses are shown under non-energy use.

Total primary energy supply (TPES)
Total primary energy supply is equivalent to total primary energy demand. This represents inland demand only and, except for world energy demand, excludes international marine and aviation bunkers.

Unconventional oil
Includes oil shale, oil sands-based extra heavy oil and bitumen, derivatives such as synthetic crude products, and liquids derived from natural gas – gas-to-liquid (GTL) or coal-to-liquid (CTL).

Venture capital
Venture capital is a form of private capital typically provided for early stage, high potential growth companies.

Regional definitions

Africa
Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo,

Côte d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, the United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia and Zimbabwe.

Central and South America

Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, the Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts-Nevis-Anguilla, Saint Lucia, St. Vincent-Grenadines and Suriname, Trinidad and Tobago, Uruguay and Venezuela.

China

China refers to the People's Republic of China including Hong Kong.

Developing countries

China, India and other developing Asia, Central and South America, Africa and the Middle East.

Former Soviet Union (FSU)

Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

Group of Eight (G8)

Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States.

G8+5 countries

The G8 nations (Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States), plus the five leading emerging economies – Brazil, China, India, Mexico and South Africa.

IEA member countries

Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

Middle East

Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the United Arab Emirates and Yemen. For oil and gas production, it includes the neutral zone between Saudi Arabia and Iraq.

OECD member countries

Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

Organisation of Petroleum Exporting Countries (OPEC)

Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates and Venezuela.

Other developing Asia

Afghanistan, Bangladesh, Bhutan, Brunei, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, the Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Vietnam and Vanuatu.

Transition economies

Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, the Federal Republic of Yugoslavia, the former Yugoslav Republic of Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

Abbreviations

CO	carbon monoxide
CO_2	carbon dioxide
CO_2-eq	carbon dioxide-equivalent
CH_4	methane
H_2	hydrogen
H_2O	water
HC	hydrocarbons
N_2O	nitrous oxide
NO_X	nitrogen oxides
$PM_{2.5}$	particulate matter with a diameter of 2.5 micrometers or less
PM	particulate matter
SO_2	sulphur dioxide
VOC	volatile organic compound

Units of measure

bbl	barrel
bcm	billion cubic metres
bn	billion
bt	billion tonne
°C	degrees Celsius
EJ	exajoule = 10^{18} joules
g	grammes
gce	grammes of coal equivalent
GJ	gigajoule = 10^9 joules
Gt	gigatonne = 10^9 tonnes
GW	gigawatt = 10^9 watt
GWh	gigawatt-hours = 10^9 watt x 1 hour
GW_{th}	gigawatt thermal capacity

D

h	hours
K	degrees Kelvin
kg	kilogrammes = 10^3 grammes
km	kilometre = 10^3 metres
km/h	kilometre per hour
km^2	square kilometre
Ktoe	kilotonne of oil equivalent = 10^3 tonne of oil equivalent
kV	kilovolt = 10^3 volt
kW_e	kilowatt electrical capacity
kWh	kilowatt-hour = 10^3 watt x 1 hour
kW_{th}	kilowatt thermal capacity
l	litres
l/100km	litre per 100 kilometres
lge	litres of gasoline equivalent
m^2	square metre
mbd	million barrels a day
MJ	megajoules = 10^6 joules
Mt	megatonne = 10^6 tonnes
Mtoe	million tonne of oil equivalent = 10^6 tonne of oil equivalent
MW	megawatt = 10^6 watt
MWh	megawatt-hours = 10^6 watt x 1 hour
pkm	passenger-kilometre
ppm	parts per million
PWh	petawatt hour = 10^{15} watt x 1 hour
t	tonne
t/y	tonne per year
tcm	trillion cubic metres
tkm	tonne-kilometres
toe	tonne of oil equivalent
trn	trillion
TWh	terawatt-hour = 10^{12} watt x 1 hour
W	watt

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