Global Industrial Energy Efficiency Benchmarking

An Energy Policy Tool

Working Paper

November 2010

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

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ABBREVIATIONS

The following abbreviations and acronyms appear in this document.

APP	Asia Pacific Partnership
BAT	Best Available Technology
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BPT	Best Practice Technology
CCS	Carbon Capture and Storage
CEC	Capital and Energy Costs
CHP	Combined Heat and Power
CSI	Cement Sustainability Initiative
DC	Developing Countries
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EC	European Commission
EEI	Energy Efficiency Index
EFTA	European Free Trade Association
EIT	Economies In Transition
EJ	Exajoule
EU	European Union
EU-ETS	European Union Emission Trading Scheme
FAOSTAT	Statistics Department of the Food and Agriculture Organization
GEA	Global Energy Assessment
GHG	Greenhouse gas
GJ	Gigajoule
GNR	Getting the Numbers Right
HVC	High Value Chemicals
IAI	International Aluminium Institute
IC	Industrialized Countries
IEA	International Energy Agency

IFA	International Fertilizer Industry Association
IIASA	International Institute for Applied Systems Analysis
IPTS	Institute for Prospective Technology Studies
ISIC	International Standard Industrial Classification
ITMF	International Textile Manufacturers Federation
MENA	Middle East and North Africa
MER	Market Exchange Rate
MI	Methanol Institute
OE	Open-end Spinning
OECD	Organization for Economic Co-operation and Development
PJ	Petajoule
PSI	Plant Survey International
SA	South America
SEC	Spefic Energy Consumption
SME	Small and Medium Sized Enterprises
UNIDO	United Nations Industrial Development Organization
UNSD	United Nations Statistics Division
VSBK	Vertical Shaft Brick Kiln
WSA	World Steel Association

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EXECUTIVE SUMMARY

Worldwide, manufacturing industry accounted for a total final energy use of 127 Exajoules (EJ) in 2007[1]. This is equivalent to one third of the total final energy consumption of the global economy[2].

Developing countries and the economies in transition account for 60% of industry's total final energy consumption. Industry has significantly improved its energy efficiency in recent decades. But industry's total energy use continues to grow as a result of continuing large increases in the volume of production. Production is expected to continue to expand very substantially in the coming decades, particularly in developing countries. As a result, modest energy efficiency improvement rates will not be sufficient to stabilise or decrease the sector's energy demand in absolute terms. In order to make significant reductions, ambitious energy savings measures need to be implemented.

As a first step, the wider adoption of Best Practice Technologies (BPT) would enable significant reductions in energy use in the short term. In this study, we assess the energy saving potential that could be realised by the wide scale implementation of BPT in number of industry sectors. For each sector, we analyse the worldwide improvement potential, distinguishing industrialised countries from developing countries and the economies in transition.

Benchmarking the energy use of manufacturing industry

International benchmarks, based on the energy use of BPTs, are estimated for a total of 26 industrial processes, products and industry sectors. These processes include the energy-intensive sectors such as the iron and steel, and chemical and petrochemical sectors, as well as number of light industries and small-scale sectors such as foundries and lime kilns. The total energy used by these processes represents approximately 60% of industry's current final energy use.

For a number of sectors, for example for steam crackers and aluminium smelters, *international benchmarks* are estimated from energy benchmark curves which are based on actual company data. For those sectors for which benchmark surveys do not exist, the report develops and compares energy indicators in different regions to provide an estimate for an international benchmark. Energy indicators are estimated based on literature data, i.e. production statistics and international energy statistics, and country-level comparisons are based either on an Energy Efficiency Index (EEI) or on an average of current levels of Specific Energy Consumption (SEC).

[1] Including petroleum feedstocks consumed for petrochemicals production.
[2] Including total non-energy used in industry, transformation, energy, transport and other sectors.

The analysis shows the existence of a worldwide potential to save 31 EJ a year if all the processes reviewed were to operate at the level of the international benchmark. Excluding feedstock use, this is equivalent to a worldwide improvement potential of 26%, comprising a 15% to 20% potential improvement in industrialised countries and a potential improvement of 30% to 35% in developing countries and economies in transition. The potential saving varies sector by sector. The percentage improvement potentials are less than the worldwide average for energy-intensive processes and sectors, although most light industry processes show higher improvement potentials.

Both Best Practice Technologies (BPT) and Best Available Technologies (BAT) offer potentials in the short- and medium-term

The future energy use of the worldwide manufacturing industry is projected to 2030 based on energy efficiency scenarios. Industry's total final energy use is projected to increase from 106 EJ[3] in 2007 to 172 EJ in 2030 in a scenario which envisages no further improvements in efficiency or to 136 EJ in 2030 in a baseline scenario which envisages an improvement rate of 1% a year. If all industrial processes were to reach the BPT level by 2030, industry's total final energy use would be only slightly lower than the baseline at 128 EJ. Still further savings would be achieved by adopting Best Available Technologies (BAT)[4]. These are some 5% to 15% more efficient than BPT. With BAT, industrial energy use would amount to 114 EJ in 2030. Newer technologies which are not yet developed could potentially offer even higher improvement rates and therefore result in a more significant level of energy and CO_2 emissions reductions.

Regional differences in achieved levels of energy efficiency

The work underpinning this report has attempted to gain a better understanding of the differences in energy efficiency in different parts of the world. The assumption that low energy prices will lead to higher SEC and vice versa has been tested. It has been found to hold only for a few sectors, for example partly for steam cracking. Higher SEC is a result of factors other than energy prices only. For example, the high capital cost of new technologies is found possibly to be holding companies back from investing in more efficient and newer technologies, particularly where economic instability raises interest rates.

Next steps for benchmarking industry's energy use

This study demonstrates the value of benchmarking as a basis from which to estimate improvement potentials and to provide valuable information on industrial energy use. However, the data used are subject to a number of uncertainties and need further refinement.

The following steps are needed to maximise the potential of benchmarks and Energy Indicators as tools for measuring industry's energy use performance:

- Regional coverage of the benchmark surveys is incomplete. Data need to be collected for those sectors for which no information is currently available, particularly in developing countries and economies in transition.
- Benchmarking surveys need to be extended. They need to cover more processes in the

[3] Excluding petroleum feedstocks used for petrochemicals production.
[4] See Section 2 for the definitions of BPT and BAT as used in this paper. The definitions used in this paper, however, may not be consistent with the BAT definition stated in the European Union Directive 96/61/EC which concerns the Integrated Pollution Prevention and Control (IPPC) (EC, 2008).

energy-intensive sectors. And they need to secure better coverage of the most important processes in light industries and small-scale clusters, most of which are made up of small and medium size enterprises. Understanding the energy use of these smaller scale industries is particularly important since they have relatively large improvement potentials in percentage terms.

- Calibration of the benchmark curves is needed to support the refinement of the international benchmark data. For an objective comparison between countries, local conditions, for example reflecting regional differences such as the availability and quality of raw materials and feedstocks, need to be accounted for. Plants currently in operation do not have control over such conditions which may constrain their ability to achieve the level of efficiency envisaged by the international benchmarks.
- More insight needs to be gained in the sectors which have not yet been analysed or where the analysis was limited to a few SEC data points only. These sectors include food and beverages, machinery, transport equipment, metals processing, construction, and leather, many of which are also large energy consumers. Most of these sectors create important value added in developing countries.
- International energy statistics, which are the basis of the EEI approach, are subject to uncertainties. Closer collaboration is required between energy experts in companies and international statistics offices for improving the quality of international energy statistics.
- A dedicated effort is required in developing countries, where industry sectors need to be informed about the importance of efficient energy use and encouraged to implement measures to enable more effective energy management and monitoring.

Key findings

- The bulk of industrial energy use is accounted for by the production of a relatively small number of energy intensive commodities. Chemicals and petrochemicals and the iron and steel sector account for approximately half of all industrial energy used worldwide. Other sectors that account for a significant share of industrial energy use are non-ferrous metals, non-metallic minerals and the pulp and paper sector.
- SEC differs significantly between countries and sectors as a result of differences in resource availability, energy prices, plant size, the age of capital stock, local factors, capital costs, awareness, opportunity costs and government policies.
- The benchmarking of the industry sector's energy use can provide valuable insights regarding energy efficiency potentials. Based on BPT data, global improvement potentials, and those for countries and regions are estimated. EEIs can supplement the benchmark surveys. They can also be used to support the estimation of improvement potentials for sectors where benchmark data are not available.
- Based on benchmark data, the current energy saving potential in manufacturing industry and petroleum refineries is estimated to be 31 EJ. This is equivalent to an energy efficiency improvement potential of approximately 26% of the industry's current total final industrial energy demand worldwide[5]. Around a quarter of the total energy saving potential (8 EJ to 9 EJ a year) is located in the industrialised countries; three-quarters of the saving

[5] Excluding petroleum feedstocks used for petrochemicals production, but including the energy use of petroleum refineries.

potential (24 EJ to 25 EJ a year) is in developing countries and the economies in transition.

- Approximately two-thirds of the total savings potential is in the most energy-intensive industrial sectors although the energy efficiency potential is lower in percentage terms in these sectors than in the non-energy intensive sectors and light industries.
- Realising these potential energy savings would result in a reduction of 3% to 4% in the total costs of production. Worldwide, the total current energy cost savings potential in industry is estimated to be around USD 230 billion a year (excluding the cost of the investments required to upgrade current levels of technology to BPT). Industrialised countries have the potential to save around USD 65 billion in energy costs. Developing countries and economies in transition have the potential to save around USD 165 billion, i.e. more than 70% of the global potential cost savings. These savings are equivalent to 2% of current industrial value added worldwide.
- Achieving BPT by 2030 would result in manufacturing industry using 162 EJ of final energy. Excluding feedstocks, this would represent an improvement of 1.2% per year in energy efficiency between 2007 and 2030. The total energy use would be 26% lower than it would be in the absence of any energy efficiency improvements.
- Implementing Best Available Technology (BAT) offers potential energy savings of up to 34% by 2030, equivalent to an energy efficiency improvement rate of 1.7% a year. Total final energy use with BAT is estimated to be 149 EJ in 2030.
- Excluding the cost of investment to upgrade existing technologies, the implementation of BPT is estimated to offer the potential to save USD 365 billion in energy costs in 2030. The implementation of BAT would offer the potential to save USD 495 billion in energy costs in 2030.
- The drivers of energy efficiency differ from country to country and from industry to industry. In some sectors, energy efficiency is partly driven by high energy prices. But in some other sectors, the high capital cost of investment in new and efficient plants is a major limitation on the rate of efficiency improvement in industry. This is particularly the case in countries where the economy is unstable, and where interest rates are high.

1. INTRODUCTION

Industrial energy use is dominated by developing countries and economies in transition, and this dominance will increase further in the coming decades

In 2007, the industry sector worldwide used approximately 127 exajoules (EJ) of final energy[6], accounting for more than one-third of global final energy use. OECD countries (generally industrialised and high-income countries, abbreviated as "IC" in this report) accounted for approximately 51 EJ, i.e. around 40% of industrial final energy use worldwide **(Figure 1)**. The remaining 76 EJ is consumed in non-OECD countries, the majority of which are developing countries and economies in transition (together abbreviated as "DC" in this report). In some manufacturing sectors such as iron and steel and non-metallic minerals industries, a larger share of energy is consumed in DCs than in ICs. In 2007, the industry spent more than USD 1 trillion on final energy (in market exchange rate (MER) terms) to produce a global value added of approximately USD 8 trillion (for 2007) (for ISIC: 15-37) (MER; World Bank, 2009) giving an average energy intensity of about 9%. Energy costs as a proportion of production costs vary significantly between different end-products, amounting to as much as 80% of ammonia production costs and between 1% and 10 % in yarn making and the machinery sector.

The bulk of industrial energy use is accounted for by the production of a small number of energy intensive commodities

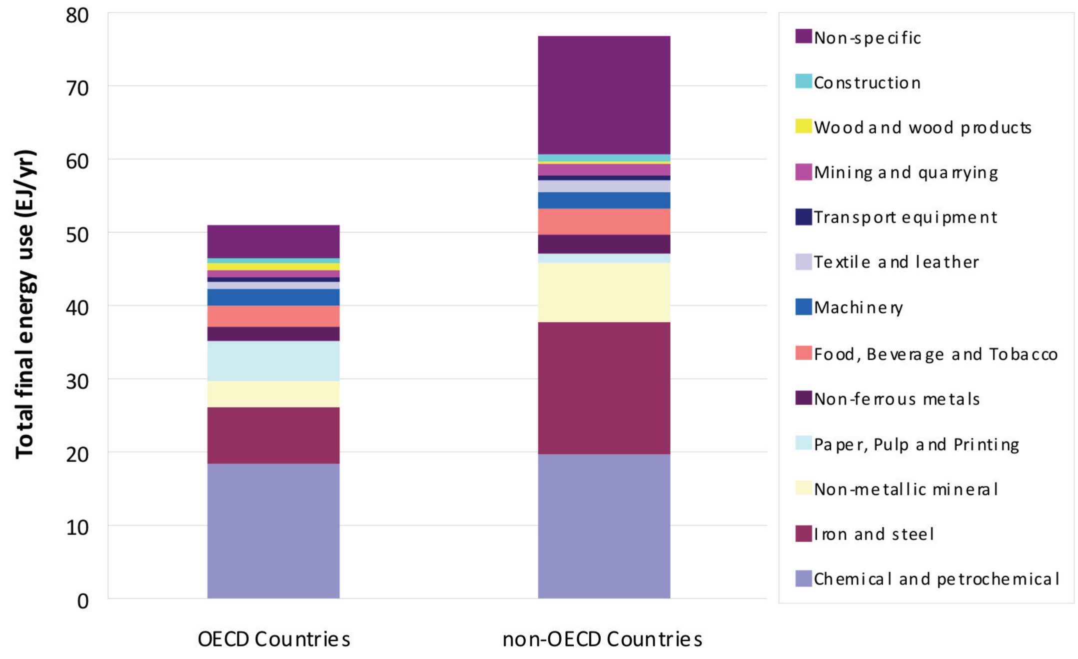
Energy-intensive sectors, especially the chemical and petrochemical sector and the iron and steel sector, dominate industrial energy demand in both ICs and DCs. They account for approximately 50% of the total final industrial energy use **(Figure 1)**.

From 1971 to 2007, the final energy demand of manufacturing industry in DCs more than doubled, growing by an average of 3.2% a year. In ICs over the same period, it practically remained constant or increased only slightly (IEA, 2009a, b). Global industrial energy use is projected to double by 2050 in the absence of any new policy measures, and to increase by at least 50% by 2050 compared to today's levels even with the most ambitious emissions reduction policy changes (IEA, 2009c).

DCs dominate global industrial energy use for a number of reasons. First, they tend to move along a fairly traditional path of economic development, which proceeds from agriculture to industry and then to the service industries. This path is driven by consumer preferences, first for food and housing, and then as people become wealthier, later on for leisure and health care.

[6] Including petroleum feedstocks for petrochemicals. Final energy use is derived from the total quantity of energy commodities (e.g. fuels, electricity, steam) delivered to consumers for their principal economic activity, excluding fuel conversion or transformation activities as defined elsewhere in the energy balances.

FIGURE 1:
Sectoral breakdown of total final industrial energy use in OECD and non-OECD countries, 2007



Note: Data includes feedstock use for petrochemicals, coke ovens and blast furnaces. It excludes petroleum refineries' energy use which is reported under the transformation and energy sector in IEA's energy statistics.

In IEA energy statistics, ideally data are provided (according to International Standard Industrial Classification (ISIC) of All Economic Activities, Rev.3.1; UNSD, 2010) for all manufacturing industry Divisions (i.e. 13-37), except for Divisions 23, 25, 33, 36 and 36. Division 23 is reported under the *own use* item of the transformation and energy sector. The other ISIC Divisions are reported under the *non-specific* item of the industry sector. However, some countries, particularly those outside the OECD, deviate from this reporting approach. In these countries, a share of the energy use or the entire energy demand of an industry sector, despite the availability of a specific item in IEA energy statistics, is reported to the *non-specific* item (see further detailed discussion in the main text).

Source: IEA, 2009a, b

Economic development and growth requires materials-intensive infrastructure and buildings, which in turn require massive amounts of cement, steel and other building materials. This pattern of development has, for example, been very clearly seen in China in recent decades.

Second, DCs account for 80% of the global population. As these countries reach industrialisation levels similar to those of the industrialised world this will inevitably mean much higher absolute levels of industrial energy use in the DCs compared to the ICs. Energy intensive industries are fairly evenly distributed around the world. This reflects the relative and often counterbalancing competitive advantages that result from specialisation, from countries with cheap energy sources attracting more energy intensive industry, and from locating industrial activity close to markets. As a result, large volumes of energy intensive materials are exported from DCs to ICs in the form of commodities and semi-finished as well as finished products, and it is expected that this activity will continue (Davis and Caldeira, 2010).

A number of factors influence differences in energy efficiency and energy intensity between countries

Energy intensities are expressed in terms of energy use per monetary unit, such as per unit of value added. The energy intensity of different end-products and sectors differs enormously. The energy intensity of similar products and products also differs very substantially between countries. A range of factors can play a role in these differences, depending on the product, sector, and country:

- **Access to resources** For many energy intensive products such as steel, cement and aluminium, access to resources and the quality of raw materials and feedstock play a key role in the energy intensity of production. For example, the production of steel from steel recycling requires worldwide 8 gigajoules (GJ) per tonne of steel, less than half the 20.6 GJ per tonne of steel that is needed for production from iron ore (Worrell et al., 2007). But the amount of scrap available for recycling is limited, and depends particularly on levels of past consumption years or even decades previously. In DCs where demand grows rapidly, the availability of scrap lags behind steel demand. As a consequence the share of steel production from virgin iron ore is much higher in DCs than in ICs, resulting in a higher level of average energy demand per tonne of steel produced. Similarly, Indian aluminium refineries are at a disadvantage with respect to energy use because local supplies of bauxite, from which the aluminium is produced, have a high share of calcium in their ore which requires larger amounts of process energy for conversion than other ores.
- **Energy prices** Where local energy supplies are relatively cheap, there is little incentive to industry to reduce its energy use. This effect is evident in major fossil-fuel producing countries such as Iran, Russia, Saudi Arabia and South Africa.
- **Plant size and age of capital stock** Older plants tend to be smaller. Smaller plants are generally less efficient. Older plants also tend to employ less efficient technologies. Investment in new plants and more efficient technologies is often not economic because the marginal production costs from existing capital stock are much smaller than they would be from new plant that was required to amortise its investment cost. For example, outdated, inefficient plants have remained in production in countries such as Russia because the capital stock invested in the times of the Former Soviet Union, which was in any case designed for much higher volumes than current production levels, has remained functional. Fortunately, the counterpart to this phenomenon is that the major growth in demand that is expected in DCs is likely to be met largely from new investment which will tend to be in new, more efficient, plant.
- **Local factors** Equipment import policies, local suppliers' strategies and limited available expertise can act as barriers for the uptake of more energy-efficient technologies. For example, many industrial plants in Russia base their operations on Russian-produced motors. These motors are relatively cheap, but they are not able to match the efficiency and quality of imported motors.
- **Capital cost** Energy efficient equipment tends to be more expensive. Many energy efficiency improvements rely on investment, the cost of which has to be recovered over time. High interest rates for capital tend to decrease investment in energy efficiency. For example

in the Ukraine, interest rates on local currency loans have reached a level of 40% in recent years. This is bound to be a significant disincentive to companies wishing to invest in energy saving measures.

- **Awareness and opportunity cost**
  In many economies, capital availability is limited, particularly in DCs. Management must choose how to use the limited capital either for capacity expansion or for investing in increasing energy and material efficiency. In many cases, expansion will be a priority since additional output will generate more revenue then efficiency improvements. Companies also often lack a good understanding of their energy use, their energy saving opportunities and the related economics. Government policies such as voluntary agreements, white certificates and energy efficiency tax incentives can help to increase awareness and encourage steps to improve energy management in companies. UNIDO is especially focusing on supporting the development of Energy Management Standards and benchmarking which can serve a similar purpose.
- **Government policies** National governments or transnational bodies such as European Commission (EC) design and apply energy and climate policies. Some of these policies directly or indirectly concern industrial energy use. Cap and trade schemes such as the European Union Emission Trading Scheme (EU-ETS), long term business-to-government commitments such as the voluntary benchmarking covenants used in the Netherlands, and fiscal instruments such as tax incentives and subsidy schemes for energy efficiency measures can all play a part in helping to drive improvements in energy efficiency and reductions in greenhouse gas (GHG) emissions. Industries in regions with relatively lax or ineffective policy environments may be less energy efficient.

Benchmark data can provide valuable insights regarding energy efficiency potentials

In recent years, in response to the need to establish national CO_2 reduction targets, substantial effort has been directed at the analysis of sectoral energy efficiency potentials at national level. The credibility of such efforts is questionable since data for individual plants or sectors in individual countries were often unavailable. Data collection, availability and coverage all need to be improved in many countries. Benchmarking and indicators analysis have an important part to play in this process.

Benchmarking is used to compare the performance of individual plants with the most energy efficient plant(s) on a sector-by-sector basis. Energy benchmarking is part of a much wider use of benchmarking as a management tool. The results of sectoral benchmark studies can be summarised in *benchmark curves* in which the energy use of individual plants is plotted as a dependent variable from the most efficient to the least efficient plant, either as function of cumulative production or of the number of plants. The information from benchmark curves can be used to assess the relative performance of individual plants. It can also, where sufficient specific information is available and the coverage of the benchmark curve is fairly comprehensive, be used to estimate the aggregate savings potential at the level of an individual country, a region, or worldwide.

A benchmark curve contains valuable information about best practice technologies (BPT), i.e. technologies that are energy efficient and already applied in practice. The most energy efficient plants in the benchmark curves are not, however, necessarily users of the most efficient technologies. They may, rather, be plants that benefit from exceptionally favourable feedstock quality or other non-technology-related factors.

Detailed information on the reasons for the position of a plant on the curve cannot be obtained from the benchmark curve itself.

Only a relatively small number of plants are involved worldwide in the energy-intensive bulk materials industry. Only around 200 integrated steel plants, 200 steam cracking installations, 400 ammonia plants, 200 aluminium smelters, and 2 000 large cement kilns are in operation worldwide. Together they account for half of the global industrial energy use. Data on their performance can be acquired relatively easily. For other sectors, however, especially those dominated by small and medium enterprises (SMEs), the number of plants increases substantially. The development of benchmark curves for these sectors presents a more significant challenge.

For some industries and countries, benchmark curves are readily available (Section 2 and Annex). But data is often much less readily available, and often less reliable, for DCs than for ICs. Even where benchmark curves are publicly available, it is often impossible to identify individual plants based on the information given. Plant data are often confidential because of antitrust regulations and market sensitivities. It is not therefore possible to develop detailed efficiency investment programmes based on a benchmark curve because it remains unknown which plants exactly are the ones with the high savings potential. Information from additional sources is needed to complement benchmark curves if governments or other organisations are seeking to target investments in energy efficiency.

Benchmark data can be supplemented by efficiency indicator data

If energy use data cannot be identified at plant level, it is sometimes possible to quantify energy efficiency improvement potentials by comparing the average energy use within a country or region with the comparable best practice plant in the world. Average energy use can be derived from publicly available information such as energy statistics and production data. But the resulting energy efficiency indicators are generally less sensitive than benchmarking data.

Goal of this report

This report compiles a range of benchmark curves and indicators for energy intensive industries and products. The data presented cover approximately 55% of final manufacturing industry energy use including energy use in refineries. The analysis differentiates between ICs and DCs.

Based on the benchmarking data, the study provides:

(i) an overview of the current technical energy saving potentials based on today's BPT. This information can be used to assess the global energy savings potential. The report does not, however, address the economics of these savings or the best means of enabling their delivery. Some of these savings will be realised through normal market pressures. Others may require governmental intervention through policy, fiscal or economic measures. Some may remain uneconomic for decades;

(ii) a simplified economic analysis to assist a better understanding of the reasons why one country has a higher level of energy efficiency than another. This analysis covers energy costs and capital investment costs and the economic circumstances in selected countries for number of sectors; and

(iii) projections through to 2030 which analyse the potential effect of implementing BPT and other best available energy saving technologies.

The following hypotheses will be tested in this report:

- The current average global energy saving potential from implementing BPT is around 15% - 35%, depending on sector and on location as between ICs and DCs.
- A number of rational explanations exist for the observed range. The relative energy efficiency of a plant or national sector does not necessarily correlate with its relative competitiveness.
- Energy audit and investment appraisal data suggest that many energy efficiency opportunities exist which offer savings of 10% to 20% in energy use and which have pay-back periods of less than two years.
- Policies can change the decision making framework and accelerate the uptake of energy efficiency improvements, thereby reducing the gap between current practice and the technical energy efficiency potential.
- Companies that benchmark their energy use and deploy energy management systems tend to achieve annual efficiency gains 1% to 2% higher than companies without such systems.
- In many countries, industrial energy is subsidised. This generates economic activity, but it also acts as a disincentive for energy efficiency improvements.
- Old plants tend to be less efficient than newer ones. Accelerating capital stock turnover can help to enhance efficiencies, but in many cases only at considerable cost.
- Industry will, with current policies and practices, achieve savings of 1% a year in process energy between now and 2030. This is treated as a baseline scenario. Implementing BPT can increase the efficiency improvement performance to 1.2% a year assuming no major structural changes.
- Based on today's energy prices and assuming no change in the fuel mix, the total value of the fuel saving would amount to USD 315 billion a year in 2030 in the baseline scenario, and USD 365 billion a year if BPT are implemented in the short-term[7]. Three quarters of these savings would accrue in DCs.
- Materials and product re-design, and the development of energy and materials management services, will help to reduce the average energy intensity of manufacturing significantly.

Section 2 explains the methodology and provides an overview of the data used. Section 3 presents the results of the analysis for each industry sector with a breakdown for the most important countries and regions. Section 4 outlines the results of the scenario analysis. Section 5 discusses the relationship of energy costs and capital costs to the energy efficiency of a number of industrial products in selected countries. Section 6 discusses the validity of the report's findings in the light of known uncertainties and lists a number of major shortcomings concerning data quality and data availability. The report concludes with a range of recommendations to governments and industry associations.

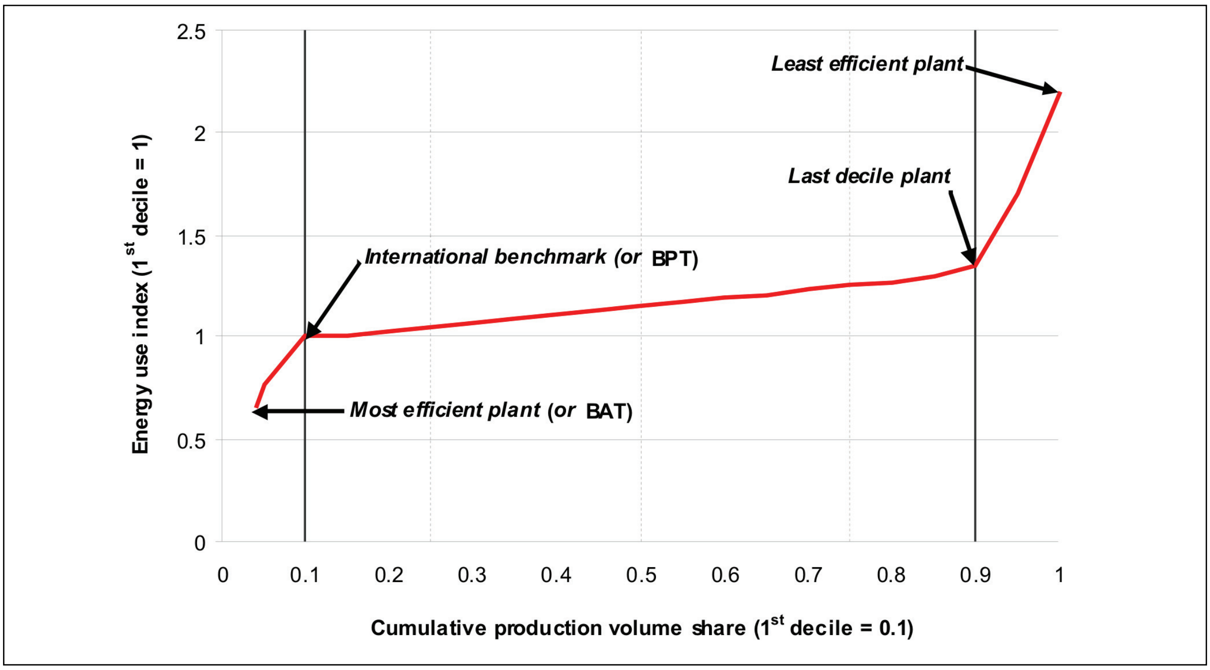
[7] Throughout this report, energy cost savings refer exclusively to the fuel savings as a result of energy efficiency improvements. They do not account for the cost of the investments required to upgrade the current technology to the level of the international benchmark.

2. GENERAL METHODOLOGY AND THE DATA SOURCES

a. Benchmarking industrial energy use

A typical benchmark curve plots the efficiency of plants as a function of the total production volume from all similar plants or as a function of the total number of plants that operate at that level of efficiency or worse **(Figure 2)**.

FIGURE 2:
Illustrative energy benchmark curve for the manufacturing industry



Note: SECs of the BAT, BPT, last decile and the least efficient plants according to this study are shown in the figure. Information on the *x* and *y*-axes has been indexed for simplicity. Normally the information would be plotted to show the specific energy consumption per unit of physical production against the cumulative production realised in the relevant year (in physical terms). The energy efficiency index for BPT is normalised to 1 for the 1st decile production share (*i.e.* the point on the *x*-axis equivalent to 0.1). More detailed explanations of the methodology are provided in the main text.

The most efficient plants are represented to the left and lower part of the curve, and the least efficient plants to the right and higher part of the curve. The shape of benchmark curves would vary for different sectors and regions. However, typically a few plants are very efficient and a few plants are very inefficient. This is generally represented by the steep slopes of the benchmark curve before the 1st decile and after the last decile respectively. Between these two deciles, benchmark curves tend to display a broadly linear relationship between energy efficiency and the share of cumulative production. This relationship can be used to support a rough assessment of the energy efficiency potential for an industrial process, which is defined as 50% of the difference between the efficiencies observed at the first and last deciles.

The most efficient plants in the benchmark curve are used to define the BPT. This report uses the 1st decile as the BPT and defines this as the *international benchmark* **(Figure 2)**. Where possible, the analysis uses physical production levels to define the deciles. Where the lack of data makes such an approach inappropriate or unreliable, deciles are based on the number of plants.

Global benchmark curves are available for the following sectors: steam crackers (Solomon, 2005 in Leuckx 2008), clinker production (CSI, 2009a), petroleum refineries (Solomon, 2000 in Matthes et al., 2008) and ammonia production (IFA, 2009a, b). Benchmark curves are also available for the cement industry, as compiled by the Cement Sustainability Initiative (CSI, 2009a), and for the aluminium industry, as compiled by the International Aluminium Institute (IAI, 2009a, b). The accuracy of these curves often suffers from incomplete data particularly for fast-growing DCs such as China. Some of these data gaps can be filled through literature survey, although the information is scattered and its compatibility with the results of published benchmark studies is often questionable.

Plant benchmark data are complemented by two further types of analysis based on (i) the average current specific energy consumption (SEC) by world region or country, and (ii) the Energy Efficiency Index (EEI) as developed by Phylipsen *et al* (2002) and Neelis *et al* (2007a) for the Netherlands.

The SEC analysis uses the average current SEC at country or regional level depending on data availability[8]. If SEC data are not available, energy statistics provide the only basis for assessing energy efficiency. Energy statistics provide information on energy use at sectoral level, thereby including all production processes within that sector.

The EEI approach estimates the EEI of country *j* for sector *x* with *i* production processes as follows:

$$EEI_{j,x} = \frac{TFEU_{j,x}}{\sum_{i=1}^{n} P_{i,j} \times BPT_{i,x}} \qquad (1)$$

where, TFEU is the actual energy use of sector x as reported in Energy Balances prepared by International Energy Agency (IEA) (in petajoules (PJ) per year), P is the production volume of product *i* in country *j* (in mega tonnes (Mt) per year), BPT is best practice technology energy use for the production of product *i* (in GJ per tonne of output) and *n* is the number of products to be aggregated. On this basis, a country is the most

[8] If SEC data at country or regional levels are not available, estimates are made wherever possible based on published information on the relative energy use across different regions.

efficient worldwide when all its processes for a given sector have adopted BPT. In that case, the country or region has an EEI of 1.

On the basis of these approaches, the energy efficiency improvement potentials in sector *x* and in country or region *j* are determined as:

$$= 1- \frac{\textit{International benchmark}\ (\text{BPT or SEC}_{\textit{lowest,x}})}{\text{SEC}_{j,x}}$$

$$\text{or} = 1- \frac{\text{EEI}_{\textit{lowest,x}}}{\text{EEI}_{j,x}} \qquad (2)$$

Supplementary datasets are provided wherever possible with a higher level of detail for individual plants. The most up-to-date available data is used; in general this is the year 2007. Where data availability constraints require, "nameplate" energy efficiency plant data are used. These do not necessarily capture the variations in efficiency that result from daily operational practices, the frequency and quality of maintenance activities or the application of measures for debottlenecking and continuous improvement (including retrofitting) that are likely substantially to change energy efficiency. If these aspects were accounted for, the SEC of the most energy efficient plants would probably be lower than the benchmark curves show (*i.e.* these plants would be more efficient); and the SEC of the least energy efficient plants would probably by higher than shown (*i.e.* these plants would be less efficient). The slopes of the benchmark curves would therefore probably be steeper at the beginning and at the end.

For some developing countries, it has not been possible to apply either SEC or EEI methodologies to some sectors, primarily due to limitations in the availability of data on physical production, SEC or sector-specific total final energy use as given by international energy statistics. For these sectors, a comparison is provided of the current average SEC in ICs and in DCs. The international benchmark for estimating energy efficiency potentials is then set by the lowest achievable SEC that is identical with the BPT energy use.

This report analyses the energy use of 26 sectors, processes and products. In 10 cases, benchmark surveys are used as the principal methodology. Among these 10 cases, indicators are used to support the benchmark surveys in 8 cases. Indicators are used alone to estimate improvement potentials in only 4 cases. In 12 cases, energy efficiency potentials are determined by reference to the limited comparison of SEC values. Table 1 and Table 2 (below) identify the methodologies that have been used in individual cases using the following annotations:

- "B" for *b*enchmark survey data,
- "I" for *i*ndicators: *i.e.* average current SEC or EEI data, and
- "*L*" for *l*imited SEC comparisons.

One international benchmark is provided for each product. The data is insufficient to support a deeper differentiation between types of raw material, feedstock or plant size. The analysis focuses on energy use only.

The products analysed (denoted as *i* in Equation 1) for each sector are chosen according to data availability and the structure of the sector. For example, numerous production processes are operated in the refinery sector, leading to a wide range of products. The product mix differs substantially across countries. The most important processes operated in the refinery sector are combined into a single EEI. In the aluminium sector, by contrast, the EEI for primary aluminium smelters or ammonia production is based on a single product.

TABLE 1:
Overview of data sources (production data and SEC) and the methodologies applied

Sectors, products and processes	DATA Production data	SOURCES SEC	Methodology applied	
Petroleum refineries	OGJ, 2003	Worrell and Galitsky, 2004; 2005; Neelis *et al.*, 2005	EEI	*I*
Chemical and petrochemical				
High value chemicals (steam crackers)	OGJ, 2008	Solomon, 2005 in Leuckx, 2008; Saygin *et al.*, 2009; Lvarious	Regional SEC	*B & I*
Ammonia	USGS, 2009a	International Fertilizer Industry Association (IFA); Saygin *et al.*, 2009 and various	Regional SEC+Literature data	*B & I*
Methanol	MI, 2009	Various	Regional SEC	*B & I*
Non-ferrous metals				
Alumina production	IAI, 2009; USGS, 2009b	IAI, 2009a,b and various	Regional SEC	*B & I*
Aluminium smelters	IAI, 2009; USGS, 2009c			
Copper smelters	Brook Hunt		-	*B*
Slab zinc	Brook Hunt		Regional SEC	*I*
Iron and steel	WSA, 2009	Worrell *et al.*, 2007	EEI	*I*
Non-metallic minerals				
Cement[1]	USGS, 2009d	CSI, 2009a	Regional SEC	*B & I*
Lime	-	Various	Limited SEC comparison	*L*
Glass	Various		Literature data	*B & I*
Ceramic[2]			Limited SEC comparison	*B*
Pulp and paper	FAOSTAT, 2009a	IEA, 2009c	-	*I*
Textile				
Spinning	Various		Limited SEC comparison	*L*
Weaving	Various		Limited SEC comparison	*L*
Food and beverage	FAOSTAT, 2009b	Various	-	
Breweries	FAOSTAT, 2009b	KWA, 2004	-	*B*
Cheese	FAOSTAT, 2009b	Xu *et al.*, 2009	Limited SEC comparison	*L*
Fluid milk	Various	Xu and Flapper, 2009	Limited SEC comparison	*L*
Ferrous and non-ferrous foundries[3]	Modern Casting, 2008	Various	Limited SEC comparison	*L*

[1] Clinker production and grinding process are analysed separately.
[2] The sector includes the separate analysis of brick making, tile making and sanitaryware products.
[3] Foundries include the separate analysis of casting iron, steel, aluminium and copper.

Table 1 provides an overview of the data sources used, the methodologies adopted, and the type of benchmark value that results. Further details are provided in the Annex. The *international benchmark* values that result from this study are based purely on publicly available benchmark surveys and other open literature sources. They have not been reviewed and agreed upon by industry experts. A review process would be desirable in order to address a number of techno-economic aspects that are beyond the scope of this report, such as whether the BPTs could be extended more widely to the relevant sector than the present work assumes.

The final results of this study provide three sets of information for each process:

- ***Ranges for average energy use.*** These provide information on the current average energy use in various regions and an estimated global average. These averages are based either on benchmark surveys (*B*) or on indicators (*I*). For sectors and products where the analysis depends on limited SEC comparison (*L*) a global average is not estimated.
- ***Energy benchmark data.***[9] These provide further information on:
  - The most energy efficient plant. This is referred to as the Best Available Technology (BAT);
  - The international benchmark (*i.e.* the plant at the 1st decile, as described above);
  - The last decile plant (*i.e.* the most efficient plant in the last decile); and
  - the least energy efficient plant in the entire dataset.
- ***Coverage of the sector:*** This provides information on the production coverage. This is estimated by comparing the data collected in this paper with publicly available production statistics. These data refer to the production coverage of the benchmark curves prepared within this study.

The SEC data cover the direct energy used at plants for manufacturing a specific product. They do not include the energy required for mining or for the manufacturing of raw materials or the energy used in producing the energy consumed at the plant (*e.g.* primary energy used in power plant for electricity production or the energy used in extraction activities for producing, for example, naphtha or natural gas). The total process energy use is provided as a single value, in GJ per tonne of output, which includes any fuel, steam and electricity use or, where relevant, feedstock use. The data distinguish between different energy types only if an individual production process is based solely on a specific energy type (*e.g.* electricity use at primary aluminium smelter).

The study also uses the improvement potentials estimated for ICs and DCs to estimate the absolute saving potentials in each region, by multiplying the improvement potentials (in %) per sector by the actual energy use of that sector as reported in international energy statistics.[10]

b. Industrial energy use scenarios until 2030

Four energy efficiency scenarios have been developed in order to give a better understanding of possible developments between 2007 and 2030. These are:

[9] In cases where data availability made it possible to apply benchmark survey (B) and indicators (I) methodologies simultaneously, the analysis gives priority to the benchmark survey for estimating the energy benchmark columns since data which originate from benchmark surveys provide information based on individual plants and are therefore more reliable. The indicators (I) data are then used as a supplementary dataset to determine the energy use in various regions.

[10] If production statistics and the current average SEC data permit, bottom-up analysis is used to estimate the current energy use of a sector. For example, the current energy use of cement production is based on clinker production (heat use) and grinding (electricity use). This total is then deducted from the non-metallic minerals sector energy use provided in IEA energy statistics to estimate the current energy use of the sector's other products such as glass and ceramics.

(i) Frozen efficiency: no additional energy efficiency savings are made, *i.e.* the current levels of energy efficiency are not improved upon.

(ii) Baseline efficiency: energy efficiency improves at a rate of 1% a year.

(iii) BPT scenario: all plants are operating at the current levels of BPT by 2030. This is equivalent to an energy efficiency improvement of 1.2% a year in the period 2007 to 2030.

(iv) BAT scenario: all plant is operating at current levels of BAT by 2030. This is equivalent to an energy efficiency improvement of 1.7% a year in the period 2007 to 2030.

Both the BPT and BAT scenarios are based on technology already available commercially somewhere in the world. They do not take into account future technology developments.

All these scenarios assume levels of production growth based on the IEA's Low growth scenario (IEA, 2009c)[11]. In this scenario, no production growth is estimated for ICs from 2007 to 2030. The average growth in China and economies in transition is estimated to be between 1% and 1.4% a year. India, other developing Asia, Middle East and Africa are assumed to grow at a much higher rate ranging between 2.5 and 4% a year.

On average, physical production growth is estimated at 2.1% p.a. worldwide. The scenarios in the present analysis do not take into account the effect of any possible future structural changes, such as a larger production share of secondary steel or aluminium, or the increased production of higher value added products in DCs.

c. Production cost analysis

As a means of assessing whether energy costs appear to have an impact on levels of energy efficiency in different countries, this study has multiplied the energy use as plotted in energy benchmark curves (see Annex) by energy prices, producing a set of *energy cost* curves, discussed in Section 5.

Capital costs are another important factor influencing commercial decisions on the implementation of energy efficiency measures. To gain insight into the effect of the capital costs on energy efficiency investments, the study has collected data on initial investment costs, most of which refer to investments in ICs. After correcting for the circumstances in DCs by distinguishing between state-owned/local company investments as opposed to foreign direct investment, the capital and energy costs (CEC) are plotted graphically against SEC values. The outcome of this analysis is also discussed in Section 5.

[11] The IEA study is limited to the energy-intensive sectors, namely chemical and petrochemical, iron and steel, aluminium, pulp and paper and cement. The present analysis applies the IEA growth rate projections, approximating cement to the entire non-metallic minerals sector and the growth of all other industry sectors on the basis of the average growth rate of these five energy-intensive sectors. The growth of petroleum feedstock use for petrochemicals is based on the physical growth of the basic chemicals which are feedstock consumers, i.e. high value chemicals from steam cracking processes, ammonia and methanol production. Due to lack of availability of regional growth data for crude oil processing, the scenario analysis excludes the activities of petroleum refineries.

3. OVERALL RESULTS

Data has been collected and analysed on regional energy use in respect of 26 energy intensive industry processes and a number of light industry sectors. These are discussed in more detail in the Annex. The findings are summarised, with an indication of the data coverage for individual products and processes, in Table 2.

For the sectors analysed (which consume an aggregate of around 74 EJ/yr[12]), the total energy that could be saved by the implementation of BPT is 16.3 EJ/year **(Table 3)**. Around a quarter of the total energy saving potential (4 EJ to 5 EJ/year) is located in the ICs. Most of the potential saving (11.5 EJ to 12.5 EJ/year) exists in DCs. Upgrading all processes of these sectors to the international benchmark (or the level of BPT) would save around 26% of the industrial current final energy use worldwide. In some energy intensive sectors, *e.g.* steam crackers and aluminium, some production processes or products have improvement potentials of around 10% to 20%. Light industries such as brick making or foundries typically have larger improvement potentials than the average.

While the average energy efficiency potential in ICs amounts to approximately 15%, the potential in DCs is around 30% on average. In some sectors, given the prevalence of small-sized plants equipped with old technology, it is as high as 40% - 50%. For some processes, such as aluminium smelting, pulp and paper and cement production, several DCs appear to be more energy efficient than the average IC. This may be explained by regional circumstances, such as the local availability of alternative fuels and blending agents in cement production, or by the fact that many DCs, as they have expanded production, have been able to adopt modern, more efficient technologies.

Achievable savings in petroleum refineries amount to 0.7 EJ a year in ICs and 2.9 EJ a year in DCs. This adds another 3.6 EJ of potential saving, resulting in potential total savings in the global industry including refineries of around 19.9 EJ. The total final energy saving potential in the industry and in refineries is more than 6% of the global final energy use (347 EJ).

[12] This includes the share of petroleum feedstocks consumed in the steam cracking process (for HVC production) and in the production of ammonia and methanol.

TABLE 2:
Overview of ranges for average energy use and energy benchmark data

Sectors (products and processes) (year data refers to)	Meth. (B/I/L)	Units	Ranges for average energy use in		Energy benchmark data					
			Selected ICs	Selected DCs (incl. EIT)	Global average	Best Available Technology (BAT)	Intl. Benchmark/ Lowest EEI	Last Decile Plant (or region)	Worst Plant (or region)	Coverage of the data (%)
Petroleum refineries (2003)[1]	*I*	EEI	0.7-0.8	1.3-3.8	1.25	1	-	-	-	90
Chemical and petrochemical										
High value chemicals[2] (2005)	*B & I*	GJ/t HVC	12.6-18.3	17.1-18.3	16.9	10.6	12.5	22.6	33.6	75
Ammonia[3] (2007)	*B & I*	GJ/t NH3	33.2-36.2	35.9-46.5	41	23.5	31.5	43	58	100
Methanol[4] (2006)	*B & I*	GJ/t MeOH	33.7-35.8	33.6-40.2	35.1	28.8	30	38.5	58	80
Non-ferrous metals										
Alumina production[5] (2007)	*B & I*	GJ/t alumina	10.9-15.5	10.5-24.5	16	7.4	7.8	14.2	18.4	100
Aluminium smelting[6] (2007)	*B & I*	MWh/t primary aluminium	14.8-15.8	14.6-15	15.5	13.4	14.2	17.1	20.8	›95
Copper[7]	*B*	GJ/t copper	-	-	13.8	6.3	7.4	22.1	50.9	50
Zinc[8] (2006)	*I*	GJ/t zinc	15.2-19.7	16.7-37.2	23.6	-	15.2	-	37.2	100
Iron and steel (2005)[9]	*I*	EEI	1.16-1.4	1.4-2.2	1.45	1	1.16	-	2.2	100
Non-metallic minerals										
Clinker[10] (2007)	*B & I*	GJ/t clinker	3.3-4.2	3.1-6.2	3.5	2.9	3	4.4	6.6	100
Cement[10] (2007)	*B & I*	kWh/t cement	109-134	92-121	109	56	88	133	144	100
Lime[11]	*L*	GJ/t lime	3.6-13	5-13	-	-	3.2	-	-	-
Glass[12] (~2000s)	*B & I*	GJ/t melt	4-10	6.8-7.8	6.5	3.4	3.6	5.7	8.7	-
Brick making[13] (~2000s)	*L*	MJ/kg fired brick	1.5-3	0.75-11	-	-	VSBK: 0.75 Tunnel: 1.5	-	-	-
Tiles[14]	*L*	GJ/t tile	1.9-7.3	3.1-8.3	-	-	1.9			-
Sanitaryware[14]	*L*	GJ/t sanitaryware	4.2-11.3	4.4-20	-	-	4.2	-	-	

Sectors (products and processes) (year data refers to)	Meth. (B/I/L)	Units	Ranges for average energy use in			Energy benchmark data				
			Selected ICs	Selected DCs (incl. EIT)	Global average	Best Available Technology (BAT)	Intl. Benchmark/ Lowest EEI	Last Decile Plant (or region)	Worst Plant (or region)	Coverage of the data (%)
Pulp and paper[15]	*I*	EEI (heat & electricity)	0.93-1.73	0.43-2.29	1.31	1	-	-	-	100
Textiles										
Spinning[16]	*L*	GJ/t yarn	Ring yarn: 3.5-3.6 OE: 2.57	Ring yarn 3.5-3.6 Other: 0.5-7.5	-	-	Ring yarn: 3.40 OE: 2.44	-	-	-
Weaving[17]	*L*	GJ/t woven cloth	11-65	5-43	-	-	-	-	-	-
Food and beverages										
Brewery (2007)	*B*	MJ/hl	-	-	229		156			26
Cheese[18]	*L*	GJ/t	4.3-35.2	-	-	-	1.8	-	-	-
Fluid milk[18]	*L*	GJ/t fluid milk product	3.1-6.5	-	-	-	0.3	-	-	-
Foundries[19]										
Cast iron	*L*	kWh/t iron melt	Cupola: 950 Electric: 525-715	780-850	-	-	-	-	-	-
Cast steel	*L*	kWh/t steel melt	Electric: 525-715	735	-	-	-	-	-	-
Cast aluminium	*L*	kWh/t Al melt	Fuel-fired: 600-1250 Electric: 440-590	590	-	-	-	-	-	-
Cast copper	*L*	kWh/t Cu melt	Electric: 400-1100	590	-	-	-	-	-	-

[1] ICs: OECD countries. DCs: EIT/China. A benchmark energy use for the 1st decile cannot be estimated. The lowest estimated EEI, for OECD Europe, is reported. The average is weighted and is estimated based on the EEI and the crude oil capacity of each region.

[2] ICs: Japan & Korea and North America.

[3] ICs: Europe and NA. DCs: MENA and China. Data includes feedstock use.

[4] ICs: Europe and NA. DCs: South America and India. Data includes feedstock use.

[5] ICs: NA and Europe (incl. Russia). DCs: South America and China.

[6] ICs: Oceania and Europe (incl. Central Europe and EIT). DCs: Africa and Asia.

[7] Data refers to copper smelters.

[8] ICs: Western Europe and Japan. DCs: South America and China. Data refers to slab zinc production in zinc smelters.

[9] ICs: Asia/Pacific and NA. DCs: China and CIS.

[10] ICs: Pacific and NA. DCs: India and CIS. All SEC data originates from Getting the Numbers Right (GNR) database (CSI, 2009a). GNR database, a voluntary and an independently managed database, covers on average 31% of total global cement production. While for some regions the coverage is as high as 80 to 90%, e.g. North America, Central America and Europe. For other regions it is quite low, e.g. 20% for CIS and only 4% for China. Data is approximated assuming that it represents the energy use of all plants in a given region. However, an exception is made for China since it accounts for approximately half of the global cement production and GNR database refers only to a limited fraction of this value. The average SEC for the remainder of clinker and cement production in China (96%) is estimated based on China total average of 4.1 GJ of thermal energy per tonne of clinker (IEA, 2009c) and a 115 kWh grinding electricity use per tonne of cement (IEA, 2007).

Waste heat recovery is a standard process applied in kilns in many countries. Typically it is used for drying raw materials; however, steam production (if potential buyers exist) or power generation is also possible. Net electricity production (after accounting for turbine and boiler operations) is rewarded. If a higher specific electricity production than 0.08 GJel per tonne of clinker is desired, modifications in kiln operation are necessary which would then lead to higher fuel demand (CSI, 2009b). These are accounted for under fuel use of clinker production as reported in GNR database.

As opposed to heat use in kilns, which is expressed per tonne of clinker, specific electricity consumption is reported separately and expressed per tonne of cement. A significant share of electricity consumption is for grinding.

[11] ICs: Europe and Canada. DCs: China and Thailand.

[12] This is the aggregate of flat and container glass production. SEC data refers to per tonne of melt glass (at furnace). It is corrected for 50% cullet.

[13] ICs: Europe (modern industrial brick kilns). DCs: Asian countries (small-medium size and very small kilns).

Low-end of the average energy use in DCs refers to VSBK technology. Despite a low SEC value, the technology has limitations in firing bricks which are >15-20% hollow since at higher hollow rates breakage is observed. Furthermore the level of quality of bricks is lower than bricks fired in tunnel kilns. In spite of these drawbacks, given the suitability of this technology in DCs and its remarkably low SEC we refer to it as one of the benchmarks.

[14] ICs: EU. DCs: India and China. SEC for ceramic tiles (wall and floor tiles) refers to firing process in kilns only. Total SEC of firing is determined based on number of firing steps (typically once, but for glazed products twice) and kiln type (roller hearth kilns versus less energy efficient tunnel kilns). In EU, the lower- and higher-ends of SEC data refer to once-fired roller hearth kilns and twice-fired tunnel kilns respectively. Process steps related to raw material preparation are less energy-intensive (less than total of 1 GJ/t). Lower end of SEC data for DCs refer to roller kiln wall tile production in India and the higher-end refers to average SEC for ceramic tiles production in China (no technology is specified).

Firing step during sanitaryware production is more energy intensive. Lower- and higher-ends of SEC data for ICs refer to the most efficient and least efficient roller hearth kilns and conventional tunnel kilns respectively. DC data refer to tunnel kilns in India and kilns in Malaysia (no technology is specified). EU reference documents (IPTS/EC, 2007) report much higher values, up to 32 GJ per tonne for sanitaryware production (including other processes: casting, drying, glazing and other treatment). Average SEC data for China are equally high, at more than 30 GJ per tonne, but the system boundaries of the data are not clear, and therefore we do not report these values.

[15] EEI values less than 1 point to serious problems in energy statistics. A country or a region can only reach the minimum achievable EEI of 1 if it applies the BAT in all its processes. So an EEI less than 1 is technically impossible. Given the data uncertainties, we do not report any energy benchmark values in these cases (except for BAT).

[16] ICs: Italy, US, South Korea. DCs: China and India, and Thailand and Indonesia.

[17] ICs: Germany. DCs: Thailand

[18] ICs: Western Europe and North America. Data refers to the averages of lowest and highest recorded SEC values in individual cheese and fluid milk plants operated in North America and Europe. International benchmark data refer to the lowest recorded SEC data in these regions. We have no data for DCs.

[19] ICs: EU and North America. DCs: an individual company in India. Data for ICs are given separately for cupola furnaces (based on coke), fuel-fired (natural gas) and electric furnaces (only electricity, no fuel). All data is expressed in kWh per tonne of molten metal (or melt). No international benchmark is given. The data excludes the material losses in foundries.

The industrial sectors not covered in detail by this study[13] consume around 53 EJ/year, equivalent to 40% to 45% of total final industrial energy use. If these sectors are assumed to present similar potential energy savings, an additional saving of approximately 11.1 EJ/year would be achievable (*i.e.* a total energy saving potential of 31 EJ). This would suggest an energy efficiency improvement potential of approximately 26% for the world as a whole, 15% to 20% in ICs and around 35% in DCs. These estimates exclude feedstock demands where no saving potentials are estimated for. If feedstock energy use is included in the comparison, total energy efficiency improvement potential reduces to 22%.

Worldwide, the largest absolute potential savings are in the energy-intensive sectors, *i.e.* (from highest to lowest potential) petroleum refineries, iron and steel, non-ferrous metals, non-metallic minerals (mostly cement), chemical and petrochemicals, and pulp and paper. The total savings achievable in these sectors are 17.4 EJ/year, equivalent to 56% of the total global saving potential of 31 EJ/year. These sectors account together for a similar share of the total potential savings in ICs and DCs. The remaining energy savings potentials are in non-energy intensive or light industries. In these industries the relative savings potentials can be very high in percentage terms, and the savings potential amounts to 44% of the total industry potential.

IEA studies (IEA, 2007; 2009c) have assessed the potential technical energy saving that would result if the energy-intensive sectors[14] were to adopt BPT. These studies estimated energy saving potentials at process level as being 11.4 EJ to 16 EJ in 2004 and 14.2 EJ in 2006, equivalent to improvement potentials of 21% to 30% in 2004 and 25% in 2006, excluding feedstock use. The improvement potential estimated in this study for the same sectors is, at 23%, at a similar level[15].

Including other industry sectors and petroleum refineries, the present study estimates an improvement potential of 26%. This is a few percentage points higher than the IEA studies, reflecting the higher savings potentials of petroleum refineries and of a number of light industry sectors and some SME clusters such as lime production, ceramics, textiles and food.

To achieve these potential savings, all plants would need to be upgraded to the level of the relevant international benchmark, *i.e.* BPT. Whether such upgrades will be implemented depends on the economic viability of the upgrade and on the energy and climate policy environment at country level. The investment costs of specific energy efficiency technologies vary widely, depending on their level of maturity. The willingness of companies to undertake investments depends on the payback period. In general, the higher the share of energy costs as a proportion of the total production costs (see the right hand column in **Table 3**), the more likely it is that investments in energy efficiency will be undertaken.

[13] These sectors are (in order of detail level provided in IEA energy balances): machinery, transport, mining and quarrying, wood and wood products, construction and non-specified sectors. The last term is subject to particularly large uncertainties in energy statistics. This is especially the case for DCs. Its share is less than 10% for ICs while in DCs it accounts for as much as one quarter of the total final industrial energy demand according to energy statistics.

[14] The chemical and petrochemical, iron and steel, cement, pulp and paper and aluminium sectors. Their energy use accounts for approximately 56% of the industry's total final energy consumption excluding feedstock use.

[15] The energy saving potential is 13.9 EJ compared to a total final energy use of 59.7 EJ (excluding feedstock use). When feedstock use for the selected chemical and petrochemical processes is included, the total final energy use is estimated as 70.4 EJ, against which energy efficiency improvements could reduce demand by around 20%.

On average, energy costs constitute around 10% to 20% of industrial production costs. In energy intensive sectors such as the chemical industry, energy costs can constitute anywhere from 20% to as much as 50% of production costs. The energy improvement potentials identified in this report suggest that production costs could be reduced on average by 1% to 15% in ICs and by 3% to 30% in DCs. For small-scale industries, particularly important in the developing world, the production cost reduction is around 3% to 4% on average, but as high as 20% in some cases, such as in brick making.

TABLE 3:
Comparison of estimated short-term industrial energy savings in industrialised and developing countries, 2007

<table>
<tr><th></th><th colspan="2">Improvement potential (%)</th><th colspan="2">Total savings potential (EJ/yr)</th><th colspan="2">Share of energy costs (%)</th></tr>
<tr><th>Sectors and products</th><th>ICs</th><th>DCs (incl. EIT)</th><th>ICs</th><th>DCs (incl. EIT)</th><th>ICs</th><th>DCs (incl. EIT)</th></tr>
<tr><td>Petroleum refineries</td><td>10-25</td><td>40-45</td><td>0.7</td><td>2.9</td><td colspan="2">50-60</td></tr>
<tr><td>Chemical and petrochemical</td><td></td><td></td><td>0.5</td><td>1.8</td><td colspan="2" rowspan="4">50-85</td></tr>
<tr><td>Steam cracking (excl. feedstock)</td><td>20-25</td><td>25-30</td><td>0.4</td><td>0.3</td></tr>
<tr><td>Ammonia</td><td>11</td><td>25</td><td>0.1</td><td>1.3</td></tr>
<tr><td>Methanol</td><td>9</td><td>14</td><td>0.0</td><td>0.1</td></tr>
<tr><td>Non-ferrous</td><td></td><td></td><td>0.3</td><td>0.7</td><td colspan="2"></td></tr>
<tr><td>Alumina production</td><td>35</td><td>50</td><td>0.1</td><td>0.5</td><td colspan="2">30</td></tr>
<tr><td>Aluminium smelters</td><td rowspan="2">5-10</td><td rowspan="2">5</td><td>0.1</td><td rowspan="2">0.15</td><td colspan="2" rowspan="2">35-50</td></tr>
<tr><td>Other aluminium sec.</td><td>0.1</td></tr>
<tr><td>Copper smelters</td><td colspan="2">45-50</td><td>0.0</td><td>0.1</td><td colspan="2">-</td></tr>
<tr><td>Zinc</td><td>16</td><td>46</td><td>0.0</td><td>0.1</td><td colspan="2">-</td></tr>
<tr><td>Iron and steel</td><td>10</td><td>30</td><td>0.7</td><td>5.4</td><td colspan="2">10-30</td></tr>
<tr><td>Non-metallic minerals</td><td></td><td></td><td>0.8</td><td>2.0</td><td colspan="2"></td></tr>
<tr><td>Cement</td><td>20</td><td>25</td><td>0.4</td><td>1.8</td><td colspan="2">25-50</td></tr>
<tr><td>Lime</td><td rowspan="3">30-35</td><td rowspan="3">40</td><td rowspan="3">0.4</td><td rowspan="3">0.2</td><td colspan="2">40</td></tr>
<tr><td>Glass</td><td colspan="2">7-20</td></tr>
<tr><td>Ceramics</td><td colspan="2">30-50</td></tr>
<tr><td>Pulp and paper</td><td>25</td><td>20</td><td>1.3</td><td>0.3</td><td colspan="2">15-35</td></tr>
<tr><td>Textile</td><td rowspan="3">10</td><td rowspan="3">20</td><td rowspan="3">0.1</td><td rowspan="3">0.3</td><td colspan="2">5-25</td></tr>
<tr><td>Spinning</td><td colspan="2" rowspan="2">5-15</td></tr>
<tr><td>Weaving</td></tr>
<tr><td>Food and beverages</td><td>25</td><td>40</td><td>0.7</td><td>1.4</td><td colspan="2">1-10</td></tr>
<tr><td>Total (excl. refineries)</td><td>10-15</td><td>25-30</td><td>4.4</td><td>11.8</td><td colspan="2" rowspan="4">-</td></tr>
<tr><td>Other sectors</td><td>10-15</td><td>25-30</td><td>2.5</td><td>8.7</td></tr>
<tr><td>Total of all sectors (incl. refineries)</td><td>15</td><td>30-35</td><td rowspan="2">7.6</td><td rowspan="2">23.4</td></tr>
<tr><td>(excl. Feedstock)</td><td>15-20</td><td>30-35</td></tr>
</table>

Source: IEA, 2009a, b; own estimates

Note: As far as possible, energy costs are given as a share of total production costs (total of fixed costs and variable costs, including depreciation).

Manufacturing industry is currently estimated to spend around USD 1 trillion a year on energy, 45% of which is spent in ICs and 55% in DCs. Savings in energy costs from implementing BPT would amount to USD 65 billion in ICs and USD 165 billion in DCs. The DC potential saving is more than 70% of the total worldwide. The total potential savings do not take account of the cost of the investment required to implement BPT.

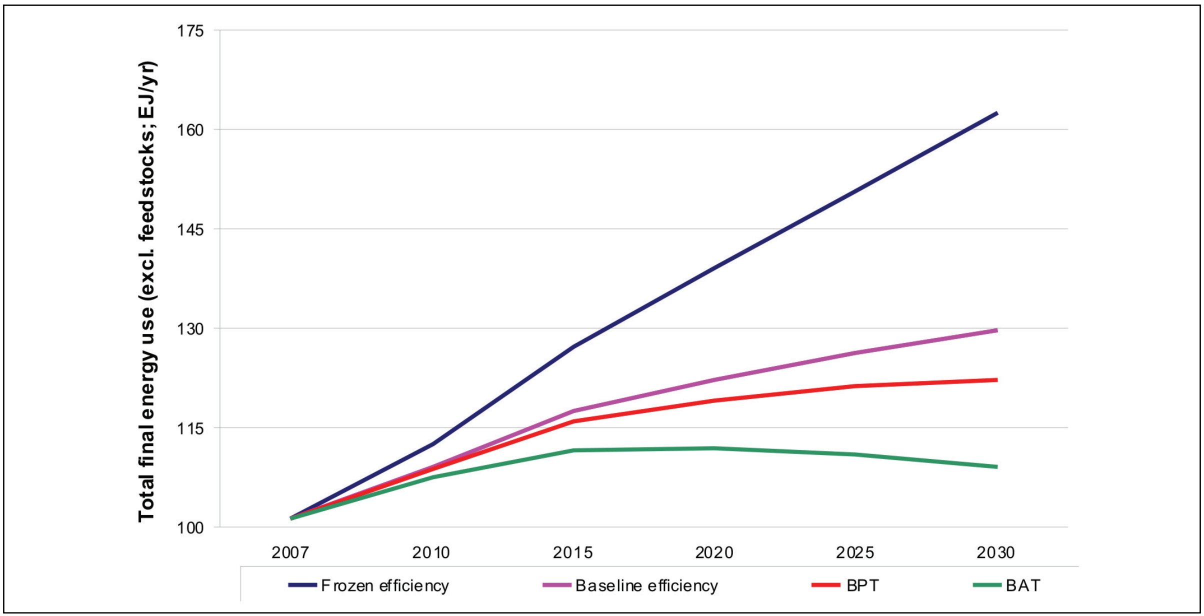
The potential savings represent approximately 2% of industry's current value added worldwide. This is significant, and should act as an incentive for more efficiency measures. But it appears that these savings are not a major driver for investment, particularly given the risk related to volatile energy prices and other factors. The way in which energy costs and other cost parameters influence the attained levels of industrial energy efficiency across different regions is further explored in Section 5.

The adoption of BAT would result in even larger energy savings than the 26% of the total energy use of manufacturing industry and petroleum refineries that could be achieved by the adoption of BPT. Adopting BAT would result in a saving some 5% to 15% higher (UN Energy, 2009).

4. SCENARIOS

Industrial energy use grows from 106 EJ in 2007 to 172 EJ in 2030 in the frozen efficiency scenario (Figure 3). The baseline scenario assumes an efficiency improvement rate of 1%, resulting in a decrease in total energy use in 2030 to 136 EJ, 21% lower than in the frozen efficiency scenario. In the BPT scenario in which it is assumed that all industries converge to the current levels of BPT by 2030, total industrial energy use reduces to 128 EJ. This is 26% lower than in the frozen efficiency scenario. It represents, on average, an annual rate of improvement of 1.2%. Those countries/regions that perform already at the level of BPT are assumed to improve their energy use by 0.5% a year. DCs, which currently have higher SEC than average, would be expected to improve their energy efficiency by 1.5% to 3% a year until 2030. In the BAT scenario, in which all industries adopt BATs by 2030, total energy use is 34% lower than in the frozen efficiency scenario at 114 EJ. This represents a rate of energy efficiency improvement of 1.7% a year.[16]

FIGURE 3:
Total final industrial energy use worldwide, 2007-2030



Note: Values exclude feedstock use

[16] The scenarios assume no savings in feedstock use for petrochemicals. Worldwide feedstock demand will increase by 2.1% a year from 20.7 EJ in 2007 to 33.4 EJ in 2030.

Assuming no change in energy prices from today's levels, the energy bill of the global industry sector will increase from USD 1 trillion in 2007 to USD 1.75 trillion a year in 2030. According to IEA's energy price projections to 2030 (IEA, 2009d), changes in energy prices could lead to an increase of USD 250 billion a year in total energy costs, i.e. to a total of USD 2 trillion a year. The efficiency improvements implicit in the baseline scenario would reduce energy costs by around USD 300 billion a year in 2030.

Worldwide annual energy cost savings amount to USD 365 billion in 2030 in the BPT scenario and to USD 495 billion in the BAT scenario, assuming no change in the current fuel mix. In practice, most of the more efficient technologies require fuel switching from the current fuel mix to more efficiently combusted but more expensive options such as natural gas. Allowing for this, energy cost savings are estimated to be approximately USD 100 billion and USD 150 billion lower than these estimates respectively, resulting in a total saving in 2030 of USD 260 billion in the BPT scenario and USD 310 billion in the BAT scenario[17].

Similar projections of industrial energy use are also made in studies prepared by International Institute for Applied Systems Analysis (IIASA) (Global Energy Assessment, GEA, *in preparation*) and IEA (2009c). In GEA's *supply* and *efficiency* scenarios, energy efficiency is projected to improve by 1.5% and 2% a year from 2005 to 2050.[18] The rate of improvement in the GEA *supply* scenario is higher than that in the BPT scenario. In the GEA *efficiency* scenario, industry improves its energy performance at a faster rate than in either the BPT or BAT scenarios. These GEA scenarios allow for the potential impact of new technologies, enhanced material flows, process integration and other system options such as combined heat and power (CHP), in addition to the implementation of BPT and BAT. None of these wider process improvement possibilities is assumed to play a role in the BPT and BAT scenarios in this report.

In the IEA scenarios (2009c), industrial energy use including feedstocks is projected to increase from 122 EJ in 2006 to 183 EJ in 2030 the Low growth *Baseline*[19] scenario and to 169 EJ in the *BLUE Map* scenario. The Baseline, BPT and BAT scenario projections for 2030 in the present study, including feedstocks, are slightly lower than these estimates at 170 EJ, 162 EJ and 148 EJ respectively.

The IEA projections assume the implementation of system measures both to increase energy efficiency and to reduce carbon emissions. These include the wider adoption of CHP, fuel switching for fuel and feedstock use, increased recycling, and carbon capture and storage (CCS). Such measures may result in efficiency gains in addition to process improvements. But some of them, for example CCS, may increase energy demand in order to achieve CO_2 emissions reductions.

[17] This assumes no changes in the prices of combustible renewable and waste products which are consumed as fuels in industry, and that the fuel mix of blast furnaces and coke ovens is unchanged. All petrochemical feedstocks are assumed gradually to switch to natural gas by 2030.

[18] The reference year for GEA projections is 2005 in which industry consumed 115 EJ of energy. In the GEA study, energy use in 2050 in the *supply* and *efficiency* scenarios is 250 EJ and 200 EJ, respectively. This is equivalent to an energy use in 2030 of 175 EJ in the supply scenario and 155 EJ in the *efficiency*.

[19] The Baseline scenario in the present study assumes a 1% p.a. energy efficiency improvement rate for all sectors, unlike the IEA Baseline scenario.

The projections underpinning this report are based on a different set of assumptions. In particular, they assume that it is technically and economically feasible for companies to implement BPT or BAT in all processes by 2030. On this basis, the scenarios project process energy efficiency improvements of 26% or 34% by implementing BPT or BAT. In practice, it is unlikely that all industrial processes will convert to BPT or BAT in this timescale. But the implementation of wider energy saving and emission reduction measures beyond the level of processes, may provide additional savings which could enable similar levels of energy efficiency saving overall still to be achieved.

5. PRODUCTION COST ANALYSIS

The analysis in Section 3 above has identified a range of energy efficiency improvement potentials. These vary sector by sector. The energy efficiency improvement potential also differs within sectors, region by region. This section explores the likely causes of such regional differences, in particular with a view to establishing the extent to which production cost parameters drive improvements in energy efficiency.

As shown in **Table 3**, energy costs account for approximately 10% - 20% of the total production cost of industry's physical output. The remaining 80% - 90% of costs are made up of components such as the cost of capital, labour, and materials. Each of these components is influenced by many factors.

For example, the capital costs of a depreciated plant are practically zero while, for a new plant, they could represent a very substantial share of production costs. Capital costs are also influenced by the local economic situation in the country where the plant is built, the agreed payback duration of the loan, the prevailing interest rate, the depreciation approach (linear or non-linear), and potentially also by the type of investor, whether it be a local company, a foreign investor, or the state, either directly or through state-owned banking mechanisms. Other factors such as government subsidies, or duties and taxation regimes if the technology is imported, can also reduce or increase capital costs.

Material and energy costs are dependent on the technology deployed and are also influenced by the location of the plant and its size. The local availability of minerals or of natural energy sources can have a major impact in reducing the costs associated with these components. Government subsidies and the availability of long term contracts also help drive down costs. Other factors such as investment in research and development or operation and maintenance costs may play a role in driving costs up or down relative to other industrial manufacturers, but their contribution is generally low for industrial commodities.

Business decisions, especially in the energy intensive sectors, are influenced by very high or very low energy costs. In Japan, high energy prices have driven the development of innovative energy efficiency measures, the implementation of which has reduced SEC. By contrast, in regions where energy prices are low, such as the Middle East and Russia, where there is ready access to large quantities of cheap energy resources such as oil and natural gas, companies have had little incentive to reduce energy use.

If energy costs were a major determinant of energy use, energy cost curves would be expected to have a flatter, less profiled shape than the energy benchmark curves discussed in Section 3 and in the Annex. In regions with high energy costs, inefficient plant should be taken out of production either entirely, or to be replaced by more efficient plant, thus flattening the energy curve. In regions with low energy costs, there would be little incentive to invest in more efficient and generally more capital intensive plant, with a similar effect on the energy cost curve.

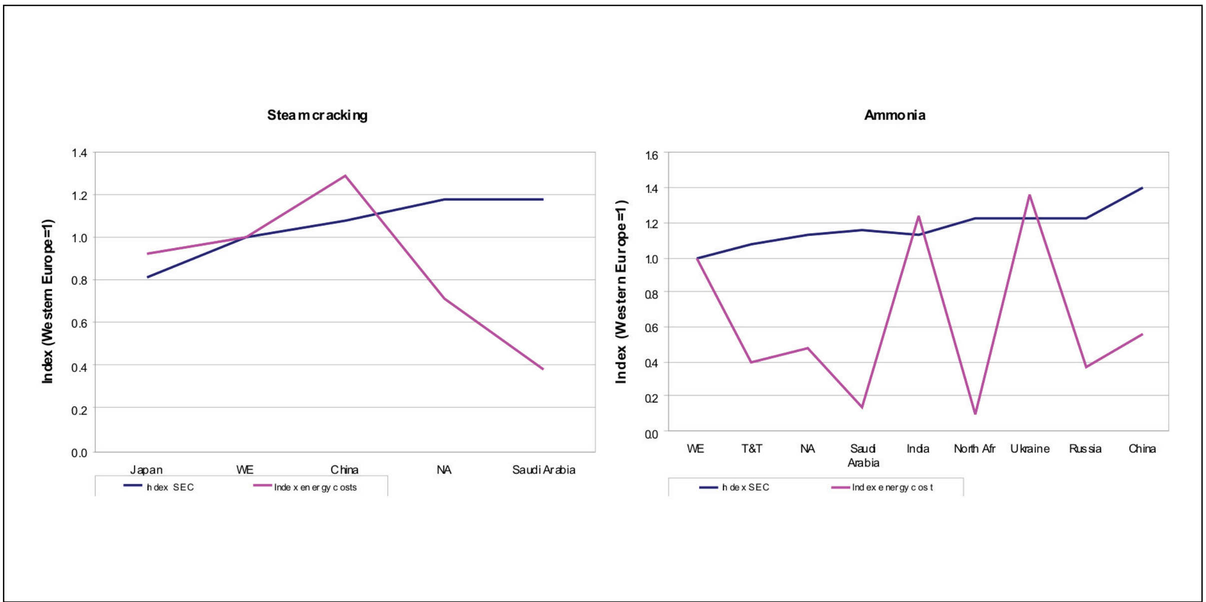
The analysis for steam cracking appears to confirm this hypothesis (left side of **Figure 4**). But the change in shape is so extreme in this case that the overall slope is inverted. Investment in the most energy-efficient steam crackers in Japan has resulted in energy savings which more than offset the disadvantage of local high energy prices. The opposite is true for the energy inefficient plants located in Saudi-Arabia, where extremely low energy prices more than offset the cost of excessively high levels of energy use.

By contrast, the data for ammonia production (right side of **Figure 4**) do not support the hypothesis. The shape of the curve is irregular, with much lower than expected efficiency levels in India and Ukraine, where high energy costs prevail. This suggests that energy prices cannot be the only significant driver of energy efficiency.

Capital investment costs may also influence energy efficiency as energy-efficient technologies, which tend to be newer and more complex; generally require higher investment than less efficient technologies.

Figure 5 (below) compares the SEC of a number of sectors with their associated capital and energy costs. Average efficiency plant is represented by white dots. This includes both plant which is already depreciated, which tends to have lower costs, and relatively new plant where investment costs still need to be paid off. Average efficiency plant is typically state-owned or operated by local investors. Plant which is as efficient as the international benchmark, *i.e.* new

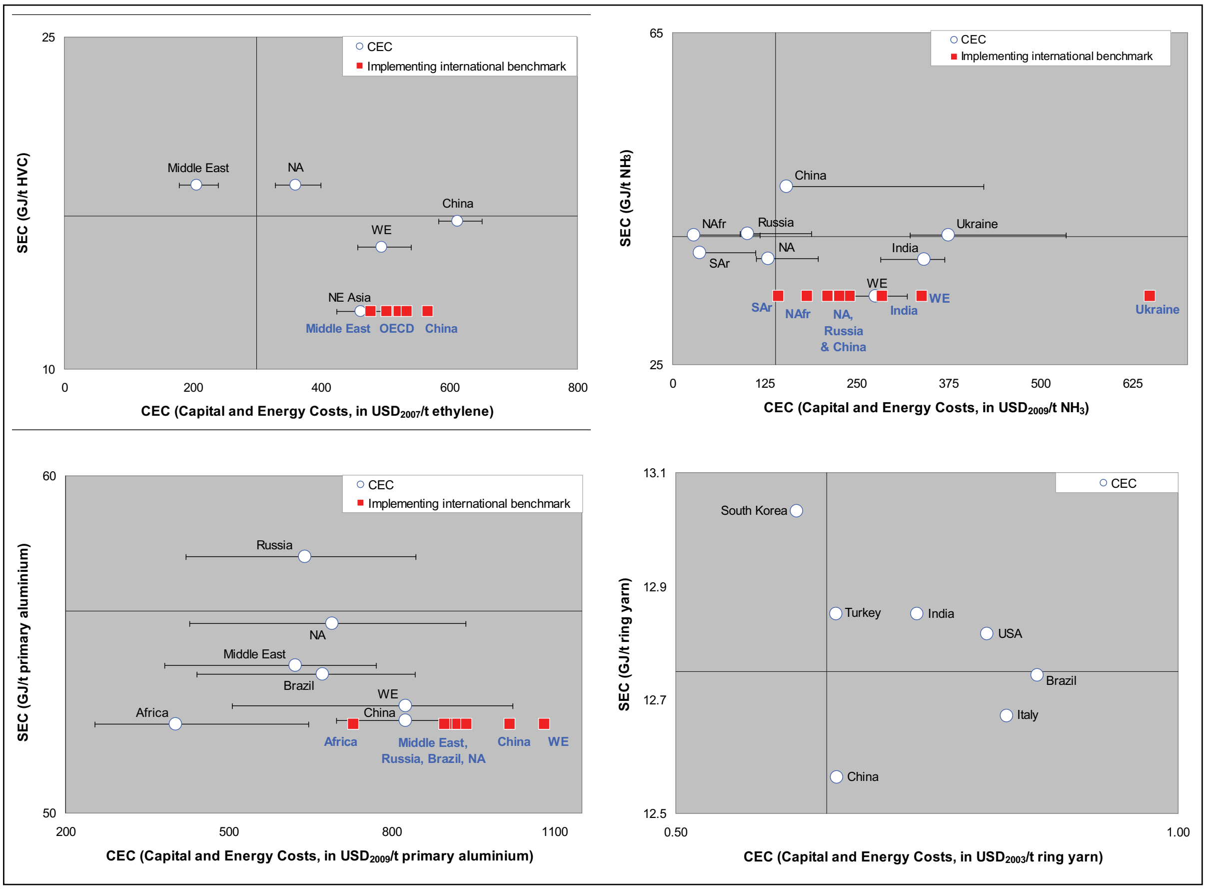
FIGURE 4:
Indexed (Western Europe=1) energy use and energy costs for steam crackers and ammonia production in selected countries



Sources for fuel prices: Steam crackers: McKinsey, 2008; Chemweek, 2007; Ammonia EFMA, 2000; PotashCorp, 2009 plant with the most efficient technology today, is represented by red squares[20].

Figure 3 shows that, in general, DCs have higher levels of SEC than ICs. This may reflect the fact that investment costs in DCs are generally higher, thereby slowing down rates of investment in newer and more energy efficient technologies. This conclusion may be supported by the observation that the Ukraine has a high SEC

FIGURE 5:
Specific energy consumption (SEC) versus capital and energy costs (CEC)



Note: Energy prices refer to: steam cracking, 2007; ammonia, 2009; primary aluminium smelters, 2009; yarn making, 2003.

In the absence of any reliable initial investment costs for yarn making, the analysis is relatively limited.

NA: North America, NAfr: North Africa, NE Asia: North East Asia, SAr: Saudi Arabia, WE: Western Europe.

Sources: Primary aluminium smelters: IAI, 2009a; CENEf, 2008; Adams, 2010. Yarn making: ITMF, 2003 in Koc and Kaplan, 2007. Investment costs are based on, steam cracking: Worrell et al, 2000; IPTS, 2003; ammonia: EFMA, 2000; Lako, 2009; aluminium smelters: Gielen and van Dril, 1997;

[20] International benchmark technology is primarily developed in ICs. When it is implemented in an IC, the investment is generally provided locally. In DCs, novel technology is often brought in through foreign direct investment. It is assumed that the investment for new capital will be granted by a local bank in the local currency of the country which receives the investment and that no additional taxes and duties are charged for importing the equipment. Such taxes and duties can increase investment costs.

despite high energy prices. Investment costs in Ukraine are comparatively high, particularly due to very high interest rates for loans borrowed in the local currency. By contrast, although many Russian ammonia plants are as inefficient as those in Ukraine, it has much lower energy prices and a relatively stable economy that leads to lower interest rates. This entails a lower cost burden when firms invest in switching to the international benchmark. This suggests that the combination of high energy prices and high capital costs may be responsible for the unfavourable position of the Ukraine in **Figure 4**.

China has the highest energy use per tonne of ammonia produced and has relatively low energy costs. But when capital costs are accounted for, production in China becomes more expensive than in a number of other countries, such as North America, which are more energy efficient. The fact that China accounts for one-third of all global ammonia production and is projected to increase its global production share in the coming decades (IEA, 2009c) shows that there are factors other than relative energy efficiency which enable Chinese companies to sustain their competitive position in the global market.

Similarly, although ring-yarn production in India has only slightly higher SEC than the USA, Italy or Brazil, India is the second largest yarn producer and one of the largest exporters of manufactured textile and apparel products[21].

In general, as shown in **Figure 4** by the red squares and white dots for the Middle East, China and Western Europe, it is difficult for new efficient plant which is amortising its investment costs to compete in a given region with older, relatively inefficient plant which has already depreciated its capital investment. The difference between the total costs of old and new plants is particularly large for DCs. In ICs, investment in new energy efficient plant is incentivised by higher energy prices and lower initial investment costs, primarily due to lower interest rates. As a result, DCs generally face a bigger challenge than ICs in moving to energy efficient technologies. Sometimes lower land and infrastructure costs, cheaper labour for construction and for local technical services, and lower equipment and material costs can help to reduce the otherwise relatively high cost of initial investment in DCs. But it is clear from the analysis in this study that low energy costs and low capital costs are not of themselves sufficient to trigger the investment needed to enable countries to become leading producers of bulk materials.

Energy inefficient industries in different countries can become or remain internationally competitive by balancing their higher energy use with lower costs for other production factors. A number of industry sectors, such as ceramics, textiles, leather, foundry and other processed metal products are dominated by SMEs in developing countries on this basis, for example by capitalising on lower labour costs, cheaper raw materials, economies of scale and lower profit margins. Further analysis could provide valuable insight into the relationship between the significance of these production factors.

[21] Product quality is another issue. For low-value added products produced in mass quantities such as ethylene, the quality of the output originating from different regions may be similar. But for other products such as steel and yarn, global competitiveness is determined not only by low production costs but also by quality.

6. DISCUSSION

This study has provided for the first time energy benchmark curves for ICs and DCs for a range of energy-intensive industries and light industries. The analysis suffers, however, from number of uncertainties which need to be taken into account in drawing conclusions.

The quality of the analysis inevitably depends on the quality of the available data. For example, benchmark curves based on the EEI approach suffer from uncertainties in the data reported in energy statistics (IEA, 2009c). The improvement potentials estimated based on EEI data need to be studied in more detail, especially since the sectors analysed with this method (iron and steel, pulp and paper, and petroleum refineries) are large energy consumers. Cross-comparisons with other studies also demonstrate the need for further investigation: the refinery estimates for 2003 in the present study (with a high level of aggregation) suggest an EEI range between 0.8 and 4.5 compared to the EII results of the benchmark survey at individual plant-level which range between 0.5 and 1.5 (Solomon, 2000 in Matthes *et al.,* 2008).

Coverage of the data is also an issue. The more limited the coverage, such as in respect of the aluminium industry or the ammonia industry, the lower the confidence that can be place in the reliability of the benchmark curves. To reduce this uncertainty, the present study has attempted to fill data gaps in reported benchmark curves with literature data to increase the production coverage. However, the data used for complementing the benchmark curves is also subject to uncertainty, primarily because the system boundaries are not fully clear.

For light industries, first attempts have been made to provide SEC data on the basis of literature reviews. Some of these data may refer to very specific technologies or circumstances in an individual plant and may therefore not be representative for the entire sector in a country or region.

For approximately 40% to 45% of total final industrial energy use worldwide, our analysis provides only a first estimate of existing energy efficiency potentials. While a large share of energy use in these sectors (*e.g.* leather, metals processing, transport equipment, construction) occurs in DCs, some of these sectors, such as wood and machinery, are also important energy users in ICs. The literature provides little evidence on SEC values or on energy efficiency for these sectors. In addition, some important energy-intensive products and processes are also excluded from the analysis, including other basic and intermediate chemicals and polymers in the chemical and petrochemical sector, and the production of non-ferrous metals other than aluminium.

IEA energy statistics do not provide the energy use of most DCs for individual sectors, except for the iron and steel, chemical and petrochemical and non-metallic mineral sectors. The energy use of all other sectors is reported under a non-specified category where data is combined to a single value. Even in cases where a more detailed breakdown of sectoral energy use is provided, it is possible that part of the energy use of specific sectors is also reported under the non-specified category. On average, the non-specified category accounts for 20% of total final industrial energy use in ICs (excluding feedstocks) and for more than 50% in respect of some DCs. This makes it impossible to conduct reliable detailed analysis. In addition, production and energy use data are possibly missing for most small plants in the informal sector in DCs, such as those involved in brick making in India.

The analysis in this report relies predominantly on detailed fuel use data, including steam and feedstocks. In the absence of sufficient data, it has not been possible to perform an in-depth analysis for electricity use. Exceptions are sectors where electricity use dominates the sector's energy use, *e.g.* primary aluminium production. In industry, on average, 65% of electricity demand is consumed by motors and drives such as pumps, compressors and fans (de Keulenaer, 2004). Sector electricity consumption varies widely from as low as 50% in the machinery and metal sector to 90% in the non-metallic minerals sector (de Almeida *et al.,* 2003). To estimate the electricity savings potential at sectoral and regional level, energy statistics would need to be improved so as to report electricity use by sector and by demand category.

Given these data availability and data quality shortcomings, further work is necessary to extend the analysis. First, a thorough review of the energy data used in collaboration with industry associations and experts would help to improve the coverage and quality of the data reported. Second, the coverage of benchmark curves should be extended to assess the performance of individual sectors, particularly in respect of the less energy-intensive sectors that are composed primarily of SMEs. Third, to support the estimation of reliable SEC data for both ICs and DCs the reliability and consistency of production and energy statistics needs to be improved. Next steps should also include the determination of uncertainty ranges for the improvement potentials of each sector, quantified by reference to the uncertainties in SEC data and energy statistics.

The scenarios show that large potential process energy savings could be achieved by the implementation of BPT and BAT. Beyond the process level, even higher reductions could be achieved through the wider use of CHP[22], the more effective integration of energy and material flows, and recycling. The potential energy savings of such options needs to be examined in more detail. It would also be very useful for further work to be undertaken to examine the likely impact of investment costs on the achievability of energy cost reduction potentials.

Further work is needed on the cost benchmark curves. The simplified approach based on energy and capital costs adopted in this study can help support an initial discussion on business decision-making. For a deeper analysis, the methodology needs to be extended to cover by-product credits, the prices of raw materials and other utilities and to account for sectoral characteristics (*e.g.* production in integrated sites). Collaboration with the finance sector, industry associations and statistics offices would help to improve the quality of the analysis and to gaining better insight to the industrial investment and production decision making.

Such further work would enable a better understanding of the reasons why energy efficiency improvements are undertaken in some parts of the world but to a much lesser extent in others.

[22] Only a share of the energy savings related to steam production in CHP has been assigned to the industrial sector. The remaining savings (related to the co-production of electricity) is attributed to the power generation sector.

7. CONCLUSIONS

This report has identified the global energy use and energy efficiency potentials of a range of energy-intensive and less energy-intensive manufacturing industries in a benchmarking analysis. The regional performance of industrialised countries (OECD countries) is differentiated from that of developing countries and economies in transition (non-OECD countries). The global manufacturing industry including petroleum refineries could save 31 EJ a year by implementing BPT. This is equivalent to a savings potential of 26% of current energy use overall or a saving of 15% - 20% in ICs and a saving of 30% - 35% in DCs.

Benchmark analysis is feasible for a number of energy-intensive sectors that produce bulk materials. The present analysis is constrained by data gaps and by low production coverage in some areas. The quality of available data, particularly SEC data, production statistics and energy statistics, is variable. The lack of monitoring systems in many DCs contributes further data uncertainty. The governments and national statistics offices of these countries need to be more active in this area in order to ensure that production and SEC data are consistent and to increase the quality of energy statistics. Collaboration with governments that already achieve better data collection can help improve statistical systems and performance in these countries.

Further assistance from industry associations and international organisations would also help in developing and applying standardised methodologies for energy management and energy efficiency. This would help raise awareness, particularly in DCs, of the importance of energy efficiency and enable a better understanding of the competitive advantage that can be gained from implementing measures for reducing energy use.

There is considerable room also for DCs to adopt policies which will encourage practical outcomes such as the training of relevant company staff with a view to improving data measurement and providing information on the potential for energy efficiency savings. The wide range of UNIDO existing activities may provide a strong basis for joint international efforts to achieve substantial improvements in energy use and the delivery of the industrial energy efficiency potentials estimated in this study. It is important that these collaborative efforts are extended to small and medium-sized enterprises where some of the highest improvement potentials are likely to exist, especially in DCs.

Industrial energy and climate policies should ideally be based on energy and emission benchmark surveys based on real data measured at companies. Currently, some sectors (*e.g.* aluminium, cement) are active in developing methodologies and accurate data collection through sectoral partnerships, while others (*e.g.* the chemical and petrochemical sector) are lagging behind due to sector-specific issues.

Worldwide, all industry sectors need to be active in such agreements in order to improve the accuracy of the data used in energy and climate policymaking.

This study suggests that there is considerable potential to achieve further energy efficiency savings. In the short term, further analysis is needed to verify and improve the benchmark data (based on extended benchmark surveys and energy indicators) reported in this study. Future research should be directed towards (i) developing strategies for realising the BAT potentials in each industry at the level of processes, (ii) improving the technologies beyond process level such as CHP, process integration and motor systems, and (iii) developing and applying novel and cost-effective technologies that could yield even higher savings than the currently available BPTs.

This study concludes that a joint international effort is required, first for increasing data availability and monitoring in developing countries, and second for harmonising data quality and consistency across all countries to enable more reliable estimates of energy efficiency improvement potentials to be made.

Corporate strategies motivated by market conditions will have important impacts on the rate of improvement in energy efficiency worldwide. Policy makers need to develop a clearer insight into the decision making processes that drive investments in energy efficiency in both ICs and DCs.

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ANNEX

Detailed sector results

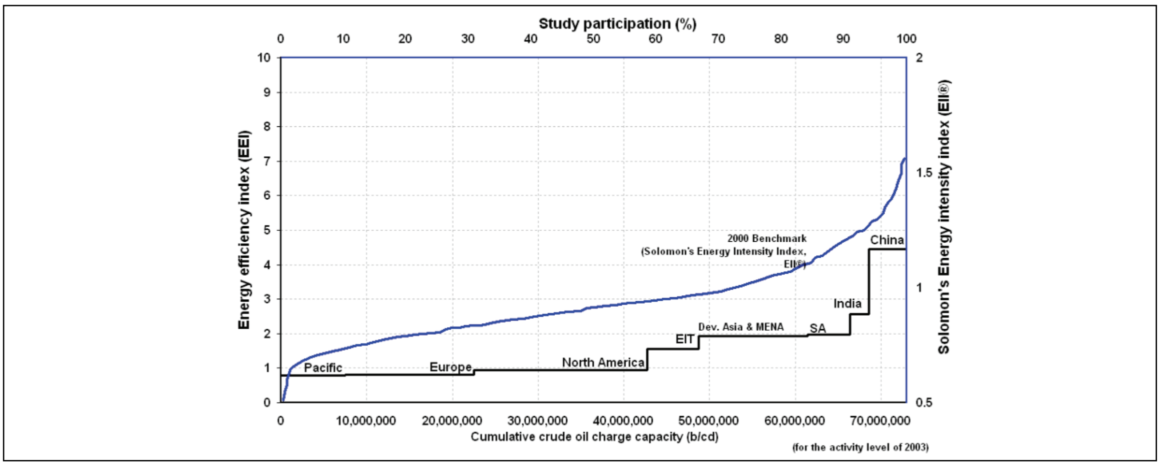
This annex presents the benchmark curves prepared for individual industry sectors. It provides background information on sectors and technologies only where such detail is relevant to the understanding of the international benchmark data.

a. Petroleum refineries

In refineries, crude oil is processed into a wide range of refinery products. In all refineries, the first step is to separate crude oil into various fractions by means of atmospheric distillation. These fractions are then upgraded and blended to produce different oil-derived products. Refineries convert crude oil to fuels and several other products such as aromatics, lubricants, sulphur and many other compounds.

For the refinery sector, it is not possible to derive a meaningful single average SEC value for different world regions. Each of the numerous processes which take place in refineries has its own BPT value. The structure and the product mix of refineries vary within the same country and across the world. The analysis takes these differences into account by estimating an EEI for each country based on the BPT of 13 refinery processes[23] and the refinery structure of each country. The actual energy use of the sector is the sum of the final energy use and transformation losses as reported in IEA Energy Statistics (IEA, 2003a, b).

FIGURE 6:
Solomon benchmark curve (2000) and the estimated benchmark curve for the refinery sector (2003)



[23] These processes are atmospheric distillation, vacuum distillation, coking, thermal operations, catalytic cracking, catalytic reforming, catalytic hydrocracking, catalytic hydrotreating, alkylation, aromatics, lubricants, and the production of hydrogen and sulphur. These processes in 2000 accounted for 70% of the total final energy use of the global refinery sector (Neelis *et al.*,2005).

Note: the black line shows the regional EEI with respect to cumulative crude oil charge capacity *(primary x-axis)*; the blue line shows the EII® of individual plants (*secondary* y-axis and *secondary* x-axis) denoted by study participation (expressed in %)).

Solomon Associates is an independent consulting firm that performs sectoral and product energy benchmarks, including for the refinery sector. The sector results prepared by Solomon Associates are expressed in an EII® (Energy Intensity Index) which accounts for the scale, location and complexity of refineries. A more detailed explanation of their approach can be found in Matthes *et al* (2008). EII=100 is defined as standard energy use. A refinery with an EII below standard is more efficient than a refinery with EII higher than the standard. In **Figure 4**, in order to be comparable with the scale of EEI, we show EII=1 as standard energy use instead of the typical Solomon approach where EII=100.

References to study participation here and later in this report refer to the proportion of the total volume of production that is covered in the relevant benchmark survey. The coverage of individual surveys is in some cases significantly less than the total global production of the relevant sector. Where quoted, participation rates describe the percentage of overall global production that is covered by each survey.

Source: OGJ, 2003; IEA, 2003a, b; Solomon 2000 in Matthes et al., 2008; own estimates

According to this analysis, OECD Pacific, OECD Europe and OECD North America have EEI less than 1[24]. This implies that they are more efficient on average than BPT. This is not technically possible. Other regions have EEIs as high as 4.5. These results point to limitations in the methodology and the data used. A country-level analysis is not possible for sectors such as the refinery sector where cogeneration and energy integration of the processes have significant impacts on levels of energy efficiency (Saygin *et al* (2009)). Site specific data are required for a meaningful analysis, as described in the main text of this report.

b. Chemical and petrochemical sector

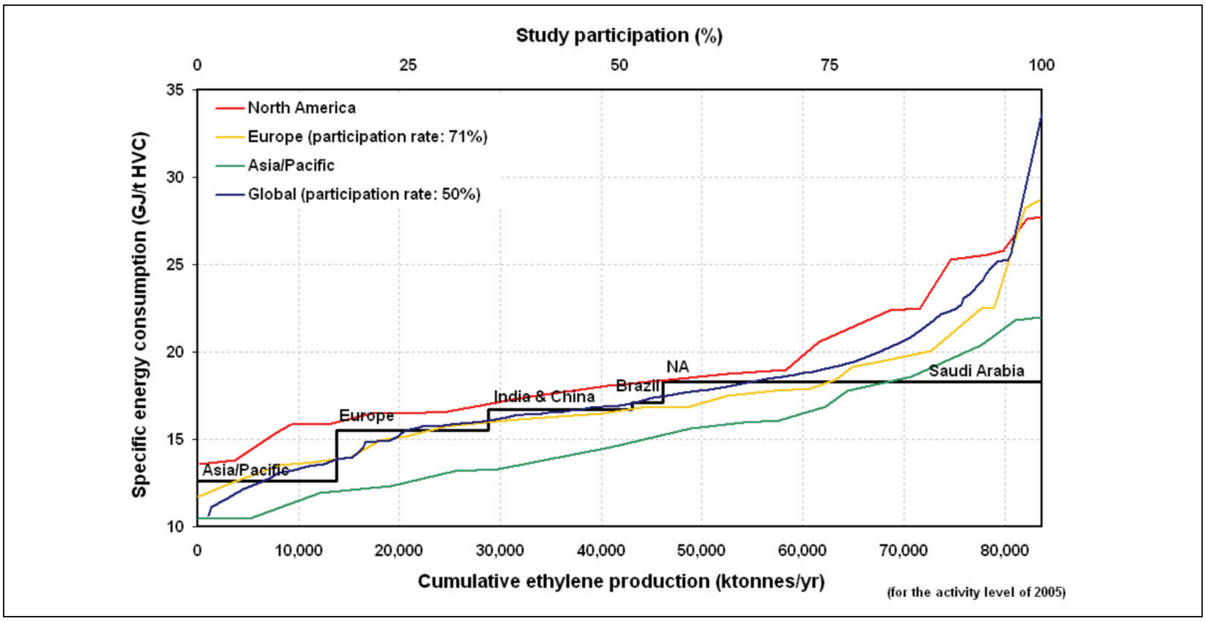
Production of ethylene and other high value chemicals (HVC) such as propylene, butadiene (C4 fraction), benzene (aromatics) and hydrogen in steam crackers, together with the production of ammonia and methanol, account for more than half of the sector's total final energy use (including the related quantities of petroleum feedstocks). Some 95% of the sector's total final energy use is accounted for by approximately 60 processes (Neelis *et al.,* 2007b; Saygin et al., 2009). However, given the lack of publicly available data it is impossible to prepare benchmark curves for all these chemical rocesses.

High value chemicals (HVCs) production in steam crackers

Steam cracking is by far the largest energy user in the chemical and petrochemical sector, accounting for more than one third of the sector's final energy use including feedstocks (IEA, 2009c). Figure 7 shows the results of a Solomon Associates survey covering more than half of the global ethylene production capacity (Solomon, 2005 in Leuckx, 2008).

[24] Solomon EIIs for the EU weighted average and EU best practice are 80.5 and 59 respectively. This is equivalent to an energy efficiency improvement potential of 27% in the EU petroleum refineries (Schyns, 2006).

FIGURE 7:
Solomon benchmark curves and the estimated benchmark curve for steam crackers benchmark, 2005



Note: the black line shows the regional current average SEC with respect to cumulative ethylene production (*primary* x-axis); the colored lines show the energy use of individual plants (*secondary* x-axis denoted by study participation (expressed in %)). SECs are expressed in terms of energy use per tonne of HVC.

Source: OGJ, 2003; IEA, 2003a, b; Solomon, 2005 in Leucx, 2008; own estimates

TABLE 4:
Energy use of the steam cracking process (in GJ/t HVC) and the improvement potentials

	2006	International and regional benchmark (2005)	Improvement potentials (%)
Global1	16.9	12.5	25
Europe1	~15.6	13.7	20
North America	~18.3	15.8	32
Asia-Pacific	~12.6	11.2	1
China	~17.1	-	27
India	~17.1	-	27
Brazil	~18.3	-	32

Source: Saygin et al., 2009 for year 2006; Solomon, 2005 in Leucx, 2008.

Note: Improvement potentials are estimated by comparing average 2006 values with the *international benchmark* (estimated at the 1st decile in the global benchmark curve as 12.5 GJ per tonne of HVC).

1 The 2001, 2003 and 2005 surveys covered 70% (14 Mt), 89% (21 Mt) and 71% (17 Mt) of the total European production respectively. The worldwide participation rates in the same years expressed in terms of physical production were 39 Mt, 69 Mt and 66 Mt respectively (Leucx, 2008). In 2005, the participation rate was equivalent to 50% of the total global production that year. In the absence of reliable production statistics covering earlier years, worldwide participation rates cannot be estimated.

TABLE 5:
IFA benchmark survey results for 2004 and 2007 (lower heating value, in GJ/t NH_3)

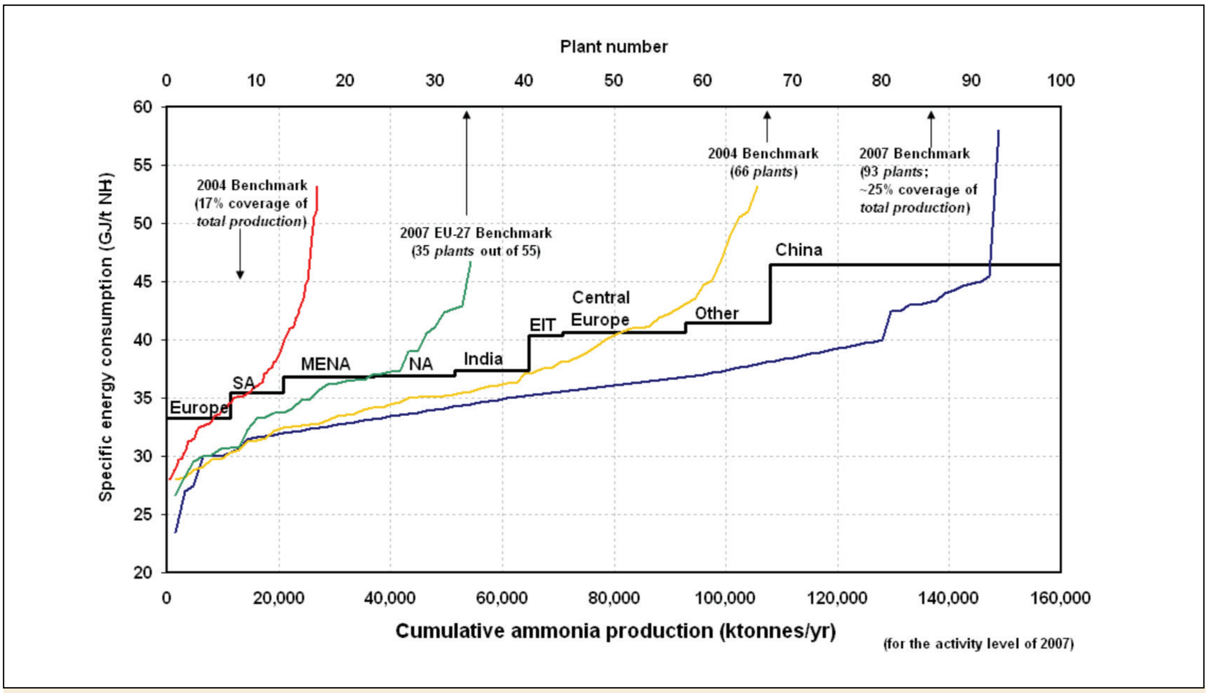
	2004 (plant)	2004 (production)	2007 (plant)	2007 EU-27 (plant)
Lowest SEC	28.0	28.0	23.5	27
1st decile	30.3	29.7	31.5	28.7
Last decile	43.5	43.3	43.0	42.9
Highest SEC	53.2	53.2	58.0	46.7
Average		36.9	36.6	35.7

Note: Plant: results of benchmark survey results based on individual plants; Production: results of benchmark survey results based on production capacity.

2004 Benchmark survey (production) is based on Lako, 2009. In the study, SEC data for 66 plants was distinguished between three categories on the basis of plant capacity, namely ‹1000 mtpd, 1000-1500 mtpd and ›1500 mtpd. In order to rank 66 plants with respect to same production scale, we assume that plants utilised 100% of their reported capacity.

Source: 2004 Benchmark (66 plants): PSI in EFMA 2008; 2004 Benchmark (production):PSI in Lako, 2009; 2007 Benchmark (93 plants): IFA in Gielen, 2009; 2007 Benchmark EU-27 (35 plants): IFA in Ecofys, 2009.

FIGURE 8:
IFA benchmark curves (2004 and 2007) and the estimated benchmark curve (2007) for ammonia industry



Note: Black and red lines refer to cumulative production (*primary* x-axis); all other curves refer to the plant number (*secondary* x-axis).

Source: 2004 Benchmark (66 plants): PSI in EFMA 2008; 2004 Benchmark (production): PSI in Lako, 2009; 2007 Benchmark (93 plants): IFA; 2007 in Gielen, 2009 Benchmark EU-27 (35 plants): IFA in Ecofys, 2009; USGS, 2009a; own estimates.

Ammonia

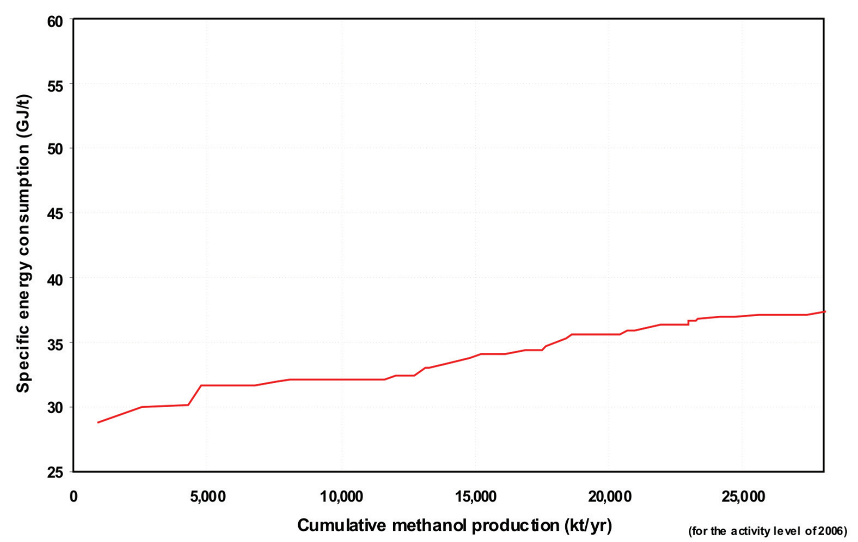
Figure 8 shows five benchmark curves, four of which were prepared by Plant Survey International (PSI). The fifth is based on new analysis for this study. Two of the curves prepared by PSI refer to the year 2004, one referring to cumulative worldwide production (red line) and the other to specific plants (yellow line). The third (blue) and fourth (green) curves prepared by PSI refer to the year 2007 and represent ammonia production worldwide and in the 27 EU member States (EU-27) respectively. Our own estimates (black line) depict the sector's energy efficiency on a regional basis. This is based on SEC values for ammonia production in different regions from various sources (IEA 2007; 2009d; Schyns, 2006; Nand, 2008; NRCAN, 2008; Yara, 2008; Lako, 2009; Zwiers, 2009; and from papers presented at IFA technical conferences). These regional datasets refer to the sector's energy use in years between 2002 and 2006, corrected to the reference year 2007 by the application of an estimated energy efficiency improvement of 0.5% a year.

We determine the international benchmark as the ammonia plant at the 1st decile on the 2007 IFA benchmark curve (*i.e.* 31.5 GJ per tonne of ammonia). Since the most efficient plants are operated on natural gas, we assume that all plants in the world will switch to natural gas in their processes.

Methanol

A detailed plant inventory of the global methanol capacity to the end of 2006 has been conducted by the Methanol Institute (MI, 2009). Ideally, this inventory should for each country or region produce information on capacity, feedstock type, the first year of operation (or age) and the technology applied in each individual plant. Much of this data is absent for China, Brazil and Russia[25]. The analysis therefore excludes the entire capacity in China and parts of the capacity in Brazil and Russia.

FIGURE 9:
First estimate of benchmark curve for the methanol industry, 2006



Source: MI, 2009; Own estimates

Note: Production is estimated by multiplying the total capacity with a capacity utilisation rate of 85%.

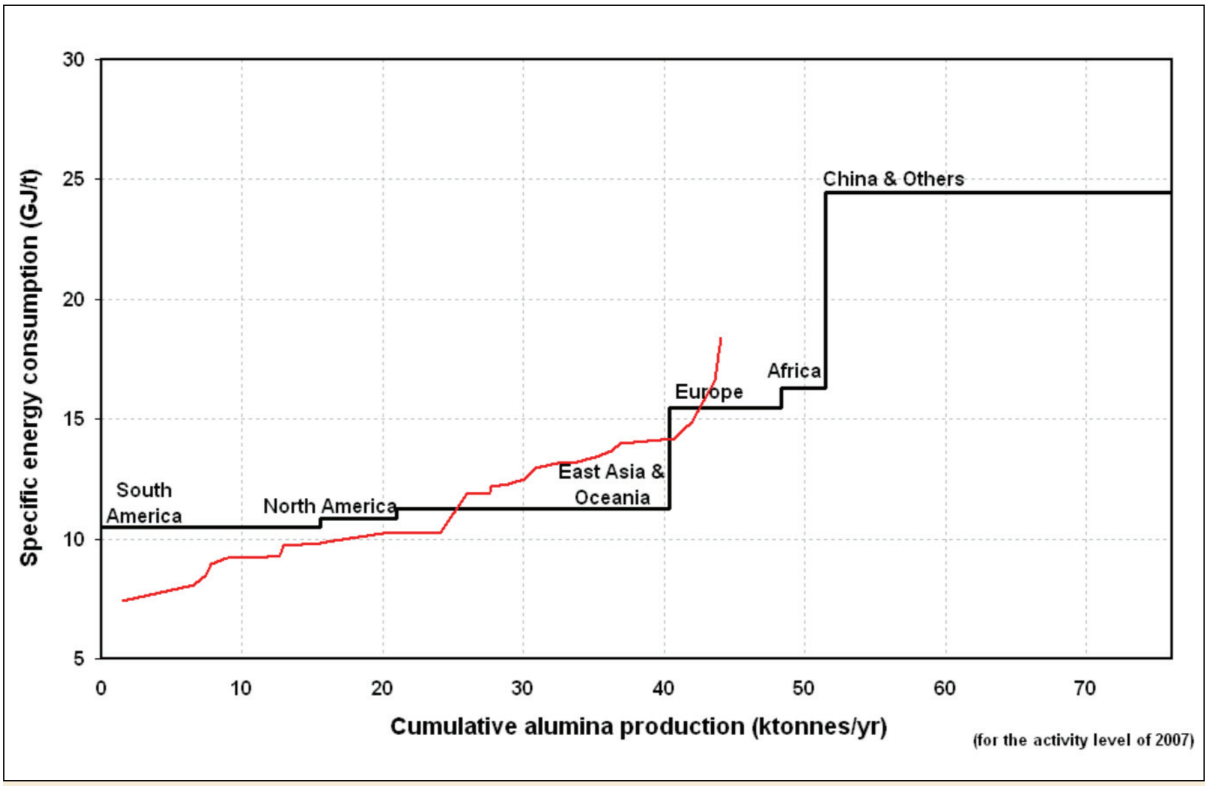
[25] These countries account for more than a quarter of the installed methanol capacity worldwide. China's capacity is unknown, but is estimated to amount to more than 15% of the total worldwide capacity.

The largest plants are operated in South America (particularly in Trinidad and Tobago and Chile) and in the Middle East (in Iran and in Saudi Arabia). These two regions accounted for more than half of the global capacity in 2006. On average, Europe and some new plants installed in these developing countries are the most energy efficient regions in methanol production with an estimated average SEC, including feedstocks, of approximately 33 GJ per tonne of methanol (Figure 9). The plants with the highest energy use are operated in developing Asia including India and in transition economies. The energy efficiency improvement potentials compared to the international benchmark are approximately 10% to 15% in Europe and as high as 25% in economies in transition and in India.

c. Non-ferrous metals

The non-ferrous metal industry is responsible for the production of aluminium, copper, chromium, nickel, zinc and other non-ferrous metals. The aluminium industry has the most detailed SEC and production data available, collected by the International Aluminium Institute (IAI). The analysis in this study reviews the production of metallurgical alumina, the raw material for primary aluminium, and the production of primary aluminium in smelters. Using benchmark surveys, copper smelters and slab zinc production are also analysed.

FIGURE 10:
IAI benchmark curve and estimated benchmark curve for alumina production, 2007



Black line: average SEC of world regions. Red line: Plant specific SEC, excluding China and parts of several other regions (IAI, 2009).

Sources: IAI, 2009a,b; IEA, 2009c; Liu et al., 2009; Xiao-wu et al., 2009 own estimations

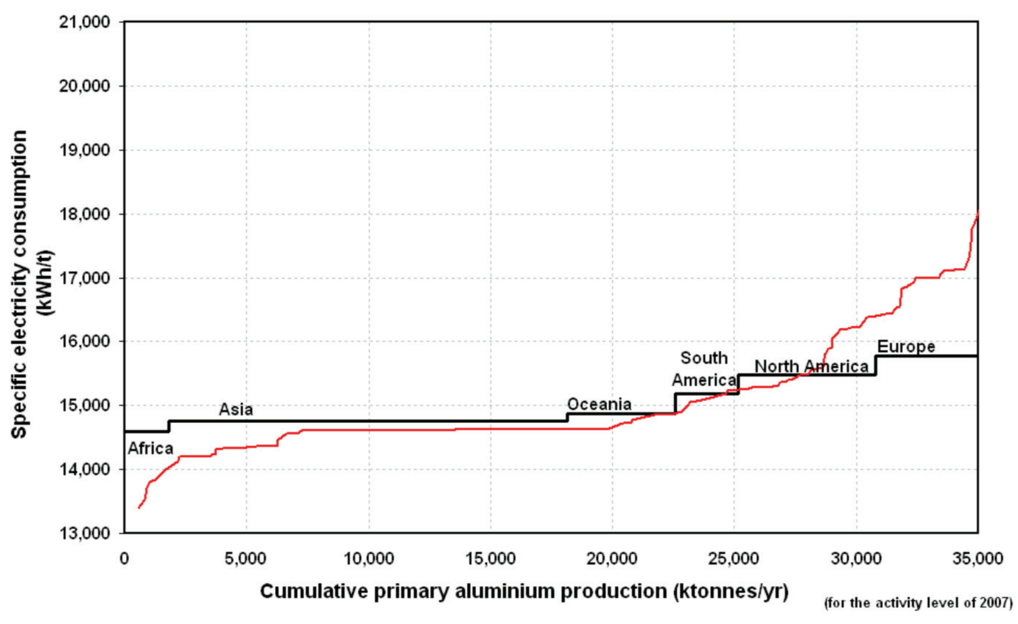
Alumina production

Based on IAI statistics, Figure 10 shows two sectoral energy use graphs for alumina production. The black line shows new estimates which include China and other countries missing in the IAI statistics. The red line shows the global benchmark curve prepared by the IAI, which covers 60% of world wide alumina production. Compared to the international benchmark (7.8 GJ/tonne, based on the global benchmark curve) North America and East Asia (including Oceania), which account for 60% of global production, have the potential to improve performance by only a few percent. Europe (including Central Europe and EIT) and Africa have the potential to improve performance by around 35% and China by up to 50%.

Primary aluminium production

Smelting is the most energy intensive step in the production of primary aluminium. The vast bulk of the energy used is used in the form of electricity. Figure 11 shows two benchmark curves for aluminium smelters. The black line shows new estimates which include China and other regions. The data originate from IAI statistics except for China for which the data are derived from on other literature. The red line shows the extended global benchmark curve which also includes China. The plant SEC data is collected by IAI. Excluding China, it covers 65% of world production (IAI, 2009a). We have estimated the energy use of the Chinese sector separately based on publicly available data (Zunhua, 2008; Yanjia and Chandler, 2010), which raises the production coverage to approximately 95%.

FIGURE 11:
IAI benchmark curve and estimated benchmark curve for primary aluminium production, 2007



Notes: IAI data refer to the SEC in primary aluminium production used for electrolysis by the Hall-Heroult processes (including rectification from alternating current to direct current). The data include smelter auxiliaries (including pollution control equipment). They exclude the power used in casting and in carbon plants.

Bosnia and Herzegovina, Iran, Poland and Romania, in total representing less than 2% of the total global primary aluminium production, are excluded from this dataset.

Source: IAI, 2009a,b; Zunhua, 2008; own estimates

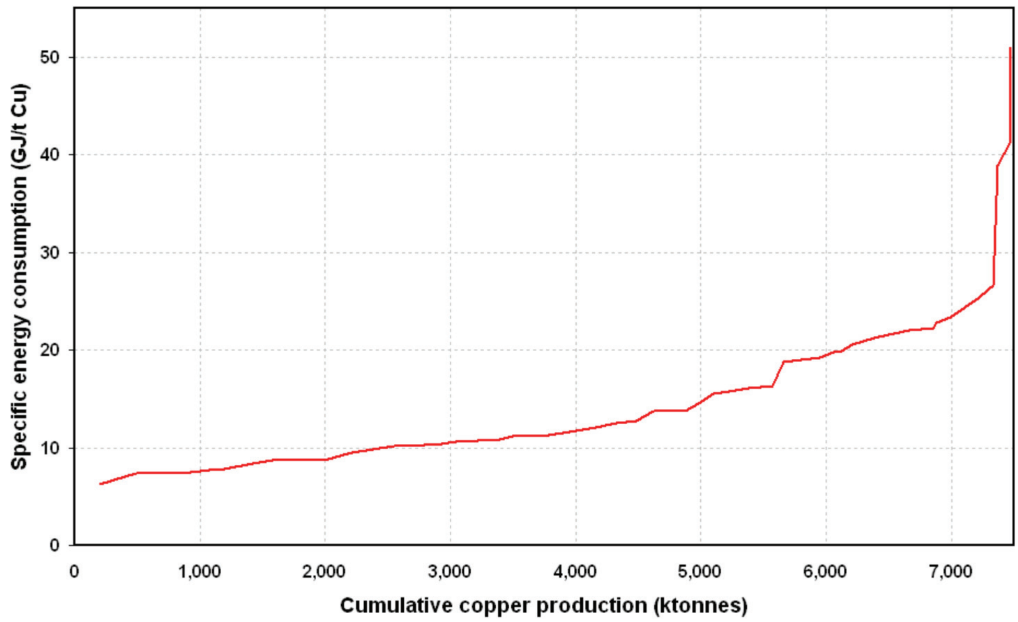
The region with the lowest SEC is Africa. This is possibly a result of recent investments in modern, large-scale plants in Mozambique and South Africa (BHP Billiton, 2006). On average, plants in China (which account for 77% of Asia's production capacity, under which they are reported) are also relatively efficient.

Worldwide, the average energy use is 15 560 kilowatt hours (kWh) per tonne of primary aluminium. The IAI is seeking to reduce the average to 14,500 kWh per tonne of primary aluminium, either by revamping or by replacing existing smelters (IEA, 2009c). This would achieve electricity savings of around 7%. New plants have energy use as low as 13,500 kWh per tonne, suggesting that up to 13% of current smelter electricity use could be saved. According to the IAI benchmark survey, the electricity use of the international benchmark is 14 215 kWh per tonne of primary aluminium produced[26].

Copper smelting

Sulphide ore concentrates, currently accounting for approximately 80% of the total primary copper production, are smelted and then refined to obtain high purity copper (Ullmann's, 2007). On the basis of the copper smelters benchmark survey (**Figure 12**), the energy use of the international benchmark is estimated to be 7.4 GJ per tonne of copper. The average energy use worldwide is 13.8 GJ per tonne. This implies the existence of a global improvement potential of 46% in the energy efficiency of copper smelters.

FIGURE 12:
Compiled benchmark curve for copper smelters based on Brook Hunt[27]

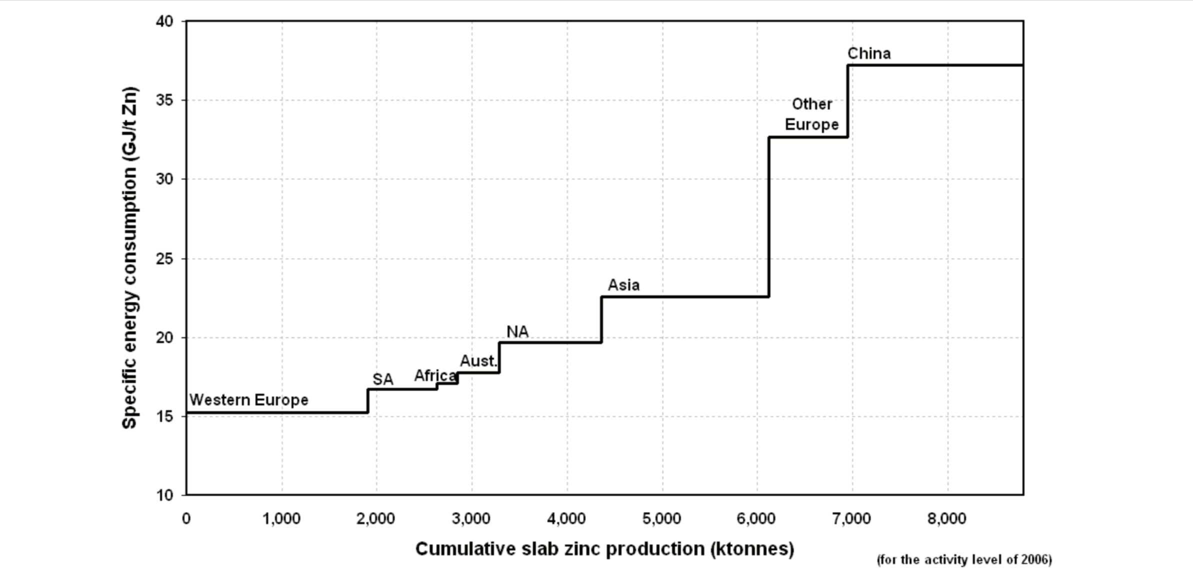


Note: Data is provided in Partinen (2008) as total net energy consumption versus total copper production for each copper smelter.

Source: Data is reproduced based on Partinen, 2008

[26] The international benchmark is estimated by including China with its estimated average SEC value in the IAI survey. Given China's large volume of production, this increases uncertainty significantly.
[27] Brook Hunt is a research and consulting company which benchmarks the production energy use and production costs of non-ferrous metals (e.g. copper, zinc, etc).

FIGURE 13:
Brook Hunt benchmark curve for zinc smelters, 2006



Source: *Data is reproduced based on Kouw, 2009*

Slab zinc production

Slab zinc is produced by smelting zinc ore concentrates either through a pyrometallurgical process or through electrolysis. Using a benchmark survey for zinc smelters (**Figure 13**), the international benchmark energy use is estimated to be 15.2 GJ per tonne of zinc, based on the performance of smelters in Europe. The average SEC worldwide is 23.6 GJ per tonne. This indicates a global improvement potential of 36%.

d. Iron and steel

The primary output of the iron and steel sector is crude steel. Across the world, four major routes are applied for the production of crude steel:

- Blast furnace (BF)/Basic oxygen furnace (BOF)
- Smelt reduction/Basic oxygen furnace (BOF)
- Direct reduced iron (DRI)/Electric arc furnace (EAF)
- Scrap/Electric arc furnace (EAF)

The process shares of crude steel production differ between countries. The most commonly used processes are BOF and EAF. BOF accounts for approximately two thirds of worldwide production, and EAF for slightly less than one-third. Around 3% of the worldwide capacity is based on open hearth furnaces. These are being phased out.

For each country, an EEI value is estimated which reflects the process mix and includes the production processes of the most important end-products into which crude steel is further processed[28]. These are:

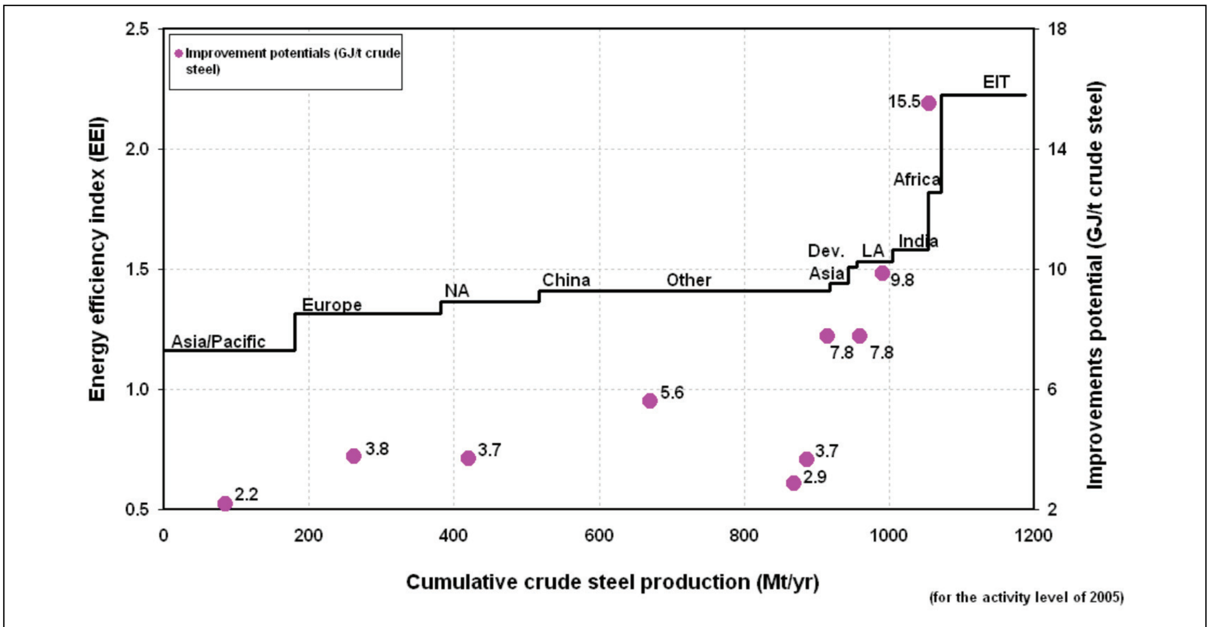
- Hot-rolled flat products,
- Hot-rolled bars and concrete reinforcing bars, and
- Wire rod.

[28] The final energy use of the iron and steel sector is only partly reported in the IEA Energy Statistics under iron and steel. Although the total final energy use for the production of crude steel from pig iron and the power use in blast furnaces are included under this item, the fossil-fuel requirements of the blast furnace are excluded. The total energy consumption for these two items is added together.

Plants in Asia/Pacific operate with the lowest energy use (EEI=1.15), followed by the plants in Europe (1.3) and North America (1.35). Iron and steel plants in India (1.55), Africa (1.8) and EIT (2.25) have relatively high levels of energy use. EEI values can also be expressed in terms of potential energy savings (in GJ) per tonne of crude steel production compared to BPT. Regional averages on this basis are shown in Figure 14 as purple dots with respect to the *secondary* y-axis. The savings potentials per tonne of crude steel do not necessarily follow the same ranking as the EEI. This reflects structural differences in the activities of the sector between countries. In countries with a high EEI and a high share of secondary steel production, the specific improvement potentials tend to be lower than in those countries that have an equally high EEI but produce more primary steel. This can be seen, for example, in the figures for North America and for Europe.

The Asia Pacific Partnership (APP) is increasingly active in collecting comparable and consistent data on the energy performance of BOFs and EAFs operating in Australia, Canada, China, India, Japan, Korea and the United States. Together, these account for around 60% of the total global iron and steel production. The APP's latest industry survey shows that the most efficient BOF in the region has an energy use of 18.2 GJ per tonne of steel and the least efficient blast furnace uses 40.9 GJ per tonne of steel. The best EAF has a specific energy use of 6.2 GJ per tonne of steel and the least efficient EAF uses 30.1 GJ per tonne of steel (APP, 2008). The coverage of the study is complete for Australia, Canada and Korea and partly so for Japan with limited coverage of EAFs. The data for all other countries have major gaps. Given this patchy coverage, the APP results are not used in the present analysis.

FIGURE 14:
Estimated benchmark curve for the iron and steel industry, 2005



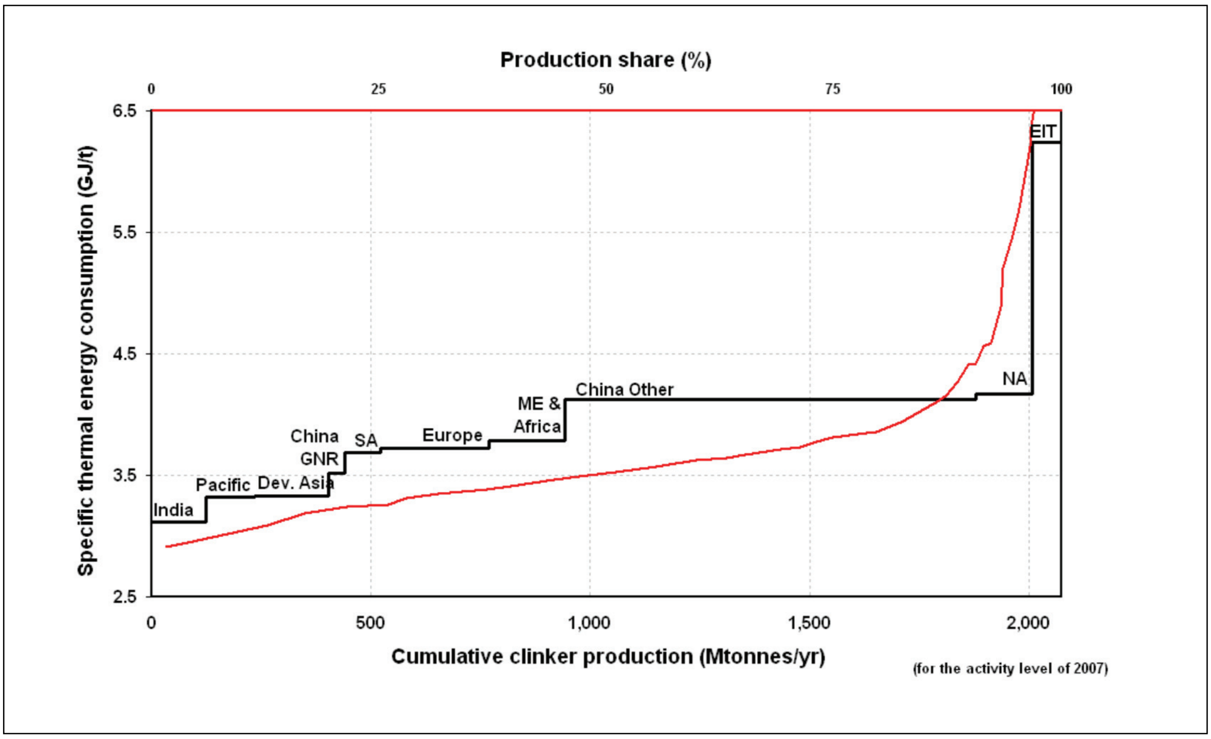
Note: The benchmark curve is based on the left hand y-axis. The dots show the specific improvement potentials in each region relative to BPT based on the right hand y-axis.

Source: WSA, 2009; IEA, 2006a, b

e. Non-metallic minerals industry

The non-metallic minerals sector includes the production of cement, lime, bricks, glass and ceramics. In most countries, cement and lime production are by far the largest energy users in the sector, accounting for more than 80% of the sector's reported energy use according to international energy statistics. Among the sub-sectors, the cement sector has the best developed arrangements for the collection of data on energy and CO2 emissions, through the Cement Sustainability Initiative (CSI). The glass industry has made efforts to produce similar data. But the production coverage is limited and the publicly available results are now out-dated. For the lime sector, a recent paper by EuLA (2009) provides benchmark curves for the European lime sector for horizontal and vertical kilns. But no data yet exist on which a global benchmark could be based.

FIGURE 15:
CSI benchmark curve and estimated benchmark curve for clinker production, 2007



Black line: own estimates based on CSI (2009a) and IEA (2009c). Red line: based on the GNR database.

Note: "China GNR" is estimated based on GNR database which covers 4% of China's cement production (from a total of 60 plants). "China Other" is our own estimate for the remaining 96% of production, based on a total China average of 4.1 GJ of thermal energy per tonne of clinker (IEA, 2009c).

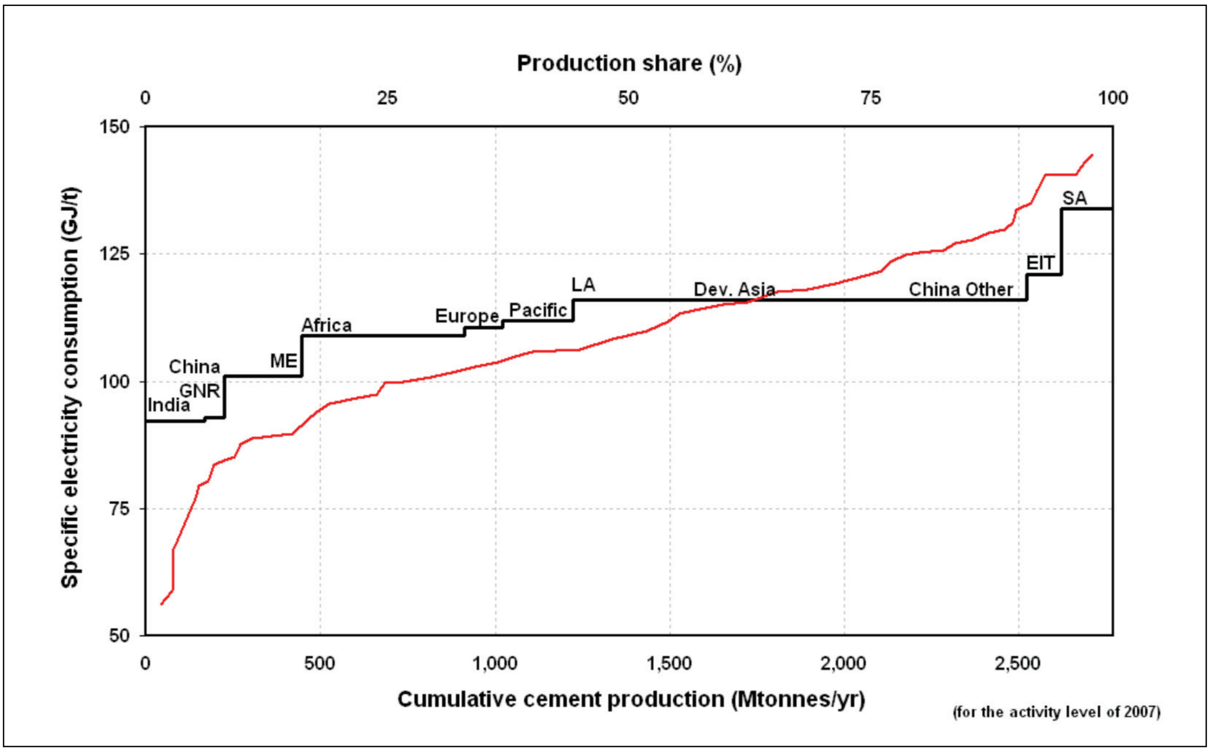
Source: GNR Database (CSI, 2009a); own estimates.

Cement

Clinker plants with the lowest final energy use[29] are operated in India at 3.1 GJ per tonne of clinker followed by the plants in the Pacific region and other developing Asia at around 3.3 GJ per tonne (**Figure 15**). The least energy efficient plants are located in North America at 4.2 GJ per tonne and in EIT countries at 6 GJ per tonne. The energy use of the BPT (a six-stage pre-heater and pre-calciner kiln) is 2.9 GJ to 3.3 GJ per tonne of clinker. The benchmark curve developed for this study indicates that the worldwide average energy use for clinker production is approximately 3.9 GJ per tonne. On this basis, the average energy saving potential is around 0.6 GJ to 1 GJ per tonne of clinker, *i.e.* approximately 24%.

The electricity consumed in cement plants (for grinding) is surveyed separately by GNR (**Figure 16**).

FIGURE 16:
CSI benchmark curve and estimated benchmark curve for cement production (electricity for grinding only), 2007



Black line: own estimates based on CSI (2009a) and IEA (2009c). Red line: based on GNR database.

Note: "China GNR" is estimated based on GNR database which covers 4% of China's cement production. "China Other" is our own estimate based on 115 kWh grinding electricity use per tonne of cement (IEA, 2007).

Source: GNR Database (CSI, 2009a); own estimates.

[29] Total final energy use for cement production in each country is estimated as the sum of (i) fuel SEC of clinker production multiplied by clinker-to-cement ratio and (ii) electricity SEC for cement production.

TABLE 6:
Specific energy consumption of lime kilns in selected countries

Region	EU-27[1] Heat use (GJ/t)	EU-27[1] Kiln electricity use (kWh/t)	US	Canada	China	India	Thailand
Horizontal kilns							
Long rotary kilns	6-9.2	18-25		7-13	-	-	-
Rotary kilns with preheater	5.1-7.8	17-45		6-9	-	-	-
Vertical kilns	-	-	-	5-7	4.5		<13.2
Parallel flow regenerative kilns	3.2-4.2	20-40	-	-	-	-	
Annular shaft kilns	3.3-4.9	18-35 (50)	-	4-4.5	-	-	-
Mixed feed shaft kilns	3.4-4.7	5-15	-	-	-	-	-
Other kilns	3.5-7.0	20-40	7.23	7.2	-	5.6	-

[1] Lower bound: large-scale kilns; upper bound: small-scale kilns.
[2] Data refer to small vertical kilns (Dankers, 1995).
[3] Refers to the energy use of lime kilns operated in US pulp and paper mills (Miner and Upton, 2002).

Source: NRCAN, 2001; CIEEDAC, 2004; IPTS, 2010; Venkatarama Reddy and Jagadish, 2003; Wei, 2007; IEA, 2007; Dankers, 1995; Miner and Upton, 2002

Lime production

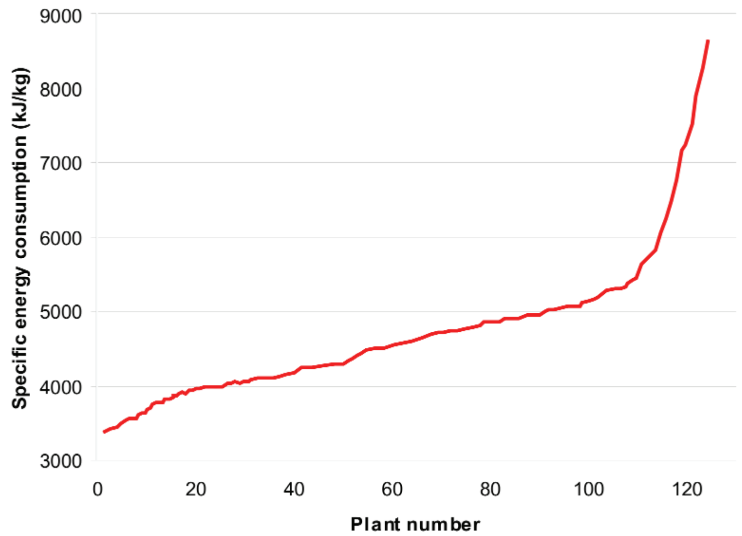
Global lime production including captive lime[30] is 172 Mt (IPTS, 2010). More than 40% is produced in China, and 16% in Europe (EU-27). In Europe (including EFTA and Croatia and Turkey) there are around 600 kilns producing lime other than for captive uses. In 2006, 5 000 kilns in China produced 75 million tonnes of lime. Most of these plants are small-sized and approximately 60% of them are based on outdated earthen kiln technology. A switch to the use of semi-mechanised and mechanized vertical kilns would achieve energy reductions of around 20%. In addition, almost all the lime kilns in China are fuelled by anthracite coal.

Glass production

Glass production typically involves the mixing of raw materials, melting in furnaces, forming and post-processing (including annealing and finishing). The first two processes are identical regardless of the type of final glass product. Melting accounts for the largest share of energy use in a glass plant (~80%). A 1999 benchmark survey covering 123 container glass and 23 flat glass furnaces operated worldwide found a difference of approximately a factor two between the best furnaces operating at 3 850 kJ/kg of glass produced, and the least efficient ones operating at more than 8 000 kJ/kg of glass (Beerkens and Limpt, 2001). The average energy use was 5 200 kJ/kg of glass (**Figure 17**). Generally, float glass production consumes more energy than container glass production. The SEC for specialty glass products such as TV panel glass is even higher, due to higher quality requirements (Ullmann's, 2007), but no reliable data is available at country level.

[30] Captive lime is lime produced for internal consumption in integrated plants (in sugar, pulp and steel industries).

FIGURE 17:
Energy requirements of 123 continuous container glass furnaces, 1999 (normalized for 50% cullet)



Source: Data and figure are reproduced based on/from Banarjee, 2006; Sardeshpende et al., 2007

TABLE 7:
Overview of specific energy consumption in continuous glass furnaces (in kJ/kg of melted glass)

	Average	1 st decile (or BPT)			Production
	Container	Flat	Container	Flat	volume (M\t/yr)
Global[1]	~5,200	-	~3,850	-	~130
US	4,000-10,000 (6,065)	5,000-8,500 (6,860)	3,270	3,690	~21
EU-27	4,000-10,000 (~5,000[2])	5,800-8,700	4,200[3]	6,300[4]	~33
China[5]		7,800		-	~27
India[6]	6,800	-		~4,400	~2
Russia				-	~5.2

Note: Production volumes are for 2005 and include the production of container glass, flat glass, glass fibres (incl. mineral wool, textile and optical) and other glass products, *e.g.* specialty glasses.
[1] Data refer to **Figure 17** where the benchmark curve represents the situation in 1999 only. Data for US and EU-27 refer to more recent years. Other studies report much lower energy use at approximately 2 650 kJ/kg for BAT (Kobayashi *et al.*, 2005). To apply a consistent methodology across all countries, we use the results of the 1999 benchmark survey.
[2] Data in brackets are own estimate based on the survey results of 256 furnaces. Data is corrected for 50% cullet.
[3] The most efficient plant applies end-fired regenerative technology. If energy required for oxygen production is excluded, then oxy-fuel technology represents the BPT with a SEC of 3050 kJ/kg to 3500 kJ/kg melted glass. Data is corrected for 50% cullet.
[4] Technology refers to modern energy-efficient cross-fired glass furnace with regenerative air preheating (float glass). Data is corrected for 20% cullet.
[5] The survey includes 28 float glass production lines.
[6] The survey includes 17 furnaces.

Source: Beerkens and Limpt, 2001; IPTS, 2009draft; Banarjee, 2006; Rue et al., 2007; Wang, 2007; Sardeshpende et al., 2007; Sarkisov et al., 2007

Table 7 compares the SEC of continuous glass furnaces operated in the four major manufacturing regions, the United States, EU, China and India. On average, US glass furnaces have the lowest SEC for container and for flat glass production. Furnaces in Europe have higher energy use for container glass production. Glass furnaces in China have the highest energy use. The energy used by batch furnaces is much higher than that used by continuous glass furnaces, ranging from 12.5 GJ to 30 GJ per tonne of glass produced (Römpp, 1995). Worldwide, the potential energy saving from moving all plants to the efficiency of the BPT amounts to approximately half of the sector's current energy use.

Ceramics

Bricks and tiles, fine ceramics, sanitary stoneware, and similar products are produced by the ceramics sector. In this section, we elaborate on brick making only due to significance of its energy use in SMEs and small-scale industries (GEA, *in preparation*) and to the availability of numerous data in literature. There are currently 300 000 kilns operating worldwide. Four countries, China (54%), India (11%), Pakistan (8%) and Bangladesh (4%) account for approximately 75% of the worldwide production (Chaisson, 2008).

TABLE 8:
Specific energy consumption of different brick making technologies in selected countries (in GJ/t)

	Intermittent kilns	Bull's trench kilns	Hoffmann kilns	Tunnel kilns	VSBK kilns
Bangladesh[1]	2-4.5	1.152			
China	2.5		1.2-1.5[3]	1.3-1.5	
India	3-11[4]	1.8-4.2 1.1-1.8	1.5-4.3	1.5-2	0.7-1.0
Indonesia[1]	2-4.5				
Nepal[1]	2-4.5				0.7-1.0
Sri Lanka	5-65				
Thailand[1]	2-4.5				
Vietnam	2.2-3.1			1.4-1.6	0.7-1.0
Brazil	2-3				
Bolivia			1.5-6		
Egypt			9-11		
Europe				1.5-3[6]	
BPT	1.5 (clamp)	1.9 (0.75)[7]	1.5	1.5	0.75

Note: 1 brick weighs 2.5 - 3 kg.
[1] Data given for intermittent kilns is average for Asia (Heierli and Maithel, 2008).
[2] Fixed chimney kilns.
[3] Artificial drying adds another 0.1-0.25 GJ/t energy use.
[4] Scotch kilns have an energy use of 1.5 GJ - 7 GJ/t. Downdraught kilns may use 9.3 GJ/t.
[5] Refers to the performance of downdraft kiln where drying takes place via natural draft.
[6] Refers to firing and drying in tunnel kilns. The manufacture of clay blocks requires slightly lower energy. In 2003, average SEC in the EU was 2.3 GJ/t (IPTS, 2007). A modern tunnel kiln in Germany uses 1.1 - 2.5 GJ/t (Heierli and Maithel, 2008).
[7] Value in brackets refers to the best fixed-chimney Bull trench kilns.

Source: AIT, 2003; Zaiyin, 2007; Schwob et al., 2009; UNFCCC, 2006; Lebbing, 1999; Nurhayati et al., 2006; IPTS, 2007; Heierli and Maithel, 2008; ESMAP, 2007; FAO, 1993

China is the largest brick producer worldwide, operating around 90 000 kilns for brick production with an output of around 900 billion bricks, two-thirds of which are solid burnt clay brick and the rest new wall materials (Zaiyin, 2007; Chaisson, 2008). 90% of the production in China is based on Hoffmann (annular) kilns. India is the second largest brick producer worldwide with an output of around 140 billion bricks from 100 000 kilns of which 70% are Bull trench kilns (Maithel, 2002; Chaisson, 2008). 80% of the capacity in South Africa is based on clamp kilns. Three quarters of the production in Bangladesh is based on more than 3 000 fixed chimney kilns (Ferdausi *et al.,* 2008).

Several kiln types are used in brick making. The most energy intensive kilns are intermittent kilns, such as clamp, scove and Scotch kilns, where bricks are fired in batches (Table 8). Continuous kilns are more energy efficient due to continuous firing. They come in two main types, depending on whether the bricks or the fire move during the process. The bricks move in tunnel kilns and vertical shaft brick kilns (VSBK) developed in China. The fire moves in Hoffmann kilns and Bull trench kilns.

VSBK is the most energy efficient kiln type **(Table 8)** and is the technology of choice in several South East Asian countries such as India, Nepal, Pakistan and Vietnam. VSBK kilns require a relatively high capital investment[31].

f. Pulp and paper sector

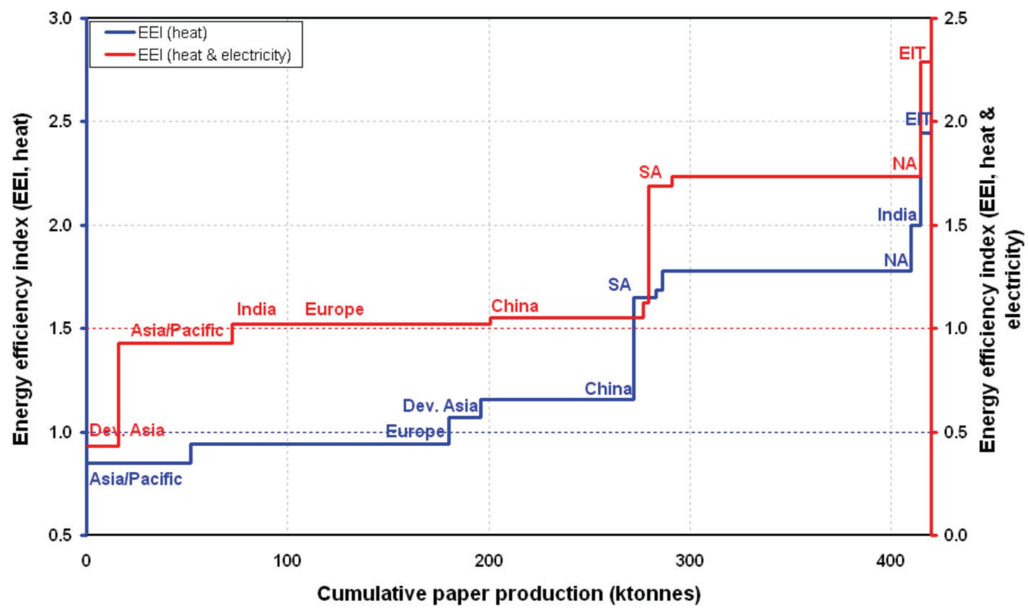
The main activities of the pulp and paper sector are chemical pulping, mechanical pulping, paper production and paper recycling. Unlike any other industry sector, the pulp and paper sector is a large generator of energy, particularly in kraft (or chemical or sulphate) pulp mills, in the form of black liquor. Black liquor is converted into heat and power which is consumed internally either in the pulp mill itself and/or at the paper mill if the site is an integrated one. Currently, around half of the sector's energy demand is met by biomass residues in this way. Mechanical pulping uses energy in the form of power only.

Energy integration in the pulp and paper sector makes it difficult to account consistently for the sector's energy demand. While many countries produce chemical pulp, the biomass energy used is not reported under the pulp and paper sector in the international energy statistics, but instead under other non-specific industries (IEA, 2009c). This makes the development of an EEI for the pulp and paper sector based on energy statistics very uncertain **(Figure)**. Some regions such as developing Asia, Asia/Pacific and Europe have EEI values less than 1. This implies that they are more efficient on average than BPT. This is not technically possible. Other regions have EEIs as high as 2 to 3.

The sector's energy efficiency potentials compared to BPT as reported by the IEA are shown in Table 9 (IEA, 2009c). The largest potentials exist in plants operated in Russia, followed by plants located in the United States and Canada, reflecting the continuing use of older capital stock in these regions. The capacity in Europe, particularly in Finland (Jokinen, 2006; IEA, 2009c) and in Brazil is amongst the newest. As a result, these regions have only limited further energy efficiency potentials. Chinese plant has a large potential to improve energy efficiency (IEA, 2007). Estimates of low specific energy saving potentials in China underline the degree of uncertainty in the energy statistics.

[31] VSBKs are generally used to fire solid bricks in South Asia although they are used extensively to fire hollow bricks in Vietnam. According to literature, this technology can fire bricks with 15-20% hollows only; for larger hollows high breakage rates are observed. Therefore VSBK technology has limitations in its ability to fire a large variety of clays and its suitability to fire a wide range of clay products (Heierli and Maithel, 2008).

FIGURE 18:
Estimated benchmark curve for the pulp and paper industry, 2006



Source: FAOSTAT, 2009a; IEA, 2009a, b, c

TABLE 9:
Theoretical energy saving potentials in the pulp and paper sector compared to BAT, 2006

Region	Specific improvement potential (GJ/t)
OECD North America	5.2-7.0
OECD Europe	0.6-2.0
OECD Asia	0.2-0.5
Brazil	2.4
China	0.9
Russia	11.6

Source: IEA, 2009c

g. Foundries

The foundry sector produces cast metal products based on either ferrous or non-ferrous alloys. Although there are reliable statistics for a number of foundries and regional physical production volumes as well as for region-wide SEC values, the foundry sector is not separately reported in international energy statistics. Foundries are dispersed across a number of sectors against which their activities are accounted for, such as the iron and steel, non-ferrous metals, and machinery sectors.

TABLE 10:
Foundry benchmark electricity use (in kWh/t of melted product, furnace electricity consumption)

		Range			International
	EU	Canada	US[1]	India[2]	Benchmark
Cast iron energy consumption	520-800	595-1,290		780- 900	520
Alloy cast steel	500-800	620-2,760		735	500
			500-825		
	1,360 for Cu	400-1,100 for Cu		590	400 for Cu
Non-ferrous	600-1,250 for Al	570-1,610 for Al			570 for Al

Note: As there is no global benchmark, improvement potentials are estimated compared to the region with the lowest SEC value.
[1] Data refers to electricity use in melting furnaces regardless of the type of metal melted. Lower energy use refers to modern and efficient induction furnaces. Higher energy use refers to electric-resistance heated reverbs. While the lower range for US is slightly less than the lower range given for EU, as it is not clear which type of metal melt this dataset represents it is excluded from the analysis.
[2] Data refer to the energy use performance of a single company in India.

Source: EU: IPTS, 2005; Canada: NRCAN, 2003; US: Energetics, 1999; India: Kirloskar, 2009

A survey of Canadian foundries covering a total of 45 foundries found that the melting process in iron foundries accounts for 54% - 84% (average 66%) of the total final energy use (NRCAN, 2003). The remaining energy use results from electricity consumption by motors (30%) and lighting (4%). 12% is consumed in air compression systems which account for around 100 kWh to 200 kWh per tonne of cast product, for example in sand casting[32]. Although lighting demand is very similar in steel and bronze and copper foundries, the energy demand for motors is higher at around 57% in bronze and copper foundries than in steel foundries (around 47%). The share of electricity demand for the melting process is however higher in steel foundries at around 45% - 65% (average 49%) than in bronze and copper foundries at around 38%.

h. Textiles

The production of textiles involves spinning, weaving, knitting and wet processing (including dyeing, printing and finishing). Most of the sector's output and energy use is located in developing countries. There are large data gaps in the energy statistics, production data and SEC values for these countries. The analysis therefore focuses on spinning and weaving, the processes for which most information is available.

Spinning

The output of the spinning process is yarn. Yarn is produced either from natural fibres such as cotton, man-made fibres such as polyamide, or a blend of these two fibre types. Total yarn production in 2007 was 63.5 million tonnes.

[32] Sand casting is a type of process applied in the production of products weighing at most 100 kg per piece. Electricity consumption for compressors is similar in the Indian foundry sector, 100-150 kWh/t in average sized foundries and 50-75 kWh/t in smaller foundries (Gandhe, 2009).

There are several types of spinning technology. Two of them, ring spindles and open-end spinning (OE), dominate. The oldest spinning technology, ring spinning, dominates the installed capacity because of the high quality yarns it produces. However, compared to other spinning systems, this technology has lower production speed and higher energy consumption (Oxenham, 2002).

Table 11 shows SEC values for modernised ring yarn and OE spindles for number of countries, based on data from a survey by the International Textile Manufacturers Federation (ITMF) alongside data based on various studies for other important manufacturing countries. Energy consumption depends both on the technology used and on the yarn count (expressed in *e.g.* tex, Ne)[33] as it determines the total production per spindle (Spinnovation, 2007). The end-use purpose of the yarn influences the final energy demand. For example, energy use increases by 20% for yarns suitable for weaving compared to knitting yarns (Koc and Kaplan, 2007). The type of fibre used has no significant effect on energy use.

Weaving

In the weaving process, yarns are processed in looms to produce woven fabric or cloth. Generally two types of looms are used in weaving, handlooms and power looms (the latter either with shuttle or shuttles).

TABLE 11:
Specific energy consumption values of spinning technologies in different countries

	SEC (kWh/kg)		
	Ring yarn (combed)	Open end yarn	Range (for all technologies)
Brazil	3.54	2.58	
China	3.49	2.58	
India	3.57	2.5	1.9-6[1]
Thailand[2]			0.55-7.3
Indonesia			1.87-5.04
Italy	3.52	2.57	
Korea	3.62	2.55	
Turkey	3.56	2.44	<4[3]
USA	3.57	2.57	

Note: Although no international benchmark is available, we estimate improvement potentials compared to the region with the lowest SEC.
1 SEC for cotton yarn production is slightly higher than 4 kWh/kg; the SEC for general yarn is less than 6 kWh/kg.
2 For Thailand, additional fuel consumption of 0.14-0.73 GJ/t is reported.
3 Approximately 20% of the total power used is consumed in air-conditioning.

Sources for specific technologies: ITMF data based on Koc and Kaplan, 2007
Sources for ranges: India: Ray and Reddy, 2008; Indonesia: PREGA, 2005; Thailand: Visvanathan et al., 2000; Turkey: Turna, 2002

[33] According to a recent study, most short staple yarn production is between yarn count Ne 18 and Ne 32. Yarn count to a maximum of Ne 60 covers 90% of the total short staple yarn production (Gherzi, 2009).

Across different weaving technologies, weft insertion systems consume a large share of the total electricity use of the equipment. Compared to the most efficient projectile looms, conventional shuttle and conventional rapier systems require much more energy in cloth production. Besides electricity use in the looms itself, there is also heat is also needed for preparation processes prior to weaving, for increasing yarn resistance and also for drying, if necessary **(Table 12)**.

TABLE 12:
Specific energy consumption values of weaving technologies in different countries

	Range for all technologies		
	Electricity (kWh/kg)	Heat (GJ/tonne)	Total (GJ/tonne)
Germany			11-65
India	4.9-5.3		27-32.4
Indonesia	0.7-2	2.9-14.1	5.4-21.3
Thailand			5-43
Turkey	2.1-5.6	8.3-17	15.9-37.2

Source: India: Sathaye et al., 2005; Indonesia: PREGA, 2005; Ray and Reddy, 2008; TERI; Thailand: Rauch, 2009; Turkey: Turna, 2002

It is not possible to report either a global benchmark curve or EEIs for the textile sector or any of its products because most production is in developing countries for which there are no reliable relevant energy statistics. For example, for India, no power use is reported. And for Pakistan, the IEA reports the energy use of the textile sector under *other sectors* (IEA, 2009a, b).

i. Food and beverages

The food and beverage sector produces a wide range of intermediate and final food products. These products are produced by processing agricultural crops and from livestock. The industry consists of a number of sub-sectors, such as the dairy, meat, fruit and vegetables, grain mill products, beverage and other sectors. The food sector is very complex, given the wide variety of material processes and the large number of intermediate steps leading to final products.

Given the complexity of the sector, SEC values are provided only for a selected number of products which represent the bulk of the sector's energy use. These data are representative for Western Europe **(Table 13)**. Although the Statistics Department of the Food and Agriculture Organisation (FAOSTAT) provides production statistics for a number of basic food products for a large number of countries, no data are reported in international energy statistics for the food sector for most developing countries.

The products in **Table 13** cover between around 15% (for Brazil and Thailand) to 50% (for EU-27) of the sector's energy use[34]. The coverage is too low to enable inter-country analyses of energy efficiency improvement potentials by developing EEI. For some developing countries, the data appear to account for more than 100% of the expected energy use in the sector. This suggests uncertainties in the reliability of the sector's reported energy data in international energy statistics. It is not appropriate to apply the OECD SEC data to analyse the global energy efficiency potential since operational conditions vary widely between ICs and DCs.

[34] If global production and SEC data were available, the production of other energy-intensive products of the sector could have been included in the analysis, e.g. tobacco, processing of fruits and vegetables (including preserving), other drinks and other food products such as flour, pasta, soups, sweets, etc. Other energy-intensive activities which are excluded are processing of starch products (especially corn and wheat), sugar and oil crops. These are important processes not only in ICs, but also in DCs, especially large producers of agricultural products (*e.g.,* Mexico, China, Brazil and South Africa (CRA, 2010).

TABLE 13:
Selected products and their specific energy consumption (in GJ of final energy per tonne of output unless otherwise stated) of the food and beverage sector in OECD countries

	Electricity	Heat	Total
Dairy sector			
Butter, ghee	0.5	1.3	1.8
Cheese	1.2	2.1	3.3
Fluid milk[1]	0.2	0.5	0.7
Milk powder	1.1	9.4	10.5
Condensed milk[2]	0.3	1.9	2.2
Whey dry	1.1	9.9	11.0
Meat sector and fish production			
Dried, salted, smoked fish	0.01	2.1	2.1
Fresh, chilled, frozen fish	0.6	0.01	0.61
Fish meals	0.7	6.2	6.9
Carcass beef, veal, sheep[3]	0.3	0.5	0.8
Carcass poultry[3]	1	0.6	1.6
Carcass pork[3]	0.5	0.9	1.4
Starch products			
Wheat starch	3	8.8	11.8
Maize starch	1	2.3	3.3
Potato starch	1.4	3.6	5
Other			
(Vegetable) Oil	0.2	2.7	2.9
Sugar (refined)	0.6	5.3	5.9
Cocoa beans[4]	-	-	6.4
Coffee[5]	0.52	2	2.5

[1] Fluid milk includes pasteurised, sterilised and long-life milk including the production of all fluid milk regardless of the fat content (whole, semi-skimmed or skimmed).
[2] Data include the production of both unsweetened (or evaporated) and sweetened condensed milk.
[3] For meat products, FAOSTAT reports the meat yield per animal. We convert this to physical production volumes in tonnes by multiplying the data with the total number of animals slaughtered in each country. Data refers to per tonne of dress carcass weight.
[4] For reasons of confidentiality, the original source provides the data in terms of primary energy (Neelis *et al.*, 2004).
[5] Data refers to roasted coffee beans.

Source: IPTS, 2006; Neelis et al., 2004; Ramirez et al., 2006a; Ramirez et al., 2006b; NRCAN, 2005

Brewery

Benchmarking studies are available for the brewery sector (KWA, 2004), indicating that the average energy use per hectolitre (hl) of beer production has decreased by more than 2% per annum **(Table 14)**.

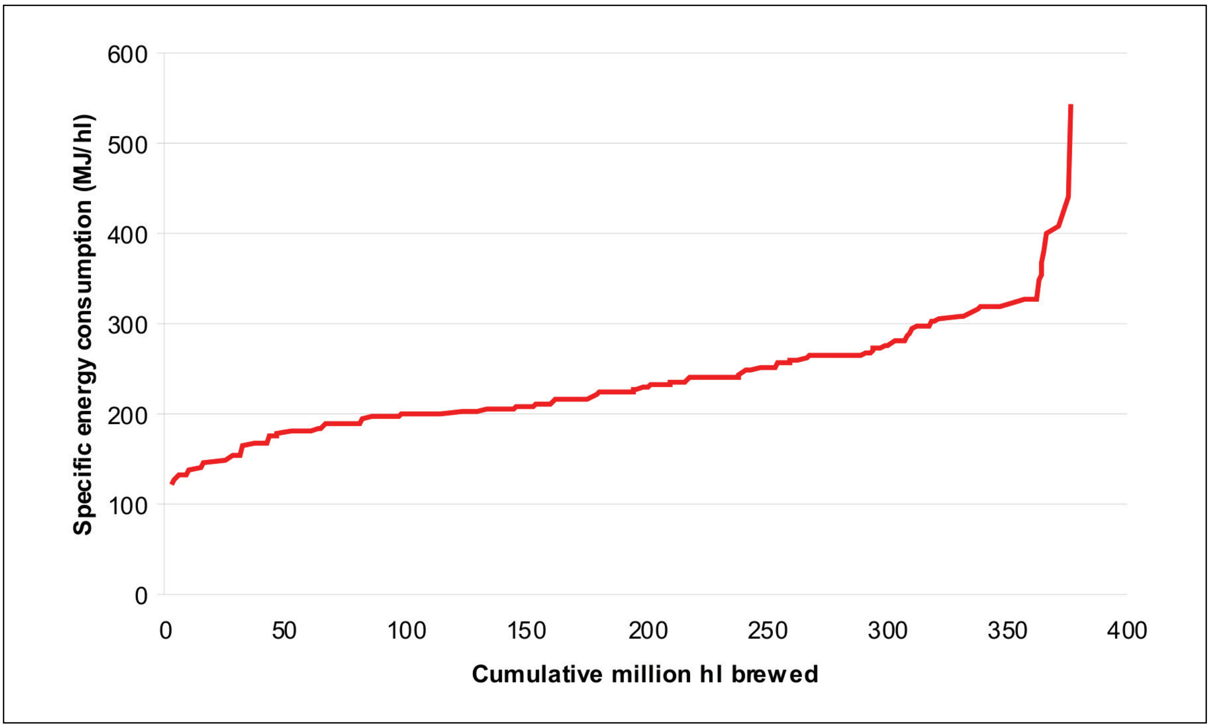
Detailed results from the 2003 brewery benchmark are shown in Figure 19 (KWA, 2004). This benchmark study covered 26% of the worldwide production. Most data originate from European breweries which together cover 43% of the total European beer production, followed by Australian and American breweries, with shares of 28% and 22% of their production respectively. The benchmark data suggests a worldwide potential to reduce the sector's energy use by approximately 30% to achieve the performance of plant in the 1st decile.

TABLE 14:
Results of the 1st, 2nd and 3rd brewery benchmark (years refer to the benchmark surveys conducted)

Year	Number of breweries	Specific energy consumption		Median	Decile
		Average	Standard Deviation		
1999	86	271	64	261	193
2003	158	239	60	233	176
2007	143	229	71	220	156

Source: Sharpe et al., 2009.

FIGURE 19:
Compiled brewery benchmark curve based on KWA, 2003



Source: Data is reproduced from KWA, 2004

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