Centre for Renewable Energy NTNU – SINTEF – IFE

R&D Strategy for Renewable Energy

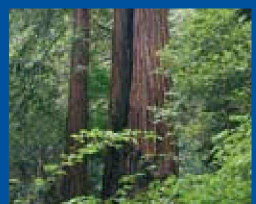
October 2008

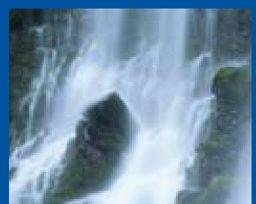
Renewable Energy

– for a better environment and increased value creation

NTNU SINTEF IFE

ISBN 978-82-997664-0-1
Text: Centre for Renewable Energy NTNU-SINTEF-IFE, www.sffe.no
Layout: FeteTyper
Print: Tapir Uttrykk
October 2008





Preface

The renewable energy sector has experienced a rapid growth internationally and a research-based industry is under development in various developed countries, as Germany, Japan and USA. The increased demand for environment-friendly energy is a strong argument for Norway to support new initiatives on renewable energy, thus creating new knowledge and giving rise to opportunities for developing new and innovative technologies in Norway.

This document is published by the Centre for Renewable Energy (SFFE) to contribute to generally increasing the efforts regarding renewable energy research and development. This document emphasises a need for continued strengthening of both education and R&D-financing of this field in Norway. By coordinating resources within a wide spectre of academic disciplines, SFFE wishes to contribute to establishing a strong knowledge industry in Norway. New initiatives should be based on cutting-edge knowledge, to increase the national supply of energy and to prepare Norwegian enterprises for a growing global market.

Professor Johan E. Hustad
Director of the Centre for Renewable Energy

ABSTRACT

Current events have led to an increased public awareness of the need for renewable energy in the near future, where the most pressing topics are climate changes and national energy supply. Increased global interest for renewable energy provides large possibilities for a new and environment-friendly knowledge industry in Norway. The total investments in renewable energy and energy economising increased from US$ 27.4 billion in 2004 to US$ 70.9 billion in 2006. Even though renewable energy only contributes to 2% of the international electricity supply, the investments come to 18% of the total investments in new power. The annual global increase for some technologies has been between 30 and 40% in recent years.

To create a knowledge intensive industry, both public and private investments in R&D are major factors. Investment by authorities in education capacity, including laboratory infrastructure, and the development of a favourable long-term industrial framework for testing new renewable energy technologies in the market is equally important. Norway is in an outstanding financial position to meet this need.

In Norway the short-term potential for new electricity and heat production from wind, hydro and biomass is estimated to be about 60 TWh annually. In addition, energy economising initiatives may lead to approximately 10 TWh in annual energy savings. Increased access to renewable energy in Norway will reduce our dependency on imported electricity, thereby reducing CO_2-emissions in Europe. By using Norwegian renewable energy to produce materials for solar cells, for example, Norway will export and «multiply» this energy in other places in the world.

This strategy document from the Centre for Renewable Energy (SFFE) calls attention to the need for a general increase in the R&D financing within renewable energy in Norway, as well as a need to strengthen the whole value chain, from research and development to the application of the knowledge in industrial and social purposes. In addition there are some areas where Norway has key expertise which may become of significant national importance if increasing the efforts within renewable energy.

Special Norwegian characteristics described include:

- The electricity grid in Norway is based on hydropower, and is an ideal basis for receiving unregulated renewable power. The demand for heat in Norway can be met by several renewable energy sources, which releases the electricity used for heating.
- Norway has a strong knowledge base within material and technical R&D in the metal industry to further develop an advanced knowledge based industry within solar electricity.
- Norway has special possibilities to utilize great wind resources nationally, and an outstanding competence base to develop offshore technologies for large-scale ocean based power in the future.
- Norway has the potential to develop advanced systems for second generation biofuels and electricity/heat from the gasification of biomass based on complementary competencies within wood conversion and land-based gas processing.
- A sustainable transport sector is necessary to reduce green house gases in Norway.

Our recommendations are as follows:

- Norway should establish a Centre for Research-based Innovation (SFI) within two areas:
  - Further development of technology for solar cells
  - Development of technology and systems for large scale offshore renewable power
- Development of technology for larger processing plants within bioenergy should be considered.
- A visibly larger effort should be placed on applied R&D, laboratory infrastructure and technology development.
- Within renewable heat and energy economising initiatives, we recommend the foundation of governmental investment programs for the implementation of technology for the end-user.
- Within the transport sector, we recommend support for increased use of electric vehicles in cities, focus on R&D within second generation biofuels, together with long term focus on hydrogen technologies.
- Allocation to prototypes (laboratories and in the field) and demonstration plants for the collection of experience within several technology areas.
- An increased basic allocation to improve the national knowledge base in this area.

ABOUT THE CENTRE (SFFE)

The objective of the Centre for Renewable Energy (SFFE) is to increase the quality, efficiency and scope of education, development and innovation in the field of renewable energy in Norway. This is to be achieved by coordinating existing activities and establishing new activities at the Norwegian University of Science and Technology (NTNU), SINTEF and the Institute for Energy Technology (IFE). The focus of this work is knowledge promotion and the implementation and utilization of the sources of renewable energy and renewable energy technologies.

The vision of the Centre

Renewable energy – for a better environment and increased value creation

About the authors

This strategy is elaborated by the management of the SFFE, with contributions from the board and professional colleagues at NTNU, SINTEF and IFE.

The management:

Director	Johan Hustad
Deputy Director	Ann Mari Svensson, SINTEF
Deputy Director	Roy Stenbro, IFE
	Turid Reenaas, NTNU
	Marianne Ryghaug, NTNU
	Inger Andresen, SINTEF
	Lars Sørum, SINTEF
	Arve Holt, IFE
Coordinator	Trygve Mongstad

The board:

Bjørn Hølaas, Statkraft, Trondheim Energi
Ann-Elisabeth Serck-Hanssen, StatoilHydro
Ola Syverinsen, Eidsiva Energi
Gunnar Halvorsen, Elkem
Professor Arne Bredesen, Department of Energy & Process Engineering, NTNU
Professor Anne Grete Hestnes Dept. of Architectural Design, History and Technology, NTNU
Torstein Haarberg, SINTEF Materials and Chemistry
Petter Støa, SINTEF Energy Research
Per Finden, IFE

This document could not have been produced without the indispensable contributions from the former coordinator Åse Lekang Sørensen, the former member of the management Øystein Ulleberg (IFE) as well as the former members of the board Alexandra Bech Gjørv (StatoilHydro) and Erlend Bjorlie (Statkraft).

SFFE's board in 2007 (photo: IFE)

Contents

1 INTRODUCTION AND OBJECTIVES

There is a strong need for development and utilization of new renewable energy resources

Various recent dramas in the world news tell us the same thing about the need for development and utilization of new renewable energy resources.

The drama of climate change is about the considerable challenges and cost in relation to global warming, an issue that concerns the whole of humanity (c.f. the report from The Norwegian Commission on Low Emissions, and the Stern report, 2007).

The drama of "Peak Oil" points out a wide range of challenges following the need to find new energy sources that can take over when the global reserves of petroleum run empty.

The drama of values treats the fact that the production and use of energy implies various moral challenges: who is the owner of the energy (local versus central ownership)? How should it be used (change of lifestyle versus standard of living)? Who is responsible for energy scarcity? Who will solve the problem of climate change?

Norway can play an important role in future development in renewable energy

The drama of "What will Norway do when the oil wells run empty?" has often been considered by Norwegian politicians and the Norwegian press. The discussion is partly about increasing funding to R&D projects, partly about the terms for industrial development, and partly about the relationship between the oil and gas industry and other industries in Norway.

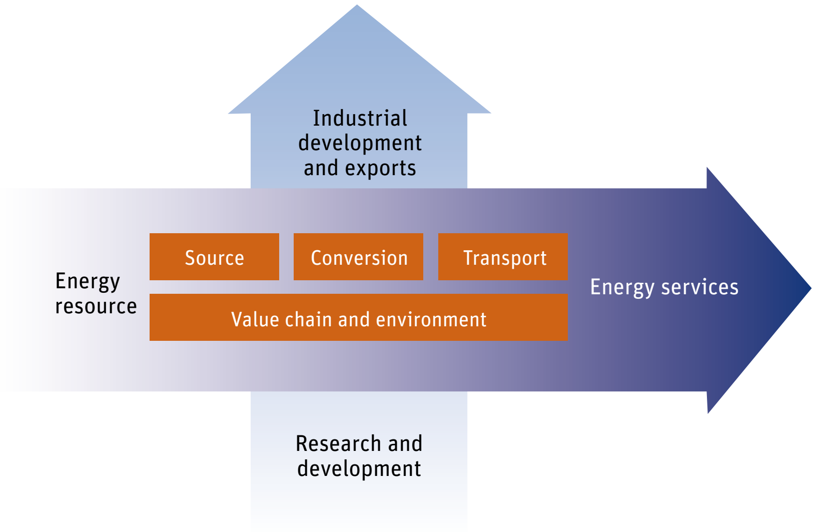


Figure: The value chains from resources to energy services and from research and development to new energy technologies.

The last drama is about the national energy supply and refers to the reliability of the energy supply. This has become an important agenda in many countries because of the increased insecurity in energy supply due to global political circumstances regarding petroleum. This is an important reason for the arguments that give priority to renewable energy in the European Union and the United States, and creates the opportunity for Norway to play an important role as a nation with considerable knowledge about energy and electricity supply.

Substantial measures in the development of renewable energy in the EU is motivated both by environmental considerations and by the security of the energy supply. By 2020, 20% of the EU consumption of energy will be covered by renewable energy production. This means that approximately 600 TWh of new renewable energy production has to be put into planning and construction. This depends on developments in various fields, such as wind power, hydropower, solar energy and bioenergy.

The Norwegian initiatives in renewable energy are mainly based on the consideration of environmental and climatic issues. Other considerations can also play a role in the evaluation of energy production, such as energy supply security. It is emphasized that energy is a critical resource for industry and the population, and its failure will have dramatic consequences. In addition, the strong arguments in the demand for renewable energy are creating considerable opportunities for Norwegian industry, on both the short and long term.

Industrial development

Since 2005, the Ministry of the Environment in Norway has been carrying out a project concerning environmental technology that is following up the European Union's Lisbon Strategy for increased innovation. This project has been followed by a proposition by the Norwegian Pollution Control Authority, Innovation Norway and the Research Council of Norway about environmental technology, including renewable energy. In 2006, The Norwegian Ministry of Trade and Industry initialized the first Report to the Storting (Norwegian parliament) about innovation politics. The report will be conductive to innovation to secure future industry, commerce and employment. Norway can play a substantial role in the development of diverse technologies for renewable energy. An example is the rapid development of the solar cell industry in Norway, which is based on the outstanding expertise in materials technology among Norwegian scientists and engineers. This achievement is the result of many years of goal-oriented development of knowledge and its commercialization in the area of aluminium and silicon. There are also other fields where considerable competence has been generated, which can find applications in the development of new, knowledge-based industries.

Energy supply

Norway also has substantial opportunities for energy production from renewable resources. The Norwegian potential for new production of energy from wind, hydropower and bioenergy on the short term is estimated to be 60 TWh yearly. It is also estimated that stimulation towards efficient energy use can save an additional of 10 TWh yearly.

The Norwegian government has set the target of a 30 TWh increase in the production of renewable energy by 2016, compared to the production level in 2001.

To strengthen the domestic market in renewable energy, there is a need to boost national competence in the implementation and use of renewable energy production.

Environmental concerns

The Norwegian Government has set another target. It will exceed the Norwegian share of the Kyoto Protocol by 10%. In accordance with Norway's strategy for sustainable development, by 2020 the country will reduce its global emissions of greenhouse gases by 30% of the total Norwegian emissions in 1990. By 2050, the global reduction will correspond to 100% of Norway's emissions in 1990. How much of the reduction that will be achieved within Norway's borders is still under discussion.

The pressing need for the development of knowledge and competence

It is important to put considerable effort into R&D and education in the field of renewable energy in the years to come. However, taking into account the many relevant technologies, it is worthwhile discussing the scope and thrust of this effort. Should it be a wide measure or a more focused initiative? Is it more important to become the leader in a specific field or is it better to follow up a wider range of technologies?

If we consider a substantial initiative towards renewable energy, the challenges in the politics of technology have four dimensions:

- Stimulation of innovation
- Improvement and extension of infrastructure, including supply
- The possibilities for reliable and efficient regulation and standardization
- Democratic dialogues, cooperation and enquiries.

Norway has substantial opportunities for energy production from renewable resources

The most common instruments are legal and financial, such as regulations and subventions. Additionally, we have the possibility to use government investments in R&D, physical and socio-economic planning, the establishment of regulatory institutions and institutions promoting democratic dialogue and enquiry.

However, the different dimensions of the politics of technology cannot be considered independently. As an example, many forms of innovation are in the need for premises concerning supply goals and the construction of an adequate infrastructure.

In this way the four dimensions of the politics of technology can constitute a framework for evaluating different renewable energy technologies and how the Norwegian effort should be realized.

There is a pressing need for the development of knowledge and competence

The R&D strategy of the Centre for Renewable Energy (SFFE) is designed to be an instrument for visualizing the opportunities that exist within the field of renewable energy in Norway. It points out where the relevant technologies stand regarding the market, the cost and the time perspective. To be able to realize these opportunities, it is vital to build demonstration projects and initialize innovation activities. By coordinating the education and research at the three largest centres of expertise in renewable energy in Norway, SFFE has a unique opportunity to get an overview and provide a general evaluation of the different technologies and energy systems. In this way, general recommendations can be given, and at the same time the greatest opportunities for Norway can be indicated.

2 NORWAY'S ADVANTAGES DUE TO ITS CURRENT EXPERTISE

Norway has excellent premises in a selection of R&D areas

In certain areas of R&D, Norway has excellent premises to become an international leader. The reasons lie in its natural resources, which have inspired leading-edge competence in a number of research fields.

Norway has very high standing in the energy sector. Within hydropower, it is the sixth-largest producer in the world, and its hydropower resources have set the stage for the development of energy-intensive industry which has also played an important role for national welfare. Its oil and natural gas resources make Norway one of the world's largest exporters, and the knowledge found in Norwegian industry in oil exploration and recovery is considered the best in the world in certain disciplines.

Norway can develop renewable energy solutions for the international market

Norway can play an important role in the development of future energy technologies, where renewable energy will become continuously more important. New knowledge and technology are vital to be able to take renewable energy into use, nationally and internationally. Here, Norway can make a significant contribution to the process of developing the required expertise and industrial systems in an expanding international market.

The areas in which Norway has an advantage due to its current competence include:

- The development of small-scale hydropower systems
  - For about a century, Norway has been constructing and developing hydropower projects, and has thereby acquired strong national competence on the relevant fields. Hydropower is now considered to be a mature technology, with a well-informed supplier industry, consultants and research centres. Experience drawn from large-scale hydropower systems has been utilized in the development of small-scale solutions, but there is still a need for further adaptation and implementation on the national level. There remains considerable potential for utilizing new hydropower resources internationally, which constitutes a great opportunity for the Norwegian hydropower industry to expand and obtain an even stronger position internationally.
- The production of solar cells
  - The aluminium- and silicon industry has a long history in Norway. An important premise for production has been the long-term contracts for the supply of electric power. This industry has developed leading competence in materials science and process engineering, and has established an excellent level in education, research and development within these fields. The solar cell industry has benefited from this, and the Norwegian solar cell industry is today among the world's largest producers of silicon wafers.
- The development of large-scale offshore power generation systems
  - In the beginning of the 1970s, underwater oil and gas reservoirs were discovered on the Norwegian continental shelf. Since then, a strong industry has developed in offshore construction and materials for marine environments. This can provide a competitive edge in the development of offshore renewable energy.
  - Although the natural premises for large-scale offshore renewable energy initiatives are excellent in Norway, it remains a challenge to realize the construction. Despite the Norwegian advantages in some of the links of the supply chain such as foundation and materials, other countries are in the lead in areas such as turbine technology.
- The development of larger process plants for bioenergy
  - To develop large process plants for bioenergy, extensive knowledge about process engineering is essential. The competence found in the Norwegian wood processing industry and the experience from oil and gas refineries provide a sound foundation for developing advanced bioenergy systems. The challenge is to couple these two industries and their experience together.
  - Products from new advanced bioenergy processing methods will be second generation biofuels and/or power and heat from the gasification of biomass. The knowledge about these processes needs refinement, but there is a vast international potential in the production of energy and the evolution of new technologies.

3 FRAMEWORK CONDITIONS FOR R&D AND COMMERCIALIZATION

Energy is a vital resource in the modern community. Thus it is a challenging task to manage the production and consumption of energy, and at the same time to fulfil the broad range of human needs in order to maintain the sustainability of our society. To meet this challenge, new strategies are required in politics, the economy, technology and everyday life. Global warming and the need to reduce the emissions of CO_2 and other greenhouse gases have intensified the focus on energy production and consumption. We need new solutions, and a modern society should act with a certain level of critical awareness regarding the management of energy and evaluate the possibilities of the future. This evaluation should include insight from social sciences and the humanities. This knowledge can play a role in bridging the gap between technologists, economists and society.

In order to strengthen initiatives in renewable energy in Norway, these problems should become more important matters of discussion between the country's decision-makers.

Framework conditions

It is possible to create Norwegian companies with expertise that deliver know-how to Norway and the international market.
This could include:

- Innovations in the national construction of renewable energy facilities such as wind turbines, bioenergy and energy-efficient buildings.
- Export-led innovation, such as the solar cell industry.

It is essential to take the entire value chain into consideration; from research to the industry's framework conditions

If the creation of industrial and commercial development in Norway is to be a viable proposition, it is essential to take the entire value chain into consideration; from research to industry's framework conditions.

Changes in the energy sector suggest investments in the infrastructure that are of importance to the entire structure of the society. The international renewable energy market is mainly controlled by politics, through instruments like investments in R&D and feed-in tariffs. A politically controlled planned development of new energy technologies gives the opportunity for long-term planning. Thereby profit can be made by developing technologies and eventually implementing mass production.

There is global competition between countries to attract companies in energy and environmental technology. Among others, Japan and Germany have realized large initiatives to attract companies so as to phase in renewable energy. As a result, Japan has become the world leader in the solar cell industry and Germany in solar heat utilization, biofuels and windpower. The Norwegian solar cell industry is among those that benefit from these framework conditions from elsewhere.

Favorable and long-term framework conditions are necessary

Reliable framework conditions are necessary for research and industrial development. Government investments in R&D are important to realize alternative energy solutions, and it has been seen so far that Norway is far behind its neighbouring countries, as well as many other countries in the EU.

The conditions for the testing of new technology are equally important. Norway's conditions in this respect are to date (2008) not competitive. The feed-in tariffs must be sufficient to attract the industry; it is not enough that the investment is considered "marginally profitable". If the conditions are better in neighbouring countries, there is a clear risk of the leakage of technology. The Norwegian media has frequently reported about Norwegian companies moving prototypes and demonstration projects to other countries such as Germany, England and Portugal, where the conditions are better.

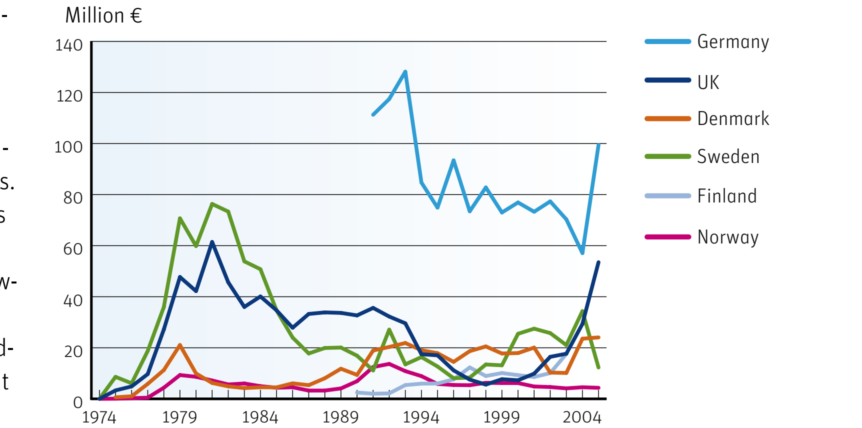


Figure: Government investments in R&D.
Source: IEA, Beyond 2020

Recommendations for future initiatives in renewable energy

To develop new technology and future industry, research-based knowledge and innovation are crucial. The Centre for Renewable Energy (SFFE) has arrived at the following advice:

- **An increase in the basic appropriation to promote knowledge in renewable energy nationally.**
  - Competence from more professional disciplines is needed to achieve research-based high quality knowledge. Establishing a large PhD programme to promote fundamental knowledge within different disciplines would be a valuable measure.
  - Enough university places should be established in the sector to deal with the needs from industry.
  - The public sector needs better competence in climate and energy issues, to be able to make the right decisions.
  - Narrow measures have a short-term perspective, while a general initiative to boost fundamental education will result in flexibility.

- **Considerably stronger measures towards applied R&D and technology development.**
  - An increase in the appropriations in the RENERGI programme of the Research Council of Norway.

- **Stronger initiatives towards the end-use of renewable energy to cover the Norwegian energy demand.**
  - Reductions in the energy consumption should be encouraged.
  - The energy supply of buildings and industry should be adapted to accept heating from renewable sources rather than electricity. This should be given incentives through financial support from the government.
  - A governmental programme for investments in the testing and implementation of renewable energy and energy conservation solutions should be established.
  - Focus should be put on the importance of politics referring to the utilization of energy.
  - Planning should start to establish a test centre for renewable energy under real conditions.

Areas of interest based on our national competence

In addition to a broad educational initiative, effort should be put into further developing Norway's existing competitive advantages. Certain targets should be agreed that are based on these advantages in order to develop advanced technology and systems for the vast international market.

Norway's competitive advantages in hydropower, solar cell production, offshore energy and process plants for bioenergy have been described in Chapter 2. Concerning hydropower it is important that the environmental aspects are considered in future initiative. Further, a particularly strong initiative is suggested in the development of future solar cells and the development of large-scale offshore energy. Another interesting field is the possibility for larger processing plants for bioenergy and second generation biofuels. However, there still exists some uncertainty concerning the opportunities for exporting this technology, considering natural resources and the strong initiatives of other countries on this area.

Future technology for solar cells

Efforts should be made to establish an even stronger knowledge-based industry in the solar cell sector. Positive development of the solar cell industry in Norway will depend on it being given equal or better conditions in Norway than elsewhere. An initiative on solar cell development should include the entire value chain, from the fundamental knowledge in materials science to the assembly of the final product. Fundamental R&D to establish new industrial initiatives is also required.

The recommended initiative involves:

- Development of specific competence for solar cell production.
- Increased financial support to R&D in solar cell technology
- Large-scale investments in modern laboratory infrastructure and scientific equipment.
- Encourage the establishment of new industry

Development of large-scale offshore energy

A strong initiative concerning offshore energy should be realized, and a Centre for Research-Based Innovation (SFI) should be established as soon as possible. A planned transfer of knowledge from the existing offshore industry to the new offshore renewable energy industry should be given an incentive.

The recommended initiative involves:

- Research and development
  - Establishment of new R&D in floating wind turbines
  - Long-term R&D within wave energy
- Demonstration projects
  - Motivate the establishment of demonstration projects in relation to existing offshore installations
- Framework conditions
  - Efforts to strengthen the Norwegian supply industry
  - Attract industrial companies for the construction of windpower plants both offshore and onshore
- Infrastructure and competence
  - Increased construction of land-based wind turbines to secure the development of the relevant competence
  - Initialize the planning for electrification of the installations on the continental shelf
  - Establish a clear regulatory system for offshore energy installations.

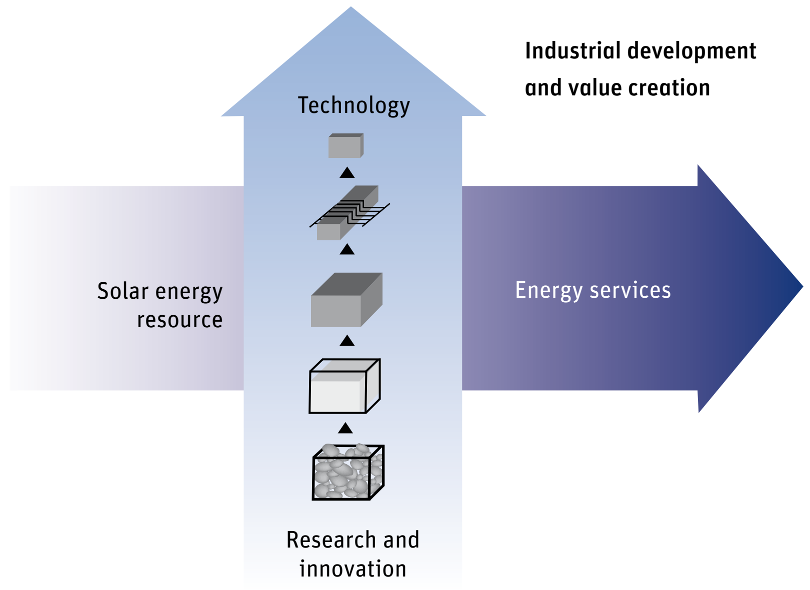


Figure: The value chains of solar cells, from materials to the final product and energy services, as well as from R&D to new technology.

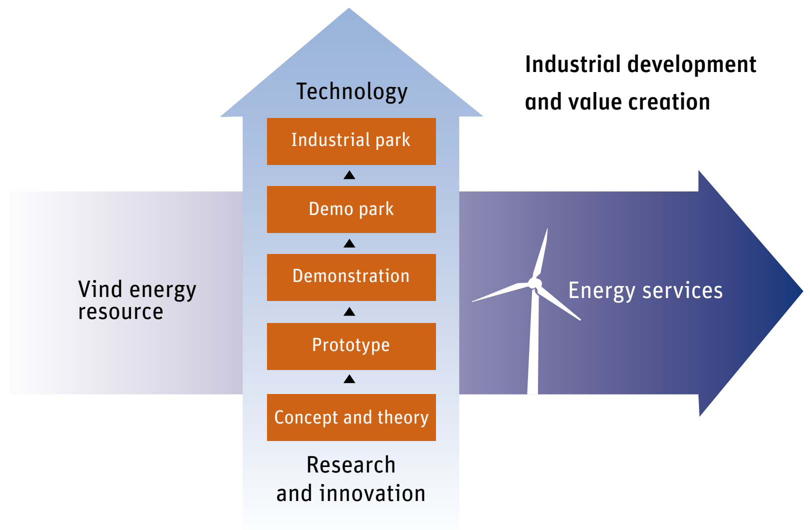


Figure: The value chains of wind power.

4 FIELDS OF INTEREST

4.1 The energy system in Norway

The Norwegian energy system differs from that in most of Europe, as Norway's land-based energy supply mainly depends on hydropower. A heavy duty electricity grid covers the country and supplies Norwegian industry and dwellings with relatively cheap and reliable electrical energy, which also constitutes the main source for heating. In 2006, the overall consumption of electric energy in Norway was 111 TWh, whereas production was 120 TWh.

Over the last few years, the attention given to energy conservation and the use of alternative energy sources has increased, due to large-scale initiatives by Enova, which was established in 2001. (This is a public enterprise owned by the Norwegian Ministry of Petroleum and Energy to contribute to environmentally sound and rational use and production of energy.) An initiative by Enova to encourage the use of central heating plants was launched in order to reduce the use of electric energy for heating. In 2005, the installed capacity of central-heating plants constituted 2.5% of the national consumption of electric energy.

A vast majority (99%) of the electric energy produced in Norway comes from hydropower plants. In 2006, only 0.5 TWh of wind energy was produced.

Potential and perspectives

Future energy systems will be based on more sources of energy and the plants will be more distributed and more flexible than today. In addition, there will be a tighter connection between the energy consumption for stationary users and transport.

The well-developed energy system based on hydropower is very flexible and therefore is ideal as a basis for the production of renewable energy from variable sources. It is considered that wind energy will give the greatest contribution to clean energy production in Norway over the next 10 to 20 years.

The greatest wind resources are found in the northern areas of Norway, which are remote with respect to the European energy market. It is estimated that further strengthening of the energy grid for the transport of electric energy from wind power in northern Norway will cost €0.7-1.0 billion.

The Norwegian renewable energy production might serve to balance and feed the Continental energy market with clean renewable energy, given that more initiatives such as the NorNed cable from Norway to the Netherlands are realized.

The Norwegian energy system based on hydropower is ideal as a basis for the production of renewable energy from variable sources.

Most of central and northern Norway is unsuited for the exploitation of solar energy, due to its high latitude. However, the south of the country is just as suited for solar cells as most of Germany, and given the right conditions, a similar introduction of solar cells as is seen in Germany could be feasible.

The cool climate generates a considerable need for heating in buildings in Norway. This need, which is currently mainly met by electric heating, could in the future be covered by other sources as bioenergy, solar heat and heat pumps, and thereby release electricity for use in transport or for energy exports.

Recommendations

A comprehensive initiative on solar energy, windpower and bioenergy in Norway should include domestic installations, to give the first-hand experience with the installations and results. This experience will provide the basis for further research and development in renewable energy technologies.

The R&D initiative should put weight on:

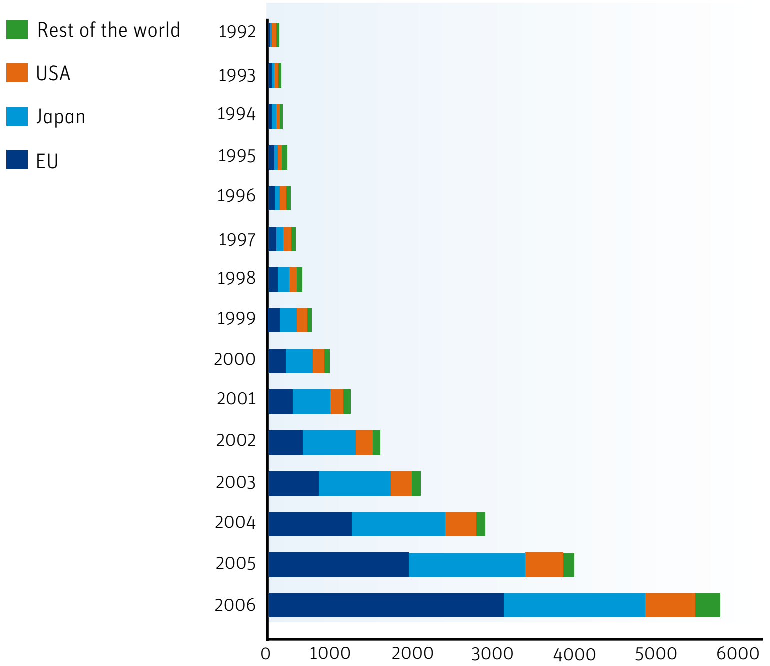
- Development and use of hybrid systems for heating, combing solar heat, bioenergy and heat pumps.
- Evaluation of systems combining the production of heat and fuels.
- Implementation of dynamic energy systems with more involvement of individual users.
- On the longer term more effort should be put on developing systems for co-generation of hydrogen fuel, electricity and heat, and following up the research on windpower generation in combination with electrolysis of water.

Future energy systems will be more distributed and more flexible

4.2 Photovoltaics

The energy from the sun that hits the earth is immense, and photovoltaic devices converting this radiation into electric power could play an important role in future energy systems.

The present market for solar cells is dominated by solar cells of wafers produced from extremely pure



Installed PV-capacity (MW). Source: Risø energy report

Silicon and solar cell production has become an important industry in Norway

silicon. Globally, the photovoltaic (PV) industry has gone through a sky-rocketing development over the last few years, and over the last three years production has increased by 50% a year. The technology in solar cell production is improving rapidly and the efficiency of commercially available solar cells is increasing.

Electricity production from solar cells in Norway is infinitesimal. However, the Norwegian industry of solar cell production has become very prominent, thanks to the company Renewable Energy Corporation (REC). REC is today one of the largest companies in the world in the solar cell industry. Due to a high degree of automation, the competition from low-cost countries is not an important concern. Because of REC and other companies associated with the solar cell and silicon industry, it is probable that Norway will retain its position as one of the largest producers of PV products.

Recommendations

The development of the solar cell and silicon industry in Norway is based on the existing technology and competence from the materials science industry. It is necessary to develop the specific competence of solar cells to continue the positive trend. The industry has an increasing need for expertise, and in order to meet the demand it is important to have higher education programmes for engineers from relevant fields. There is also a need for large investments in laboratories dedicated to PV research.

4.3 Wind and offshore energy

The wind resources of Norway are vast, and can be exploited by both onshore and offshore installations. The onshore installations are influenced by the general opinion about landscape conservation as well as financial concerns. On the other hand, installations offshore are yet not common, and depend upon new technological developments. Norway has the opportunity to take advantage of the competence from marine installations in the oil and gas industry, and thereby can become a leading nation in the field of offshore wind energy. It is a global market, and it has been estimated that it can reach €80 billion by 2020.

The wind energy industry has seen substantial growth over the last 20 years, where Germany, Denmark and Spain have led the way. In 2006, the industry had a turnover of €20 billion.

Developments have to a great extent been politically motivated, driven by arguments such as the reliability of the energy supply, the reduction of greenhouse gas emissions and industrial value creation.

Out of a world capacity of approximately 74 GW, only 0.9 GW is installed off-shore, and then only in shallow water, at depths less than 30 m. At larger depths, floating wind turbines can be an alternative. Floating turbines represent a new technology that so far not has been realized on large scale.

Only a small percentage of the wind parks is installed offshore

Norwegian industry has started an initiative in R&D for floating turbines. The concepts HyWind and SWAY are under development, and full-scale prototypes are expected to be finished by 2010. The idea of deep-water offshore wind energy production is to establish large windfarms out of sight from land in the North Sea and the Norwegian Sea, which can be connected both to land and the offshore installations of the oil and gas industry.

Floating wind turbines need more R&D. Several concepts are under development in Norway

Another potential in offshore energy is wave power. It has been estimated that it is feasible to produce 40 TWh/year of renewable energy from wave power installations in Norway. However, this technology is still in an early stage of development, and further research initiatives are necessary. Norway has various projects under development; among these are Wave Energy, Fobox and Pelagic power.

Recommendations

A firm initiative on wind power is recommended, thereby:

- Further construction of onshore windfarms, to produce more renewable energy and gain experience and knowledge in the handling and construction of wind turbines in general.
- Establish a large R&D initiative to develop floating windfarms.
- Arrange centres for the testing and demonstration of new concepts associated to onshore windfarms and existing offshore installations.
- Establish good financial framework conditions for the construction of onshore and offshore windpower.
- Construct a grid to supply the oil and gas installations on the Norwegian continental shelf with electrical energy from offshore and onshore renewable resources.
- Establish clear regulatory conditions for the construction of offshore windfarms and power grids.

4.4 Bioenergy

Energy from biomass is traditionally utilized for heating purposes in Norway, but can also be converted to biofuels, biogas, electricity or hydrogen. The Norwegian annual consumption of bioenergy is of 15 TWh, mainly from domestic heating. The dominant source of fuel is from the forestry industry.

The price of heat from biomass is competitive to alternatives like electricity, oil and gas. There has been a steady growth recently in the number of central-heating plants. By 2007, this amounted to a total consumption of 2 TWh.

Biogas is created when biological material decomposes without access to oxygen. There are several installations that are commercially available, and the interest in biogas is increasing. The production of biogas from sewerage systems is now a mature technology, and it is considered a necessity to introduce these systems where it is possible.

In Norway approximately 200 GWh of electrical power is produced annually from biomass. This mainly comes from waste combustion plants.

The geographic location of Norway rules out the possibility to produce large quantities of biodiesel and other first generation biofuels. However, second generation biofuels will be a sustainable alternative for transportation. Projects have been initiated in Norway to produce such fuel from wood and waste from forestry. The target has been set so that biofuels will

Bioenergy can be converted to heat, biofuels, biogas, electricity or hydrogen

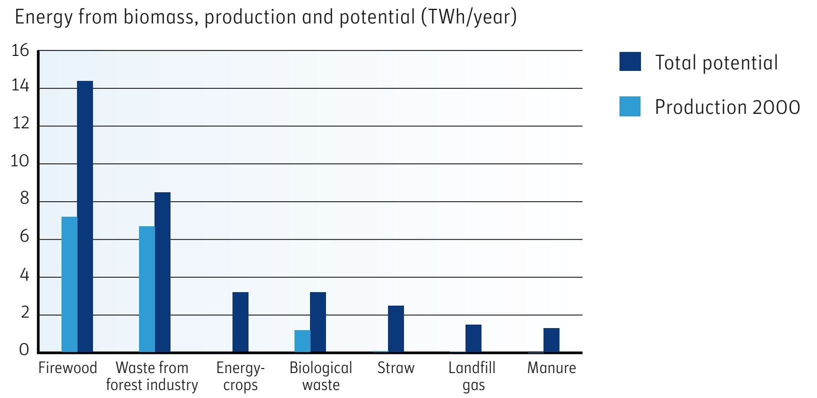


Figure: Gross production and potential for increased use of biomass. Source: Enova's heat study 2003 / Hohle 2001.

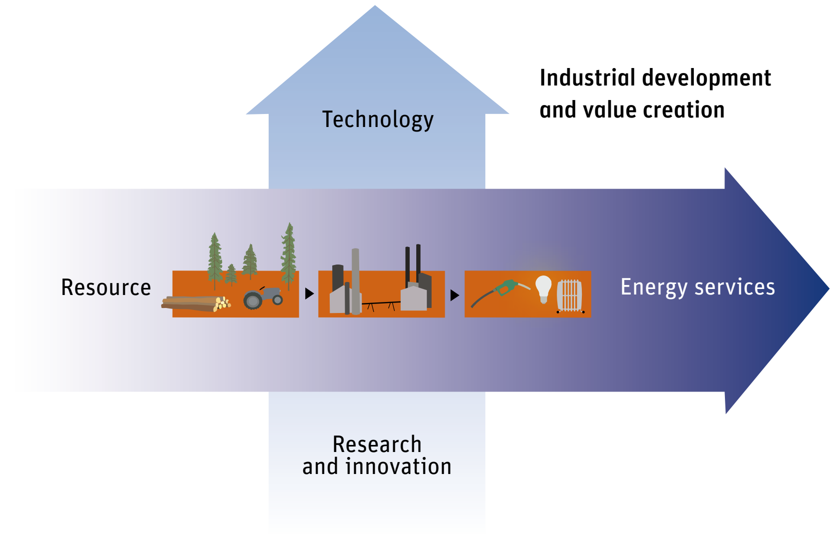


Figure: The value chains of bioenergy

constitute 2% share of the fuel sales in this country by 2008 and 5% by 2009.
It is estimated that there is a potential for increasing the energy production from biomass by 15-30 TWh annually in Norway, basically from wood. With a fuel cost of €0.014/kWh, it is considered that the production of biomass from wood for heating purposes can increase by up to 15 TWh.

The greatest research effort that is needed regarding bioenergy, is in second generation biofuels. We consider Norway to be in a strong position, due to its long-standing competence from the paper and processing industry, and its extensive unused forest resources.

Norway holds a strong position regarding the development of second generation biofuels and advanced systems for bioenergy

Recommendations

An R&D initiative on bioenergy in Norway should be focused on

- The development of large-scale advanced systems for co-generation of biofuels and electricity or heat from biomass. The entire value chain should be analysed, and the characteristics of the fuel as well as the environmental consequences should be taken into account.
- The utilization of microorganisms for biofuel production, based on fermentation of sugar from cellulose, which for a long time has been under investigation internationally. More attention should be given to these processes in Norwegian R&D.

85% of the energy use in Norwegian buildings comes from electricity

- Investment in laboratory infrastructure as well as facilities for demonstration of new technology.

4.5 Renewable heat and energy savings

Renewable heat refers to solar heat, bioheat and heat pumps, whereas energy savings includes all measures to reduce the need for primary energy in buildings.

Approximately 50 TWh/year is spent for heating each year in Norwegian buildings. New regulations introduced in 2007 demand a reduction of 25% in the energy use in new buildings compared to the traditional standards. Over the last few years, the interest for low-energy and passive houses has also increased. Low-energy houses are defined as houses with at least 50% lower energy use than the normal and passive houses with at least 75% less. There are today approximately 10 000 low-energy houses under planning or construction in Norway.

Solar heating has become increasingly popular internationally, but has not yet experienced a breakthrough in Norway. It is calculated that there is a practical potential of 4 TWh/year for solar heat utilization in Norway.

The number of installed heat pumps has increased over the last ten years. In 2004, 150 000 heat pumps were installed, with a total production of 6 TWh/year of heat. The price of heating from heat pumps is considered competitive to alternative sources. There is, however, no large producer of heat pumps in Norway and suppliers rely on imports.

The estimated potential for energy savings and the use of renewable heat are respectively 12 TWh/year and 10 TWh/year. For heat pumps, the realistic potential is estimated to 10-16 TWh/year.

The greatest opportunity for innovation in these areas in Norway is within the development of integrated solutions for buildings that combine energy savings and heat utilization. Further innovations make it foreseeable to produce houses, combining renewable heat utilization with power generation systems, which are net producers of energy.

Recommendations

- Increasing the knowledge in the construction business, regarding development and implementation of low energy solutions
- Gradually intensify the regulations for energy consumption in new buildings.
- Long-term framework conditions to provide incentives for the use of renewable heat.
- Establishment of long-term R&D programmes for the utilization of renewable heat and energy savings.

4.6 Hydropower

As mentioned, hydropower represents 99% of the total electricity production in Norway. The hydropower system is a very favourable one to combine with new non-controllable energy sources as windpower and wave energy, as it can balance the power production in periods of light wind and low waves.

Recently increased attention has been given to small hydropower systems (less than 10 MW) as most of the large hydropower resources have already been utilized in Norway. Small hydropower systems can produce power at competitive prices. The cost- efficient potential for installation of small hydropower plants is estimated to be 25 TWh/year.

Modernization of existing plants also represents an opportunity. The potential for upgrading and extending existing plants has been estimated to 10 TWh/year.

Considerable national competence has been developed in this area for both small and large installations. This competence has proved to be a good resource for exports.

Recommendations

R&D is relevant for some areas, as

- The environmental aspects of hydropower systems
- Control systems and maintenance of hydropower plants.
- Improved turbine designs.
- Utilization of pump turbines.
- Sand erosion in hydraulic machines.
- Enhance efficiency measurement techniques.

R&D is also important to maintain existing competence, and to provide research-based education.

4.7 Tidal and osmotic power

There is a large potential for innovations on energy savings in buildings

There is increasing interest in energy production from ocean energy like tidal forces, wavepower and osmotic energy. Tidal power has an energy concentration of 500 to 1000 W/m2 on the Norwegian coast. A prototype of a tidal water turbine has been installed in Hammerfest in northern Norway by Hammerfest Energi. The experience gained from this prototype will lead to the installation of a new prototype, which will be installed in Scotland due to better framework conditions. Tidal power is not a strong resource in Norway, but can be exploited in certain locations, generally in the northern parts of the country. However, the Norwegian competence in offshore installations is considered to be valuable in the development of new concepts for generation of energy from tidal currents.

Hydropower represents 99% of the total electricity production in Norway

Osmotic power is based on the energy generated from mixing freshwater with salt water. The theoretical osmotic pressure from this mixture corresponds to a column of 270 m of water. The Norwegian energy company Statkraft is constructing a pilot plant for osmotic power of 10 kW, starting in 2008. Statkraft has estimated a realistic potential of 12 TWh/year of installed osmotic power in Norway.

Recommendations

These are immature technologies, which need substantial R&D to become commercially viable. Tidal power is dependent on development of low-maintenance solutions and light gear-free generator systems. Osmotic power is dependent on a clear R&D initiative to increase the efficiency of the membranes needed to separate and transport water.

The development of concepts for tidal and osmotic power is in its early stage

4.8 Electrification of the transport sector

Transportation is responsible for 37% of the global emissions of greenhouse gases in Norway. The yearly consumption of 57 TWh in fuel is dominated by fossil fuels used in combustion engines. Electric engines are more efficient and result in large reductions in emissions and a reduction in the general energy consumption. For flexibility, hybrid systems with both electric and combustion engines have been introduced to the market, and are commercially available today.

Purely electric vehicles are also commercially available, and are competitive in price for some applications. By January 2007, 1667 electrical vehicles were registered in Norway. The commercially available electric vehicles are based on battery storage of energy. An alternative to battery storage is hydrogen, which should be able to store large amounts of energy in a confined volume. Hydrogen, produced from renewable energy, represents a zero emission alternative. However, the technology is still immature, and further R&D is a pressing need.

Electrification of the transport sector will give a strong reduction in emissions

There is a small industry in Norway producing electric cars. ElBil Norge produces the small and cost-effective Kewet Buddy. The company Think has developed some unique solutions for electric cars, and will start delivering new vehicles by 2008. Hydrogen Technologies has for some time been a key supplier of electrolyte technology to the international market.

Recommendations

Initiatives on the electrification of transport should include

- Encouraging the use of electric vehicles where it is reasonable.
- Research initiatives in battery technology.
- Strengthening of the existing competence on hydrogen production, storage and utilization.

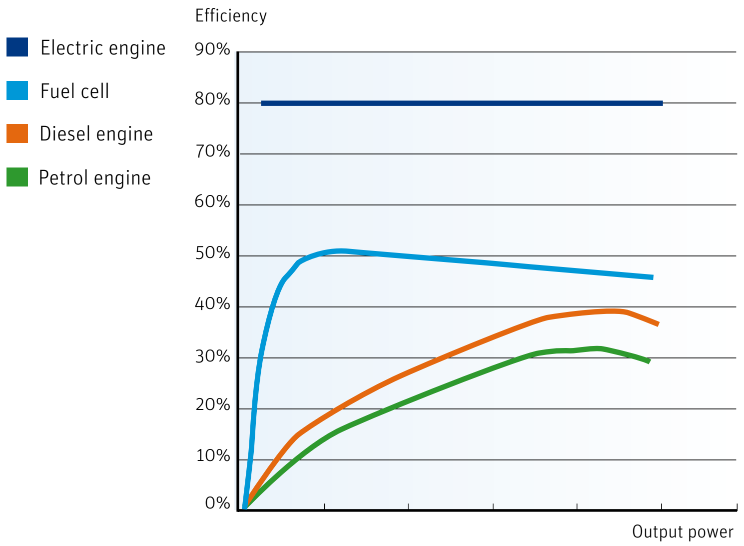


Figure: The efficiency curve for various engines

Figure: The Norwegian electric car Think City (Photo: Think)

APPENDIX:

More information, typical energy use and production, energy units, energy potential in Norway

More information

Centre for Renewable Energy NTNU – SINTEF – IFE	www.sffe.no/index_e.htm
Institute for Energy Technology (IFE)	www.ife.no
SINTEF	www.sintef.no/home
The Norwegian University of Science and Technology (NTNU)	www.ntnu.no/english
Renewable energy in Norway	www.renewable.no
The Norwegian Research Council	www.forskningsraadet.no
Energi21 (national strategy on ren. energy)	www.energi21.no
Innovation Norway	www.innovasjonnorge.no
Enova	www.enova.no

Typical energy consumption and production

Energy consumption, Norwegian dwelling	In Norwayin 2004, the total yearly consumption of energy per household was of 21,100 kWh, whereas the average electricity consumption amounted to 16,000 kWh.
Total energy consumption	The total energy consumption in Norway in 2005 was of 225TWh. From this, about two thirds were used by stationary consumers. The net consumption of electricity was of 112 TWh in 2005. The stationary consumption of petroleum was of approximately 20TWh and the consumption of gas was of 6.6 TWh. The consumption of bioenergy was of 12.4 TWh and the production of heat in central heating plants was of 2.4 TWh. The average electricity consumption per capita was of 24.650 kWh/year in Norway, whereas the world average was of 2.516kWh/year.
Energy production from hydropower	The average production of electricity from hydropower is of approximately 120 TWh/year, but the production varies from year to year depending on the precipitation. Installed capacity of hydropower is 28,300 MW, distributed over 620 plants with a capacity of more than 1 MW. The world's total installed hydropower amounted to approximately 800GW in 2005.
Energy production from wind power	By the end of 2005, 280 MW of wind power had been installed in Norway. This gives a yearly production of 0.85 TWh, sufficient to supply 40,000 households. By 2004, 40,000 MW of wind power had been installed in the world, out of this 75% in Europe.
Energy production from solar cells	The average yearly insolation in Oslo is of 830 kWh/m2. With a cell of 15% efficiency, the yearly production would be of 125 kWh/m2. There are few solar installations connected to the grid in Norway. The largest solar power plant is installed on the roof of the Opera house in Oslo, this has a yearly production of approximately 20,000 kWh.

Source: OED Fakta 2006 om energi og vannressurser i Norge; IEA 2006 Key World Energy Statistics; IEA Photovoltaic Power Systems Programme

Energy Units

Power [W]	Energy per time unit [J/s] 1 TW = 1,000 GW = 1,000,000 MW = 1,000,000,000 W
Energy [kWh]	Kilowatt hour, one kilowatt produced or consumed over one hour. Example: A light bulb of 40W which is switched on for one hour, consumes 40Wh.
Energy [J]	Joule. One watt produced or consumed over one second. 1 kWh = 3,600,000 J = 3.6 MJ
Energy [BOE]	Barrel of oil equivalent. The chemical energy contained in one barrel of oil. 1 BOE = 6.1 GJ = 1.7 MWh
Prefixes	k = kilo = 1,000 M = mega = 1,000,000 G = giga = 1,000,000,000 T = tera = 1,000,000,000,000 P = peta = 1,000,000,000,000,000

Potential energy production in Norway

Wind energy	By 2020, a yearly production of 20 TWh from wind power is considered a realistic goal. To achieve 20 TWh/year, installation of approximately 7 GW of production capacity is necessary, where of a large share can be installed off shore.
Renewable heat and energy savings	The realistic and profitable potential for use of renewable heat and energy savings in constructions is evaluated to, respectively, 12 TWh/year and 10 TWh/year by 2020.
Hydropower	The remaining energy potential in rivers which are not preserved in Norway, amounts to about 41 TWh/year. Of this, the potential in small plants of less than 10 MW and within an investment limit of 0.35 €/kWh/year is evaluated to 25 TWh/year. Modernization and upgrading of existing plants could release a potential production of 10 TWh/year.
Bioenergy	The potential for increased utilization of biomass for energy purposes is evaluated to 15-30 TWh/year (mainly from wood).