EXECUTIVE SUMMARY

Introduction

At their 2005 Gleneagles Summit the Group of Eight (G8) leaders asked the IEA to provide advice on a clean, clever and competitive energy future, including a transformation of how we use energy in the industrial sector. This study was prepared in response to that request and a complementary request from the Energy Ministers of IEA countries. The primary objective of this analysis is to develop ways to assess the state of worldwide industrial energy efficiency today and estimate additional technical savings potential.

Nearly a third of the world's energy consumption and 36% of carbon dioxide (CO_2) emissions are attributable to manufacturing industries. The large primary materials industries – chemical, petrochemicals, iron and steel, cement, paper and pulp, and other minerals and metals – account for more than two-thirds of this amount. Overall, industry's use of energy has grown by 61% between 1971 and 2004, albeit with rapidly growing energy demand in developing countries and stagnating energy demand in OECD countries. However, this analysis shows that substantial opportunities to improve worldwide energy efficiency and reduce CO_2 emissions remain. Where, how and by how much? These are some of the questions this analysis tries to answer.

This is a pioneering global analysis of the efficiency with which energy is used in the manufacturing industry. It reveals how the adoption of advanced technologies already in commercial use could improve the performance of energy-intensive industries. It also shows how manufacturing industry as a whole could be made more efficient through systematic improvements to motor systems, including adjustable speed drives; and steam systems, including combined heat and power (CHP); and by recycling materials. The findings demonstrate that potential technical energy savings of 25 to 37 exajoules[1] per year are available based on proven technologies and best practices. This is equivalent to 600 to 900 million tonnes (Mt) of oil equivalent per year or one to one and a half times Japan's current energy consumption. These substantial savings potentials can also bring financial savings. Improved energy efficiency contributes positively to energy security and environmental protection and helps to achieve more sustainable economic development. The industrial CO_2 emissions reduction potential amounts to 1.9 to 3.2 gigatonnes per year, about 7 to 12% of today's global CO_2 emissions.

The estimates employ powerful statistical tools, called "indicators", which measure energy use based on physical production. This study sets out a new set of indicators that balance methodological rigour with data availability. These indicators provide a basis for documenting current energy use, analysing past trends, identifying technical improvement potentials, setting targets and better forecasting of future trends. The advantages of this approach include that these indicators:

1. One exajoule (EJ) equals 10^{18} joules or 23.9 Mtoe.

- are not influenced by price fluctuations, which facilitates trend analysis. In detail, these indicators provide a closer measure of energy efficiency.
- can be directly related to process operations and technology choice.
- allow a well-founded analysis of efficiency improvement potentials.

This study builds on other IEA work on energy indicators, a series of workshops and dialogue with experts from key industries, a comprehensive analysis of available data and an extensive review process. The IEA Implementing Agreement on Industrial Energy-Related Technologies and Systems and individual experts from around the world provided valuable input.

One important conclusion is that more work needs to be done to improve the quality of data and refine the analysis. Much better data is needed, particularly for iron and steel, chemicals and petrochemicals, and pulp and paper. This study is presented for discussion and as a prelude to future work by the IEA.

Key Trends

Overall, ***industrial energy use has been growing strongly*** in recent decades. The rate of growth varies significantly between sub-sectors. For example, chemicals and petrochemicals, which are the heaviest industrial energy users, doubled their energy and feedstock demand between 1971 and 2004, whereas energy consumption for iron and steel has been relatively stable.

Much of the ***growth in industrial energy demand has been in emerging economies.*** China alone accounts for about 80% of the growth in the last twenty-five years. Today, China is the world's largest producer of iron and steel, ammonia and cement.

Efficiency has improved substantially in all the energy-intensive manufacturing industries over the last twenty-five years in every region. This is not surprising. It reflects the adoption of cutting-edge technology in enterprises where energy is a major cost component. Generally, new manufacturing plants are more efficient than old ones. The observed trend towards larger plants is also usually positive for energy efficiency.

The concentration of industrial energy demand growth in emerging economies, where industrial energy efficiency is lower on average than in OECD countries means, however, that ***global average levels of energy efficiency in certain industries, e.g. cement, have declined less than the country averages*** over the past twenty-five years.

Broadly, it is the ***Asian OECD countries***, Japan and Korea, that ***have the highest levels of manufacturing industry energy efficiency***, followed by Europe and North America. This reflects differences in natural resource endowments, national circumstances, energy prices, average age of plant, and energy and environmental policy measures.

The ***energy and CO_2 intensities of emerging and transition economies show a mixed picture***. Where production has expanded, industry may be using new plant with the latest technology. For example, the most efficient aluminium smelters are in Africa and some of the most efficient cement kilns are in India. However, in some industries and regions where production levels have stalled, manufacturers have failed to upgrade to most efficient technology. For example, older equipment remains dominant in parts of the Russian Federation and Ukraine. The widespread use of coal in China reduces its energy efficiency, as coal is often a less efficient energy source than other fuels due to factors such as ash content and the need for gasification. In China and India, small-scale operations with relatively low efficiency continue to flourish, driven by transport constraints and local resource characteristics, *e.g.* poor coal and ore quality. The direct use of low grade coal with poor preparation is a major source of inefficiency in industrial processes in these countries.

Tracking Energy Efficiency

Basic industrial processes and products are more or less the same across the world. This enables the use of universal indicators. However, as usual, the devil is in the detail. Comparing the relative energy performance of industries around the world needs to consider that individual technologies, qualities of feed stocks and products are often different in various countries even for the same industry. In order to make proper comparisons, system boundaries and definitions need to be uniform. Indicators complement benchmarking, but they should not be used as a substitute. Industrial energy use indicators can serve as the basis for identifying promising areas by sub-sector, region and technology to improve efficiency. This is, for example, the case for the cement industry in China and industrial motor and steam systems worldwide, which this study shows to have significant potential for energy and/or CO_2 savings.

Reliable indicators require good data. Currently the data quality is often not clear, even those from official sources. As indicators may become the basis for policy decisions with far-reaching consequences, data gaps need to be filled and the quality of data needs to be regularly validated and continually improved.

In all countries, government and industry partnerships, incentives, and awareness programmes should be pursued to harvest the widespread opportunities for efficiency improvements. New plants and the retrofit and refurbishment of existing industrial facilities should be encouraged.

Small-scale manufacturing plants using outdated processes, low quality fuel and feedstock, and weaknesses in transport infrastructure contribute to industrial inefficiency in some emerging economies. Policies for ameliorating these problems should be strongly supported by international financial institutions, development assistance programmes and international CO_2 reduction incentives.

Energy and CO_2 Saving Potentials

This analysis estimates the technical energy and CO_2 savings available in energy-intensive industries worldwide. The ranges of potential savings on a primary energy basis are shown in Table 1 in two categories, either as "sectoral improvements", *e.g.* cement, or "systems/life cycle improvements", *e.g.* motors and more recycling. Improvement options in these two categories overlap somewhat. As well, system/life cycle options are more uncertain. Therefore, with the exception of motor systems,

Table 1 ▶ ***Savings from Adoption of Best Practice Commercial Technologies in Manufacturing Industries***

(Primary Energy Equivalents)

	Low – High Estimates of Technical Savings Potential			Total Energy & Feedstock Savings Potentials
	EJ/yr	*Mtoe/yr*	*Mt CO_2/yr*	*%*
Sectoral Improvements				
Chemicals/petrochemicals	5.0 – 6.5	120 – 155	370 – 470	13 – 16
Iron and steel	2.3 – 4.5	55 – 108	220 – 360	9 – 18
Cement	2.5 – 3.0	60 – 72	480 – 520	28 – 33
Pulp and paper	1.3 – 1.5	31 – 36	52 – 105	15 – 18
Aluminium	0.3 – 0.4	7 – 10	20 – 30	6 – 8
Other non-metallic metals minerals and non-ferrous	0.5 – 1.0	12 – 24	40 – 70	13 – 25
System/life cycle Improvements				
Motor systems	6 – 8	143 – 191	340 – 750	
Combined heat and power	2 – 3	48 – 72	110 – 170	
Steam systems	1.5 – 2.5	36 – 60	110 – 180	
Process integration	1 – 2.5	24 – 60	70 – 180	
Increased recycling	1.5 – 2.5	36 – 60	80 – 210	
Energy recovery	1.5 – 2.3	36 – 55	80 – 190	
Total	**25 – 37**	**600 – 900**	**1 900 – 3 200**	
Global improvement potential – share of industrial energy use and CO_2 emissions	**18 – 26%**	**18 – 26%**	**19 – 32%**	
Global improvement potential – share of total energy use and CO_2 emissions	**5.4 – 8.0%**	**5.4 – 8.0%**	**7.4 – 12.4%**	

Note: Data are compared to reference year 2004. Only 50% of the estimated potential system/life cycle improvements have been credited except for motor systems. The global improvement potential includes only energy and process CO_2 emissions; deforestation is excluded from total CO_2 emissions. Sectoral savings exclude recycling, energy recovery and CHP.

only 50% of the potential system/life cycle improvements have been credited for the total industrial sector improvement potential shown in Table 1. The conclusion is that manufacturing industry can improve its energy efficiency by an impressive 18 to 26%, while reducing the sector's CO_2 emissions by 19 to 32%, based on proven technology. Identified improvement options can contribute 7 to 12% reduction in global energy and process-related CO_2 emissions.

The single most important category is motor systems, followed by chemicals/petrochemicals on an energy savings basis. The highest range of potential sectoral savings for CO_2 emissions is in cement manufacturing. The savings potential under the heading "system/life cycle improvements" is larger than the individual sub-sectors in part because those options apply to all industries. Another reason is that these options have so far received less attention than the process improvements in the energy-intensive industries. Generally, these are profitable opportunities, though they are often overlooked, particularly in the parts of manufacturing where energy is not a main operating cost.

The estimated savings based on a comparison of best country averages with world averages, or best practice and world averages. They do not consider new technologies that are not yet widely applied. Also they do not consider options such as CO_2 capture and storage and large-scale fuel switching. Therefore, these should be considered lower range estimates of the technical potential for energy savings and CO_2 emissions reductions in the manufacturing industry sector. These estimates do not consider the age profile of the capital stock, nor regional differences in energy prices and regulations that may limit the short- and medium-term improvement options. The economic potentials are substantially lower than the technical estimates. Moreover, technology transfer to developing countries is a major challenge. Yet the sheer magnitude of the savings opportunties indicates that more effort is warranted.

Some of these savings will occur outside the manufacturing industry sector. For example, CHP will increase the efficiency in power generation. Energy recovery from waste will reduce the need to use fossil energy for power or heat generation. Increased recycling of paper leaves more wood that can be used for various bioenergy applications. Therefore, these savings estimates are not suited to set targets for sectoral energy use due to the dynamic interaction between sectors.

About 10% of the direct and indirect industrial CO_2 emissions are process-related emissions that are not due to fossil energy use. These CO_2 emissions would not be affected by energy efficiency measures. Another distinguishing feature of the manufacturing sector is that carbon and energy are stored in materials and products, *e.g.* plastics. Recycling and energy recovery make good use of stored energy and reduce CO_2 emissions, if done properly. Currently, these practices are not applied to their full extent.

Sectoral Results

Chemical and Petrochemical

- ▷ The chemical and petrochemical industry accounts for 30% of global industrial energy use and 16% of direct CO_2 emissions. More than half of the energy demand is for feedstock use, which can not be reduced through energy efficiency measures. Significant amounts of carbon are stored in the manufactured products.

- An indicator methodology that compares theoretical energy consumption using best available technology with actual energy use suggests a 13 to 16% improved energy efficiency potential for energy and feedstock use (excluding electricity). The potential is somewhat higher in countries where older capital stock predominates. The indicator results suggest problems with the energy and feedstock data for certain countries.
- The regional averages for steam crackers suggest a 30% difference in energy use between the best (East Asia) and worst (North America). Feedstock use dominates energy use in steam crackers, which can not be reduced through energy efficiency measures.
- Benchmarking studies suggest that potential energy efficiency improvements for olefins and aromatics range from 10% for polyvinyl chloride to 40% for various types of polypropylene.
- About 1 exajoule (EJ) per year (20%) would be saved if best available technology were applied in ammonia production. Coal-based production in China requires considerably more energy than gas-based production elsewhere.
- In final energy terms, the savings potential ranges from 5 to 11 EJ per year, including process energy efficiency, electric systems, recycling, energy recovery from waste and CHP.

Iron and Steel

- The iron and steel industry accounts for about 19% of final energy use and about a quarter of direct CO_2 emissions from the industry sector. The CO_2 relevance is high due to a large share of coal in the energy mix.
- The iron and steel industry has achieved significant efficiency improvements in the past twenty-five years. Increased recycling and higher efficiency of energy and materials use have played an important role in this positive development.
- Iron and steel has a complex industrial structure, but only a limited number of processes are applied worldwide. A large share of the differences in energy intensities and CO_2 emissions on a plant and country level are explained by variations in the quality of the resources that are used and the cost of energy.
- The efficiency of a plant in the iron and steel industry is closely linked to several elements including technology, plant size and quality of raw materials. This partly explains why the average efficiency of the iron and steel industries in China, India, Ukraine and the Russian Federation are lower than those in OECD countries. These four countries account for nearly half of global iron production and more than half of global CO_2 emissions from iron and steel production. Outdated technologies such as open hearth furnaces are still in use in Ukraine and Russia. In India, new, but energy inefficient, technologies such as coal-based direct reduced iron production play an important role. These technologies can take advantage of the local low-quality resources and can be developed on a small scale, but they carry a heavy environmental burden. In China, low energy efficiency is mainly due to a high share of small-scale blast furnaces, limited or inefficient use of residual gases and low quality ore.

- Waste energy recovery in the iron and steel industry tends to be more prevalent in countries with high energy prices, where the waste heat is used for power generation. This includes technology options such as coke dry quenching (CDQ) and top-pressure turbines. CDQ also improves the coke quality, compared to conventional wet quenching technology.
- The identified primary energy savings potential is about 2.3 to 2.9 EJ per year through energy efficiency improvements, *e.g.* in blast furnace systems and use of best available technology. Other options, for which only qualitative data are available, and the complete recovery of used steel can raise the potential to about 5 EJ per year. The full range of CO_2 emissions reductions is estimated to be 220 to 360 Mt CO_2 per year.

Cement

- The non-metallic mineral sub-sector accounts for about 9% of global industrial energy use, of which 70 to 80% is used in cement production.
- The average primary energy intensity for cement production ranges from 3.4 to 5.3 gigajoules per tonne (GJ/t) across countries with a weighted average of 4.4 GJ/t. Averages at a country level have improved everywhere, with the weighted average primary energy intensity declining from 4.8 GJ/t in 1994 to 4.4 GJ/t in 2003. Much of this decline has been driven by improvements in China, which produces about 47% of the world's cement.
- The efficiency of cement production is relatively low in countries with old capital stock based on wet kilns and in countries with a significant share of small-scale vertical kilns.
- In primary energy terms, the savings potential ranges from 2.5 to 3 EJ per year, which equals 28 to 33% of total energy use in this industry sector.
- Cement production is an important source of CO_2 emissions, accounting for 1.8 Gt CO_2 in 2005. Half of cement process CO_2 emissions are due to the chemical reaction in cement clinker production. These process emissions are not affected by energy efficiency measures. Yet it might be possible to reduce clinker production by 300 Mt with more extensive use of clinker substitutes which could reduce CO_2 emissions by about 240 Mt CO_2 per year. Therefore the CO_2 reduction potential could be higher than the energy saving potential.
- The average CO_2 intensity ranges from 0.65 to 0.92 tonne of CO_2 per tonne of cement across countries with a weighted average 0.83 t CO_2/t. The global average CO_2 intensity in cement production declined by 1% per year between 1994 and 2003.

Pulp, Paper and Printing

- The pulp, paper and printing industry accounts for about 5.7% of global industrial final energy use, of which printing is a very small share. Pulp and paper production generates about half of its own energy needs from biomass residues and makes extensive use of CHP.
- Among the key producing countries examined, the heat consumption efficiency in the pulp and paper sub-sector has improved by 9 percentage points from

1990 to 2003. This is a notable improvement, while an additional 14% improvement potential exists when a comparison with best available technology is made.

- This analysis shows relatively little change in the overall energy efficiency of electricity consumption in pulp and paper manufacturing. The weighted average efficiency of electricity use has improved by three percentage points from 1990 to 2003. There is an additional 16% improvement potential based on a comparison with best available technology.
- Increased recycled paper use in many countries could help reduce energy consumption. While Western Europe appears to be close to its practical limit for paper recycling, other parts of the world, *e.g.* North America and parts of Asia, could benefit from more effective policies on waste disposal to encourage higher rates of recycling.
- CO_2 reduction potentials in the pulp and paper industry are limited due to the high use of biomass. However, the more efficient use of biomass still makes sense from an energy systems perspective, as it frees up scarce wood resources which could provide savings elsewhere.
- In primary energy terms, the savings potential ranges from 1.3 to 1.5 EJ per year, which equals 15 to 18% of total energy use in this sub-sector.

Aluminium

- Aluminium production is electricity intensive. Global average electricity use for primary aluminium production is 15 300 kWh per tonne (kWh/t). This average has declined about 0.4% per year over the last twenty-five years. On a regional basis, the averages range from 14 300 kWh/t in Africa to 15 600 kWh/t in North America. Africa is the most efficient region due to new production facilities. New smelters tend to be based on the latest technology and energy efficiency is a key consideration in smelter development.
- The regional average energy use for alumina production ranges from 10 to 12.6 GJ/t.
- With existing technology, energy use in the key steps of aluminium production can be reduced by 6 to 8% compared with current best practice, which equals 0.3 to 0.4 EJ per year in primary energy equivalents.

Other Non-Metallic Minerals and Other Non-Ferrous Metals

- This category includes a wide range of products such as copper, lime, bricks, tiles and glass.
- The resource quality and the product quality is very diverse. This complicates a cross-country comparison. However, the available data suggests that important efficiency potentials remain based on options such as waste heat recovery.
- In primary energy terms, the savings potential ranges from 0.5 to 1 EJ per year. This equals approximately 13 to 25% of total energy use in these sub-sectors.

Systems Optimisation

- ▷ Based on hundreds of case studies across many countries, it is estimated that the improved efficiency potential for motor systems is 20 to 25% and 10 to 15% for steam systems. This is 6 to 8 EJ savings in primary energy per year in motor systems and 3 to 5 EJ in steam systems. Process integration could save an additional 2 to 5 EJ.
- ▷ Combined heat and power (CHP) is a proven industrial energy efficiency measure. Globally, CHP generates about 10% of all electricity today, resulting in estimated energy savings of more than 5 EJ annually. Up to 5 EJ of primary energy savings potential remain for CHP in manufacturing, equal to 3 to 4% of global industrial energy use.
- ▷ These systems options overlap and compete with the other sectoral options and the life cycle options. This interaction must be considered if the total industry potential is to be accurately estimated.

Life Cycle Optimisation

- ▷ Industrial energy use is different from other end-use sectors, because important quantities of energy and carbon are stored in the products. Therefore, it is particularly important to consider efficiency improvement options on a life-cycle basis including recycling, energy recovery and the efficiency of materials use.
- ▷ Countries differ vastly in their levels of recycling and energy recovery from waste materials. Substantial amounts of waste materials are land filled. Untapped global recycling potential and energy recovery potential are each in the range of 3 to 5 EJ per year. Better materials/product efficiency and waste management could cut some 0.3 to 0.8 gigatonne of CO_2 emissions per year.
- ▷ Life cycle optimisation competes with the other options and this reduces the potential for the total industry sector.

Next Steps

This study is a first attempt to provide a reliable and meaningful set of global indicators of energy efficiency and CO_2 emissions in the manufacturing industrial sector. They will be useful for industries, governments and others to improve forecasting of industrial energy use; to provide a realistic basis for target setting and effective regulation; and to identify sectors and regions for more focused analysis of improvement potentials.

This study needs to be followed by more work, as further improvements are possible. Future studies could be more meaningful for the benefit of all parties, including industry itself, if sensitivity and confidentiality issues could be overcome to allow a more detailed, complete, timely, reliable and open database to be developed. Policy makers, industry, analysts and others are calling for more reliable estimates of energy savings and CO_2 emission reductions potentials. This can only be achieved if accurate and complete energy use and efficiency data are available for the analysis of future potential based on best practices to pave the way for adoption of state-of-the-art technologies.

The methodology used here, which is often constrained by data limitations, can be improved. Feedback will be an important component of making future analysis more effective. However, an improved methodology will be more beneficial only if companies and countries make a concerted parallel effort to improve the quality and availability of the manufacturing industry energy data.

Apart from the improvement of the indicators analysis, future work will focus on assessing the potential of new technologies and analysing the integrated reduction potential by running scenarios that assess the economic potential of different technologies given current energy efficiencies and technology use. This work is expected in the first half of 2008.

Indicator and Data Issues

In most energy-intensive industrial sub-sectors, ten to twenty countries account for 80 to 90% of global production and CO_2 emissions from manufacturing. These are the countries where further analysis should focus initially.

There is not a single "true" indicator of energy and CO_2 intensity for an industry. In general, a number of indicators should be used to give an adequate picture of both energy and CO_2 intensity levels of a particular industry in a country. System boundary and allocation issues are very important in the design of indicators and other performance measures for comparative purposes. For example, the allocation of upstream emissions, particularly for power generation, and downstream energy recovery benefits is an element that can affect performance significantly. If indicators are used for policy purposes, the boundaries and allocations may affect industry operating practices. Some choices may favour behaviour that reduce plant-specific CO_2 emissions but increase emissions elsewhere. Examples include if energy intensive parts of the production are outsourced, or higher quality resources are used such as a switch from iron ore to steel scrap in steel production. Indicator development for all industry sectors should be co-ordinated in order to avoid double counting and omissions or perverse incentives.

Product categories are of key importance. Various products in a single category may require considerably different amounts of energy for their production, *e.g.* a coarse versus highly-refined paper. If the product mix within a category varies within or across countries, it will affect the indicator performance measurement in comparisons.

In this study, indicators are developed on a country level. They do not account for variations in plant performance within a country. Therefore, benchmarking and/or auditing activities are needed to complement the indicators approach to better understand energy use in industry.

Some governments have successfully used international benchmarking approaches for industrial energy efficiency targets, *e.g.* Belgium and the Netherlands. Detailed energy benchmarking studies are done on a regular basis in some industries, based on data provided by companies that operate plants. These studies are usually done on a global basis and individual plants are not identified for antitrust reasons.

Usually, these studies are confidential and the benchmarking activities are often limited to the main producers in industrialised countries. This can create a bias in favour of the more efficient plants, which overestimates the industry's average energy efficiency. Benchmarking generally focuses on plants based on the same industrial process and similar product quality. Benchmarking is therefore not suited to evaluate some improvement options such as process integration, feedstock substitution, recycling or energy recovery from waste materials. The same caveats apply for benchmarking and for indicators: the results are influenced by methodological choices. Important efforts are continuing in many industries to expand and improve international benchmarking.

Energy data availability poses a major constraint for developing meaningful indicators. The industrial sub-sector data that countries report to the IEA are not sufficiently detailed to allow country comparisons of physical indicators at a level of relevant comparable physical products. Therefore, other data sources must be used.

The study therefore builds on various sources of data collected through a network of contacts in countries and industries. However, one of the clear outcomes of the study is that more work needs to be done to improve the quality of the data and refine the analysis. In many cases, data are either not available due to a lack of structure or interest and commitment in collecting the data or for confidentiality reasons.

New government and industry co-operation schemes are evolving. For example, the Asia-Pacific Partnership plans to collect additional data on a plant level for iron and steel, cement and aluminium for its six participating countries. Confidentiality rules will apply. It is recommended that such efforts be co-ordinated.

Data on the level of on-site process integration and combined heat and power are lacking, and energy efficiency performance data for actual motor and steam systems are almost non-existent. It is recommended to strengthen the data collection system for such key energy saving options and develop suitable indicators, since a large body of case studies suggests important improvement potentials based on these existing technologies.

In cases where energy use data are lacking, technology data can serve to estimate energy efficiency. Unfortunately, such data are usually not available from government statistics. Capital stock vintage data also can help to determine efficiencies and potential improvements, but such data are scarce and incomplete. In some cases, engineering companies and consultancies that serve the sector have such data, but access is restricted. It should be noted that technology use data can be misleading, for example in situations where operational practices and process integration can have an important impact on the overall industry performance.

Care should be taken when data of different quality are mixed for country comparisons. The quality of data is not always evident. If data are to be used for international agreements, a monitoring and verification system will be needed.