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Energy End-Use: Industry

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Executive Summary

The industrial sector accounts for about 30% of the global final energy use and accounts for about 115 EJ of final energy use in 2005.[1] Cement, iron and steel, chemicals, pulp and paper and aluminum are key energy intensive materials that account for more than half the global industrial use.

There is a shift in the primary materials production with developing countries accounting for the majority of the production capacity. China and India have high growth rates in the production of energy intensive materials like cement, fertilizers and steel (12–20%/yr). In different economies materials demand is seen to grow initially with income and then stabilize. For instance in industrialized countries consumption of steel seems to saturate at about 500 kg/capita and 400–500 kg/capita for cement.

The aggregate energy intensities in the industrial sectors in different countries have shown steady declines – due to an improvement in energy efficiency and a change in the structure of the industrial output. As an example for the EU-27 the final energy use by industry has remained almost constant (13.4 EJ) at 1990 levels. Structural changes in the economies explain 30% of the reduction in energy intensity with the remaining due to energy efficiency improvements.

In different industrial sectors adopting the best achievable technology can result in a saving of 10–30% below the current average. An analysis of cost cutting measures for motors and steam systems in 2005 indicates energy savings potentials of 2.2 EJ for motors and 3.3 EJ for steam. The payback period for these measures range from less than 9 months to 4 years. A systematic analysis of materials and energy flows indicates significant potential for process integration, heat pumps and cogeneration for example savings of 30% are seen in kraft, sulfite, dairy, chocolate, ammonia, and vinyl chloride.

An exergy analysis (second law of thermodynamics) reveals that the overall global industry efficiency is only 30%. It is clear that there are major energy efficiency improvements possible through research and development (R&D) in next generation processes.

A comparison of energy management policies in different countries and a summary of country experiences, program impacts for Brazil, China, India, South Africa shows the features of successful policies. Energy management International Organization for Standardization (ISO) standards are likely to be effective in facilitating industrial end use efficiency. The effective use of demand side management can be facilitated by combination of mandated measures and market strategies.

A frozen efficiency scenario is constructed for industry in 2030. This implies a demand of final energy of 225 EJ in 2030. This involves an increase of the industrial energy output (in terms of Manufacturing Value Added (MVA)) by 95% over its 2005 value. Due to normal efficiency improvements the Business as Usual scenario results in a final energy demand of 175 EJ. The savings possibilities in motors and steam systems, process improvements, pinch, heat pumping and cogeneration have been computed for the existing industrial stock and for the new industries. An energy efficient scenario for 2030 has been constructed with a 95% increase in the industrial output with only a 17% increase in the final energy demand (total final energy demand for industry (135 EJ)). The total direct and indirect carbon dioxide emissions from the industry sector in 2005 is about 9.9 $GtCO_2$. Assuming a constant carbon intensity of energy use, the business as usual scenario results in carbon dioxide (CO_2) emissions increasing to 17.8 $GtCO_2$ annually in 2030. In the energy efficient scenario this reduces to 11.6 $GtCO_2$. Renewables account for 9% of the final energy of industry (10 EJ in 2005). If an aggressive renewables strategy resulting in an increase in renewable energy supply to 23% in 2030 is targeted (23 EJ), it is possible to have a scenario of constant greenhouse gas (GHG) emissions by the industrial sector (at 2005 levels) with a 95% increase in the industrial output.

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[1] This includes energy for coke ovens, blast furnaces and feedstock for petrochemicals.

Several interventions will be required to achieve the energy efficient or constant GHG emission scenario. For the existing industry measures include developing capacity for systems assessment for motors, steam systems and pinch analysis, sharing and documentation of best practices, benchmarks and roadmaps for different industry segments, access to low interest finance etc. A new energy management standard has been developed by ISO for energy management in companies. Its adoption will enable industries to systematically monitor and track energy efficiency improvements. In order to level the playing field for energy efficiency a paradigm shift is required with the focus on energy services not on energy supply per se. This requires a re-orientation of energy supply, distribution companies and energy equipment manufacturing companies.

Planning for next generation processes and systems needs the development of long term research agenda and strategic collaborations between industry, academic and research institutions and governments.

8.1 Introduction

The industrial sector is an important end-use sector, since all industrial processes require energy for the conversion of raw materials into desired products. The objective of this chapter is to assess the end-use efficiency of different industrial processes and systems. Earlier assessments include the End-Use Efficiency chapter of the World Energy Assessment (UNDP, 2000), the Industry chapter of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2007) and the Energy Technology Perspectives 2008 scenarios and strategies for 2050 (IEA, 2008a).

The present analysis uses 2005 as the base year. We document time-series trends as well as regional variations in industrial energy use. The aim is to provide insights to understand parameters that affect global industrial energy use, review technological options, and identify potential for energy efficiency improvements. A review of industrial energy efficiency policies is also included.

Based on the status review, an energy efficiency scenario for 2030 is developed and the savings in energy and carbon dioxide (CO_2) emissions compared with respect to a frozen efficiency scenario and a business-as-usual (BAU) scenario.

8.2 Analysis of Industrial Energy Use Trends

The industrial sector accounted for 27% of the total global energy use in 2005 (IEA, 2008a). The total energy use by industry in 2005 was about 115 EJ (excluding traditional biomass and wood, which may add another 17 EJ). The share of final energy use by different industrial sectors in the world is shown in Figure 8.1.

8.2.1 Trends in Material Usage

Industry produces several products that are used by society on a daily basis. These products contain materials extracted from the environment. The conversion of the extracted feedstocks consumes large amounts of energy. A small number of key materials – cement, iron and steel, chemicals (plastics, fertilizer), pulp and paper, and aluminum – account for half of the global industrial energy use. Figure 8.2 shows trends in the global production of these materials.

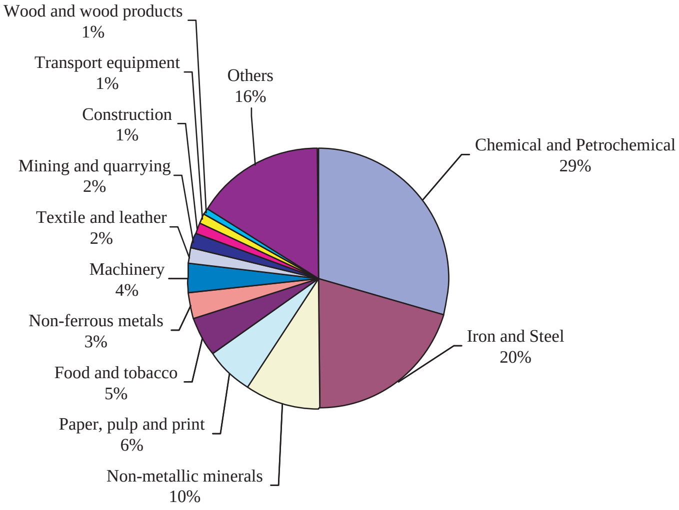

Figure 8.1 | Share of industrial final energy use in 2005. Source: data based on IEA, 2008a.

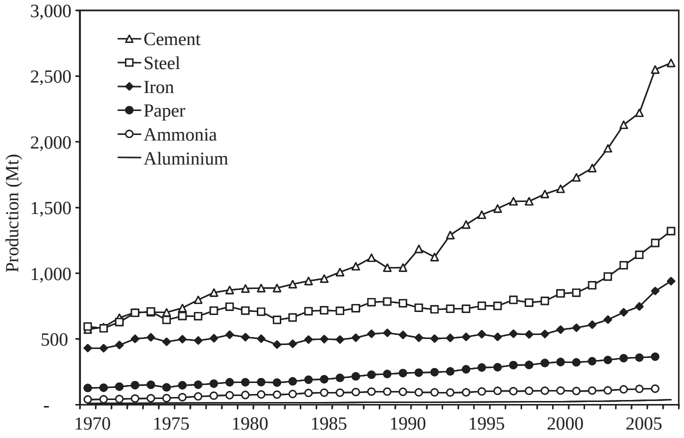

Figure 8.2 | Global production of key materials from 1970–2007. Source: data based on USGS, 2005; 2007; 2008 (cement, iron, steel, aluminum); IFA, 2009 (ammonia); FAO, 2009.

Today, developing countries produce the majority of primary materials such as cement, steel, and fertilizers for infrastructure development. China alone produces about 46% of all the cement and 31% of the iron and steel in the world. As the industrial sectors of developing countries continue to grow, the same trend is likely to occur for other materials. Table 8.1 shows the comparison of production quantities of key energy-intensive materials in different countries. Among the developing countries, China and India show much higher growth rates and would be responsible for the increased demand for materials in the future. Understanding future industrial energy use is based on future trends in material consumption and production. Generally, per capita materials demand increases with economic development and income, and is assumed to stabilize at a given level (following a so-called Kuznets curve; Mills and Waite, 2009). However, differences in the material intensity of different economies and regions suggest the potential to improve the efficiency with which we use materials.[2] Figures 8.3 and 8.4 depict the material intensity for cement and steel of various world regions.

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[2] Note that data availability also affects the material intensities. Consumption figures are given as apparent consumption, which equals domestic production plus imports minus exports of the material. Trade in products containing these materials (e.g., steel in a car) is not included in the apparent consumption. Hence, national-level data should be interpreted carefully. At a regional level, the data may provide a more consistent result.

Table 8.1 | Comparison of material production and growth rates in selected countries (2000–2007).

Regions	Material production in 2007 (Mt) Steel	CAGR	Cement	CAGR	Paper and board	CAGR	Ammonia	CAGR	Primary aluminum	CAGR*
US	98	-0.5%	97	1.1%	84	-0.4%	9.5	-5.7%	2.6	-5.0%
Europe	202	1.1%	263	2.4%	100	4.2%	15.9	-0.3%	2.8	0.8%
South Korea	52	2.6%	57	1.5%	11	2.3%	0.1	-17.0%	N/A	N/A
Japan	120	1.8%	68	-2.5%	29	-1.4%	1.4	-3.3%	0.0	0.0%
China	495	21.4%	1361	12.5%	78	12.3%	51.6	6.3%	12.6	24.0%
India	53	10.2%	170	8.7%	4	1.4%	13.4	1.2%	1.2	9.6%
Brazil	34	2.8%	46	2.4%	9	4.7%	1.2	0.4%	1.7	3.8%
South Africa	9	1.0%	14	8.0%	3	5.7%	0.6	-2.2%	0.9	4.2%
World	1351	6.9%	2811	7.8%	386	2.6%	160	2.9%	38.0	6.5%

* CAGR = Compound Annual Growth Rate

Source: IISI, 2008; FAO, 2009; USGS, 2011.

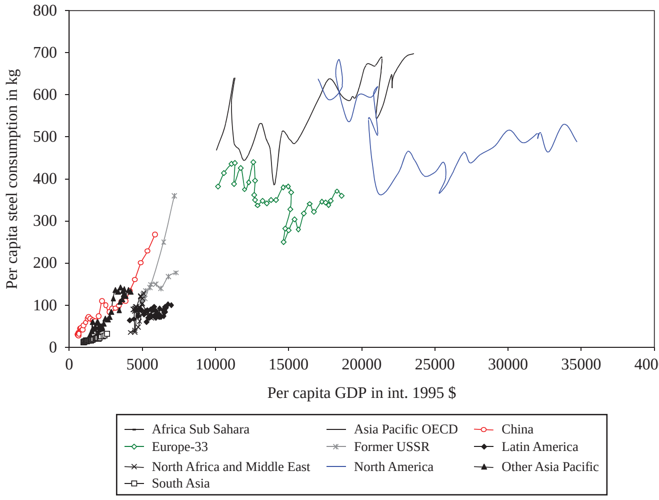

Figure 8.3 | Apparent steel consumption (expressed as kg/capita/yr) as a function of income (expressed as US$_{1995}$\$/capita) for different regions in the world.

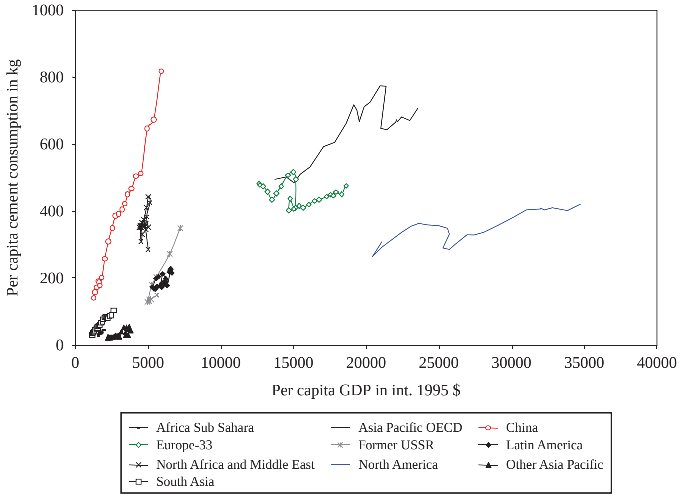

Figure 8.4 | Apparent cement consumption (expressed as kg/capita/yr) as a function of income (expressed as US$_{1995}$\$/capita) for different regions in the world.

The figures show that consumption levels in industrialized countries seem to stabilize at about 400–500 kg/capita for cement and about 500 kg/capita for steel. However, it also shows the rapid growth of China as a major consumer due to high growth in the infrastructure and industrialization policies. The apparent consumption numbers shown are affected by exports. For instance China's apparent steel consumption also includes the steel that is used in automobiles and other products that are exported. It may be noted that other developing regions have relatively low consumption levels.

Table 8.2 shows the conclusions obtained by Jänicke et al. (1992) for bulk material consumption and production per capita for different countries as a function of per capita Gross Domestic Product (GDP). De Vries et al. (2006) analyze trends in the per capita use of bulk materials including paper and board (see Figure 8.5), ammonia, bricks, polymers, and aluminum, in addition to cement and steel. For materials such as paper and aluminum, there does not appear to be a saturation level. This could be due to an increase in the growth of the information and communications technology and aircraft sector.

The structure of the GDP and growth of the service sector for industrialized countries affect the overall trends. De Vries et al. (2006) conclude that there is no general trend for decoupling between physical and economic growth for industry.

The case of China is atypical. For example, China's 2005 production of cement of 1064 million tonnes (Mt) corresponds to a per capita production of 806 kg/capita. The cement industry in China is growing at more than 10%/yr. This is probably due to the high share of industry in China's GDP, high growth rates of infrastructure, and its export-oriented industrial development strategy. It is unlikely that other developing countries will reach this level of consumption/growth, as illustrated by the trends

Table 8.2 | General trends of per capita bulk materials production and consumption for 32 industrialized countries 1970–1990.

Product	Parameter	General trend
Paper and Paperboard	per capita production	increasing production at all income levels
Cement	per capita production	increasing producing until per capita GDP levels of US$5000–8000 generally decreasing production at higher GDP levels
Chlorine	per capita production	increasing production at all income levels
Pesticide	per capita production	increasing production at all income levels
Fertilizer	per capita production	increasing production until per capita GDP levels of US$9000 generally stabilizing production at higher GDP levels
	per capita consumption	increasing consumption until per capita GDP levels of US$8000 stabilizing consumption at higher GDP levels
Crude Steel	per capita production	increasing production until per capita GDP levels of US$6000–10000 decreasing or stabilizing production at higher GDP levels
	per capita consumption	increasing consumption until per capita GDP levels of US$5000–9000 Stabilizing or slightly decreasing consumption at higher GDP levels
Aluminum	per capita production	increasing production at all income levels
	per capita consumption	strong increase of consumption at all income levels

Source: Jänicke et al., 1992.

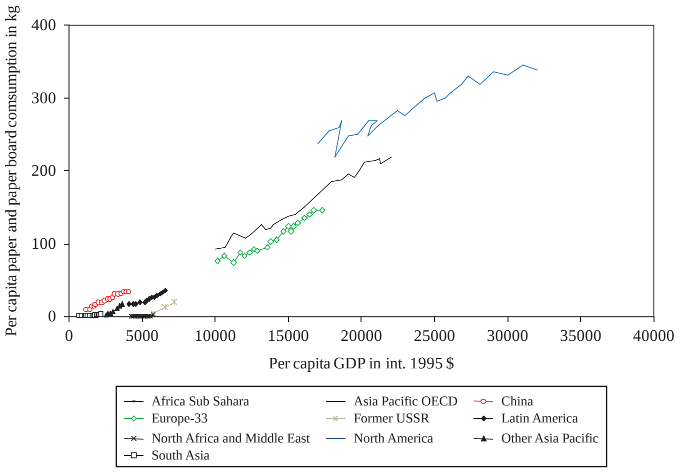

Figure 8.5 | Paper and paper-based board – per capita consumption. Source: De Vries et al., 2006; Chateau et al., 2005.[3]

for India and Brazil, unless they focus on increasing their manufacturing capacity of cement for exports.

Despite this, the implication of these trends is the likely predominance of developing countries as major consumers (and producers) of energy-intensive materials during the next few decades. Investments in new, energy-efficient processes and plants, and efficient material usage (dematerialization) in developing countries will be important for managing the global industrial energy use.

8.2.2 Regional Variations

Table 8.3 shows a comparison of industrial energy use for select countries of the world. The Manufacturing Value Added (MVA) per capita, total primary energy supply, and final energy and electricity use by industry are compared for different countries.

Different countries have different mixes of energy supply and sectoral energy use patterns. One of the factors affecting future global industrial energy use patterns is the growth of industry in developing countries. This is exemplified by the high growth rate of China in the production of energy-intensive materials, as shown in Table 8.4.

The trends of growth in developing countries and saturation in the energy-intensive industries of developed countries have implications on the future energy mix.

8.2.3 Structural Change

Overall in the economy there are structural shifts from agriculture to manufacturing to services. As countries develop, these structural shifts also result in changes in the overall energy intensity. Many countries have achieved a significant reduction in energy intensity in the industrial sector. Some of this effect has been due to a change in the structure of the industry, with a shift to less energy-intensive industry. These effects can be separated by decomposition analysis.

In the European Union (EU), the final energy use of industry in the 27 EU countries has remained almost constant since 1990 at 320 Mtoe (13.4 EJ). This has been possible through a 30% improvement in energy efficiency from 1990 to 2007 (2.1%/yr). For the EU-27, about 30% of the reduction has been due to structural changes. There are differences in the EU Member States. Figure 8.6 shows the changes in energy intensity for EU Member States from 2000–2007.

The example of the former Soviet Union illustrates the impact of structural change on industrial energy use. Olshanskaya (2004) revealed

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[3] This figure is from De Vries et al. 2006 which is based on (cites) the VLEEM Project report of Chateau et al., 2005.

Table 8.3 | Comparison of industrial energy use in selected countries for 2005.

	TPES (EJ)	Final Energy Use by Industry[2] (EJ)	Electricity use by Industry (EJ)	Industrial Share of GDP	MVA/capita[2]
World	478.9	115	22.2	32%	1014
Brazil	9.1	3.3	0.6	15%	594
China	72.7	24.6	4.9	34.1 %	492
India	22.5	5.5	0.8	14.1%	80
S. Korea	8.9	3.2	0.66	40.3%	187
Germany	14.4	2.38	0.83	21.4%	5090
UK	9.8	1.33	0.43	13.6%	3683
France	11.5	1.37	0.5	13.94%	3291
Japan	22.1	6.3	1.2	22.1%	8608
Russia	27.4	7.2	1.2	19.0%	461
South Africa	5.3	1.2	0.4	16.4%	550
USA	97.9	16.6	3.3	15.3%	5604

1 includes feedstocks (non-energy use); see Chapter 1, Section 1.2.2.

2 in constant US2000$ prices.

Source: IEA Database, 2011; UNIDO Database, 2011.

Table 8.4 | Production of energy-intensive materials in China, 2000–2005, in 10,000 tonnes.

Material	2000	2001	2002	2003	2004	2005	CAGR% (2000–2005)
Steel	128.5	151.6	182.2	222.2	272.8	352.4	22.4
Finished Steel	131.5	157	192.5	241.1	297.2	396.9	24.7
Nonferrous	7.8	8.8	10.1	12.3	14.3	16.4	15.8
Included Copper	1.4	1.5	1.6	1.8	2.2	2.6	13.7
Aluminium	3.0	3.6	4.5	6.0	6.7	7.8	21.1
Cement	597	661	725	862.1	966.8	1064	12.3
Flat glass	183.5	209.6	234.5	277	300.6	350	13.8
Ethylene	4.7	4.8	5.4	6.1	6.3	7.6	10.0
Synthetic ammonia	33.5	34.3	36.8	37.9	42.2	45	6.1
Caustic soda	6.7	7.9	8.8	9.5	10.6	12.6	13.6
Soda	8.3	9.1	10.3	11.3	13	14.7	12.0
Paper and paper board	30.5	37.8	46.7	48.5	54.1	54.0	12.1

Note: CAGR = Compound Annual Growth Rate.

Source: China Energy, 2009.

that in the Russian industrial sector there were changes toward a more energy-intensive industry between 1994–1997 which contributed positively to the increase in industrial energy intensity in that period. The trend reversed in the late 1990s, and until 2002 the aggregated contribution of structural changes within industry on industrial energy intensity was insignificant. Resulting positive changes in industrial energy intensity may be attributed to improvements in industrial energy efficiency per se (see Figure 8.7).

A decomposition analysis by Howarth et al. (1991) showed that the energy intensity of manufacturing declined by 45% in Japan during 1973–1987 (11.5% decline due to structure; 36.4% due to energy efficiency improvements), while for the United States the decline was 44.3% (14.8% due to structure; 32.4% due to energy efficiency improvements). An analysis of energy intensity trends in the US economy (Huntington, 2010) between 1997 and 2006 shows that structural change (within industries) accounted for more than half of the total energy intensity reduction in the United States.

In most economies there is a structural change where the share of energy-intensive industries is reducing in the total industrial mix. In order to account for this in an aggregate analysis, the decomposition analysis can

Table 8.5 | Energy use in the chemical and petrochemical industry, 2004 (excluding electricity).

	Amount	LHV	Feedstock Energy Needed	Fuel		Total Fuel + Feedstock
	Mt/yr	GJ/t	EJ/yr	GJ/t	EJ/yr	EJ/yr
Ethylene	103.3	47.2	4.9	13	1.3	6.2
Propylene	65.3	46.7	3.0	13	0.8	3.9
Butadiene	9.4	47.0	0.4	13	0.1	0.6
Butylene	20.3	47.0	1.0	10	0.2	1.2
Benzene	36.7	42.6	1.6	7	0.3	1.8
Toluene	18.4	42.6	0.8	7	0.1	0.9
Xylenes	33.7	41.3	1.4	7	0.2	1.6
Methanol	34.7	21.1	0.7	10	0.3	1.1
Ammonia	140.0	21	2.9	19	2.7	5.6
Carbon black	9.0	32.8	0.3	30	0.3	0.6
Soda ash	38.0	0.0	0.0	11	0.4	0.4
Olefins processing excl. polymerization	100.0	0.0	0.0	10	1.0	1.0
Polymerization	50.0	0.0	0.0	5	0.3	0.3
Chlorine and Sodium Hydroxide	45.0	0.0	0.0	2	0.1	0.1
Total			17.0		8.2	25.2

Source: IEA, 2007a.

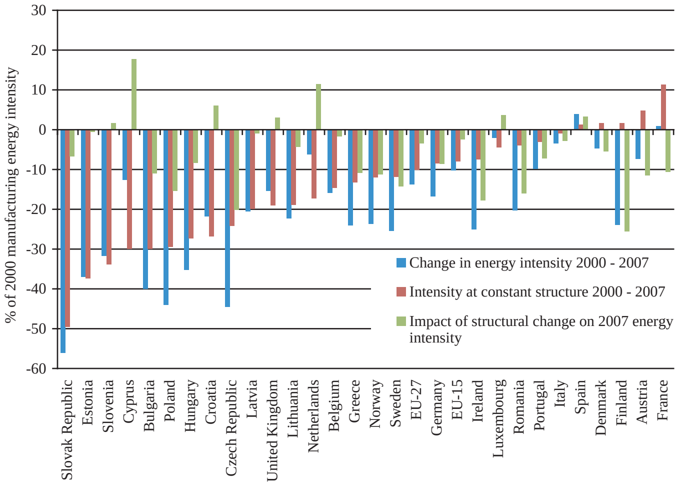

Figure 8.6 | Structural change impact for the EU. Source: Odyssee, 2009.

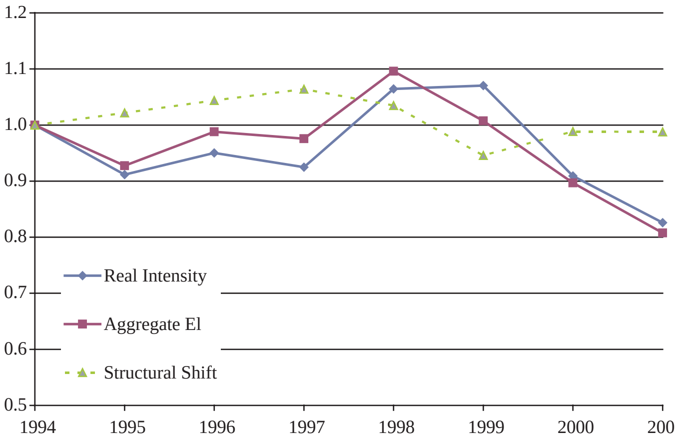

Figure 8.7 | Fisher ideal indices[4] for structural shift and real intensity in Russia, 1994 = 1. Source: Olshanskaya, 2004.

be used to reveal the actual impact of energy efficiency improvements in industry, as illustrated by the example shown in this section.

8.3 Consumption and Opportunities: Key Sectors

Industrial processes have significant variations in the energy use per unit of output depending on the vintage (age), process technology employed, quality of input new materials, and scale. Revamping old process plants often requires significant capital investment. In most industrial processes there is a learning curve effect with newer plants being more energy efficient than earlier process plants. A few decades ago, developing countries often only had access to second hand plants and outdated technologies, and hence were often more inefficient than process plants in developed countries. This generalization is no longer possible with the world's most efficient aluminum smelters located in Africa and the most efficient cement plants located in India. Globalization has also resulted in new capital stock being of larger capacity with cutting edge

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[4] The Fisher ideal index is the geometric average of the Laspayre's and Paasche's price indices (Boyd and Roop, 2004).

Table 8.6 | Process-specific energy efficiency opportunities in ammonia production.

Measures
Highly integrated primary and secondary reformers
Improvements in reformers
Pre-reformer installation
Low-pressure ammonia synthesis
Highly efficient catalysts
Physical absorption CO_2 removal
CO_2 recovery with improved solvents and other improvements
Hydrogen recovery
Improved process control
Process integration

Source: FEMA, 2000; Nieuwlaar, 2001; Rafiqul et al., 2005; EC, 2007; EC, 2007; Worrell et al., 2008.

Table 8.7 | Revamp investments in natural gas-fueled steam reforming plants.

Retrofit measure	Average improvement	Range	Uncertainty Parameter	Cost	Applicability		
	(GJ/t)	(GJ/t)	(%)	(€ per t/yr)	EU (%)	US (%)	India (%)
Reforming large improvements	4.0	±1.0	17	24	10	15	10
Reforming moderate improvements	1.4	±0.4	20	5	20	25	20
Improvement CO_2 removal	0.9	±0.5	33	15	30	30	30
Low pressure synth	0.5	±0.5	67	6	90	90	90
Hydrogen recovery	0.8	±0.5	50	2	0	10	10
Improved process control	0.72	±0.5	50	6	30	50	30
Process integration	3.0	±1.0	23	3	10	25	20

Source: Rafiqul et al., 2005.

technologies. In some countries, (e.g., Russian Federation and Ukraine) the existing process plants that are inefficient have not been modernized due to the lack of capital investments (IEA, 2007a). This section provides an overview of chemicals and fertilizers, iron and steel, cement, pulp and paper, and aluminum, and discusses the factors affecting the energy use in these sectors.

8.3.1 Chemicals and Fertilizers

The chemical industry is highly diverse, with thousands of companies producing tens of thousands of products in quantities varying from a few kilograms to thousands of tonnes (t). Due to this complexity, reliable data on energy use are not available (Worrell et al., 2000a). However, a small number of (intermediate) products make up a large share of energy use in this sector – e.g., ammonia, chlorine and alkalines, ethylene, and other petrochemical intermediates. The chemicals and petrochemicals sector has a large number of products. Table 8.5 (IEA, 2007a) lists the major products that account for about 80% of the total energy use of the chemicals and petrochemicals sector.

Ethylene is a basic chemical that is used in the production of plastics and other chemical products. This is produced by steam cracking of hydrocarbon feedstocks. During this process several by-products are obtained like hydrogen, methane, propylene and other heavier hydrocarbons. Steam cracking consumes about 65% of the total energy used in ethylene production (Worrell et al., 2000a; Ren et al., 2006). Technology options like improved furnace and cracking tube materials, and cogeneration using furnace exhaust can result in 20% of total energy savings (IPCC, 2007). Improved separation and compression techniques (e.g., absorption technologies for separation) can result in 15% of total energy saving. Instead of steam cracking, alternative processes have been developed for converting methane in natural gas to olefins. However state of the art stream cracking of naphtha is more efficient than these processes (Ren et al., 2006).

Global ammonia (NH_3) production (mainly for fertilizer production) was estimated at 125 Mt in 2007. The main producers are China, Russia, India, the United States, Trinidad and Tobago, Indonesia, and Ukraine. The fertilizer industry accounts for about 1.2% of world energy use, and more than 90% of this energy is used in the production of ammonia. Modern

Table 8.8 | Summary of process-specific energy efficiency opportunities.

Process Specific Measures	
Process	**Measures**
Ethylene	More selective furnace coils
	Improved transfer line exchangers
	Secondary transfer line exchangers
	Increased efficiency cracking furnaces
	Pre-coupled gas turbine to cracker furnace
	Higher gasoline fractionator bottom temperature
	Improved heat recovery quench water
	Reduced pressure drop in compressor inter-stages
	Additional expander on de-methanizer
	Additional re-boilers (cold recuperation)
	Extended heat exchanger surface
	Optimization steam and power balance
	Improved compressors
Aromatics	Improved product recovery systems
Polymers	Low pressure steam recovery
	Gear pump to replace extruder
	Online compounding extrusion
	Re-use solvents, oils and catalysts
Ethylene Oxide / Ethylene Glycol	Increased selectivity catalyst
	Optimal design EO/EG-sections
	Multi-effect evaporators (Glycol)
	Recovery and sales of by-product CO_2
	Process integration
Ethylene Dichloride / Vinyl Chloride Monomer	Optimize recycle loops
	Gas-phase direct chlorination of ethylene
	Catalytic cracking EDC
Styrene	Condensate recovery and process integration

Source: Neelis et al., 2008.

ammonia plants are designed to use about half the energy per tonne of product than those designed in the 1960s, with energy use dropping from over 60 GJ/t of ammonia in the 1960s to 28 GJ/t of ammonia in the most recently designed plants (Worrell et al., 2009). Benchmarking data indicate that the best-in-class performance of operating plants ranges from 28.0 GJ/t to 29.3 GJ/t of ammonia (Chaudhary, 2001; PSI, 2004). Individual differences in energy performance are mostly determined by feedstock (natural gas compared with heavier hydrocarbons) and the age and size of the ammonia plant (Phylipsen et al., 2002; PSI, 2004).

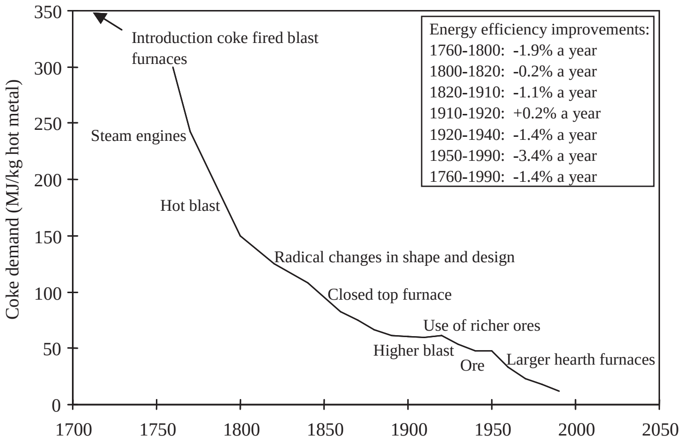


Figure 8.8 | Change in coke demand due to efficiency improvement in the blast furnace process. Source: de Beer et al., 1998.

Ammonia plants that use natural gas as a feedstock have an energy efficiency advantage over plants that use heavier feedstocks, and a high percentage of global ammonia production capacity is already based on natural gas. China is an exception, in that 67% of its ammonia production is based on coal (CESP, 2004) and small-scale plants account for 90% of the coal-based production. The average energy intensity of Chinese coal-based production is about 53 GJ/t, compared with a global average of 41.4 GJ/t (Saygin et al., 2009). A summary of process-specific options for ammonia is shown in Table 8.6, while Table 8.7 from Rafiqul et al. (2005) shows the investments and energy-saving possibilities available from revamping ammonia plants.

A summary of process-specific energy efficiency opportunities in the petrochemical industry is shown in Table 8.8 below. The selection is limited to commercially available technologies and excludes emerging and cross-cutting technologies. Process integration offers significant scope for energy savings and is discussed in a subsequent section.

The use of nanocomposites as a filler material can help in reducing the energy use in polymer manufacture by 20% (Roes et al., 2010).

8.3.2 Iron and Steel

Steel is an important metal. The total global production of steel in 2007 was about 1350 Mt. The major steel producers were China (36% of global steel production), EU25 (15%), Japan (9%), and US (7%) (IISI, 2008). The main route used for steel making is the blast furnace route using coke or coal to reduce iron-ore oxides in a blast furnace to molten iron that is then processed to steel. About 60% of the global steel production is from this route (IPCC, 2007). Another important route accounting for 32% of steel production is the production of steel from melting scrap steel in an electric arc furnace (EAF). Since the raw material used in this route is scrap steel, the specific energy use in this process is only 30–40% of the blast furnace steel process route.

An alternative route is the use of natural gas or coal to produce direct reduced iron (DRI) that can be used in an electric arc furnace. DRI use and production is expected to grow as the share of electric arc furnaces grows in industrialized countries and globally. At present DRI accounts for only about 3% of total steel production.

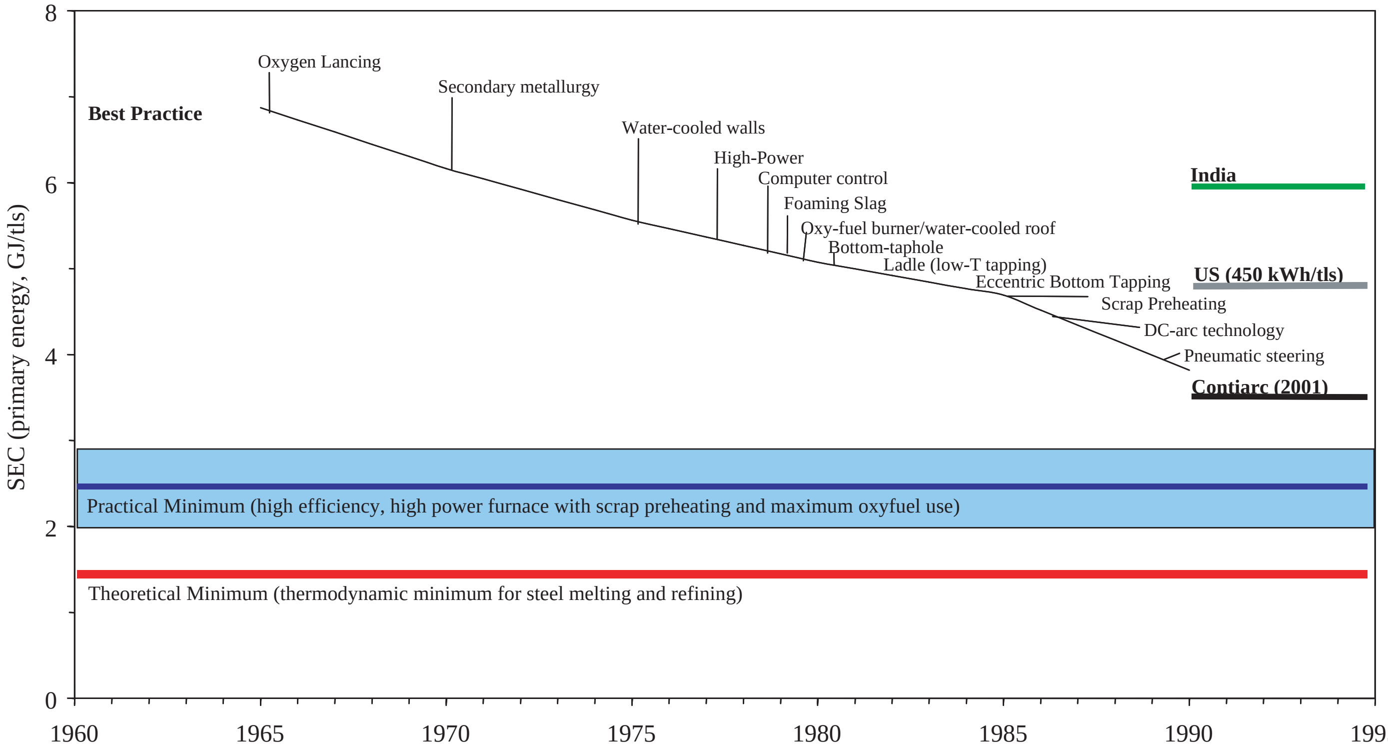


Figure 8.9 | Time-series trend of specific electricity consumption (SEC) values for the EAF process. Note: The Contiarc electric arc furnace was introduced in 2001 and provides an energy efficient option for the production of cast iron. tls = tonne of liquid steel.

Iron and steel making traditionally includes several batch processes. The introduction of continuous casting in steel making in the 1970s and 1980s resulted in significant energy and material savings. Continuous casting now accounts for about 93% of the world's steel production (IISI, 2008). Some major energy efficiency measurement adopted by the steel industry are enhancing continuous production processes to reduce heat loss, increasing recovery of waste energy and process gases, and efficient design of electric arc furnaces – for example, scrap preheating, high-capacity furnaces, foamy slagging, and fuel and oxygen injection. The effect of efficiency improvements on coke demand in the blast furnace process is shown in Figure 8.8. A time-series trend of specific energy use improvement is also shown for the EAF process in Figure 8.9.

Energy savings can be achieved by a combination of stock turnover and equipment retrofit. An analysis of electric arc furnaces in the US steel industry from 1990–2002 showed an efficiency improvement of 1.3%/yr (0.7% due to stock turnover and 0.5% due to equipment retrofit) (Worrell and Biermans, 2005).

Process modifications like near-net shape casting and smelt reduction, which integrates ore agglomeration, coke making and iron production in a single process, offering an energy-efficient alternative at small to medium scales (de Beer et al., 1998) offer scope for further improvements in energy efficiencies.

POSCO, a Korean steel producer, has developed a technology to replace the blast furnace (FINEX process technology) and constructed a demonstration plant with a capacity of 600,000 t/yr in 2003. The coal consumption is about 770 kg/t of hot metal. (Siemens VAI, 2009).

A summary of process-specific energy opportunities in the iron and steel industry is shown in Table 8.9.

8.3.3 Cement

Cement is needed in the construction sector and is important for the growth of any economy. Cement is produced in almost all countries of the world. Developing countries account for about 73% of the global cement production (2811 Mt in 2007). China (1361 Mt in 2007) accounts for almost half of the global cement production (USGS, 2011).

Cement production is also highly energy- and CO_2-intensive. Clinker is the output of the cement kiln. Depending on the type of cement to be manufacture the clinker is further processed in a set of finishing operations. The production of clinker, the principal component of cement, consumes virtually all the fuel and emits CO_2 from the calcination of limestone. The major energy uses are fuel for the production of clinker and electricity for grinding raw materials and the finished cement. Coal dominates in clinker making.

The technical potential for energy efficiency improvements is about 40% (Worrell et al., 1995; Kim and Worrell, 2002b). An analysis of the US cement industry identified 30 opportunities for energy saving in the

Table 8.9 | Summary of process-specific energy opportunities in the iron and steel industry.

Iron Ore and Ferrous Reverts Preparation (Sintering)	
Heat recovery from sintering and sinter cooler	Use of waste fuel in sinter plant
Reduction of air leakage	Improve charging method
Increasing bed depth	Improve ignition oven efficiency
Emission Optimized Sintering (EOS®)	Other measures
Coke Making	
Coal moisture control	Coke dry quenching (CDQ)
Programmed heating	Coke oven gas (COG)
Variable speed drive coke oven gas compressors	Next generation coke making technology
Single Chamber System (SCS)	
Iron Making – Blast Furnace	
Injection of pulverized coal	Recovery of blast furnace gas
Injection of natural gas	Top gas recycling
Injection of oil	Improved blast furnace control
Injection of plastic waste	Slag heat recovery
Injection of coke oven gas and basic oxygen furnace gas	Preheating of fuel for hot stove
Charging carbon composite agglomerates (CCB)	Improvement of combustion in hot stove
Top-pressure recovery turbines (TRT)	Improved hot stove control
Steelmaking – Basic Oxide Furnace	
Recovery of BOF gas and sensible heat	Improvement of process monitoring and control
Variable speed drive on ventilation fans	Programmed and efficient ladle heating
Ladle preheating	
Steelmaking – EAF	
Increasing power	Refractories using engineering particles
Adjustable speed drives (ASDs)	Direct current (DC) arc furnace
Oxy-fuel burners/lancing	Scrap preheating
Post-combustion of flue gases	Waste injection
Improving process control	Airtight operation
Foamy slag practices	Bottom stirring/gas injection
Casting and Refining	
Integration of casting and rolling	Tundish heating
Ladle preheating	
Shaping	
Use efficient drive units	Installation of lubrication system
Gate Communicated Turn-Off (GCT) inverters	
Hot Rolling	
Recuperative or regenerative burners	Integration of casting and rolling
Flameless burners	Proper reheating temperature
Controlling oxygen levels and variable speed drives on combustion air fans	Process control in hot strip mill
Avoiding overload of reheat furnaces	Heat recovery to the product
Insulation of reheat furnaces	Waste heat recovery from cooling water
Hot charging	
Cold Rolling	
Continuous annealing	Inter-electrode insulation in electrolytic pickling line
Reducing losses on annealing line	Automated monitoring and targeting systems
Reduced steam use in the acid pickling line	

Source: Worrell et al., 2010.

cement industry with an economic potential of 11% savings in energy and 5% savings in emissions (Worrell et al., 2000b; Worrell and Galitsky, 2005). Blending of clinker with alternative cementitious materials like blast furnace slags, fly ash from coal fired power plants and natural pozzolanes can result in reduced energy and CO_2 emissions (IPCC, 2007). Worrell et al. (1995) and Humphreys and Mahasenan (2002) estimate that the use of blended cement has the potential to reduce CO_2 emissions by more than 7%.

Geo polymers and other alternatives to limestone-based cement are being studied (Humphreys and Mahasenan, 2002; Gartner, 2004) but are currently not economical for widespread deployment.

The energy use of the cement industry in China in 2005 was about 50% of energy consumption of the building materials industry, and became the largest energy consumer in the industry. From 2000 to 2005, the cement industry's energy consumption dropped from 5.0 GJ/t in 2000 to 4.36 MJ/t in 2005 (as shown in Table 8.10).

The small-scale cement industries in India had an average fuel consumption of 3.7 GJ/t of clinker and an average electricity consumption of 104 kWh/t of cement, while the average fuel consumption for large cement industries was 3.29 GJ/t and electricity consumption was 92 kWh/t (Bhushan and Hazra, 2005). The Indian cement industry is among the most efficient in the world. But there is still considerable scope for improvement in the energy use per tonne of output compared to the world's best, due to the potential of more blending in the cement, as shown in Figure 8.10. The blending of fly ash in the cement results in a reduction in the specific energy use. The figure also shows a high clinker content compared to the world's most efficient cement industries. The energy-efficient practices and technologies in cement production are shown in Table 8.11.

An analysis of ten large cement plants in India that account for 16% of total production has been carried out based on data from projects implemented between 2001 and 2006 (Bureau of Energy Efficiency Awards, 2006). The measures have been grouped into different categories, and the conservation supply curve is shown in Figure 8.11. About 8% of annual electricity consumption has been saved by these measures. The cost of saved energy (CSE) is computed by annualizing the cost of the measure and dividing by the annual electricity saving. The CSE varies from INR0.1–1.7/kWh, which is lower than the average price of electricity (INR4.5/kWh or US$0.10/kWh).

Table 8.10 | Specific energy use for cement in China.

	unit	2000	2001	2002	2003	2004	2005	Descending rate/yr
Cement energy use	GJ/t	5.0	4.9	4.7	4.6	4.5	4.4	2.8%

Source: Xiong, 2007.

Table 8.11 | Energy-efficient practices and technologies in cement production.

Raw Materials Preparation	
Efficient transport systems (dry process) Slurry blending and homogenization (wet process)	
Raw meal blending systems (dry process)	
Conversion to closed circuit wash mill (wet process)	
High-efficiency roller mills (dry process)	
High-efficiency classifiers (dry process) Fuel Preparation: Roller mills	
Clinker Production (Wet)	**Clinker Production (Dry)**
Energy management and process control Seal replacement Kiln combustion system improvements	Energy management and process control Seal replacement Kiln combustion system improvements
Kiln shell heat loss reduction	Kiln shell heat loss reduction
Use of waste fuels	Use of waste fuels
Conversion to modern grate cooler	Conversion to modern grate cooler
Refractories	Refractories
Optimize grate coolers	Heat recovery for power generation
Conversion to pre-heater, pre-calciner kilns Conversion to semi-dry kiln (slurry drier) Conversion to semi-wet kiln	Low pressure drop cyclones for suspension pre-heaters Optimize grate coolers Addition of pre-calciner to pre-heater kiln
Efficient kiln drives	Long dry kiln conversion to multi-stage pre-heater kiln
Oxygen enrichment	Long dry kiln conversion to multi-stage pre-heater, pre-calciner kiln
	Efficient kiln drives
	Oxygen enrichment
Finish Grinding	
Energy management and process control Improved grinding media (ball mills)	
High-pressure roller press	
High efficiency classifiers	
General Measures	
Preventative maintenance (insulation, compressed air system, maintenance)	
High efficiency motors	
Efficient fans with variable speed drives	
Optimization of compressed air systems Efficient lighting	
Product & Feedstock Changes	
Blended Cements Limestone cement	
Low Alkali cement	
Use of steel slag in kiln (CemStar®) Reducing fineness of cement for selected uses	

Source: Worrell and Galitsky, 2008.

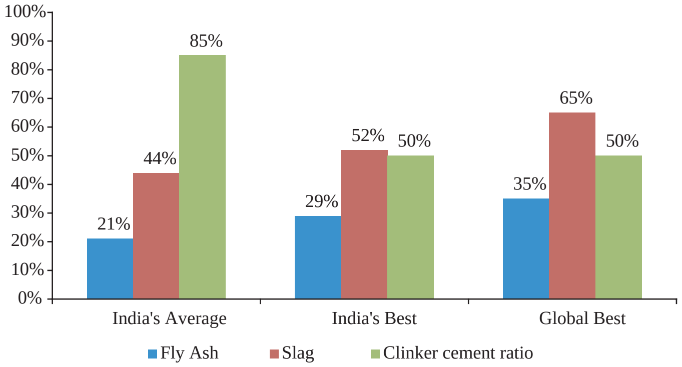


Figure 8.10 | India cement blend ratio – cement clinker ratio comparison with global best, 2005. Source: Bhushan and Hazra, 2005.

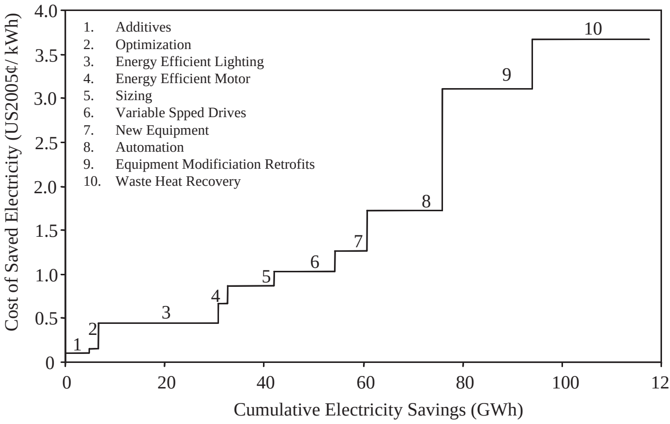


Figure 8.11 | Conservation supply curve for electricity savings in the Indian cement industry. Source: Rane, 2009.

The graph shown in Figure 8.12 covers 80% of global cement production. Note that the lower energy intensity of cement production is the effect of energy efficiency and the use of additives to blend cement. The low energy intensity does not necessarily mean that a country is more energy efficient. The Colombia Kiln (Zeman and Lackner, 2008) proposes a reduced-emission oxygen kiln for cement production. The concept is to use oxyfuel combustion and integrate with carbon capture and storage to reduce CO_2 emissions from the plant by 90%.

8.3.4 Aluminum

Global primary aluminum production was estimated at 38 Mt in 2007 and has grown by an average of 5%/yr over the last 10 years. The key producing countries are China, Russia, Canada, Australia, Brazil, India, and Norway.

Table 8.12 | Energy use in the Brazilian aluminum industry, 2002–2006.

		2002	2003	2004	2005	2006
Production	(10^3 t)	1318.4	1380.6	1457.4	1497.6	1603.8
Domestic consumption	(10^3 t)	715.5	666.0	738.5	802.3	837.6
Electricity consumption	(GWh)	19474.5	20758.9	22076.7	22939.6	23973.8
Fuel oil	(t)	58300	61000	62400	59100	54200

Source: data based on ABAL, 2008.

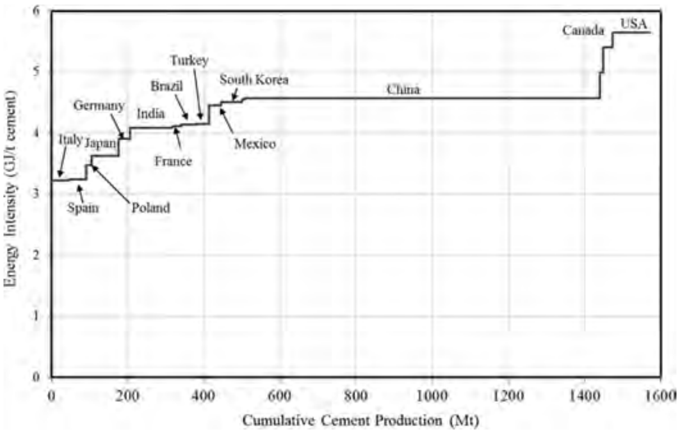


Figure 8.12 | Energy intensity of cement production in selected key cement-producing countries, expressed as primary energy (GJ/t).

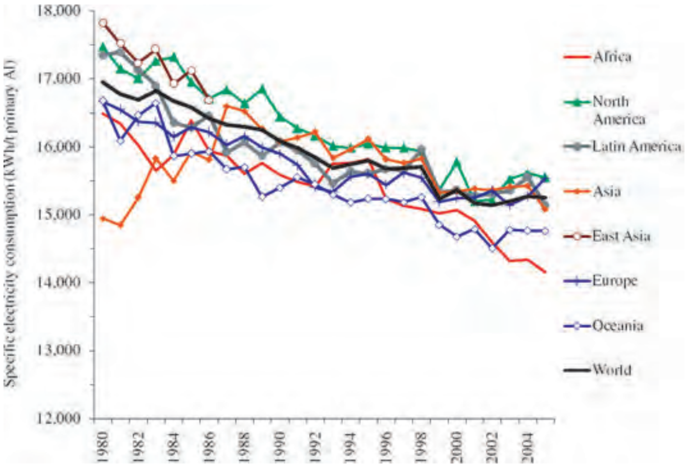


Figure 8.14 | Specific electricity consumption of the aluminum industry (kWh/t) by Region and for the world (black), 1980–2005. Source: data from IAI, 2007. Al = aluminum.

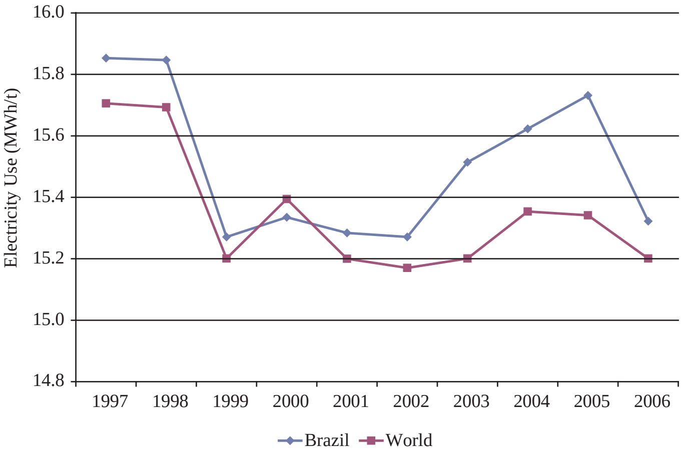


Figure 8.13 | Specific electricity consumption of the aluminum industry (MWh/t) – Brazil and world average, 1997–2007. Source: data based on ABAL, 2008.

Aluminum is produced by the electrolytic reduction of alumina (Al_2O_3). The process is energy intensive, using electricity. Apart from the CO_2 emissions associated with the electricity used, the process also results in emissions of perfluorocarbons (PFCs), carbon tetrafluoride (CF_4), and hexafluoroethane (C_2F_6) (IAI, 2007), which are all greenhouse gases (IAI, 2007). The International Aluminum Institute, a group of aluminum producers (accounting for 70% of the global production) committed to reducing their smelting energy use by 10% between 1990 and 2010 (IAI, 2007), achieved an actual reduction of 6% by 2004 (IPCC, 2007).

Additional energy efficiency improvements are possible through increased penetration of state-of-the-art, point feed, prebake smelter technology (replacing Söderberg cells), process control, and an increase in recycling rates for old scrap (IEA GHG, 2001). Figure 8.13 shows the trend in the specific electricity consumption in the aluminum industry in Brazil along with the world trend. Table 8.12 shows the trend in aluminum production and domestic consumption in Brazil. Almost 50% of production is for the export market. The time-series trend of electricity intensity of the aluminum industry across the regions of the world is shown in Figure 8.14.

Ongoing research to develop an inert anode is expected to reduce the energy used for anode baking and electrolysis. Though inert anodes are currently not viable, it is projected that commercially viable designs may be developed by 2020 (IAI, 2011).

Figure 8.15 shows the average specific electricity consumption for aluminum production in different regions of the world. Note that the International Aluminium Institute (IAI) data do not cover China completely. Hence, Figure 8.15 underestimates the relatively high specific electricity consumption for aluminum production in China. Europe includes the EU, Russia, and other countries. The high specific electricity consumption in Europe is due to Russian production capacity.

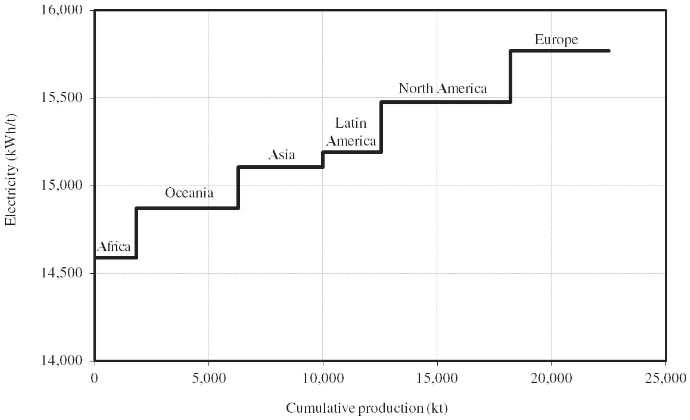


Figure 8.15 | Specific electricity consumption vs. production for world regions. Source: Production data based on USGS (2005; 2007; 2008) and electricity consumption data based on IAI, 2007.

8.3.5 Pulp and Paper Industry

The global pulp and paper industry is an important industry in many countries, from both an economic and an energy use perspective, consuming globally around 6.5 EJ (including printing). This makes the sector one of the largest energy-using sectors in industry after chemicals, iron and steel, and cement. The four largest paper-producing regions (the EU, the US, China, and Japan) account for 80% of energy use and CO_2 emissions. Despite recent changes in the drivers for paper demand, global paper demand is still growing at rates of over 3%/yr over the past 40 years.

The industry is also unique in its reliance on biomass as the key feedstock (besides recycled paper) and primary energy source. This means that while the energy intensity of the sector is high, the CO_2 intensity is far less. The most important processes are pulping (both mechanically and chemically) and papermaking. Energy is used in the pulping of the wood to prepare the fiber, which is processed in the paper machine, the other key energy-using process. About half of the energy is used in pulping, while the other half is used in papermaking. Energy use in the paper machine varies with the paper grade produced. Paper can be made in integrated mills (pulping and papermaking), in standalone pulp (for market pulp) or in paper mills (using imported pulp and recycled paper). Most energy is used in the form of heat (steam) and power. This makes the sector a large user of cogeneration (both using biomass as fossil fuels), but it still also provides a large opportunity for energy efficiency improvements.

Benchmarking and other studies (see, e.g., IEA, 2007a) have demonstrated a substantial potential for efficiency improvement, if best practice technology would be used (see, e.g., Worrell et al., 2008), both in heat use (varying between 0–40%) and electricity use (globally around 20–30%). Combined heat and power (CHP) use varies from 20% of the share of power use to highs of 60% or more (e.g., the United Kingdom, the Netherlands). The countries with the largest potential for energy efficiency improvement typically operate small-scale mills (e.g., China, India) or outdated process equipment (e.g., the United States), while energy-efficient countries operate modern, large-scale mills (e.g., Japan, Scandinavia). China is an interesting example. Just a few decades ago, the majority of the paper industry consisted of very small, inefficient and polluting mills mainly using straw as the main fiber source. Today, China's share of global production is rapidly increasing, and this expansion is based on large, modern paper machines using (imported) recycled paper.

Table 8.13 provides a summary of process-specific energy efficiency opportunities (based on Martin et al., 2000; Kramer et al., 2009). Beyond these opportunities, cross-cutting options exist in motor systems and steam generation and distribution. New technology is being developed, of which black liquor gasification is the most important in pulping, and various new drying technologies are under development for papermaking. Moreover, paper recycling is an important option to reduce energy use (reducing the need for wood pulping) and save resources. Some paper-producing countries rely almost completely on the use of recycled fiber as feedstock (e.g., in Europe).

8.3.6 Small- and Medium-Sized Enterprises

The definition of Small- and Medium-Sized Enterprises (SMEs) varies by country. In some countries it is based on the value added, in others, it is based on the number of employees. Typically these are companies with up to a few hundred employees and a turnover of less than US$100 million. Some of the SME activities are energy intensive (see also Chapter 6). Substantial amounts of energy are used for the production of ferrous and non-ferrous foundries, ceramics, bricks, glass, lime, concrete, wood processing, food and beverages, small-scale pulp and paper mills, cement kilns, steel production and steel rolling mills, and DRI production. Reliable statistics in terms of economic activity and energy use are lacking. However, it is possible to make a rough estimate based on the physical production volume and the typical energy use per unit of product (Table 8.14 and Figure 8.16).

SMEs make economic sense in several sectors where there are no economies of scale. SMEs are adaptable and a source of technology innovation. Rapidly growing economies usually have a large share of SMEs. Access to large-scale production technology is an issue in certain countries. In countries that are members of the Organisation for Economic Co-operation and Development (OECD), where capital is cheap, labor expensive, and technology development has been targeting upscaling for decades, SMEs play a secondary role. However, in many developing countries they are the cornerstone of industrial development. In the context of the changing mix of global industrial output, SMEs in developing countries deserve special attention.

Estimated current final energy use of selected SMEs and small-scale clusters of the manufacturing industry is between 18–32 EJ. This is equivalent to 14–25% of the total final energy use of the manufacturing sector including feedstock use in 2007 (127 EJ), and 17–30% of the total process energy use when feedstock use is excluded (106 EJ).

Table 8.13 | Summary of process-specific energy efficiency opportunities in the pulp and paper industry.

Raw Material Preparation	
Cradle debarkers	Automatic chip handling and screening
Replace pneumatic chip conveyors with belt conveyors	Bar-type chip screening
Use secondary heat instead of steam in debarking	Chip conditioning
Chemical Pulping	
Pulping	
Use of pulping aids to increase yield	Digester blow/flash heat recovery
Optimize the dilution factor control	Heat recovery from bleach plant effluents
Continuous digester control system	Improved browstock washing
Digester improvement	Chlorine dioxide (ClO2) heat exchange
Bleaching	
Heat recovery from bleach plant effluents	Chlorine dioxide (ClO2) heat exchange
Improved brownstock washing	
Chemical Recovery	
Lime kiln oxygen enrichment	Improved composite tubes for recovery boiler
Lime kiln modification	Recovery boiler deposition monitoring
Lime kiln electrostatic precipitation	Quaternary air injection
Black liquor solids concentration	
Mechanical Pulping	
Refiner improvements	Increased use of recycle pulp
Refiner optimization for overall energy use	Heat recovery from de-inking plant
Pressurized groundwood	Fractionation of recycled fibers
Continuous repulping	Thermopulping
Efficient repulping rotors	RTS pulping
Drum pulpers	Heat recovery in thermomechanical pulp
Papermaking	
Advanced dryer controls	Waste heat recovery
Control of dew point	Vacuum nip press
Energy efficient dewatering – rewetting	Shoe (extended nip) press
Dryers bars and stationary siphons	Gap forming
Reduction of blow through losses	CondeBelt drying
Reduction air requirements	Air impingement drying
Optimizing pocket ventilation temperature	

Source: Kramer et al., 2009.

Policymakers can affect the sector's energy use. Interventions can be in the form of energy pricing, energy cost information systems, energy audits, workshops and conferences organized in cooperation with industry associations, technology cooperation schemes with technical universities and research institutes, and energy technology knowledge systems (centers, books, curricula, etc.).

One program considered successful at providing technical assistance comes from the US Department of Energy (US DOE). The program targets SMEs and has created a number of Industrial Assessment Centers housed within US universities. Engineering students from the centers are "seconded" to SMEs to provide relevant technical assistance, such as conducting energy audits and assessing potential energy efficiency projects (Mallett et al., 2010). SMEs like the program, as there are no costs involved on their part, and it also provides practical experience for the students. Many participating firms undertake the energy efficiency opportunities presented to them by the students, and some firms hire the students to continue working at their firm after graduation. An assessment of the program found that it helped to overcome informational barriers – there were significant changes in decision-making on energy efficiency within a relatively short period of time (Mallett et al., 2010).

Table 8.14 | Estimated total final energy use of the selected SMEs and small-scale clusters worldwide, 2007.

SMEs and small-scale clusters	Final Energy (PJ/Year)
Ferrous and non-ferrous metals	950 – 1750
Non-metallic minerals	7400 – 12,500
Bio-based chemical products	200 – 400
Food and beverage	2150 – 4400
Textiles and leather	950 – 1800
Building and construction	1450 – 2500
Wood processing	1200 – 2000
Energy transformation processes	925 – 1800
Small-scale energy-intensive sectors in developing countries	2450 – 5000
Total final energy use of SMEs and small-scale clusters	**17,675 – 32,150**

Table 8.15 shows the summary of a study by the Confederation of Indian Industry and Forbes Marshall of fuel, electricity, and water in several SMEs in India. It is clear that significant savings are possible with respect to the best performance in each sector. The options considered in this study do not include process changes. An analysis of brick kilns shows significant potential for savings by introducing energy-efficient vertical shaft brick kilns. There is a need for increased efforts for benchmarking and analytical studies for energy efficiency in SMEs.

8.3.7 Industrial Benchmarking: A Tool for Realistic Assessment of Energy Efficiency Potentials

Benchmarking is a management tool that is used to compare similar plants. This is done for many operational aspects such as energy use and energy efficiency.

Benchmarking is primarily a tool that helps plant managers to gauge their improvement potential. However, if it is done for a representative set of plants or for a significant share of the total production volume, it can be used to estimate the improvement potential for the whole sector compared to best process technology. This is valuable information for policymakers.

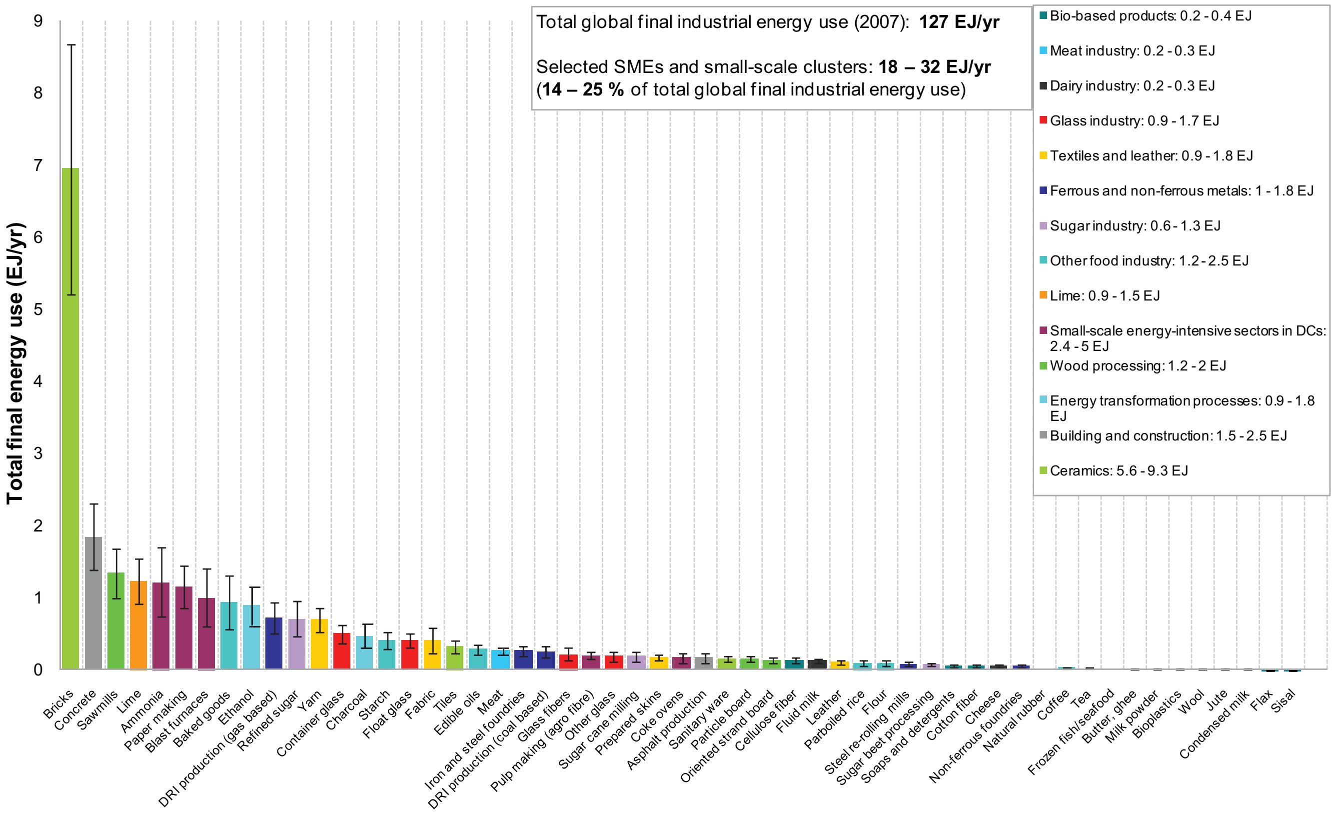


Figure 8.16 | Estimated total final energy use of selected SMEs and small-scale clusters worldwide, 2007.

Table 8.15 | Specific energy use savings for SMEs in India.

SMEs in India		Fuel			Electricity (kWh)			Water (m³)		
	Unit for Fuel	Average	Best	Savings	Average	Best	Savings	Average	Best	Savings
Breweries	Fuel L/kL Beer	58	44	24%	156	100	36%	9.1	7.9	13%
Beverage	Fuel L/kL Beverage	9.35	5.29	43%	–			–		
Tire	Fuel kg/t Finished Tire	210	162	23%	872	780	11%	8.4	4.8	43%
Textile	Coal kg/1000 Mt	390	168	57%	195	44	77%	10.15	7.43	27%
Soya	Coal t/t Seed Crushed	63	47	25%	40	21	48%	–		
Rice bran	Husk t/t Seed Crushed	111	100	10%	27	25	7%	–		
Paper	Coal kg/t Paper	360	259	28%	–			–		

Source: CII and Forbes Marshall Study, 2005.

The fact that benchmarking only considers measured data avoids a lengthy discussion about best available technology. As technology evolves over time and new technologies are gradually introduced, there is always a grey area between proven technology that can be applied in the short term in practice and technologies that are not yet fully mature or commercially available.

A challenge for benchmarking is the comparability of individual units. For example: feedstock quality may differ, the product quality may not be exactly the same and local climate conditions or opportunities for process integration may differ. Therefore, care must be taken to compare “like with like.” For benchmarking curves, a widely used approach is one where the 10th percentile is used to define the best available technology. Typically the benchmarking curves show a virtually linear rise from the 10th to the 90th percentile. This allows a comparatively straightforward estimate of the improvement potential: the average efficiency/energy use of the 10th and 90th percentile is the average for the whole group of plants, and the improvement potential is the percentage gap between this average and the 10th percentile.

This approach has been applied for primary aluminum, ammonia, cement clinker, and ethylene, as shown in Figure 8.17. A similar effort

Table 8.16 | Comparison between sectoral average energy intensities, best values, and potential savings.

	Specific Energy Consumption in 2005 (GJ/t)			
Regions	**Steel**	**Cement**	**Paper**	**Aluminum**
China	22.3	3.9	30.7	51.5
India	22.8	3.3	26.7	94.7
Brazil	26.6	3.9	22.0	61.6
World average	19.4	4.0	18.4	103
Thermodynamic Min (GJ/t)	6.9[1]	1.76		21.6[2]
Best Available Technology	16.3	2.9	17.6	70.6
Saving Potential %	16%	28%	4%	31%

Source: Worrell and Galitsky, 2008; IEA, 2008a;

1 IISI, 2008;

2 IEA, 2008a.

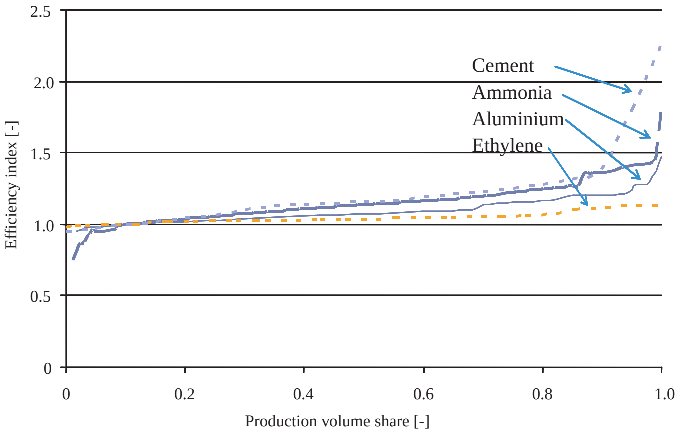


Figure 8.17 | Benchmarking curves for aluminum (2007), ammonia (2006/7), cement clinker (2006), and ethylene (2005). Source: IAI, 2007; IFA, 2009; CSI, 2006.

is ongoing for iron and steelmaking as part of the Task Force under the Asia-Pacific Partnership.

Typically the benchmarking curves suggest an average 10–20% efficiency potential. However, it should be considered that the coverage varies. China is missing from these datasets, and the average efficiency in China is relatively low. This raises the efficiency potential by a quarter to a half.

But what these numbers suggest is that the efficiency potentials based on best available technology in key energy-consuming sectors are significantly lower than other parts of the economy, such as buildings (typically with an average improvement potential of over 50%; see Chapter 10) and the power sector. Table 8.16 shows average energy intensities (GJ/t) in select industries and comparisons with international best averages.

Benchmarking curves do not account for the efficiency potential based on new technology. In all these sectors there are efforts to improve efficiency further. Inert anodes in combination with drained cells for aluminum smelters, new gas separation membranes for ammonia plants, low-temperature heat recovery for cement kilns, and gas turbines and new separation systems for steam crackers are examples of such developments. The theoretical minimum energy use is typically half of the global average today. This does not mean that this minimum can be reached, but it indicates that further improvements can be expected as technology improves. Most benchmarking studies are based on statistical techniques by comparing existing plants. An alternative approach is model-based benchmarking (Sardeshpande et al., 2007) applied to industrial furnaces for glass manufacture. The model is used for predicting an achievable minimum energy use for a given furnace configuration based on design and operating parameters. This approach provides a rational basis for target setting and energy performance improvements for existing processes and can be extended to other industrial processes in metallurgical, cement, paper, petrochemical, and textile industries.

However, the large gains will not come from narrow process efficiency improvement but from the application of broader systems optimization strategies. Use of electricity outside the plant boundaries is often excessive, and here significant savings can be achieved. Also, options such as heat integration, cogeneration, recycling, and a change of process inputs can contribute to savings. Improved materials use efficiency does not contribute to savings per tonne of materials produced, but it reduces the materials production volume. Benchmarking curves do not capture all these improvement options or may do so only partially. Data are sketchier, but typically they can raise the average efficiency potentials by 5–10 percentage points. However, the economics of these improvements are not well established and they may vary widely.

The energy-saving potentials based on benchmarking and indicator data for OECD and non-OECD regions are shown in Table 8.17.

In 2007, the global manufacturing industry used 127 EJ of final energy (40% in industrialized countries and 60% in developing countries). More than half of the industrial energy use is due to the activities of

Table 8.17 | Energy efficiency improvement potentials in the manufacturing industry based on benchmarking and indicator data, 2007.

	Improvement potential (%)		Total Savings Potential (EJ/yr)		Global Subtotal (EJ/yr)
	Industrialized countries	Developing countries	Industrialized countries	Developing countries	
Chemical and petrochemical					
High value chemicals	15–25	25–30	0.4	0.3	2.3
Ammonia, methanol	10–15	15–30	0.1	1.4	
Non-ferrous metals					1
Alumina production	30–40	40–55	0.1	0.5	
Aluminium smelters	5–10	5	0.2	0.2	
Cast non-ferrous and other non-ferrous	35–60				
Ferrous metals					6.1
Iron and steel	10–15	25–35	0.7	5.4	
Cast ferrous	25–40				
Non-metallic minerals					2.8
Cement	20–25	20–30	0.4	1.8	
Lime	10–40	20–50	0.4	0.2	
Glass					
Ceramics					
Pulp and paper	20–30	15–30	1.3	0.3	1.6
Textile					
Food, beverages and tobacco	25–40		0.9	1	1.9
Other sectors	10–15	25–30	2.5	8.7	11.2
Total	10–20	30–35	7.2	20.1	27.3
Total (excl. feedstock)	15–20	30–35			

Source: Saygin et al., 2010.

the energy-intensive sectors: chemicals and petrochemicals (selected processes in Table 8.17), non-ferrous and ferrous metals, non metallic minerals, and pulp and paper (66 EJ/yr including feedstocks). According to benchmarking and indicator data, best practice technologies can reduce energy-intensive industry's final energy use by 11–17 EJ. This is equivalent to an improvement potential of 17–26% including feedstock use.

Additional energy efficiency potentials in light industries (e.g., textiles, food, beverages, and tobacco, etc.) are estimated at 12–16 EJ. This adds up to a total industrial energy-saving potential of 22–31% EJ if all industrial processes were to adopt best practice technologies (or 22–31 EJ improvement potentials excluding feedstock use).

Approximately three-quarters of this energy-saving potential are located in developing countries (17–23 EJ), with the estimated improvement potentials higher than worldwide, between 30% and 35%. The remaining 6–9 EJ of the potential is in industrialized countries. In the coming decades, industrial energy use is projected to increase much more in developing countries than in industrialized countries. Given the high improvement potentials in developing countries and the future growth projections, improving energy efficiency at process level is a key measure to reduce energy demand and related carbon emissions.

Benchmarking has grown as an industrial management tool. Its use for sectoral agreements or for target setting raises new needs. For example, today in all benchmarks individual plant data are confidential for antitrust and competitiveness reasons. Also, participation is voluntary, coverage is incomplete, and the process is driven by consultancies that have a natural interest to keep information confidential. These aspects need to be addressed to make the benchmarking tool more useful for the climate policymaking process.

Industries have recognized the importance of the benchmarking tool for a rational decision-making process. Certain sectors such as the European Chemicals Industry have devised innovative schemes for integrating benchmarking with emissions trading. In recent years efforts have been increased in iron and steel, cement, pulp and paper, and other sectors. More attention is needed for the use of benchmarking in the

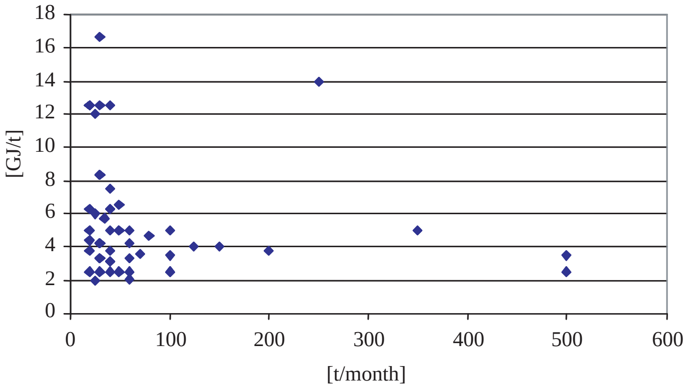
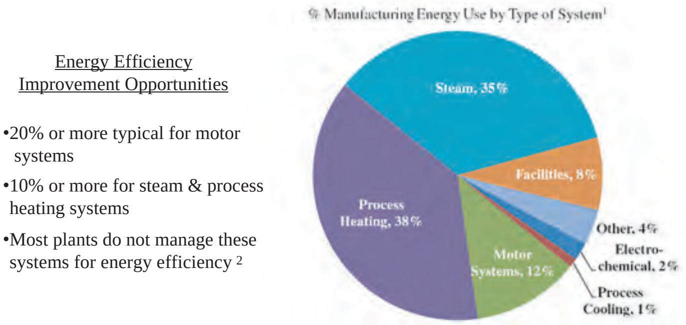


Figure 8.18 | Typical efficiency distribution for an iron SME cluster in India. Source: Gielen, 2010.



Energy Efficiency Improvement Opportunities

- 20% or more typical for motor systems
- 10% or more for steam & process heating systems
- Most plants do not manage these systems for energy efficiency ²

Figure 8.19 | Share of manufacturing energy use by system type. Source: data based on US DOE, 2004b.

1 Does not include offsite losses.

2 2002 MECS – plants indicated energy management activities for 6.3% steam, 16.6% compressed air, 7.5% process heating systems.

SME sector. The inclusion of broader system boundaries is also a theme that deserves policy attention.

The use of benchmarking curves is less established for sectors such as pulp and papermaking, SMEs, and less energy-intensive sectors. Typically these sectors account for 25–50% of total global industrial energy use. The issues are often very different than for large companies. Small-scale operations are in many cases operated intermittently, often based on outdated equipment and without much attention to energy use. As a consequence, the efficiency potentials in percentage terms tend to be much higher than for large industries.

As an example, a benchmarking effort for an Indian iron casting cluster is shown in Figure 8.18. While the larger plants in this cluster tend to be more efficient than the smaller ones, at the same time the small plants show a wide range of efficiencies, reflecting differences in operational practices. A shift to large plants would be an option to increase efficiency, but such an approach would be politically and socially unacceptable. An alternate approach would be to focus on energy efficiency improvements in smaller plants. Such considerations must be taken into account when estimating the improvement potential.

8.4 Consumption and Opportunities: Cross-Cutting End-Uses

8.4.1 Industrial Systems: Overview

System energy efficiency affords industrial facilities the opportunity to readily identify energy efficiency projects that can contribute to continuous improvement for energy management (UNIDO, 2007). However at present, most markets and policymakers tend to focus on individual system components (e.g., motors and drives, compressors, pumps, boilers) with an improvement potential of 2–5% – which can be seen, touched, and rated – rather than systems. While systems have impressive improvement potentials – 20% or more for motor systems and 10% or more for steam and process heating systems (see Figure 8.19) – achieving this potential requires engineering and measurement (US DOE, 2004a; IEA, 2007a).

Though equipment manufacturers are steadily increasing equipment efficiencies, the effect on the system efficiency needs greater attention.

A study of 41 completed industrial system energy efficiency improvement projects in the US between 1995 and 2001 documented an average 22% reduction in energy use. In aggregate, these projects cost US$16.8 million and saved US$7.4 million and 106 million kWh (0.38PJ), recovering the cost of implementation in slightly more than two years (Lung et al., 2003).

8.4.2 Motor Systems

Motor systems account for about 60% of industrial electricity use and about 15% of global final manufacturing energy use (17 EJ in 2005). The International Energy Agency (IEA) estimates global potential from motor system energy efficiency to be of the order of 2.6 EJ annually of final energy use for motor electricity consumption of 13 EJ (IEA, 2007a). Motor systems lose on average approximately 55% of their input energy before reaching the process or end-use work (US DOE, 2004c). Some of these losses are inherent in the energy conversion process – for example, a compressor typically loses 80% of its input energy to low-grade waste heat as the incoming air is converted from atmospheric pressure to the desired system pressure (US DOE, 2004d). Other losses can be avoided through the application of commercially available technology combined with good engineering practices (see Table 8.18) (UNIDO, 2007b). These improvements are cost-effective, with costs typically recovered in two years or less. Figure 8.20 provides an illustration of how a system approach can result in a substantial improvement in system operating efficiency.

Table 8.18 | Energy savings potential by compressed air improvement.

Compressed Air System Improvement Option	% Potential Energy Savings
Replace current compressor with more efficient model	2
Reconfigure piping to reduce pressure loss	20
Add compressed air storage	20
Add small compressor for off-peak loads	2
Add, restore, upgrade compressor controls	30
Install or upgrade distribution control system	20
Rework or correct header piping	20
Add, upgrade or reconfigure air dryers	1
Replace or repair air filters	10
Replace or upgrade condensate drains	5
Modify or replace regulators (controls at the process)	20
Improve compressor room ventilation	1
Install or upgrade (ball) valves in distribution system	10

Note: Does not account for interactions or inappropriate use.

Source: US DOE, 2004d.

In some industrial processes and utility compressed air systems where the delivery pressures are high (greater than 12 bar) it is better to opt for multi-stage compressors. Multi-stage compressors are a move toward the ideal isothermal compression process and results in significant electricity savings.

Even modern, well-maintained industrial systems can benefit from optimization. For example, the Canadian utility, Manitoba Hydro, offers industrial facilities system assessments through its PowerSmart program. System optimization projects completed and documented in 2004 reduced the energy requirements of compressed air systems at a milk plant and a garment manufacturer by more than 60%. One compressed air system was only nine years old with well-maintained, energy-efficient equipment (see Manitoba Hydro, 2011).

The total savings potential in motor systems is expected to range between 15–25%. It is estimated that this will result in a 3.5 EJ of final energy saving from the existing industry. The study by de Keulenaer et al. (2004) estimated annual savings of 202 TWh (0.72 EJ) in the EU with an investment of US$500 million and annual savings of US$10 billion. This would imply an investment requirement of US$2.4 billion for energy efficiency in motors globally for the 3.5 EJ savings.

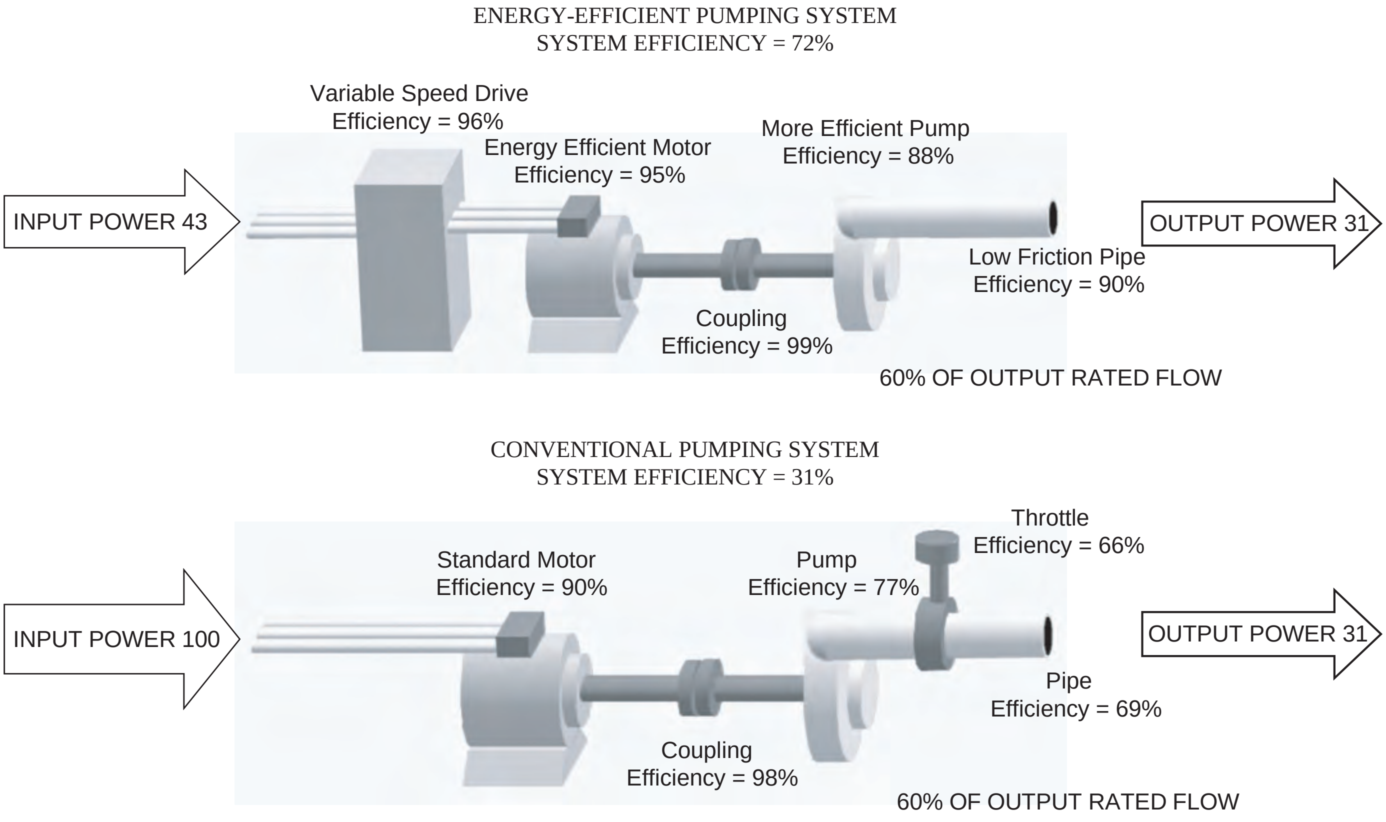


Figure 8.20 | Reconfiguration of pumping system to improve efficiency. Source: Almeida et al., 2005.

Table 8.19 | Total annual electricity saving and CO_2 emission-reduction potential in industrial pump, compressed air, and fan systems.

	Total Annual Electricity Saving Potential in Industrial Pump, Compressed Air, and Fan System (GWh/yr)		Share of Saving from Electricity use in Pump, Compressed Air, and Fan Systems in Studied Industries in 2008 (%)		Total Annual CO_2 Emission Reduction Potential in Industrial Pump, Compressed Air, and Fan System ($ktCO_2$/yr)	
	Cost-Effective	Technical	Cost-Effective	Technical	Cost-Effective	Technical
United States	71,914	100,877	25%	35%	43,342	60,798
Canada	16,461	27,002	25%	40%	8185	13,426
European Union	58,030	76,644	29%	39%	25,301	33,417
Thailand	8343	9659	43%	49%	4330	5013
Vietnam	4026	4787	46%	54%	1973	2346
Brazil	13,836	14,675	42%	44%	2017	2140
Total (sum of six countries)	172,609	233,644	28%	38%	85,147	117,139

* In calculation of energy savings, equipment 1000 hp or greater are excluded

Source: UNIDO, 2010a.

Motor system efficiency supply curves have been developed for the United States, Canada, the EU, Thailand, Vietnam, and Brazil (UNIDO, 2010a). Table 8.19 shows a summary of the results. Cost-effective savings of 172,600 GWh/yr are estimated in these six regions, accounting for 28% of the electricity use. Figures 8.21, 8.22, and 8.23 show the EU's pumping system efficiency curve. The discount rate used is 10%. Similar conservation supply curves have been drawn up for all the six regions studied.

8.4.3 Steam and Process Heating Systems

Steam systems are estimated to account for 38% of global final manufacturing energy use or 44 EJ in 2005. The IEA estimates global potential from steam system energy efficiency to be of the order of 3.3 EJ annually of final energy use for steam energy use of 33 EJ (IEA, 2007a). For steam systems, the losses are only marginally better than motor systems, with 45% of the input energy lost before the steam reaches point of use (US DOE, 2004c).

The best option for improving the energy efficiency of a steam system (Figure 8.24 shows a typical steam system) is through a CHP system. Particularly in more mature industries, excess steam production is fairly common and may be a cost-effective source for on-site generation. Higher-efficiency boilers currently under development offer the promise of higher efficiencies.[5] Sometimes other processes can be used in lieu of steam to perform the same work; for example, in recent decades the chemical industry has successfully developed new catalysts and process routes that reduce the need for steam.

In 2006, the US DOE created the Save Energy Now program based on more than a decade of experience in industrial system energy efficiency. The program offers system assessments to companies with an energy use of 1 TBtu (1.1 PJ) or more annually (over 50% of US industrial energy use). DOE energy experts work with plant energy teams to identify opportunities for improving steam, process heating, pump, or compressed air systems through Energy Savings Assessments. There is a focus on transferring skills to plant personnel and identifying specific energy efficiency opportunities from one system type. The first year of program implementation focused on steam and process heating systems, with motor systems added in the second year. A total of 717 assessments have been completed, with implemented energy savings of US$135 million and planned energy savings of US$347 million. Recommended energy-saving projects totaled 87.2 TBtu (92 PJ), with more than US$937 million in energy cost savings and total potential reductions in CO_2 emissions of 7.9 $MtCO_2$. The payback periods from the measures are very cost-effective, as illustrated in Figure 8.25.

A study conducted in India in several industry segments revealed a potential for steam savings of 25% in breweries, 36% in paper, 28% in starch, 23% in tires, 28% in textiles, and 21% in starch. It is estimated that there is a savings potential of 20% or 8.8 EJ from cross-cutting measures in steam systems from the existing industry in 2005.

8.4.4 Barriers to Improving System Efficiency

The use of Energy efficient components does not guarantee the efficiency of the overall industrial system. Oversizing and incorrect application of energy efficient equipment such as Variable speed drives is common. System assessment to identify the end uses and optimization to determine the best configurations to meet these requirements can help improve energy efficiency (UNIDO, 2007).

System assessment services can provide high value to an industrial facility both in terms of lower operating costs and greater reliability.

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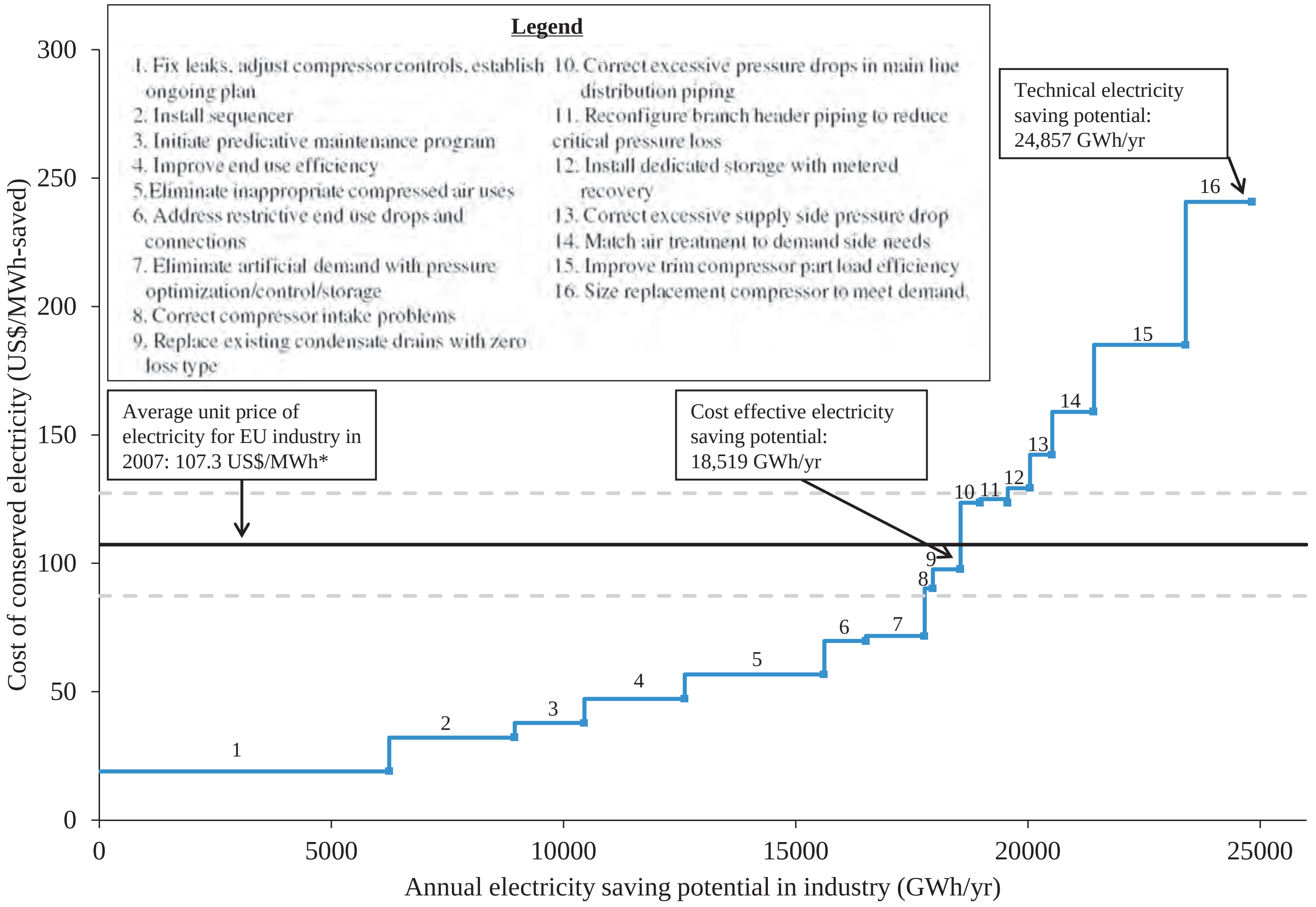
[5] US DOE is supporting the development of a 94% efficient boiler.



* The dotted lines represent the range of price from the sensitivity analysis.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the regional level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Figure 8.21 | EU compressed air system efficiency supply curve. Source: UNIDO, 2010a.

However, it is difficult for plant personnel to easily identify quality services at market-appropriate prices. A typical facility engineer does not have time to research the detailed system-specific information necessary for an informed, but infrequent, purchase of these services. The lack of market definition also creates challenges for providers of quality system assessment services to distinguish their offerings from others that are either inadequate to identify energy efficiency opportunities, or thinly-veiled equipment marketing strategies.

Furthermore, little data are available to support trending of performance for motor, steam, and process heating systems. Measuring the energy efficiency of the components (motors, furnaces, and boilers) is reasonably straightforward and well documented, allowing that some differences in the testing and rating of components still exist. The same is not true in the measurement of system energy efficiency, where most of the energy efficiency potential resides. Few industrial facilities can quantify the energy efficiency of motor, steam, or process heating systems without the assistance of a systems expert. Even experts can fail to identify large savings potentials if variations in loading patterns are not adequately considered in the assessment measurement plan. If permanently installed instrumentation such as flow meters and pressure gauges are present, they are often non-functioning or inaccurate. Often orifice plates or other devices designed to measure flow actually result in restricting flow, as they accumulate scale with age (UN Energy, 2010).

8.4.5 Realizing System Energy Efficiency Potential

Expert knowledge based on assessments carried out in industrial systems in the United States, United Kingdom, and Canada have resulted in the identification of best practices. These assessment techniques have been further refined in recent years in the United States.[6]

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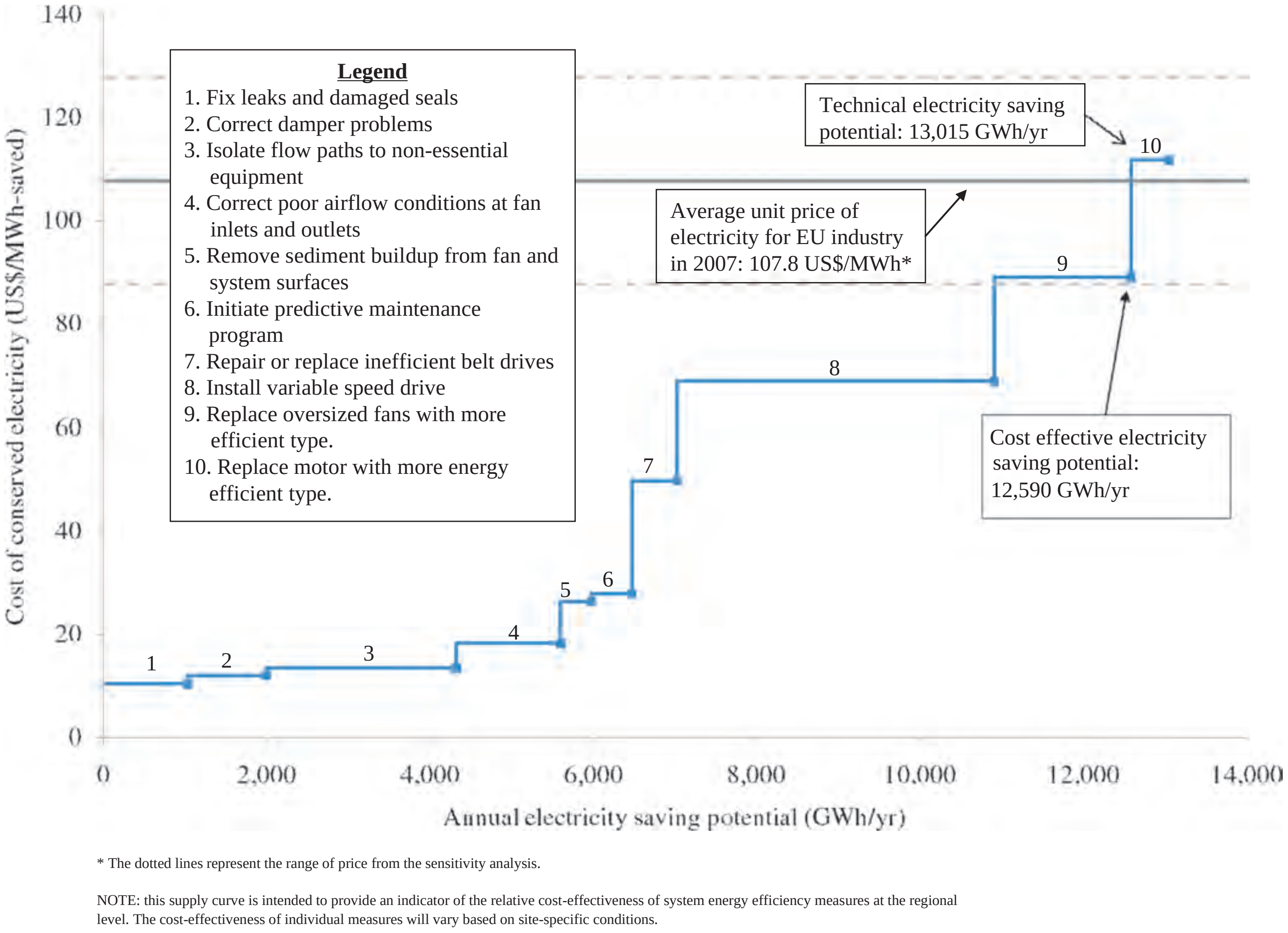
[6] US DOE's Energy Savings Assessments and Industrial Assessment Center Programs and the Compressed Air Challenge™. As an example, the Compressed Air Challenge's Best Practices for Compressed Air Systemscontains an appendix entitled "Detailed Overview of Levels of Analysis of Compressed Air Systems."



* The dotted lines represent the range of price from the sensitivity analysis.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the regional level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Figure 8.22 | EU fan system efficiency supply curve. Source: UNIDO, 2010a.

Best practices that contribute to system optimization are system-specific but normally include:

- evaluating work requirements and matching system supply;
- eliminating or reconfiguring inefficient uses and practices (throttling, open blowing);
- identifying and correcting maintenance problems;
- upgrading ongoing maintenance practices; and
- documenting these practices.

These systems remain inefficient primarily due to a series of institutional and behavioral barriers. Some of the important barriers are the limited awareness of the energy efficiency opportunities by industry, consultants, and suppliers, lack of understanding on how to implement energy efficiency improvements; and, most importantly, absence of a consistent organizational structure within most industrial facilities to effectively manage energy use.

Since energy use is rarely measured at the system level, there are few data available. Without performance indicators that relate energy use to production output, it is difficult to document improvements in system efficiency. If the facility also uses energy as a feedstock, even large system energy efficiency improvements can be lost in the "white noise" of overall plant energy usage, especially if production levels vary. System energy efficiency offers large improvement potential but is complex; a "one size fits all" approach will not work (McKane et al., 2007).

The Superior Energy Performance partnership, a collaboration involving the US DOE's Industrial Technologies Program, industrial companies, the American National Standards Institute (ANSI), non-profit organizations, the US Environmental Protection Agency (US EPA), and the US Department of Commerce's National Institute of Standards and Technology, is facilitating the development of a market-based program for certifying industrial plants for energy efficiency (UN Energy, 2010). As part of this effort, a portfolio of System Assessment Standards has been published by the American Society of Mechanical Engineers (ASME) for compressed air, process

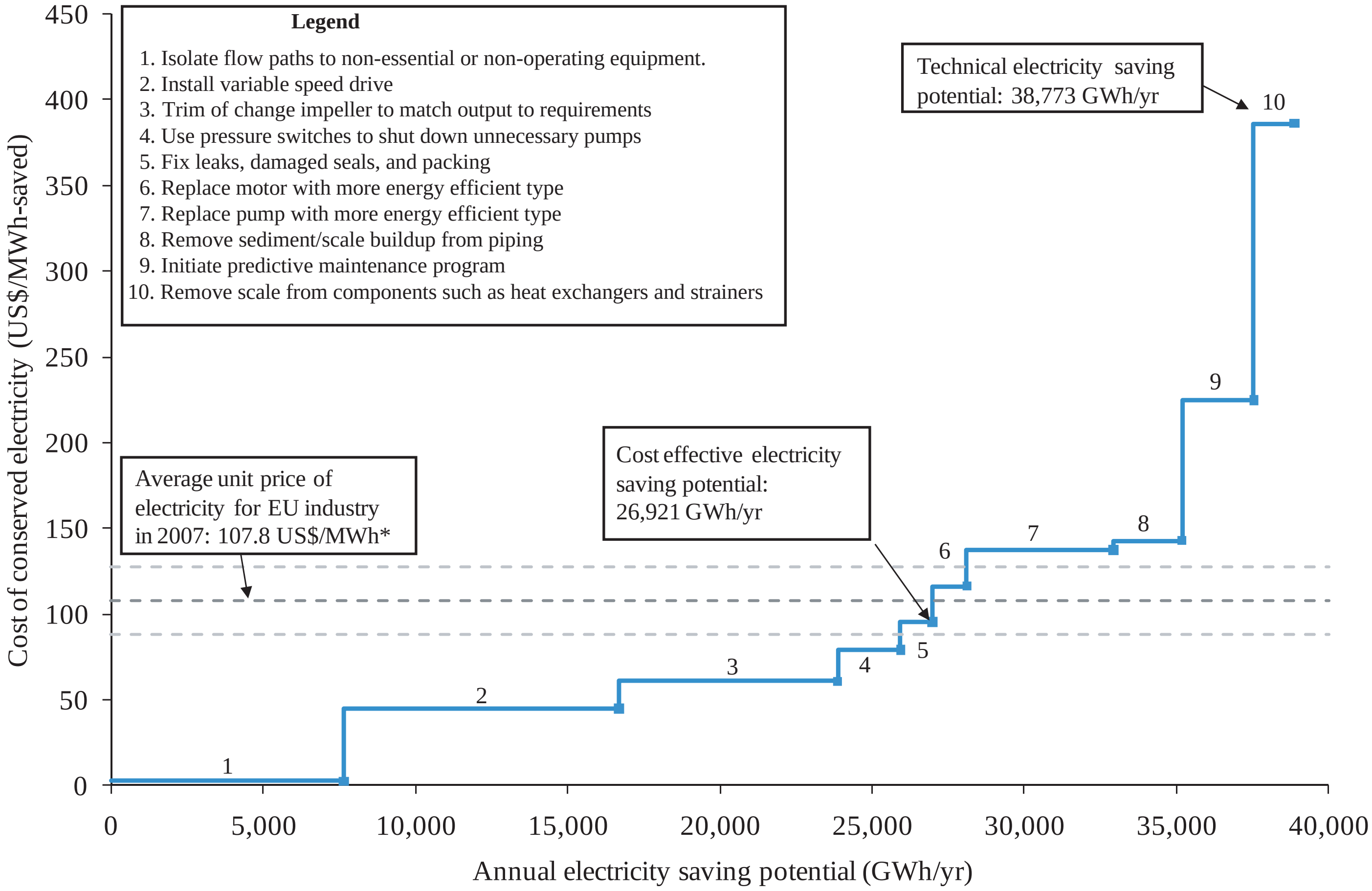


Figure 8.23 | EU pumping system efficiency supply curve. Source: UNIDO, 2010a.

heating, and pumping. Collaboration has already begun for one system type (compressed air) to develop an International Organization for Standardization (ISO) standard modeled on the approach used in the ASME standard.

The System Assessment Standards are designed to create a market threshold for industrial system energy efficiency assessments from the current body of expert knowledge and techniques. The standards will provide a common framework for conducting assessments of industrial systems that will help define the market for both users and providers of these services. By establishing minimum requirements and guidance for scope, measurement, and reporting, these standards will offer greater transparency and higher value to industrial facilities by providing assurance to plant managers, financiers, and other non-technical decision-makers that a particular assessment meets or exceeds a best practice threshold for accuracy and completeness. The existence of System Assessment Standards will also assist in training graduate engineers and others desiring a higher level of skill in the area of system optimization for energy efficiency. To assist industrial firms in identifying individuals with the necessary skills to apply the standards correctly, the US initiative will also include the creation of a professional credential with the working title of Certified Practitioner for each system type.

8.4.6 Process Integration, Heat Pumps, and Cogeneration

Industrial processes are systems (see Figure 8.26) in which raw materials are converted into products and by-products. Such transformations are realized by a succession of process units that use water or solvents and in which energy is the transformation driver. To realize the transformation, energy resources are first converted before being distributed and used in the process units. Applying mass and energy balances to the system shows that what are not useful products, goods, or services leave the system as waste in solid, liquid, or gaseous form, or as waste heat radiated to the environment.

By systematically analyzing the materials and energy conversion processes in the different unit operations in the system and representing their possible interactions, process integration aims at identifying synergies between the process units by allowing the following processes:

- *Recycling of materials and energy*: reuse materials – for example, by converting a waste into a product, to recycle waste streams, or to convert waste streams into useful energy.

- *Heat recovery*: utilization of the heat of the hot streams (streams to be cooled down) to heat up cold streams (streams to be heated up).

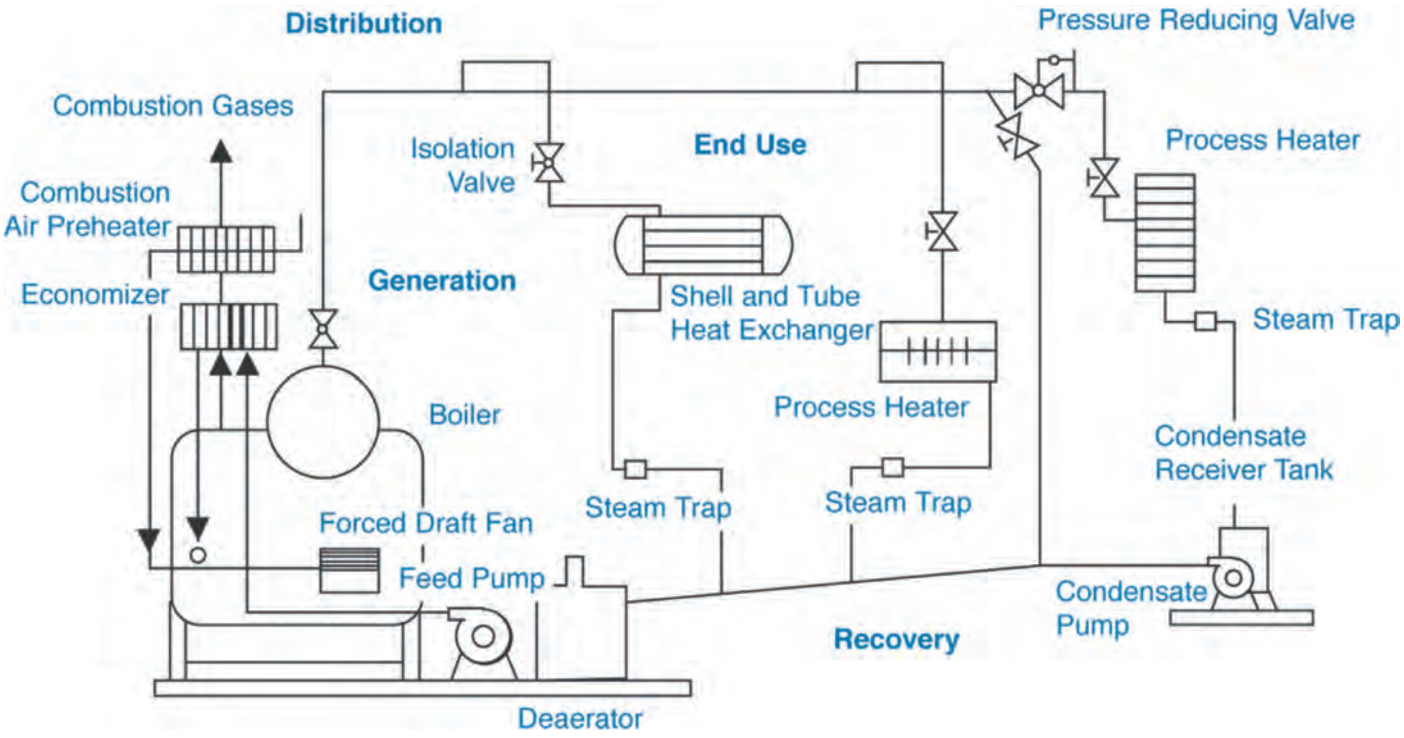


Figure 8.24 | Steam system schematic. Source: based on US DOE, 2002.

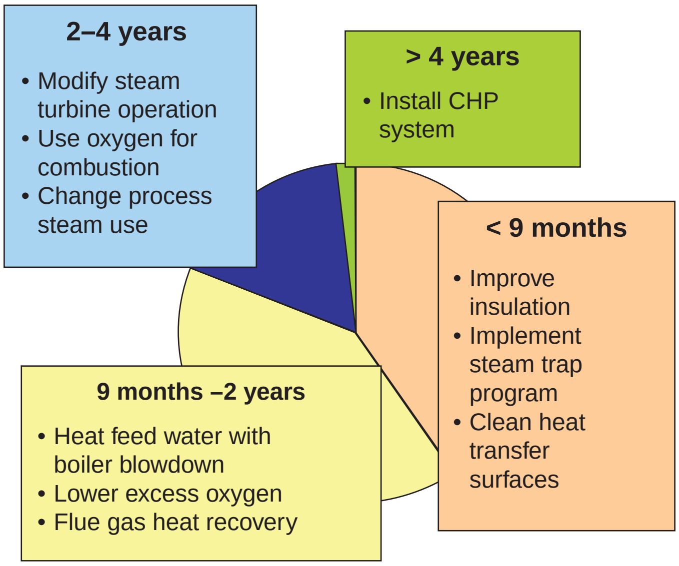


Figure 8.25 | Estimated payback periods for steam-based systems in 2006.

- *CHP production*: CHP – or, more generally, polygeneration – production is typically used to convert fuels into useful heat/cooling and electricity as a by-product or to convert the available exergy in the heat exchange system into useful mechanical power.

- *Waste heat utilization/upgrade in the system*: when the temperature level of waste heat is sufficient and the heat support media is available (e.g., hot water), waste heat can be converted into mechanical power by thermodynamic cycles or can be upgraded by increasing its temperature level using heat pumping systems.

- *Waste heat upgrade*: by extending the system boundaries to other energy users, such as other processes or district heating systems.

Although there is a hierarchy between these different energy efficiency options, they have to be considered simultaneously within a systemic framework and applied considering local conditions and boundaries of the technically and economically accessible system. Extending the system boundaries may change the impact of the energy-saving actions and lead to different solutions. For example, if the waste heat of a process can be reused to heat up other processes in the surroundings, the use of a heat pump to recover waste heat for the reference process will become counterproductive at the system level.

8.4.6.1 Pinch Analysis

Recovering heat from hot streams to preheat cold streams is constrained by the temperature levels of the heat required, by topological constraints, and by the investment in heat exchangers. Pinch analysis is used to estimate the maximum heat recovery that can be realized in a system (without limitations on the number of streams

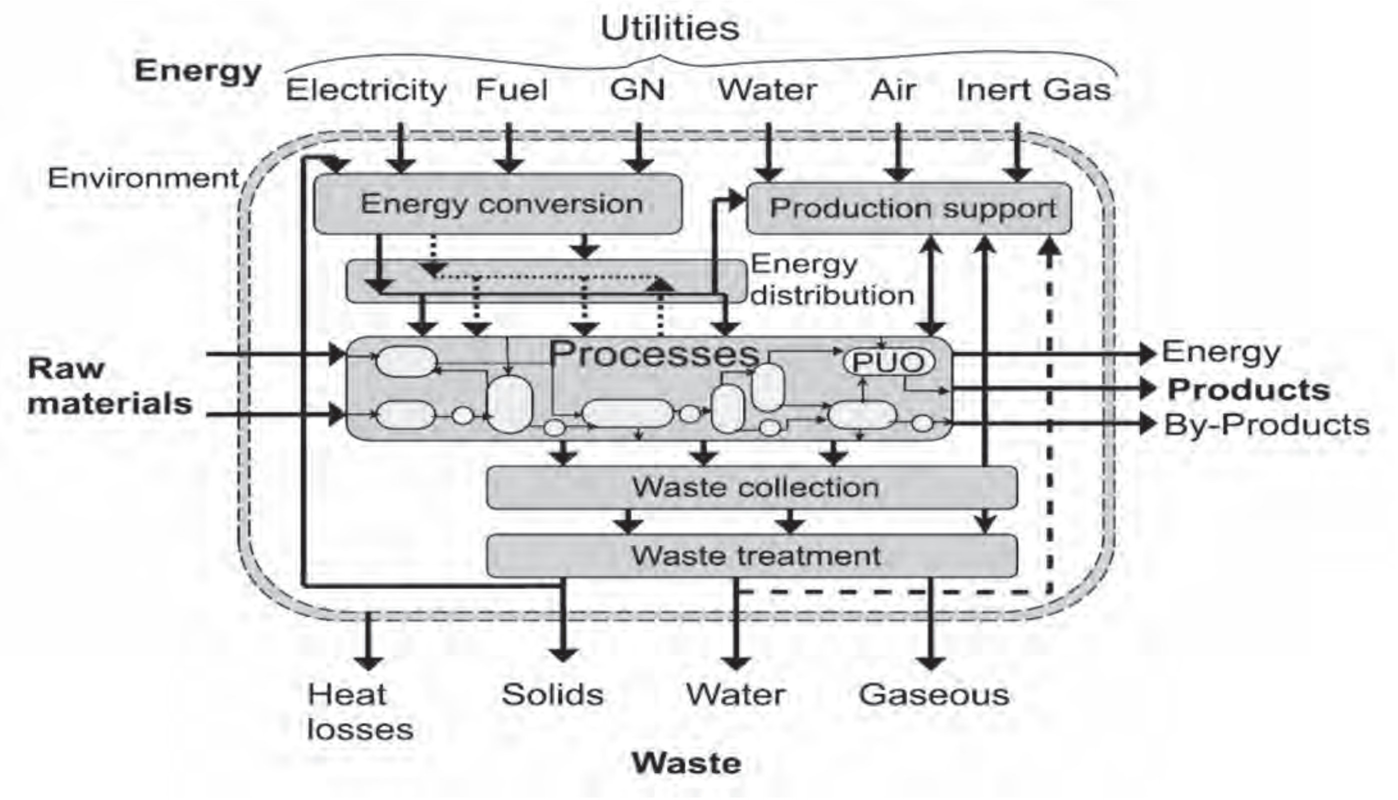


Figure 8.26 | The systemic vision of an industrial process.

and the size of the system) and without having to practically define the heat exchange interconnections. Pinch analysis takes into account the temperature levels of the heat requirement and uses a parameter to represent the energy recovery/capital trade-off that limits the heat exchanger cost by setting a minimum temperature difference (ΔT_{min}) between the hot and the cold streams considered for the heat recovery. The maximum heat recovery is obtained by calculating the integral of the heat available in the hot streams of the system and of the heat required by the cold streams as a function of the temperature. This draws respectively the hot and cold composite curves (see Figure 8.27) that represent the system as one overall hot and overall cold streams between which counter current heat exchange will be used to recover heat.

The maximum heat recovery is obtained by considering that the temperature difference between the two curves must always be higher than the ΔT_{min}. The point at which the curves are the closest is the pinch point. It divides the system into two subsystems: above the pinch point, the process features a deficit of heat (heat sink), and below it, the process has a surplus of heat (heat source). Having defined the maximum heat recovery, the minimum energy to be supplied and removed from the system is obtained by energy balance, while the heat cascade defines their corresponding temperature levels in the grand composite curve. Comparing the minimum energy requirement with the present energy use defines the amount of energy that is directly transferred from the resources to the environment without having any real use in the process, as if this energy were brought to heat up the environment.

8.4.6.2 Optimizing Process Operating Conditions

The process composite curves can be used to adapt the process operating conditions in order to maximize the heat recovery potential. Based on the location of the pinch point location, the goal is to transfer heat excess from below the pinch point to above the pinch point, or heat demands from above to below the pinch by changing the process operating conditions. Important unit operations concerned are chemical reactors and evaporation systems (distillation or evaporators), in which the pressure can be modified to change the temperature of the evaporation and/or condensation. Multi effect evaporation is a good example of this mechanism: changing the operating pressure of the evaporation allows the recovery of the condensation heat to evaporate water in an effect with a lower pressure. Staging the evaporation in multi stages allows one to reduce the energy use for evaporation. For example, a three stage evaporation process will allow the reduction of 60% of the heat needed for evaporation. When considered along with process integration, the use of multi effect evaporators has to be considered with a holistic vision, considering the possible heat recovery and use elsewhere in the process, leading to even higher energy savings. Examples show that a well-integrated multi-effect

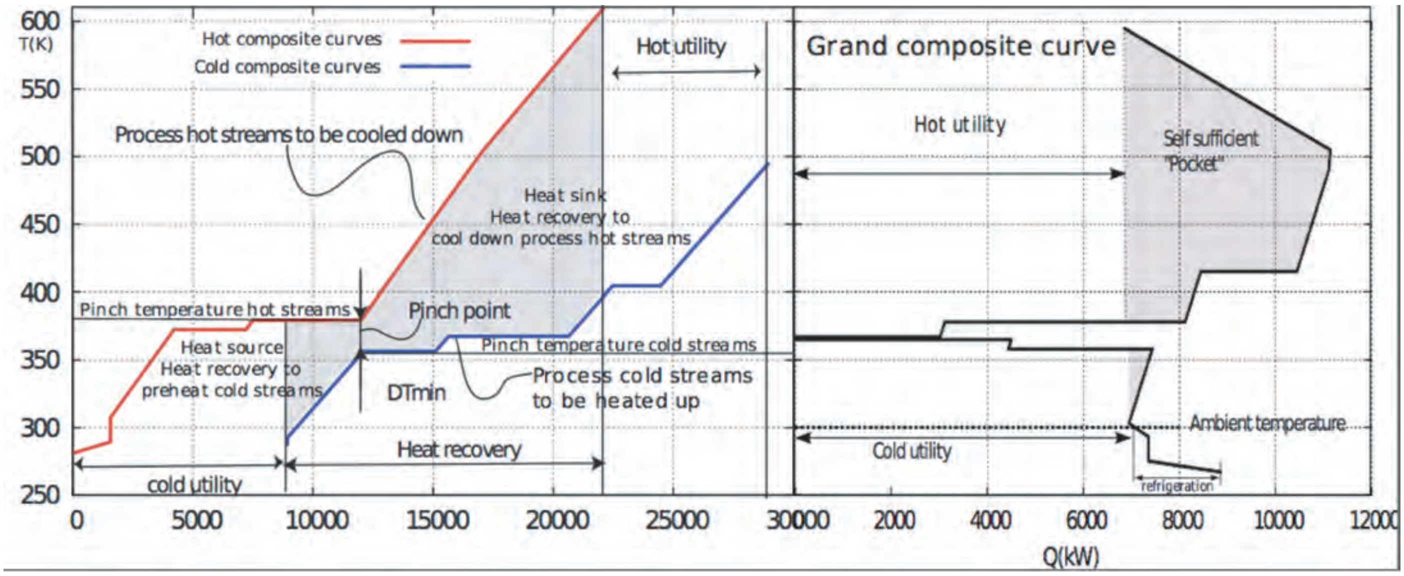


Figure 8.27 | Hot and cold composite curves and possible heat recovery in the system.

evaporation system can save an additional 30% of the remaining heat required.

8.4.6.3 Combined Heat and Power Production

In a CHP production system, energy resources are converted into useful process heat, and electricity. As the heat is supplied to the process by heat transfer, it must have a temperature level compatible with the heat requirement of the process as defined by the grand composite curve (see Figure 8.27) resulting from the pinch analysis. Only the heat of cogeneration that is compatible with the heat sink above the pinch point will create a cogeneration effect.

The different type of cogeneration units are given in Table 8.20. The specific investment, and the electrical (η_e) and thermal (η_{th}) efficiencies depend on the size of the unit. The primary energy savings related to the integration of a cogeneration unit depends on how the co-produced electricity is accounted. One may distinguish the avoided electricity import that substitutes a centralized electricity production facility and that is accounted with the electricity mix efficiency (η_{grid}) from the electricity export that could be considered as an additional electricity production unit. In addition, one may also consider the fuel substitution effect. When the overall heat available from the cogeneration unit is used in the process, the primary energy saving (see Equation 1) is calculated by comparing the resource consumed in the cogeneration unit with the one that would have been consumed for the separate production of heat in a boiler and of electricity from the grid.

$$\text{Energy savings } [\%] = 1 - \frac{1}{\frac{\eta_e}{\eta_{grid}} + \frac{\eta_{th}}{\eta_b}} \qquad (1)$$

with η_e – the electrical efficiency of the cogeneration unit

η_{th} – the thermal efficiency of the cogeneration unit

η_{grid} – the efficiency of the grid electricity production [38%]

η_b – the efficiency of the boiler replaced by the cogeneration unit [90%]

Rankine cycle-based CHP systems have several industrial applications. A typical example is the steam network of industrial processes, where high-pressure steam is produced in boilers or in the process, and is expanded in steam turbines to produce mechanical power before being condensed to supply heat to the process. Rankine cycles are also used to upgrade waste heat below the pinch point. In this case, the heat excess of the process is converted into mechanical power, and the environment is used as a heat sink. When operated under low temperature conditions (typically below 100°C), the fluid used in the cycle is an organic fluid such as the one used in refrigeration or heat pumping.

It is important to mention that the CHP unit will produce its benefit only when it is located entirely above (in the heat sink sub-system) or below (in the heat source sub-system) the pinch point. The heat that crosses the pinch point has no useful CHP effect. In addition, the CHP system allows one to convert the exergy available in the process hot streams.

8.4.6.4 Heat Pumping

In industrial processes, heat pumps are used to upgrade the temperature level of a heat source. Referring to the pinch analysis, heat pumping will be profitable only if it allows transfer of heat from below to above the pinch point, i.e., if it transforms excess heat from the system heat source into useful heat for the system heat sink. All the other situations do not lead to an overall saving. When operated only above the system

Table 8.20 | Examples of cogeneration units to supply heat to processes.

Type	Typical size	η_e	η_{th}	Investment	Energy Savings
	MWe	%	%	US$/kWe	%
Gas turbine	[1:50]	[30:40]	[40–45]	[1000:2500]	[29:36]
Gas turbine combined cycle	[10:100]	50	35		[41]
Engines	[0.1:10]	[30:50]	[55:40]	[800:4000]	[29:43]
Steam turbine	[0.1:15.0]	[20:25]	[74:69]	[69–71]	[26:30]
SOFC fuel cell	0.1	40	40	[NA]	[33]
Hybrid Gas turbine fuel cell	0.2	70	15	[NA]	[50]

pinch point, the heat pump is an expensive electrical heater for the system, while when operated only below the pinch point, the heat pump is an electrical heater that heats up the environment. The integration of a heat pump must therefore be studied with care.

Heat pumping systems may also use the environment as a heat source and the process as a heat sink. The different types of heat pumps are:

- *Mechanical vapor recompression (MVR):* a vapor stream of the process in the heat source is compressed before being condensed to supply heat to the heat sink. MVR heat pumps are typically used in evaporation, distillation, or drying processes.
- *Mechanical heat pumps*: a fluid (typically a refrigerant) is evaporated using heat from the process heat source and compressed before being condensed to supply heat to the process heat sink.
- *Absorption heat pumps*: instead of using mechanical power, the absorption heat pumps are tri-therm systems. High-temperature heat is used as a driver to raise the temperature of a fluid that is at a lower temperature in the heat source. The heat is sent back to the process at a medium temperature in the process heat sink.
- *Heat transformers*: heat transformers use the same principle as the absorption heat pump, but the driver in this case is at a medium temperature (evaporation from the process heat source) and sends the heat back at a higher temperature (in the heat sink), while the remaining heat is sent back at the lowest temperature (typically to the environment).

Especially in mechanical heat pumps, the temperature level of the heat delivered and the temperature lift define the heat pump's performance. The coefficient of performance (COP) of a heat pump represents its amplifying effect and is used to compute its primary energy saving. Considering constant temperature for the heat source ($\bar{T}_{source}$) and for the heat sink ($\bar{T}_{sink}$), the COP of the heat pump is given by Equation 2, where η_{COP} is the efficiency of the heat pump with respect to the theoretical COP. Typical values for η_{COP} are around 50%.

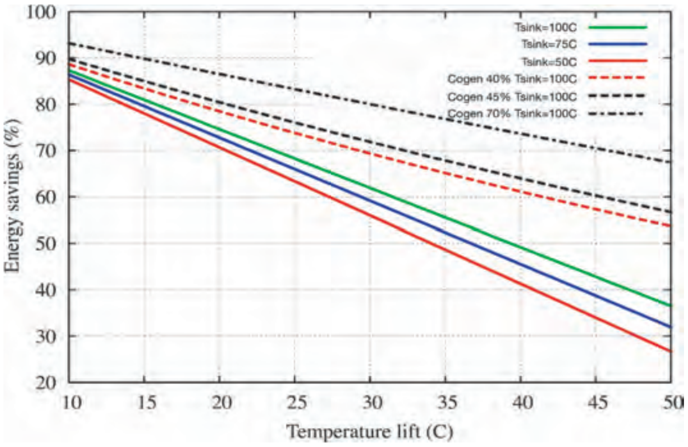


Figure 8.28 | Primary energy savings by the integration of heat pumps (η_{grid} = 38%, η_{boiler} = 90%. η_{COP} =50%) and of a cogeneration unit and heat pumps ($\eta_{electrical}$ = 40%, 45% and 70% with $\eta_{electrical} + \eta_{thermal}$ = 85%). Where η_{COP}= efficiency of the heat pump with respect to the theoretical COP.

$$COP = \frac{\dot{Q}_{th}}{\dot{E}_{hp}} = \eta_{COP} \frac{\bar{T}_{sink}(K)}{\bar{T}_{sink}(K) - \bar{T}_{source}(K)} \tag{2}$$

In integrated systems, the flow of the heat pump and heat recovery are limited by the heat which is available and required by the process. Heat pumps are mainly used in processes with low to medium temperatures (up to 120°C), especially in processes with evaporation systems such as in the food industry or in drying processes. On the grand composite curves, the flow limitation corresponds to the activation of a new pinch point in the system and, therefore, introduces the possibility of cascading heat pumps.

The primary energy saving of a heat pump depends on the heat pump COP and on the efficiency of the grid electricity production, as shown in Figure 8.28. When the temperature level of the CHP permits, then the integration of heat pumps together with CHP units is an attractive option. In this case, the electricity required by the heat pump is produced by the CHP unit that supplies an additional amount of heat to the process. The primary energy savings in this case are even higher (see Figure 8.28).

Table 8.21 | Case studies of process integration, polygeneration, and heat pumping. In this Table the numbers are normalised so that the fossil fuel use in the present situation is taken as the base (100). All other quantities are computed with reference to the fossil fuel use. The savings for the improved scenarios are compared as a percentage of the existing scenario.

Kraft process	Present situation	Process modification	Heat exchangers
Fossil fuel	100	28.5(71.47%)	2.3 (97.74%)
Biomass	269.2	269.2	269.2
Electricity	353.1	289.8 (17.92%)	322.9 (8.56%)
Primary energy	1029.2	791.2 (23.12%))	851.9 (17.22%)
Cogeneration	5.6	68.9 (x12.3)	35.9 (x6.4)
Primary energy cogen.	354.3	116.4 (67.16%)	177.1 (50.03%)
Sulfite process	**Present situation**	**Process integration**	
Fossil Fuel	100	13 (85%)	
Biomass	11	11	
Electricity	48	36 (25%)	
Primary energy	237	110 (53.4%)	
Cogeneration	7	19 (x2.7)	
Primary energy cogen.	104	–23 (120%)	
Dairy	**Present situation**		**Heat pump + cogen.**
Fossil Fuel	100		21 (79%)
Electricity	15		10 (36%)
Primary energy	140		47 (67%)
Chocolate	**Present situation**	**Process integration**	**Heat pump + cogen.**
Fossil Fuel	100	53 (46%)	30 (70%)
Electricity	9	3 (66%)	0 (100%)
Primary energy	123	61 (50%)	30 (75%]
Ethylene	**Present situation**	**Process integration**	
Fossil Fuel	100	55 (45%)	
Electricity	18	7 (59%)	
Primary energy	147	74 (49%)	
Ammonia	**Present situation**	**Process integration**	**High temp. cogen.**
Fossil Fuel	100	38 (62%)	77 (33%)
Electricity	0	13	–3
Primary energy (38%)	100	71 (29%)	70 (30%)
Primary energy (58%)	100	60 (40%)	73 (27%)

8.4.6.5 Case Studies

The Kraft process is the dominant paper making process based on chemical pulping using sulfate. Case studies of a typical kraft pulp and paper process, the food industry (chocolate and dairy), and industrial chemicals (ethylene and ammonia) show benefits of applying process integration concepts, heat pumps, and cogeneration.

Table 8.21 shows the savings obtained against existing practice. It is clear that savings of more than 30% are possible through process integration, polygeneration, and heat pumping. It is, however, difficult to extrapolate the potentials, since most of the results refer to specific systems and conditions.

8.5 Renewables in Industry

In the present mix of energy use in industry, renewables account for about 9% of the final energy. This is mainly due to bagasse and rice husk in sugar and other traditional industries, biogas from sewage and farms, and black liquor in pulp and paper. It is technically feasible to plan a significant share of renewables for industry for process heating, cooling, and power. An analysis by UNIDO (2010b) estimates that renewable energy use in industry is likely to grow to about 50 EJ/yr of final energy by 2050. In 2006, cement manufacturers reported that 10% of total fuel use was from alternative fuels, of which 30% was biomass (CSI, 2006). IEA's analysis (IEA, 2006) reveals that more than 80 solar thermal plants with total collector areas of about 34,000 m^2

were being used for industrial heating, mainly in textiles, the food industry, chemical plants, car washing, and metal treatment facilities.

At present, solar-based thermal energy for low-grade steam and biomass-based thermal energy are feasible for replacing oil. In India, successful examples of thermal applications of biomass gasifiers are in steel rolling mills, the ceramic tile industry, and CO_2 manufacture. Solar thermal systems have been installed in dairies (a 160 m^2 dish replaced the 1 t/hour oil-fired boiler in a dairy in western India). The payback periods for thermal applications for gasifiers is one to two years, while for solar-based heating or steam systems for oil replacements the payback period ranges between four and six years. Biomethanation plants have also been applied in dairies, brewery waste, distillery waste, etc. These have been used for power generation; for example, the biomethanation plant at Haebowal Dairy in Ludhiana, Punjab, India (MNRE, 2010) generates a steady power output of about 1 MW of electricity based on the collection and use of 235 tonnes of animal waste per day. The cost of the plant installed in 2004 was INR134 million (US$3 million). This provides for cogeneration of heat and power and also provides stabilized organic manure. In sugar factories, bagasse-based cogeneration systems are cost-effective and can provide significant surplus power to the grid.

It is possible to increase the share of renewables in industry. In order to do this, it is proposed that a number of demonstration systems be financed in different industrial segments. This would facilitate the dissemination of renewables in the industrial sector. Bio-based renewables can also be used as a feedstock for chemicals (Hermann et al., 2007; Shen et al., 2010), resulting in energy and emissions reductions in the industrial sector.

8.6 Thermodynamic Limits

8.6.1 Analysis of the Global Industrial Sector

In this report, the focus is on the global industrial sector, which is composed of many industries. The energy used by each of these industries in 2005 is shown in Table 8.22. The most significant industries, based on quantity of energy used in 2005, are seen in Table 8.22 to be iron and steel; chemicals and petrochemicals; non-metallic minerals; paper, pulp, and printing; and food and tobacco. With this and other data, energy and exergy utilization in the global industrial sector is evaluated and analyzed. Note that all of the energy forms in Table 8.22 are primary

Table 8.22 | Energy input for the global industrial sector by industry and energy type, 2005 (in PJ).

Industry[1]	Coal and coal products	Crude, NGL and feedstocks	Petroleum products	Natural gas	Geothermal	Solar, wind, other	Combustible renewables and waste	Electricity	Heat	Total
Iron and steel	7910.3	0.2	635.0	2452.8	0.0	0.0	268.6	3259.0	494.3	15020.2
Chemical and petrochemical	1832.1	2.0	2550.3	4742.8	0.0	0.0	95.3	3570.5	1447.1	14240.1
Non-ferrous metals	486.1	0.0	326.2	605.4	0.0	0.0	4.9	2127.3	86.5	3636.3
Non-metallic minerals	5716.9	1.3	1520.9	2103.9	0.0	0.0	210.4	1346.8	105.7	11005.8
Transport equipment	150.6	0.0	126.3	422.8	0.0	0.0	0.6	589.7	136.8	1426.8
Machinery	416.2	0.4	472.9	879.0	0.0	0.0	2.5	2091.2	191.7	4054.0
Mining and quarrying	303.5	0.0	570.7	402.8	1.3	0.0	0.4	824.9	104.4	2208.0
Food and tobacco	794.2	1.5	1085.4	1367.7	0.2	0.0	1107.7	1284.1	356.7	5997.6
Paper, pulp and printing	794.9	0.0	601.1	1068.3	5.7	0.0	2069.0	1701.0	210.2	6450.3
Wood and wood products	87.1	0.3	140.4	121.0	0.0	0.0	414.6	348.6	213.3	1325.3
Construction	215.1	1.1	837.4	155.9	0.0	0.0	6.1	215.1	49.1	1479.9
Textile and leather	450.6	0.5	366.7	364.7	0.0	0.0	10.0	793.1	239.2	2224.8
Non-specified industry	2364.4	155.7	4214.8	3406.7	5.0	5.1	3322.6	4112.5	965.4	18,552.2
Total	**21,522.1**	**162.9**	**13,448.2**	**18,093.8**	**12.3**	**5.2**	**7512.7**	**22,263.9**	**4600.4**	**87,621.3**

Note: For the overall global industrial sector and all industry categories within it, there are no inputs of nuclear energy, or hydro, or heat production from non-specified combustion fuels. Units are petajoules (PJ), which is equal to 1015 Joule (see Chapter 1, Figure 1.3).

1 excludes feedstocks (non-energy use), see Chapter 1, Section 1.2.2.

Source: IEA, 2007a and 2007b.

energy resources or refined versions of them, except for electricity and heat, which are secondary energy carriers.

8.6.1.1 Methodology and Energy Data for the Global Industrial Sector

Each industry category in the industrial sector is analyzed separately, and then combined in a comprehensive assessment of the sector. To simplify the analysis of energy and exergy flows and efficiencies for a complex sector such as the one considered here, the most significant industries, in terms of proportion of total sector energy use, may be taken as representative of the overall sector. Many industries have been assessed individually (Brodyanski et al., 1994).

In the global industrial sector, most of the input energy is used to generate heat for production processes, mechanical drives, lighting, and air conditioning. Heating processes for each industry can be further divided into low-, medium-, and high-temperature categories. This differentiation is important in exergy analysis, as the temperature at which heat is supplied and used greatly affects the exergy associated with the heat.

Several steps are used to derive the overall efficiency of the sector:

- Energy and exergy efficiencies are obtained for process heating for each of the product-heat temperature categories.
- Mean heating energy and exergy efficiencies for the main industries are calculated using a two-part procedure:
  - (i) weighted mean efficiencies for electrical heating and fuel heating are evaluated for each industry; and
  - (ii) weighted mean efficiencies for all heating processes in each industry are determined with these values, using as weighting factors the ratio of the industry's energy use(electrical or fuel) to the total consumption of both electrical and fuel energy.
- Efficiencies are determined for other processes (i.e., heating, mechanical drives, and other processes).
- Weighted mean overall efficiencies for each industry are evaluated using as the weighting factor the fractions of the total sector energy input for heating, mechanical drives, and other processes (Dincer et al., 2004).
- To determine the industrial sector's efficiencies, weighted means for the weighted mean overall energy and exergy efficiencies for the major industries in the industrial sector are obtained, using as the weighting factor the fraction of the total industrial energy demand supplied to each industry (Utlu and Arif, 2008).

In the present analysis, a simplified approach is taken to evaluate exergy parameters. Here, we utilize global energy data for the industrial sector in 2005 as provided by IEA (2007a; b), which provides energy inputs, in terms of energy type, to each industry category in the global industrial sector. We then incorporate the energy and exergy efficiencies for the utilization of the different energy commodities in the industry sector, as determined in a previous global energy and exergy analysis (Nakicenovic et al., 1996). The assumption incorporated here is that efficiencies have not changed significantly on a global scale over the last ten to 15 years for the different industries in the global industrial sector. This assumption may not introduce significant inaccuracies, because although the efficiencies of technologies utilized in highly developed countries may have risen over the last decade, the same phenomenon may not be true in many developing countries, where the focus has been on increased energy use to drive economic development. In addition, the observation of Nakicenovic et al. (1996) that heat input to the industrial sector is predominantly for low- and medium-temperature heating, as well as process heating, is used, so the exergy of the heat input to the sector is thus taken to be 28% of the energy.

8.6.1.2 Energy and Exergy Flows and Efficiencies for the Global Industrial Sector

The energy and exergy inputs and outputs for the overall global industrial sector are presented in Table 8.23. For simplicity, exergy and energy values are assumed equal for commodities that normally exhibit an exergy-energy ratio of approximately one (e.g., most fossil fuels). Also, it is assumed for biofuels that the energy-exergy ratio is unity, and that the energy-exergy ratio for biofuels is representative of that for all renewables. In the present analysis, a reference environment which emulates the actual physical environment is utilized.

Energy and exergy flow diagrams for the overall global industrial sector for 2005 are presented in Figures 8.29 and 8.30, respectively. The input energy to the 2005 global industrial sector of 87.6 EJ shown in the present energy and exergy analyses (Figures 8.29 and 8.30) is less than 115 EJ reported in Section 8.1 (IEA, 2008a). The difference is due to the exclusion of coke ovens, blast furnaces and feedstock energy for petrochemicals from the industrial sector in the present analysis. The addition of the energy inputs for these sub-sectors provides a final energy input of 115 EJ in 2005.

This difference does not affect the overall results and conclusions as the efficiencies and fractional conversions of energy and exergy in the present analysis do not change significantly if coke ovens, blast furnaces and feedstock energy for petrochemicals are included. These figures illustrate the variations in flows shown on the basis of energy or exergy. In these figures, losses and wastes of energy involve only emissions, while losses and wastes of exergy involve emissions and internal destructions (with internal destructions normally being the most significant). It can be seen that the energy and exergy values of most of the inputs (except

Table 8.23 | Energy and exergy flows (in EJ) in the global industrial sector by energy commodity type, 2005.

Energy commodity	Input energy[1]	Product energy	Input exergy	Product exergy
Coal and coal products	21.5	9.3	21.5	3.3
Crude, NGL and feedstocks (including petroleum products)	13.6	3.4	13.6	3.0
Natural gas	18.1	10.2	18.1	3.7
Electricity	22.3	15.7	22.3	12.7
Heat	4.6	4.6	1.3	1.3
Renewables (including combustible renewables and waste, geothermal, and solar/wind/other)	7.5	1.5	7.5	1.0
Total	87.6	44.6	84.3	25.1

Note: Columns may not sum exactly due to round-off errors.

1 excludes feedstocks (non-energy use), see Chapter 1, Section 1.2.2.

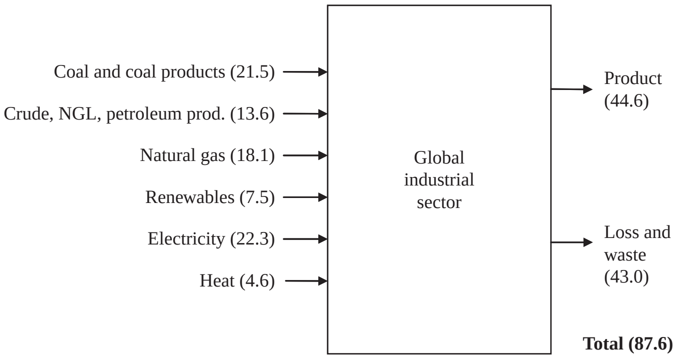


Figure 8.29 | Energy flows (in EJ) for the global industrial sector, 2005. Note: Final energy data excludes feedstocks (non-energy use), see Chapter 1, Section 1.2.2.

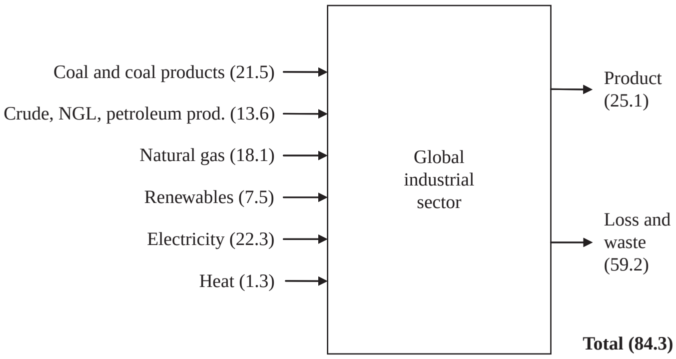


Figure 8.30 | Exergy flows (in EJ) for the global industrial sector, 2005.

heat) are similar, but the product and waste flows have significantly different energy and exergy values.

The overall efficiencies for the global energy sector, evaluated as the ratio of product to input using values from Table 8.23, are found to be 51% based on energy and 30% based on exergy. Consequently, exergy analysis indicates a less efficient picture of energy use in the global industrial sector than energy analysis does. A larger margin for improvement exists from an exergy perspective, compared to the overly optimistic margin indicated by energy.

An energy analysis of energy utilization in the global industrial sector does not provide a true picture of how well energy resources entering it are utilized. An assessment based on energy can be misleading because it often indicates the main inefficiencies to be in the wrong sectors, and a state of technological efficiency higher than actually exists. To accurately assess the true efficiency of energy utilization, exergy analysis must be used. Exergy parameters provide a powerful tool for indicating to industry and government where emphasis should be placed in programs to improve the use of the exergy associated with the main energy resources (Dincer et al., 2004). This analysis provides important insights about potential priorities for future research and development (R&D) initiatives and directions.

It is instructive to compare energy and exergy utilization for the industrial sector with that for other sectors, based on previous analyses of all sectors. Two key points are noted:

- Significant variations are usually exhibited between energy and exergy efficiencies in the residential/commercial and industrial sectors, but not in the utility and transportation sectors. This observation is mainly attributable to the high degree of heating and cooling processes that occur in the residential/commercial and industrial sectors.

- The industrial sector is relatively efficient on an exergy basis compared to other sectors. The reason for the low exergy efficiencies in some sectors is inefficient utilization of the quality of the input energy. The residential/commercial sector, in particular, has a notably low exergy efficiency, mainly because much of the primary use of energy is to produce cold or heat at near environmental temperatures, whereas in the industrial sector high-quality energy is used to produce higher-temperature heating and lower-temperature cooling (which are higher-quality energy forms). Thus the high quality of energy inputs, as reflected by their exergy values, is better utilized in the industrial sector. The production of low-quality products from a fossil fuel or electricity leads to a loss in energy quality that is only reflected properly with exergy analysis. Exergy methods clearly demonstrate that the closer the temperature of the environment to the temperature of the heat produced, the lower the exergy efficiency of the process.

Clearly, exergy provides important insights into the behavior and efficiency of the industrial sector in terms of efficiency limits and margins for improvement. Energy and exergy losses can be viewed as representing, respectively, perceived and actual inefficiencies. It is seen that actual inefficiencies in the residential/commercial and industrial sectors are much higher than the perceived inefficiencies. For the transportation and utility sectors, the actual inefficiencies are lower than the perceived inefficiencies.

8.7 Industrial Energy Efficiency and the Economy

8.7.1 Industrial Energy Efficiency and Economic Growth

At first sight, increased industrial energy efficiency should encourage economic growth. In fact, there is quite a lot of evidence that it has done so in the past by cutting costs, leading to lower prices of goods and, ultimately, increased demand for those goods or for new products and services that did not exist previously. Nielson's use of preheated air made blast furnaces more efficient and cut the cost of pig iron dramatically in the early 19th century. This, in turn, made wrought iron rails much cheaper and helped in the spread of railroads. Later, Bessemer's clever way of decarbonizing molten iron by blowing air through it to make steel was a tremendous gain in efficiency and made steel much cheaper than the older processes. The result was to substitute steel rails for iron rails, and to create immense new markets for steel products, especially in construction, ship-building, and, later, the manufacture of automobiles.

The invention of steam turbines in the 1880s made steam power cheaper and more efficient. The main application was for electric power generation. Cheaper electricity resulted in the rapid spread of electric lighting, replacing gas lights, candles, and acetylene lamps, and the substitution of electric motors for steam engines in factories and on railways. Cheap electric power also created new markets, including the aluminum and chlorine industries, the use of electric furnaces to refine metals with high melting points such as chromium and nickel (for stainless steel), tungsten (for light bulbs), and synthetic carbides to permit high-speed grinding machines that are essential for manufacturing complex automobile engine parts such as cam-shafts and crank-shafts. Electrification was arguably the single most important driver of economic growth in the first half of the 20thcentury.

Aluminum followed a similar trajectory. In the mid 19th century, aluminum was an expensive luxury metal used, for example, to put the cap on the Washington Monument in Washington DC. After the introduction of the more efficient electrolytic process, however, the price of aluminum dropped rapidly, creating new markets such as pots and pans, window frames and beer cans, electrical transmission lines (replacing copper), as well as aircraft and truck bodies. Cheap plastics from petrochemicals have also created vast new markets for packaging materials, furniture, toys, and so on.

Plastics derived from petrochemicals have contributed significantly to economic growth in the second half of the 20thcentury. However, exergy efficiencies at the process level are now approaching 50% for some primary products, such as ammonia. While some further gains can be expected, the best that can be hoped for in the basic materials subsectors is typically an improvement in the range of 15–30% beyond the current best available technology. Gains of that magnitude will not lead to cost or price reductions sufficient to create significant new products, and only minor increases can be expected in price-driven demand for existing industrial products.

The most promising approach to reducing industrial energy use in the future is to sharply increase recycling (in the case of metals, glass, paper, and some plastics), and to use secondary materials, such as fly-ash, in the manufacture of cement. Another promising approach, albeit several decades in the future, will be to find ways of skipping intermediate process steps and/or to develop plastic substitutes from waste biomass, such as ligno-cellulose. Recycled metals from scrap are far less energy intensive than virgin metals. In the case of aluminum and copper the difference is more than a factor of ten. Unfortunately, there has been little progress in remanufacturing or recycling technology in recent decades (notwithstanding their potential importance) because of a lack of sustained support for the necessary collection and sorting activities by governments. The major exception seems to be some progress in recovering precious metals (mainly gold and silver) from electronic waste. But even in this case, most electronic waste is processed inefficiently by unskilled labor, with little or no concern about pollution or public health hazards.

However, all things considered, the energy intensity of new manufactured products cannot be expected to decrease significantly in the coming decades. The only way to cut energy use by industry more than marginally is to use much less of the products of industry and to sharply increase the rate of product reuse, renovation, remanufacturing, and recycling. This is technically feasible but will be politically difficult. The case of ammonia, the primary source of all nitrogen fertilizers, offers a possible example. The excessive use of nitrogen fertilizers is responsible for several environmental problems, such as pollution of ground water and eutrophication of rivers and streams. Precision agriculture offers the potential for actually cutting nitrogen fertilizer use by reducing waste and simultaneously reducing environmental harm.

8.7.2 Energy, Exergy and Economic Growth

As increased efficiency cuts costs and prices, it also follows that shortages and price increases will have a negative impact on economic growth, at least in the short and medium term. There have been many observations of growth slowdowns following energy price spikes (Hamilton 1983; 2003; 2005). While it is true that shortages induce invention and innovation, this is a slow process. The slow introduction of renewables (especially wind and solar photovoltaics), which may be the long-term substitutes for fossil fuels, illustrates the problem. Renewables only account for a tiny fraction of global electricity generation, and still cost considerably more per unit of delivered power than conventional coal-burning power plants. Introduction would be faster if the price of fossil fuels reflected the unpaid environmental damages they cause, but governments seem generally unwilling to impose those costs on the producers.

Parenthetically, it seems very likely that the high oil prices of the first half of 2008 hastened the end of the US real estate price boom by squeezing household expenditures at a time when many people already had credit card debts and no savings. This, in turn, caused an increase in foreclosures. That may have triggered the financial meltdown, which followed from the realization that mortgage-based securities could not be priced realistically, which meant that many financial institutions and banks were over-leveraged.

More importantly, in the long run, the forthcoming advent of "peak oil," whether it has already happened or whether it occurs ten or 20 years in the future, must have a significant negative impact on future global economic growth, at least until energy-related innovation creates a new boom (or "bubble"). The reason is that energy in general, and oil in particular, are essential to virtually all economic activity, with marginal productivity (output elasticity) far greater than its still small – though increasing – cost share. As the price of oil (and oil substitutes, such as they are) rises, the demand for energy-intensive products will fall, as happened in late 2008. That brings the price of oil temporarily back down, which encourages renewed consumption but discourages investment in energy conservation measures that depend on higher prices. This, in turn, delays needed economic adjustment while accelerating the onset of the next crisis.

Skipping over the details, in our multi-sector, multi-product economy there is econometric evidence that the output elasticity of an essential (non-substitutable) input, such as petroleum, or more generally, energy, tends to be much larger than its cost-share, whereas the output elasticity for labor in the industrialized countries tends to be much smaller than its cost-share. Simply put, it can be argued that raw (unskilled) labor is over-priced in modern economies, whereas flows of energy, especially petroleum, have been relatively underpriced up to now. The econometric evidence for this would take us far afield. However, the simple observation that most firms are able to increase profits by reducing employment seems to suggest that employment is being kept artificially high, partly for social and political reasons, and partly as a way of supporting consumption.

The non-equality of output elasticities and cost-shares has important consequences for the standard theory of economic growth. The first implication is that the Cobb-Douglas production function must be discarded, because it assumes that output elasticities are equal to cost-shares and that the latter are constant. Dropping this assumption implies that the output elasticities of factor inputs must be functions of all the input variables, namely capital, labor, and energy or energy services. Kuemmel et al. (2008) have shown that the simplest functional form for a production function that allows for non-constant output elasticities, takes into account the energy flows in a physically plausible way, and permits an explicit parametric formulation of the constraints is the so-called LINEX production function (Kuemmel et al., 2002; 2008; Ayres and Warr, 2005). Its mathematical characteristics have been discussed elsewhere and need not be recapitulated here.

When growth theory is suitably modified to reflect the true importance of energy as an input, it turns out that the primary driver of growth, apart from capital deepening, is the increasing supply of "useful work" (mechanical work, chemical work, electrical work, etc.) in the economy (Ayres et al., 2003; Ayres and Bergh, 2005; Ayres and Warr, 2005; 2009). This has been a consequence of two past trends: (1) the discovery of huge oil and gas reserves, and (2) the increasing efficiency of conversion of primary energy (fossil fuels) into various forms of useful work, such as electric power and motive power.

The advent of peak oil means that, as the supply of oil and gas cannot be expected to continue to increase in the future, driving energy prices down – as it did for most of the last two centuries – future economic growth will depend more than in the past on technological progress, especially in the area of increasing energy (exergy) efficiency in the economy. Yet, the rate of exergy efficiency increase (in the United States, at least) has been slowing down since the 1970s. The bottom line here is that either US economic growth will slow down permanently (with global consequences) or effective measures to increase the rate of increase of exergy efficiency must be undertaken to compensate for the coming decline in the availability of natural resources. Such an acceleration of technological progress vis-à-vis exergy efficiency is technically possible but politically difficult due to resistance from entrenched special interests, especially the electric utility monopolies.

8.8 Realizing the Opportunities – Policies and Programs

The principal business of an industrial facility is production, not energy efficiency. High energy prices or constrained energy supply will motivate industrial facilities to try to secure the amount of energy required for operations at the lowest possible price. However, price alone will not build awareness within the corporate management culture of the potential for energy use and cost savings, maintenance savings, and production benefits that can be realized from the systematic pursuit of industrial energy efficiency. It is this lack of awareness and the corresponding failure to manage energy use with the same attention that is normally provided to production quality, waste reduction, and labor costs, i.e., at the root of the opportunity.

To be effective, energy efficiency programs need to engage industry at the management level as well as facilities engineering. Since industrial decision-making is largely driven from the top, failure to engage management results in missed opportunities for energy efficiency improvement, even when the technical staff is educated and aware of the opportunities.

A number of countries have demonstrated the value of effective industrial energy efficiency programs. The IEA's (UN Energy, 2010) World Energy Outlook Policy Database has compiled information on industrial energy efficiency programs from the IEA Climate Change Mitigation Database, IEA Energy Efficiency Database, IEA Global Renewable Energy Policies and Measures Database, the European Conference of Ministers of Transport, and contacts in industry and government (IEA, 2008b). The IEA's Energy Efficiency Database contains 170 industrial energy efficiency policies and measures in 32 countries and the EU (IEA, 2008c).

Barriers to improved energy efficiency include lack of information regarding energy efficiency, limited awareness of the financial or qualitative benefits arising from energy efficiency measures, inadequate skills to implement such measures, capital constraints and corporate culture leading to more investment in new production capacities rather than energy efficiency, and greater weight given to addressing upfront (first) costs rather than recurring energy costs, especially if these costs are a small proportion of production costs (Monari, 2008).

In addition, for developing countries the marginal cost of adopting an industrial policy can be substantially greater than in a developed country that already has supportive institutions in place (Monari, 2008). For new technologies, the slow rate of capital stock turnover in many industrial facilities (Worrell and Biermans, 2005), coupled with the perceived risks of adopting new technologies, can hamper adoption. Table 8.24 (below) provides an overview of industrial needs and goals addressed by industrial policies and programs.

8.8.1 Energy Management

The implementation of successful national energy management programs is dependent on legislation, incentives and policies, and the institutional mechanisms for energy efficiency.

8.8.1.1 International Energy Management Standards

The purpose of an energy management standard is to provide guidance for industrial facilities to integrate energy efficiency into their management practices, including fine-tuning production processes and improving the energy efficiency of industrial systems (UN Energy, 2010). Energy management seeks to apply to energy use the same culture of continuous improvement that has been successfully used by industrial firms to improve quality and safety practices. An energy management standard is needed to influence how energy is managed in an industrial facility, thus immediately reducing energy use through changes in operational practices, as well as creating a favorable environment for adopting more capital-intensive energy efficiency measures and technologies. Although the focus of this chapter is industrial energy efficiency, it is important to note that the energy management standards mentioned here are equally applicable to commercial, medical, and government facilities.

An energy management standard requires a facility to develop an energy management plan. In companies without a plan in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or a perceived change from the status quo. Without performance indicators that relate energy use to production output, it is difficult to document improvements in energy intensity (UNIDO, 2007).

Companies that have voluntarily adopted an energy management plan (a central feature of an energy management standard) have achieved major energy intensity improvements. Some examples include:

- Dow Chemical achieved a 22% improvement (saving US$4 billion) between 1994 and 2005, and is now seeking another 25% from 2005 to 2015.
- United Technologies Corp. reduced global GHG emissions by 46% per dollar of revenue from 2001 to 2006, and is now seeking an additional 12% reduction from 2006 to 2010.
- Toyota's North American Energy Management Organization has reduced energy use per unit by 23% since 2002; company-wide energy efficiency improvements have saved US$9.2 million in North America since 1999.

Denmark, Sweden, Ireland, South Korea, Spain, Thailand, and the United States have national energy management standards. Japan has a legal requirement for its more energy-intensive industrial facilities to have an energy manager and an energy management plan. These requirements also extend to large commercial facilities and parts of the transportation sector. The Netherlands has an energy management specification closely linked to long-term agreements. The European Committee for Standardization and the European Committee for Electrotechnical Standardization developed a common standard for the EU in mid-2009. China and Brazil both have national energy management standards under development.

Table 8.25 compares the elements of the energy management standards in seven countries or regions with existing energy management standards (or specifications), two under development, and one country for

Table 8.24 | Industrial energy efficiency needs and goals addressed by policies and programs.

	Target-Setting Voluntary Agreements	Industrial Energy Management Standards	Capacity-Building for Energy Management and Energy-Efficiency Services	Delivery of Energy-Efficiency Products and Services	Equipment & System Assessment Standards	Certification and Labeling of Energy-Efficiency Performance	Financial Mechanisms and Incentives
ENERGY EFFICIENCY (EE) INFORMATION AND TOOLS							
Increased information on EE technologies and measures			X	X	X	X	
Increased information on EE standards			X	X	X	X	
Improved access to high-quality energy auditing services and assessment tools			X	X		X	
Access to training and tools for energy management (EM)			X			X	
Increased tracking of EE/GHG emissions: GHG inventories, product life-cycle and supply chain energy/GHG assessments	X		X			X	
Robust measurement, monitoring, and verification	X	X	X	X	X	X	
Development of high-quality EE data for analysts, policymakers	X					X	
International best practice information	X	X	X	X	X	X	X
SKILLED PERSONNEL							
Increased EE training at the college level			X	X			
Technical assistance providers for energy management			X			X	
Improved capability of EE service providers – assessment and EE services		X		X	X		
Increased EE focus of equipment suppliers and vendors		X	X	X	X		
Increased and enhanced skills of independent measurement and verification experts (GHG, EM, EE)		X	X	X	X	X	
Increased capacity for energy management at industrial facilities	X	X	X	X		X	
INCREASED MANAGEMENT ATTENTION TO EE							
Increased upper management support for energy efficiency/GHG mitigation investments	X	X				X	X
Management commitment to an energy management system	X	X				X	
Sustained, continuous improvement in EE/GHG mitigation	X	X				X	
EE/GHG MITIGATION COSTS AND FINANCING							
Improved access to capital for EE/GHG mitigation investments	X			X			X
Reduce transaction costs associated with smaller EE projects				X			
Improved understanding of among investors and financiers of potential financial returns		X				X	
Training in preparing project and loan request documents				X			
Pricing of energy to reflect actual costs, encourage EE efficiency							X
Reduce risks associated with assessing and securitizing revenues generated through using less energy				X		X	

which energy management is a legislated practice for many industries. In all instances, the standard has been developed to be entirely compatible with the ISO quality management program (ISO 9001:2000) and environmental management program (ISO 14001).

Typical features of an energy management standard include:

- a strategic plan that requires measurement, management, and documentation for continuous improvement for energy efficiency;
- a cross-divisional management team led by a representative who reports directly to management and is responsible for overseeing the implementation of the strategic plan;
    - policies and procedures to address all aspects of energy purchase, use, and disposal;
    - projects to demonstrate continuous improvement in energy efficiency;
- creation of an energy manual, a living document that evolves over time as additional energy-saving projects and policies are undertaken and documented;
- identification of key performance indicators, unique to the company, that are tracked to measure progress; and
    - periodic reporting of progress to management based on these measurements.

As shown in Table 8.25, the existing energy management standards have many features in common. ISO now identifies energy management as one of the top five fields meriting the development and promotion of international standards.[7] Energy management received this priority focus based on its enormous potential to save energy and reduce GHG emissions worldwide.

The United Nations Industrial Development Organization (UNIDO) recognized the industry's need to mount an effective response to climate change and to the proliferation of national energy management standards. In March 2007, UNIDO hosted a meeting of experts, including representatives from the ISO Central Secretariat and nations that have adopted energy management standards. That meeting led to the submission of a formal request to the ISO Central Secretariat to consider undertaking work on an international energy management standard.

In February 2008, ISO's Technical Management Board approved the establishment of a new project committee to develop the new ISO Management System Standard for Energy. ANSI and the Associação Brasileira de Normas Técnicas are jointly serving as the secretariat to lead development of ISO PC 242, Energy Management.

The new ISO 50001 establishes an international framework for industrial plants or companies to manage energy, including all aspects of procurement and use. The standard provides organizations and companies with technical and management strategies to increase energy efficiency, reduce costs, and improve environmental performance (ISO 50001, 2011). Based on broad applicability across national economic sectors, the standard could influence up to 60% of the world's energy demand (US EIA, 2007). Corporations, supply chain partnerships, utilities, energy service companies (ESCOs), and others are expected to use ISO 50001 as a tool to reduce energy intensity and carbon emissions in their own facilities (as well as those belonging to their customers or suppliers) and to benchmark their achievements. ISO 50001, published in June 2011, is expected to promote industrial energy efficiency globally.

A successful program in energy management provides an organizational framework for a company to respond effectively through a program of continuous improvement to a national program that establishes energy intensity improvement and/or GHG reduction targets. UNIDO has identified a package of policies described as the "Industrial Standards Framework" that outlines the policy relationships among target-setting agreements, energy management standards, system optimization, and their intended impact on industrial markets (see Table 8.26).

UNIDO is currently engaged with ten countries in the development of industrial energy efficiency programs based on the framework described in Table 8.26.

8.8.1.2 Country Experiences in Energy Efficiency Implementation

A review of the national experiences of a few selected countries on industrial energy efficiency policies illustrates the state of energy policies in the world. The countries selected are Brazil, China, India, South Africa, and the United States. These countries account for almost half of total industrial consumption. Table 8.27 provides a summary of the country experiences for a few select countries in different regions of the world in energy efficiency implementation and impacts.

Brazil

Although a national electricity conservation program (Programa Nacional de Conservação de Energia Elétrica (PROCEL)) was implemented in 1985, energy policies have never addressed energy efficiency

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[7] Priorities also include calculation methods, biofuels, retrofitting and refurbishing, and buildings.

as a relevant issue. In particular, there has been very little attention to industrial energy efficiency policies, despite industry being the most important energy-consuming sector.

More comprehensive energy efficiency policies were only implemented in the country after a severe electricity supply crisis occurred during 2001–2002. Two main regulatory and legislative achievements which took place in the late 1990s and after the energy crisis were important to establish basic instruments for further advancement of energy efficiency in the country: the creation of a public benefit wire charge, and the energy efficiency law created after the energy crisis.

The public benefit wire charge sets aside 1% of electricity revenues to investments in energy R&D and energy efficiency. Since 1998 about R$2 billion (US$980 million) has been invested in energy efficiency utility programs. However, only 10% of these resources have been dedicated to the industrial sector so far. Energy efficiency programs are implemented by utilities under the regulator's oversight and also by a public fund called CTenerg.

During the crisis a series of measures were taken which saved 26 TWh (of a total national consumption of 284 TWh) and 13,000 MW peak, compared to PROCEL's estimated savings during 1994–2000 of 10.7 TWh and 640 MW peak (Maurer et al., 2005). In 2001, a national law was approved that introduced legal instruments to establish energy efficiency standards for appliances, buildings, and motor cars commercialized in the country. Electrical motors (three-phase) were the first equipment to receive mandatory minimum energy efficiency standards. More stringent standards and concentrated efforts in R&D (with the use of the public benefit funds) have the potential to accelerate the improvement of energy efficiency in the country, particularly in the industrial sector.

In general, energy efficiency has not been a priority for the industrial sector. There have been very few energy efficiency programs initiated by the local industries themselves using their own investment capital. In most cases, they are part of corporate policies related to environmental protection and improving the quality of their products, and have been restricted to larger corporations.

There is a preference for investments with a short payback (less than two years). Energy efficiency achieved has been the result of changes in production lines and products. However, there is a lack of expertise in industry in general, particularly in SMEs. Projects that have combined public and private funds have produced significantly better results. In some cases, there has been an increase in the specific energy use in energy-intensive industries due to stricter environmental rules and quality demand in the international market.

Since 1998, utilities have been required by the National Regulator to invest part of their revenues in energy efficiency programs. Up until 2007, a little less than US$1 billion was invested in energy efficiency programs, but only 10% of this was targeted at the industrial sector, achieving an estimated savings of 376 GWh/yr. Figure 8.31 shows a supply curve for end-use efficiency in the electricity sector for Brazil in 2020.

Recent studies in Brazil have estimated opportunities to introduce energy efficiency measures and fuel substitution away from fossil fuels. A supply curve of conserved electricity for 2020 (base year 2004) is presented in WWF-Brazil, 2007 and shows a potential of 55 TWh at a cost of R$130/MWh (approximately US$80/MWh) with the replacement of motor systems (Figure 8.31). This was the largest potential depicted by this study.

Energy subsidies persist in the industrial sector and distort the cost-effectiveness of existing opportunities. For the most part, industrial energy costs are still irrelevant when compared to other inputs, taxes, and personnel costs. National energy conservation programs have focused more on the residential and public sectors, rather than the industrial sector. There are significant opportunities for more efficient technologies and processes in industry that have not been implemented on a significant scale. Opportunities to combine water and energy efficiency seem to be a better way to accelerate the improved use of resources in the industrial sector, since water usage is increasingly coming under the scrutiny of both policymakers and the population. Regulatory barriers still exist to impede energy companies from investing in efficiency programs for their end-use customers.

China

In 2005, China's government raised a strategic target to reduce its energy use per GDP by 20% by 2010. Industrial energy efficiency is expected to provide 80% of the reduction. To achieve this target, the Chinese government developed a series of initiatives:

- It emphasized regulation of the industrial structure. The government issued policies to import equipment and keep free import and export tariffs and VAT; release loans and lands dependent on energy efficiency standards; and phase out inefficient production capacities in iron and steel, cement, power generation, coal mining, etc. It is expected that 50 million kW in small thermal power units, 100 Mt of iron, 55 Mt of steel, and 250 Mt of cement will be phased out during China's 11th Five-year Plan.

- It established a responsibility mechanism to ensure that disaggregated energy conservation targets are achieved in each province. The central government signed energy-saving target responsibility agreements with 30 provincial governments and the top 1000 enterprises, which consumed energy of over 180,000 tonnes of coal equivalent (tce) annually (approximately 5.28 PJ), and set up a performance assessment system to track and evaluate energy-saving activities under the responsibility agreement mechanism. In May 2008, the National Development and Reform Commission and six other ministries implemented on-site assessment and evaluation of the performance of energy conservation target implementation for 30 provincial governments and released the results. The central

Table 8.25 | Comparison of national energy management standards.

Participating Countries	Management Commitment Required	Develop energy management plan	Establish energy use baseline	Management Appointed Energy Representative	Establish Cross-Divisional Implementation Team	Emphasis on Continuous Improvement
			Existing			
Denmark	yes	yes	yes	yes	yes	yes
Ireland	yes	yes	yes	yes	yes	yes
Japan[3]	yes	yes	yes	licensed	implied	yes
Korea	yes	yes	yes	yes	yes	yes
Netherlands[5]	yes	yes	yes	yes	yes	yes
Sweden	yes	yes	yes	yes	unclear	yes
Thailand	yes	yes	yes	yes	implied	yes
United States	yes	yes	yes	yes	yes	yes
			(Under Development)			
CEN (EU)	yes	yes	yes	yes	implied	yes
China	yes	yes	yes	yes	yes	yes

1 Certification is required for companies participating in voluntary agreements (also specified interval in Sweden). In Denmark, Netherlands & Sweden linked to tax relief eligibility.

2 As of 2002, latest date for which data is available

3 Japan has the Act Concerning the Rational Use of Energy, which includes a requirement for energy management

4 Korea invites large companies that agree to share information to join a peer-to peer networking scheme and receive technical assistance and incentives

5 Netherlands has an Energy Management System, not a standard, per se, developed in 1998 and linked to Long Term Agreements in 2000.

6 800 companies representing 20% of energy use have LTAs and must use the Energy Management System. The 150 most energy intensive companies, representing 70% of the energy use, have a separate, more stringent, bench marking covenant and are typically ISO 14000 certified, but are not required to use the EM System.

7 Thailand has made the energy management standard is mandatory for large companies, linked it to exisitng ISO-related program activities, coupled with tax relief; program evaluation not yet available

8 To date, the US government has encouraged energy management practices, but not use of the standard. A program was initiated in 2008 to address this which also includes validation; program evaluation results anticipated in 2011.

NOTE: National standards and specifications were used as source documents to develop this table Source: McKane, 2007 as updated by the author in 2008

Source: McKane et al, 2007.

government will reward the best-performing provinces and penalize the provinces which underperformed.

- It set up an energy conservation supervision and monitoring mechanism. Energy Conservation Supervision Centers were established in more than 19 provinces and cities. The centers are responsible for ensuring that enterprises and buildings follow the updated Energy Conservation Law, as well as mandatory energy efficiency standards and codes.

- It launched the Top 1000 Enterprises Energy Conservation Action. The 1000 enterprises are those 998 enterprises with annual energy use at or over 180,000 tce (5.28 PJ). According to statistics, comprehensive energy use of the 1000 enterprises in 2004 was 670 million tce (19.6 EJ) – 33% of the nation's total energy use and 47% of total industrial energy use. The purpose of the program is to encourage enterprises to carry out energy audits, work out energy saving plans, strengthen the implementation of energy efficiency standards, implement energy efficiency benchmarks, and to achieve the target of 100 million tce (2.9 EJ) of energy savings in 2010.

- Due to these policies, the following results were obtained:

- Energy use per GDP was reduced by 1.37% by 2006 and continued to decline (as shown in Figure 8.32).

- The specific energy use for key products from energy-intensive sectors has declined since 2006. Specific energy use per unit of thermal

Document Energy Savings	Establish Performance Indicators & Energy Saving Targets	Document & Train Employees on Procedural/ Operational Changes	Specified Interval for Reevaluating Performance Targets	Reporting to Public Entity Required	Energy Savings Externally Validated or Certified	Year Initially Published	Approx Market Penetration by Industrial Energy Use
yes	yes	yes	suggests annual	yes	optional[1]	2001	60%2
yes	yes	yes	industry sets own	yes	optional[1]	2005	25%
yes	yes	yes	yes, annually	yes	yes	1979	90%
yes	yes	yes	yes, annually	optional	optional[4]	2007	data not yet available
yes	yes	yes	yes	yes	optional[1]	2000	20–90%[6]
yes	yes	yes	yes[1]	yes	optional[1]	2003	50%elect
yes	yes	yes industry sets own	yes	evaluation plan	2004	not known[7]	
yes	yes	yes	annual recomm	no	no[8]	2000	<5%[8]
yes	yes	yes	industry sets own	national schemes	national schemes		
yes	yes	yes	industry sets own	not available	not available		

Table 8.26 | Industrial standards framework.

Policy Objective	Policy Response	Market Response
Establishing National Goals for GHG Reduction	Voluntary or Target-setting Agreements; Tax incentives	Companies commit to energy intensity reduction targets
Capacity Building	System Optimization Training of plant engineers/consultants/suppliers/ESCOs	Trained experts conduct plant assessments, sell system services
Integrating Energy Efficient Practices	Energy Management Standard, Guidance, Training	Plants actively manage energy like other resources
Identifying Energy Saving Projects	-Trained System Experts -System Optimization Library -Standardized Assessments	Plant managers used trained experts to identify projects
Implementing Energy Efficiency Projects	Financial incentives, loan guarantees & subsidies, energy efficiency credits, ESCOs	Plants implement more projects, buy system services, accrue credits
Documenting for Sustainability	-Energy Management Plan -System Optimization Library -Measurements & Verification	Energy savings continue through project lifetime & are tradable as credits
Market Recognition	Recognition Programs, Energy Efficiency Credits, Certification	Companies & financial institutions value energy efficiency

Source: UNIDO, 2010a.

power, crude steel, cement, petro-processing, crude copper, alumina, sodium carbonate, and ethylene declined by 3–10.5% by 2006. The energy intensity of steel and cement declined by about 3% by 2007, and thermal power-generating units over 6000 kW consumed 335 gce per kWh – 10 g lower than in 2006.

India

The Energy Conservation Act 2001 enacted by the government mandated the creation of the Bureau of Energy Efficiency (BEE) which promotes energy efficiency. The BEE has taken the following initiatives in the industrial sector:

- *National awards scheme* – an annual awards scheme which provides a mechanism to reward industries in different sectors based on their performance and initiatives in energy efficiency. This resulted in the creation of a database on the BEE website of energy conservation measures and their costs, encouraging other industries to adopt similar measures.

- *Designated consumers* – eight sectors have been designated as energy-intensive sectors: power plants, steel, cement, fertilizers, pulp and paper, chlor-alkali, textiles, and railways. For these sectors, all industrial units with total energy use above specified limits have to provide annual data regarding their energy performance. Designated consumers need to have certified energy managers employed in their plant and have

Table 8.27 | Type of industrial energy efficiency programs in selected countries.

Country	IN-Informational Programs; TP-Tax policies (incentives and/or penalties); REG-Regulations for energy efficiency; TSA-Target-setting Agreements w/ industry; FEII-Focus on Energy-Intensive Industries; EMS-Energy Management Standard; SA-Subsidized Energy Assessments or Audits; FEEP-Financial assistance for Energy Efficiency Project Implementation; TREM-Training for Energy Managers; TRSA-Training on System Assessments; IEES-Industrial Equipment Energy Efficiency Standards; RP-Recognition Program										
	IN	TP	REG	TSA	FEII	EMS	SA	FEEP	TREM	TRSA	IEEES	RP
Argentina	✓					(a)	✓					
Brazil	✓		✓			(a)	✓				✓	
Canada	✓		✓	✓	✓	(a)	✓			✓	✓	✓
Chile	✓				✓	(a)						
China	✓	-	✓	✓	✓	✓	✓	✓	✓	-	✓	✓
Colombia	✓					(a)	✓			✓		✓
Denmark	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Egypt	✓							✓	pend	pend		
Finland	✓				✓		✓	✓		✓		
France	✓	✓	✓		✓	(a)					✓	✓
Germany	✓	✓	✓		✓	(a)					✓	✓
India	✓		✓	pend	✓	(a)			✓			✓
Ireland	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Japan	✓	✓	✓		✓	(a)	✓	✓	✓	✓	✓	✓
Korea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mexico												
Netherlands	✓	✓	✓	✓	✓	(a)	✓	✓	✓	✓	✓	✓
Norway	✓	✓	✓		✓		✓	✓				✓
Philippines	✓								pend	pend		✓
South Africa	✓			some	✓	pend		DSM	private		✓	
Spain	✓	✓				✓						
Sweden	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
Thailand	✓	✓	✓		✓	✓	✓		pend	pend		✓
United Kingdom	✓	✓	✓	✓	✓	(a)	✓				✓	✓
United States	✓	-	-	new	✓	✓	✓	-	-	✓	1	✓

audits carried out at specified intervals. BEE plans to establish benchmarks in the future for energy use for designated consumers.

- *National energy managers and auditors certification* – BEE initiated a process for the creation of certified energy managers and energy auditors. A syllabus has been drawn up and an annual examination carried out. About 4500 certified energy managers qualified through this process (3400 of them are also certified energy auditors). This process is expected to provide the skilled manpower needed to implement energy efficiency schemes in the country. Apart from these schemes, BEE plans to establish state energy conservation funds to facilitate and strengthen the implementation of energy efficiency by the state nodal agencies. BEE also plans to launch an initiative for small- and medium-sized industries.

India launched a National Mission on Enhanced Energy Efficiency (NMEEE) in April 2010 as a part of the National Climate Change Action Plan. The NMEEE includes a market-based mechanism to enhance energy efficiency in large energy-intensive industries and facilities (the Perform, Achieve and Trade scheme). This involves setting goals for specific energy use for each plant for reduction below the baseline. Industries are expected to meet their reduction targets within a three-year period. Industries which exceed their targets will be credited with tradable energy permits. Industries that fail to meet targets can either buy energy permits or pay penalties. The NMEEE will set up two fiscal instruments – the Partial Risk Guarantee Fund (PRGF) and the Venture Capital Fund for Energy Efficiency (VCFEE). The PRGF will provide commercial banks with partial coverage of risk exposure against loans made for energy efficiency projects. The VCFEE will facilitate the

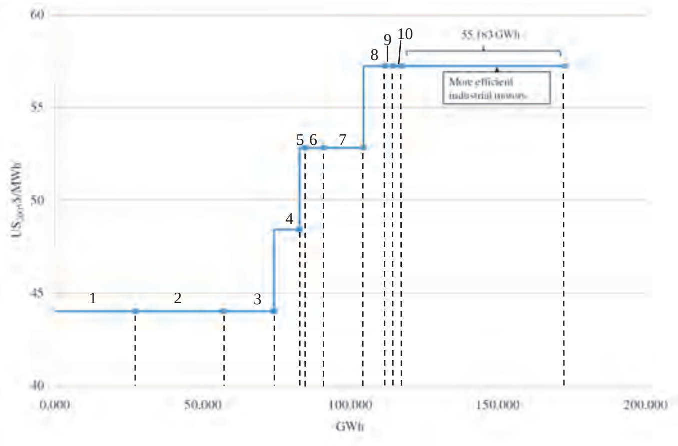

Figure 8.31 | Supply curve of saved electricity for 2020 (base year 2004). Source: adapted from WWF-Brazil, 2007.

Notes: 1- solar water heating, 2- efficient lighting (public and commercial), 3- other appliances (residential and commercial), 4- residential lighting, 5- air conditioning (residential), 6- air conditioning (commercial), 7- direct heat (industrial), 8- efficient refrigerator (residential), 9- freezer (commercial), 10- refrigerator (commercial).

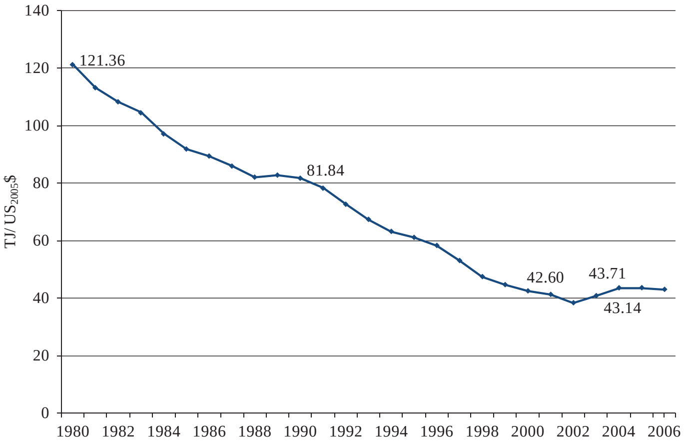

Figure 8.32 | Energy use of GDP per unit in China (TJ/US$_{2005}$\$), 1980–2006. Source: adapted from China Energy, 2009.

availability of venture capital to energy supply companies and other companies investing in energy efficiency and demand-side management (DSM).

The Indian government has announced the establishment of Energy Efficiency Services Limited (EESL) with equity of INR1.9 billion (about US$43 million) from four public-sector companies: National Thermal Power Corporation, Power Finance Corporation, Rural Electrification Corporation, and Power Grid. EESL will work as an ESCO and lead the market-related actions of the NMEEE.

South Africa

In 2005, the South African government in the form of the Department of Minerals and Energy (DME) launched the "Energy Efficiency Strategy of the Republic of South Africa." This strategy addresses all sectors within South Africa and targets an overall improvement in energy efficiency of 12% by 2015. Specifically, the industry target is 15%. These targets do not refer to a baseline at a particular date. Instead, they refer to reductions against the projected use in 2015 if energy efficiency measures are not employed.

Although the strategy was divided into phases for implementation over the period, little to no funding, encouragement, or incentives were put in place to ensure a significant take-up. The DME did not have the resources to "make things happen."

There is generally low awareness in South Africa of the benefits of energy efficiency, and the cost of energy as a fraction of business expense is usually very small and, consequently, does not attract management's attention to reduce it. During times of economic well-being (as in recent years), business owners do not see the value in releasing additional profit in this way. Yet energy efficiency is cost-effective and very quickly pays back the initial investment.

In 2005 an (Industrial) Energy Efficiency Accord was signed between the DME and 30 of the country's largest energy users and business associations. No such accord was mentioned in the strategy, but it effectively became the mechanism for encouraging energy efficiency in industry. Many of the participants regularly attended meetings, particularly the Technical Committee meetings. The very large users of energy had an inherent incentive to reduce energy use, but the only financial incentive available to less energy-intensive users was the one generally available to all under the Energy Efficiency and Demand-Side Management (EEDSM) program. The rules were published by the National Electricity Regulator (subsequently the National Energy Regulator of South Africa) in 2004.

The EEDSM program is administered by Eskom, a vertically integrated national electricity monopoly. The energy efficiency component attracted a subsidy of 50% of the cost of implementation up to a maximum value set at a fraction of the cost of constructing a new power station. The approval process at Eskom became unacceptably long for many potential customers, and few Energy Efficiency Accord members ultimately used this route. The programme has been recently restructured and a number of options are now available in an attempt to simplify and facilitate adoption The National Energy Efficiency Agency was established in 2006. It was initially envisaged that it would oversee the implementation of DSM and energy efficiency projects undertaken by Eskom and other entities in the country. However, the agency was never appropriately resourced and did not grow beyond having a single staff member.

South Africa is now in a position where electricity demand often exceeds the supply capability, and a power curtailment program is in place. Legislation has recently been enacted that will require more attention to energy-saving and efficiency measures.

The national electricity utility, Eskom, has been piloting DSM for a number of years. In 2001 it began to formalize the process and procedures. The program is specified and monitored by the National Energy Regulator of South Africa, and Eskom acts as the facilitator. The early mechanism was to uses ESCOs as agents to "pull through" projects which the ESCOs had found. Measurement and verification teams were established at several universities with the express purpose of providing independent auditing of the results of the ESCO projects. Progress was very slow initially because there are not enough skilled ESCOs in South Africa. Many ESCOs have come from the realms of lighting suppliers, as there has been considerable attention paid to replacing the incandescent lamps with compact fluorescent lamps. Many of the linear fluorescent fittings with electro-magnetic ballasts have been replaced with electronic ballasts and small-diameter tubes.

Eskom lacks the capability to manage the program, and the extremely slow rate of project approval has frustrated many ESCOs, some of which no longer serve the program. It can be argued that a program that forces a supplier to curtail its supply without compensation is not properly located within a utility.

The DSM program is financed from public funds in the form of a levy on the tariff. Initially the need was to reduce or shift peak demand, but the emphasis has now moved to energy efficiency. A Rand/MW hurdle rate was established for various interventions, and ESCO proposals had to fall below this rate to be eligible for further consideration. Funding is at 100% of the project value up to the hurdle rate for load-reduction projects and at 50% for energy-reduction projects.

United States

Since 1993, the US DOE has been developing and offering an extensive array of technical training and publications to assist industrial facilities in becoming more energy efficient through its Best Practices program. As a result of these program activities, the US has developed a great deal of technical capability in industrial energy efficiency, especially motor, steam, and process heating systems (UNIDO, 2007). Under the program name of Save Energy Now, the US DOE initiated a series of program activities beginning in 2006 with the Energy Saving Assessments previously described in Section 8.3.3 (US DOE, 2010) also includes the Industrial Assessment Centers, a university-based program with a successful 30-year track record of training engineering students while conducting approximately 500 walk-through energy assessments annually, primarily of small- to medium-sized industries.

In 2002, the US EPA began a voluntary program called "Climate Leaders," which works with companies to develop long-term comprehensive climate change strategies. Using the GHG emissions protocol developed by the World Resources Institute and the World Business Council for Sustainable Development, 59 companies have set and report progress on a corporate-wide GHG reduction goal to be achieved over five to ten years. These goals are evaluated against the projected performance of the relevant sector. In 2003, the US EPA began offering information on energy management guidelines and benchmarking as part of its ENERGY STAR for Industry program.[8] The US ENERGY STAR has developed a benchmarking tool called the Energy Performance Indicator for the cement, corn refining, and motor vehicle assembly industries that ranks a facility among its peers based on energy use, normalizing for specific activities or factors that influence energy use (UN Energy, 2010).

In 2007, the US DOE and EPA joined together with industry, ANSI, and the National Institute of Standardization and Technology to develop Superior Energy Performance, a collaborative program to certify plants for energy efficiency based on implementation of an energy management system and improvements in energy intensity measured against a baseline.[9] This program is centered on ANSI MSE 2000:2008, the national energy management standard developed by the Georgia Institute of Technology, which will be supplanted by ISO 50001. The Superior Energy Performance program creates a framework for fostering energy efficiency at the plant level and a methodology for measuring and validating energy efficiency/intensity improvements in a process that is voluntary, performance-based, and technically sound. The proposed approach can be integrated into existing corporate management systems, such as ISO 9001:2000 and 14001:2004. Certification will also position plants to be recognized by the financial community for superior energy management practices and their contribution to climate change mitigation. The strategic goals of Superior Energy Performance are:

- to foster an organizational culture of continuous improvement in energy efficiency;
- to develop a transparent system to validate energy intensity improvements and management practices; and thus
- create a verified record of energy source fuel savings and carbon emission reductions with potential market value that could be widely recognized both nationally and internationally.

Use of the ASME System Assessment Standards (see Section 8.3.5) is not required for participation in Superior Energy Performance, but the standards provide a clearly defined pathway for quickly achieving energy savings. Superior Energy Performance underwent an 18-month pilot period in Texas and launched in 2010.

8.8.2 Demand-side Management

Industries can participate in utility DSM programs to reduce their energy costs and contribute to the efficient operation of the energy supply system (see Chapter 15 for a description of DSM and its implementation).

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[8] See www.energystar.gov/index.cfm?c=in_focus.bus_industries_focus.

[9] For more information, see www.superiorenergyperformance.net.

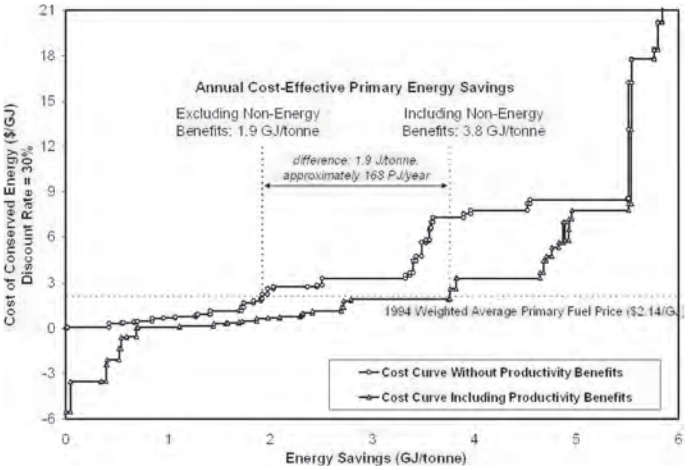

Figure 8.33 | Conservation supply curves for the iron and steel industry without productivity benefits and including productivity benefits. Source: Worrell et al., 2003

Table 8.28 | Additional demand-side investment in industry, 2005–2030, US2005$ billions.

	OECD	Non-OECD	World
APS	210	152	362
of which electrical equipment	121	74	195

Source: IEA, 2006.

Industrial programs can result in energy efficiency, load shifting and peak clipping, cool storage, cogeneration, deferrable interruptible load, and viable options for the industrial sector. Utility incentives can help facilitate widespread adoption of industrial DSM programs and can be part of the least-cost power plan for society.

8.8.3 Co-benefits for Industrial Energy Efficiency

Most industrial energy efficiency improvements also have additional benefits (co-benefits). These include reduced emissions and waste, improved product quality, increased product output and reduction of operation and maintenance costs (Worrell et al., 2003; IPCC, 2007).

Pye and McKane (1999) found that industrial efficiency projects adopted through the "Motor Challenge" program resulted in improved operations, extended lifetime of system components, and reduced expenditures and capital costs.

Worrell et al. (2003) quantified the monetary value of productivity benefits from 52 case studies. This revealed that the payback period for the measures based on energy savings only was 4.2 years. This reduced to 1.9 years when non-energy benefits were included.

Figure 8.33 shows the conservation supply curve for 14 measures in steelmaking with only energy benefits and including productivity benefits.

8.8.4 Financing

Energy efficiency is a largely invisible and nascent market. The financial benefits of energy efficiency accrue to end-users, representing a cost savings, rather than a financial return. Cost savings are difficult to collateralize, which makes it difficult to secure external financing for energy efficiency projects. Therefore, industrial energy efficiency is normally financed internally and is not generally identified as an investment or structured as a separate project.

In 2006, US$1.1 billion was invested in energy efficiency technologies, compared with US$710 million in 2005 (UNEP and New Energy Finance, 2007). These figures include both supply- and demand-side energy efficiency measures across all sectors. This is only a small fraction of the total investment in the industrial sector in 2005 of US$1379 billion (UNFCCC, 2007).

8.8.4.1 IEE Financing Requirements

Based on the IEA World Energy Outlook 2006 Alternative Policy Scenario (APS),[10] industrial energy demand in 2030 will be 337 million tonnes of oil equivalent (Mtoe) (9% lower than in the Reference Scenario). Over half of global energy savings in the industry sector can be achieved as the result of more energy-efficient production of iron and steel, chemicals, and non-metallic products.

The additional demand-side investment in APS amounts to US$360 billion to be financed by various industrial end-users, including about three-quarters to purchase more energy-efficient electrical equipment (see Table 8.28).

The UNFCCC (2007) estimates that an additional US$19.1 billion[11] of annual investments will be needed in 2030 to stabilize energy-related CO_2 emissions at the 2005 level (as set out in the IEA Beyond Alternative Policy Scenario (BAPS)).[12] This additional investment on the demand side can, however, is offset on the supply side by a decreased need for investment in new power-generation capacity and fossil fuel (US$60 billion less). The BAPS assumes that to achieve the GHG stabilization targets, industrial energy efficiency would need to improve by a further 7% compared to APS.

According to the UNFCCC (2007), most projected industrial energy efficiency measures can be achieved, as they assume very short payback periods (less than four years), and further additional investment needs

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[10] The APS considers how the global energy market can evolve by 2030 if countries are to adopt all policies they are considering related to energy security and energy-related CO_2 emissions (note: in APS global GHG emissions are 8Gt higher in 2030 than in 2006).

[11] US$11.5 billion in OECD and US$8 billion in non-OECD countries.

[12] The BAPS considers policies and changes in global energy market which need to be effected to stabilize GHG emissions at the 2004 level of 26.1 $GtCO_2$.

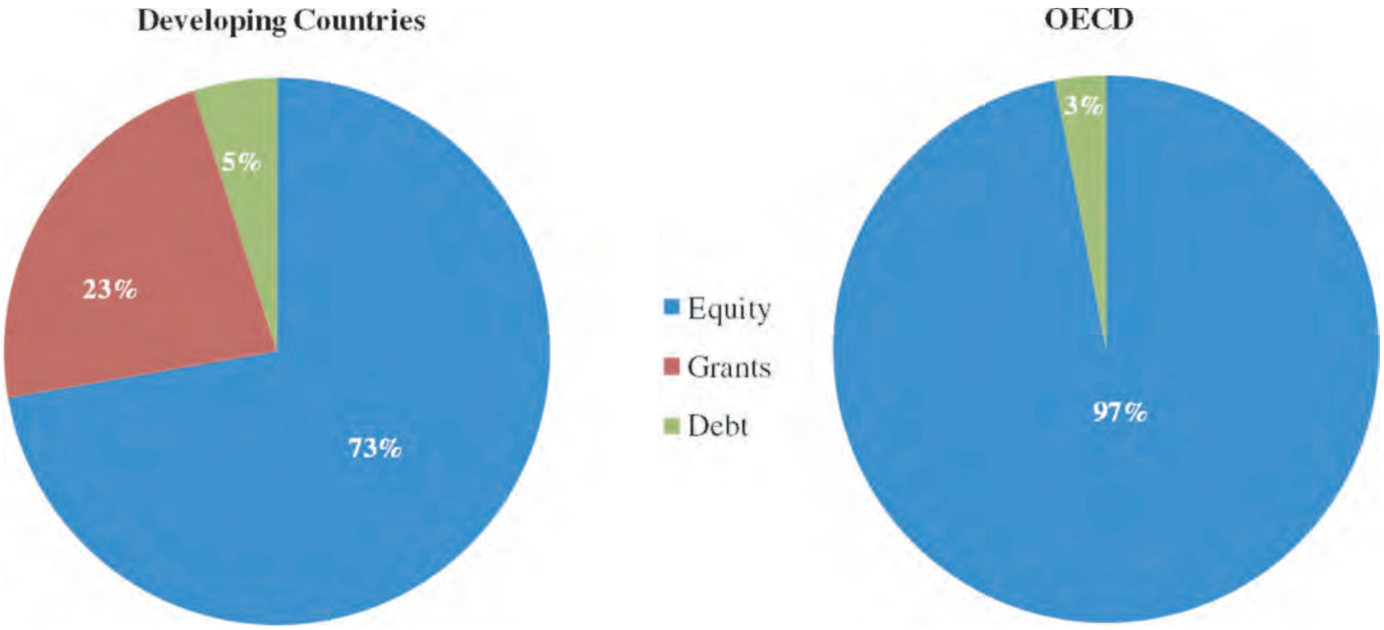

Figure 8.34 | Sources of energy efficiency investment in OECD and developing countries. Source: data based on UNFCCC, 2007.

constitute a small share (1%) of the total projected investment in the industrial sector.

The key bottleneck is that 75% of savings are projected to occur in non-OECD countries, where availability of capital is scarce, political and economic risks are high, financial markets are not sufficiently developed, and an enabling policy environment and technical skills are lacking.

8.8.4.2 Traditional Sources of Financing for Industrial Energy Efficiency

Patterns of investment in industrial energy efficiency (see Figure 8.34) generally mirror those for investment in the industrial sector in general, where the largest part (72%) comes from domestic sources, particularly in developing and transition economies. Foreign direct investment provides 22% of the global total, but more in OECD countries (up to 37% in North America). Debt plays a small role, while Official Development Assistance (ODA) barely registers as a source of industrial investment (UNFCCC, 2007).

Private equity/venture capital – as for energy efficiency financing, venture capital (primarily in OECD countries), and private equity (in developing and transition countries) provide the largest share of the total investment flows. Venture capital funds backed by the public sector can also be found in the United States, the United Kingdom, and Australia. For example, roughly one-third of the technology start-ups incubated by the United Kingdom's Carbon Trust operate in energy efficiency (UNEP and New Energy Finance, 2007).

Self-financing – in developing and transition economies, investment in industrial energy efficiency is mostly undertaken with companies' own funds. Key limitations in this respect are: energy efficiency is not part of the companies' core business and hence it has a low priority and needs to compete for scarce capital with other strategic projects; a lack of internal capacity for energy audits, project design, and implementation; and a lack of an enabling policy environment and motivation stemming from low/subsidized energy prices or an absence of mandatory energy performance targets.

Debt finance plays a very small role in financing industrial energy efficiency projects. This is due to the high cost of debt finance; the lack of long-term funds in the financial sector to invest in energy efficiency projects; the lack of understanding of how to evaluate energy efficiency investments on the part of the financial institutions and hence a higher perception of risk; and a lack of experience in structuring energy efficiency investment projects by companies, combined with a scarcity of competent local consultants and/or other intermediaries (e.g., ESCOs – see below) who could assist potential clients.

International Financial Institutions are an important source of funding for energy efficiency in developing and transition economies. In 2006, the World Bank (WB) committed more to energy efficiency projects (US$447 million) than to renewable energy (US$412 million) (WB, 2008). More than half of the WB's energy efficiency investment went into Central and Eastern Europe. Other important players are the European Bank for Reconstruction and Development, the Asian Development Bank, and the Global Environment Facility (GEF).

Public funds and other types of state financial support to industrial energy efficiency play a critical role in promoting investment in industrial energy efficiency in both developed and developing countries.

Following are examples of public support schemes and their impacts in developing countries.

It is very unlikely that initiatives in energy efficiency and energy (R&D) in Brazil would have taken place without the regulators' enforcement of compulsory programs in 1998 and later with the implementation of Law 9.991/00 by the National Congress. This initiative allocated 1% of annual utilities' revenues to energy efficiency and R&D programs. In 2000, a national law was approved by the congress that changed the allocation of the resources from the 1% obligation and created a national fund called CTEnerg, responsible for investing in energy efficiency and energy R&D in the public interest. Reforms in the power sector in Brazil provided the opportunity to enhance support and, in fact, increase significantly the level of funding in these areas. While PROCEL, the national electricity conservation program initiated in 1985, invested an annual average of US$14 million during 1994–2003, utilities' compulsory investments averaged US$57 million/yr during 1998–2004.

8.8.4.3 New Financing Sources for Industrial Energy Efficiency

ESCOs can be effective models for private-sector delivery of energy-efficient technologies and services. They had a global market volume of approximately US$2.5 billion in 2000 (Goldman et al., 2005; Vine, 2005). The role of an ESCO in structuring financing is to take on (fully or partially) energy efficiency project risks by guaranteeing with its own assets that a certain level of energy and cost saving will be achieved, thereby reducing project risks vis-à-vis potential financiers (a bank or the company itself). The ESCO model proved particularly successful in the United States, which still accounts for 75% of global ESCO operations (Goldman et al., 2005), and is gaining momentum in the EU (Bertoldi et al., 2005), but its prospects in developing and transition countries are limited by several factors: weak financial markets, companies without credit histories, the absence of risk-hedging instruments, and the absence of supportive governmental policies, which were critical for the success of ESCO business in the United States and the EU.

ODA is needed to overcome numerous barriers preventing cost-effective industrial energy efficiency measures from materializing in developing and transition economies (where countries lack resources and capacities to do so on their own). These include supporting governments in designing and implementing energy efficiency policies; building capacity of companies and other market participants to identify, structure finance for and implement projects; and promote technology transfer from developed to developing countries. All in all, the main role of ODA is to reduce risks of investment in energy efficiency, thereby making projects more attractive to financiers (see Figure 8.35). Figure 8.35 shows the effect of ODA in reducing the risk associated with a project (movement in the horizontal direction along the x-axis). The additional benefit of carbon finance results in an improved rate of return (movement in the vertical direction along the y-axis). The combination of these two effects can result in changing a low return high risk industrial efficiency project to a high return low risk viable project. The GEF is the largest source of ODA for industrial energy efficiency projects.

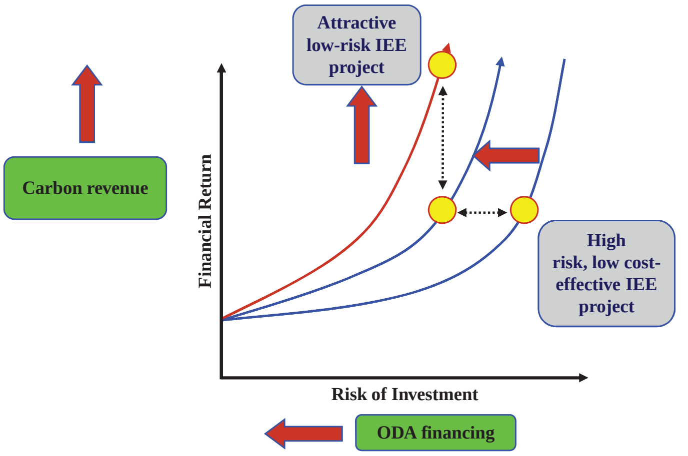

Figure 8.35 | Use of ODA and carbon finance for IEE projects. Source: modified from Glemarec, 2011.

Carbon finance is a new and rapidly growing market for clean energy financing and was valued at US$64 billion in 2007 (WB, 2008), including US$8 billion for projects under the Clean Development Mechanism (CDM). In contrast to ODA, the role of carbon markets in securing financing for industrial or other types of clean energy projects is to increase project profitability (i.e., Internal Rate of Return) or decrease the investment payback period by adding an additional revenue stream to the project (and in the case of industrial energy efficiency, the only cash revenue stream) through commercialization of CO_2 reductions associated with the project (see Figure 8.33). Despite early criticism, the volume of energy efficiency projects[13] constituted 44% of all projects in the CDM pipeline in 2007, compared to only 1% in 2005. Still, industrial energy efficiency projects represent a very tiny share of the market both in terms of size and volume (see Table 8.29).

Why is the carbon market slow to deliver the expected boost for investment in industrial energy efficiency? There are a number of barriers: first and foremost, industrial energy efficiency projects are less cost-effective than other alternatives for GHG mitigation. Average CO_2 abatement costs for industrial energy efficiency amount to €22/Certified Emissions Reduction (CER), while current prices for CDM in various market segments are between €10/CER and €20/CER (PointCarbon, 2008). In addition, projects are normally small, while transaction costs of structuring CDM projects are high (especially if new monitoring methodology needs to be designed), which prohibits their wide-scale application.

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[13] Including both energy-efficient supply- and demand-side measures in all economic sectors.

Table 8.29 | Industrial energy efficiency projects in the clean development mechanism pipeline.

CDM projects in the pipe-line	Projects, number (%)	kCERs till 2012 (%)
Cement	36 (1)	35,484 (1)
EE in industry	159 (5)	30,868 (1)
TOTAL	*3498 (100)*	*2,639,741 (100)*

Source: UNEP Risø, 2008.

In the post-2012 (post-Kyoto) scenario there are several carbon finance schemes to help carbon trading at the national and international level. For example, the European Investment Bank (EIB) has a Multilateral Carbon Credit Fund in Europe and Central Asia; the EIB/KfW Carbon Purchase Program to help SMEs to comply with the EU's emissions trading schemes, the WB-EIB Carbon Fund for Europe, and the Fonds Carbone Capital Maroc (in French-speaking Africa) (Garcia and Roberts, 2008), with a total fund in these programs of more than €600 million.

Global carbon markets were worth about €40 billion in 2007 (PointCarbon, 2008), with the EU emissions trading scheme contributing to a trading volume of 1.6 $GtCO_2$-eq of carbon and a value of €28 billion, while the CDM market saw a volume of 0.95 $GtCO_2$-eq and a value of €12 billion.

Energy efficiency financing is a largely "invisible" market that represents a tiny share of global investment flows to the industrial sector but mirrors its structure. To move to a sustainable energy pathway, investment flows need to shift from west to east (from OECD countries to the developing world) and from the supply to the demand side. Projected increases in investment flows will be offset by decreased needs on the supply side (due to decreased energy demand compared to BAU). Given the variety and magnitude of risks facing industrial energy efficiency investment projects in developing countries, more attention needs to be paid to creating an enabling policy framework and support mechanisms to reduce these risks.

8.8.5 Technological development, R&D, and Technology Transfer

The thermodynamic analysis clearly reveals that industrial energy systems have relatively low exergetic efficiencies and significant potential for improvement. R&D can help in designing more efficient processes and utility systems. Most national energy efficiency programs focus on identifying and replicating "best practices." This is important from an implementation perspective, as it will result in significant energy savings in the short term. In addition to this, there should also be a focus on the evolution of "next practices" or future generation equipment and processes resulting in drastic reductions in energy use. A combined strategy that combines moving from existing processes to best practices and also invests in R&D to evolve next practices is desirable. This will combine medium- and long-term energy efficiency needs.

The major portion of industrial energy use is accounted for by the production of a few energy-intensive materials. Demand for these materials in developed countries has become saturated, and the growth in consumption is mainly in developing countries. Developing countries such as China and India account for the largest share of these materials. If future capacity is to be more energy efficient, it is important that developing countries have access to these technologies.

In process plants, the energy use targets depend on local conditions such as ambient temperatures, raw materials, and scale. It is essential to develop the capability for R&D in developing countries for benchmarking and setting ambitious energy efficiency targets. Innovation in energy-efficient equipment or processes needs a critical amount of R&D funding. Most of the intellectual property and new technology know-how is available in the private sector, predominantly in developed countries. In the United States, the EU, and Japan there have been government-funded R&D programs to support industrial innovation to develop energy-efficient and clean technology.

Many countries have bilateral grant and assistance programs in the area of clean technologies. However, these are usually tied to the promotion or licensing of technologies developed by the donor country. For example, the Japanese Green Assistance plan resulted in the transfer of dry coke quenching technology from Japan to China. However, the technology was not to be adapted or indigenized by Chinese industry for a period of ten years.

Privately funded research initiatives usually have a short-term focus. Long-term initiatives for new materials, equipment, and process design need to involve researchers at universities. The evolution of road maps for the development of energy-efficient technology needs strategic partnerships between competing industries and academic and research organizations.

The challenge is to develop mechanisms to provide access to new technologies and build R&D capacity in the developing countries where the majority of the future industrial energy growth is likely to occur.

8.8.5.1 Dematerialization, Substitution and Eco Design

As material usage saturates, it is expected that there will be trends towards dematerialization. It is also expected that energy-intensive materials will be substituted by less energy-intensive materials. Table 8.30 shows an example of materials substitution in automobiles in the United States. The weight of the car decreased from 1663 kg in 1997 to 1524 kg in 2003 (8.4% dematerialization). The shares of aluminum, plastics, and composites have increased, while the share of conventional steel has decreased.

Table 8.30 | Examples of weights of materials used in cars.

Material	1977		1987		2003	
	kg	%	kg	%	kg	%
Conventional steel	904.9	54.4%	661.8	45.9%	614.6	40.3%
High-strength steel	56.7	3.4%	103.4	7.2%	171.9	11.3%
Stainless steel	11.8	0.7%	14.5	1.0%	25.6	1.7%
Other steel	25.4	1.5%	25.2	1.7%	12.0	0.8%
Iron	244.9	14.7%	208.7	14.5%	148.8	9.8%
Aluminum	44.0	2.6%	66.2	4.6%	125.9	8.3%
Rubber	68.0	4.1%	61.5	4.3%	67.6	4.4%
Plastics/composites	76.2	4.6%	100.5	7.0%	115.9	7.6%
Glass	39.7	2.4%	39.0	2.7%	44.7	2.9%
Copper	17.5	1.1%	20.9	1.4%	22.7	1.5%
Zinc die casting	17.2	1.0%	8.2	0.6%	3.9	0.3%
Powder metal parts	7.0	0.4%	8.8	0.6%	18.1	1.2%
Fluids n Lubricants	90.7	5.5%	83.0	5.8%	89.8	5.9%
Magnesium parts	58.1	3.5%	1.1	0.1%	4.3	0.3%
Other materials	0.5	0.0%	38.8	2.7%	57.8	3.8%
Total	1662.9	100%	1441.5	100%	1523.6	100%

Source: American Metal Market, 2003.

There are no aggregate estimates of the impacts of dematerialization and substitution on the energy required in the industrial sector. An analysis of buildings and selected industrial products would be useful to understand the potential for dematerialization and substitution.

A study by Fraunhofer and Eichammer (2010) shows that industrial energy use in Germany could be reduced by 13% through material efficiency. Germany has set up an agency for material efficiency[14] that document several case studies of targeted and achieved improvements in material and energy efficiency in German industry. Case studies include the use of structured composites, nano-coatings in automobile components, and biogenic raw materials.

The eco design process in the EU was mandated by a directive of the European Parliament in October 2009. This establishes a framework for setting eco design requirements for energy-related products. The commission supports life cycle thinking and has currently included more than 30 energy-using product categories with an eco-design regulation[15] that sets minimum energy efficiency requirements and environmental performance norms based on a life cycle approach. The systematic information dissemination mechanism followed for the introduction of eco design can be extended to other countries and regions and for other industrial products.

8.8.6 Capacity-building for Energy Efficiency

Energy systems and institutions are supply focused. The dominant principle is increased affluence, which requires increased consumption and, therefore, production of materials and products. The industrial system projects new manufacturing capacity and new utility systems to cater to increasing future demand. This results in an increasing amount of fuel and electricity used.

To level the playing field for energy efficiency, a paradigm shift is required with the focus on energy services – not on energy supply *per se*. This requires a re-orientation of energy supply, distribution companies, and energy equipment manufacturing companies.

What are the skills required to identify and implement the energy efficiency potential in industry? It is important to promote a systems approach and thinking. Motors, steam systems, cogeneration, and process integration need systems analysis capabilities. The US approach to developing systems assessment training modules is a replicable model. Several countries have evolved mechanisms for training and certification of energy auditors and energy managers (e.g., India's BEE has set up a syllabus, examination, and certification for energy auditors and managers). The development of ESCOs is also important for the success of industrial energy efficiency. ESCOs should be able to provide a complete energy efficiency solution to industry and should be able to take on the performance and financing risks of energy efficiency projects. ESCOs have not taken off in many markets. Most of the future growth in industry is expected in developing countries, which lack capital. Monitoring

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[14] See www.demea.de.

[15] See www.inforse.org/europe/eu_Ecodesign.htm#Products.

and verification of savings for performance contracting also needs independent assessment, measurement, uncertainty analysis, quantification of effect of production changes and product mix, and clearly enforceable contracts for benefit-sharing.

Many countries have developed energy efficiency cells in regions or provinces (e.g., China has more than 400 energy management cells in provinces). These cells need access to information, training, research results, and support to plan their audits and energy management plans.

Regulators and government officials who deal with energy supply sectors and energy planning for the future need to be trained to integrate DSM and energy efficiency into the future supply mix.

There needs to be training for industry personnel at different levels. Short (half-day or one-day) workshops for top management (Chief Executive Officers and other key decision-makers) should ensure that energy efficiency and sustainability receive the necessary attention in the boardroom. Hands-on training modules need to be developed for technicians to inculcate the necessary skills for efficient operating and maintenance practices (steam trap maintenance, leakage reduction in compressed air systems, etc.) and retrofitting for energy efficiency. Plant engineers and managers should be familiarized with life cycle costing and sustainability analysis.

Planning for next-generation processes and systems needs the development of a long-term research agenda and strategic collaborations between industry, academic and research institutions, and governments.

International best case studies of new energy-efficient technologies and systems should be publicized and made available for industry. Searchable databases with information on plant-specific measures should be provided with translations into major languages.

8.8.7 Implementation Strategies

Investments in energy efficiency of even 1.6% of the present global fixed capital investment annually up to 2020 would provide an annual average return of 17%/yr. Investments of US$170 billion would result in US$900 billion a year in energy cost savings in 2020 (Farrell and Remes, 2008; UN Energy, 2010).

Country examples illustrate the importance of national energy efficiency action plans. Proprietary energy-efficient technologies and policies should be identified and methods to facilitate their access and deployment in developing countries should be supported. Capacity-building and information dissemination needs to be strengthened. Adoption of global ISO energy efficiency standards should be encouraged.

Policies need to address and overcome multiple barriers that exist at different levels. (Brunner et al. 2009) present an analysis of barriers to business at the sector level, to manufacturers at the original equipment manufacturer level, and regarding wholesale planning, engineering, investment and energy management for electric motors. Figure 8.36 shows an approach to having multiple policy instruments in different parts of the product life cycle for electric motors. The adoption of life cycle costing would be an important step in promoting industrial energy efficiency, as the annual energy cost predominates in the life cycle cost for most energy utilization equipment in industry (motors, boilers, furnaces) but gets hidden in the conventional simple payback period analysis.

A locally organized energy efficiency network was created in Switzerland in the 1990s (Jochem and Gruber, 2007). This was facilitated by a stimulus from the Swiss Energy Agency for Industry to exempt participating industries from a fossil fuel surcharge of CHF 25/tCO_2. Participating companies agree to reduce energy-related CO_2 emissions to a negotiated target and undergo yearly evaluations.

The Swiss experience was replicated by an energy efficiency learning network in Baden-Württemberg in Germany in 2002 with 17 companies. The total energy use of the companies was 731 TJ in 2001. Participants agreed to 7% energy savings and 8% CO_2 emission reductions within four years (by 2005). Figure 8.37 shows the target and achievements of the companies (Jochem and Gruber, 2007). Encouraging the establishment of learning networks locally in different countries can help to facilitate sharing of experiences, increasing industrial energy efficiency, and setting group wide voluntary targets. National emissions trading schemes may provide a mechanism for funding and incentivizing industrial energy efficiency.

8.9 World Industrial Energy Projections up to 2030

8.9.1 Business-as-usual Scenario

Industrial energy use depends on the output of the industry sector. The Manufacturing Value Added (MVA) is used as a proxy to measure this output. The MVA for industry is disaggregated into developing and developed countries. The average annual growth rate in MVA of developing countries during 2000 to 2005 was 6.1%, and an average growth rate of 6%/yr was used to project the MVA in 2030. Zero growth rate in MVA has been assumed for industrialized countries (i.e., saturation).[16]

Energy intensity is the industrial energy use per unit of MVA. It is seen that in the past ten years the energy intensity value declined at a rate of 1.6%/yr. An annual decline of 1% in energy intensity is assumed as the BAU trend till 2030. Based on these assumptions, the industrial energy demand of the world in the BAU case is 175 EJ for 2030, as shown in Table 8.31.

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[16] The MVA values have been taken from the UNIDOdatabase (UNIDO Database, 2011) and the industrial energy consumption values from the IEA database (IEA Database, 2011).

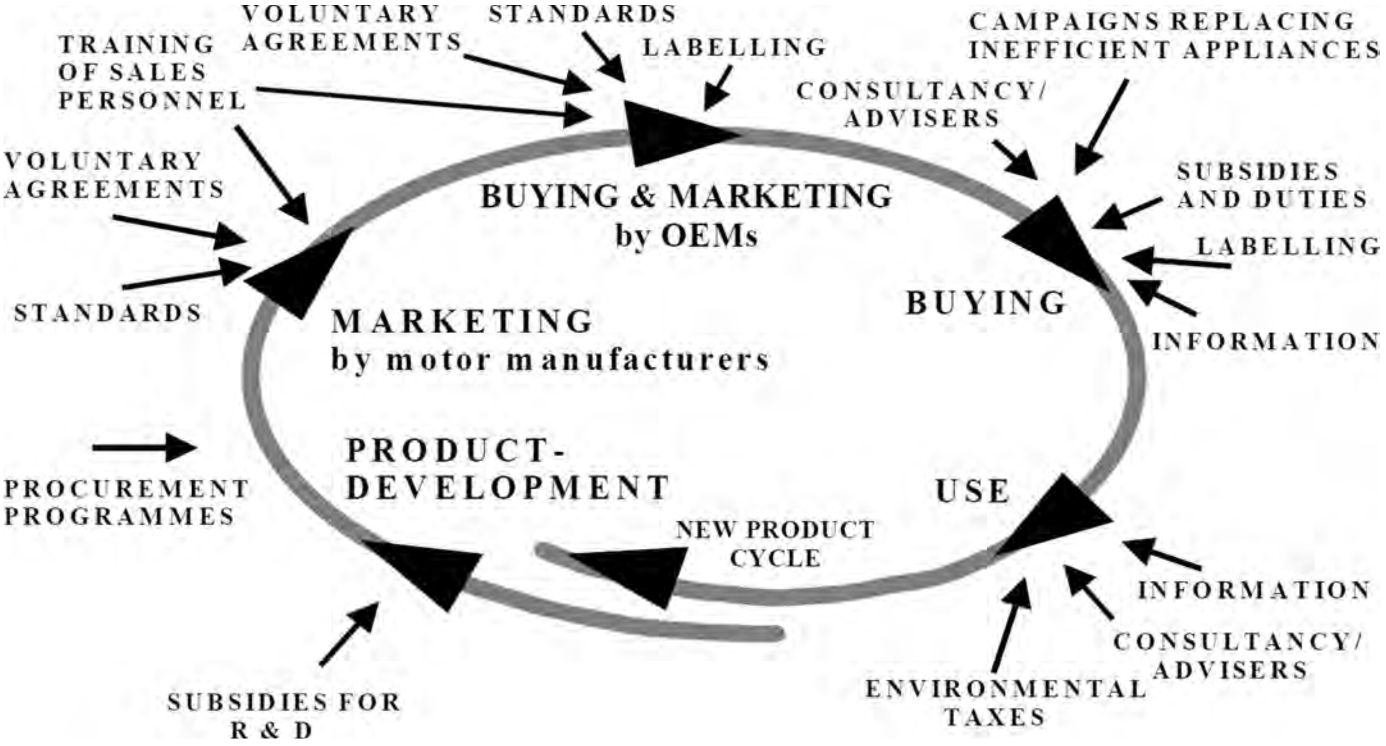

Figure 8.36 | Obstacles influencing the diffusion of highly efficient electrical motors. Source: IEA, 2011. ©OECD/International Energy Agency 2011.

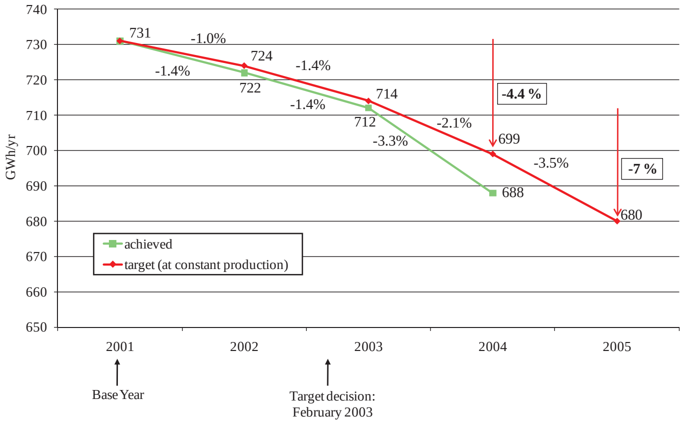

Figure 8.37 | Joint energy efficiency target path of 17 companies of the efficiency table and achieved energy savings (temperature adjusted). Source: Jochem and Gruber, 2007.

The country estimates are obtained from national plans and included for comparison. The forecasts for 2030 for the world are given in Table 8.32.

Predicted industrial final energy use and its share of total energy demand for selected countries in 2030, according to government estimates, are summarized in Table 8.33.

Material production growth estimates for 2030 by country, according to the countries' official projections, are listed in Table 8.34. The selected industries presently account for about 40% of the world's energy use.

The specific energy consumptions for the countries are projected up to 2030. The data are given in Table 8.35, based on government estimates.

The CO_2 emission projections for 2030 for the world are given in Table 8.36. The figures for 2030 are based on the assumption of no improvement in specific energy consumption and the same fuel mix for material production.

8.9.2 Energy-efficient Scenario

The exergy analysis shown earlier reveals that industrial processes are not near the thermodynamic limits and significant potential for improvements exist. The exergy efficiency of 30% reveals the potential for further process improvements. Based on this potential in 2030 it is assumed that there is a 40% reduction in the energy intensity for the new stock with respect to the existing frozen efficiency (exergy efficiency of 50% for the new processes).

To compute the energy-efficient scenario, we differentiate between new stock (NS) and existing stock in 2005 (ES_{2005}). Of the existing stock in 2005, some fraction (*f*) will be retired or replaced. We consider a fraction

Table 8.31 | Basis for industrial energy demand in the BAU scenario.

Country	MVA-2005 (US$ billion)	CAGR (2000–2030)	MVA-2030 (US$ billion)	EI-2005 (MJ/$)	EI-2030 (MJ/$)	Industrial Energy (EJ)	Individual Country Estimates (EJ)
World	6536.6	–	12766	17.6	13.7	175	–
United States	1657.4	0%	1657.4	9.9	7.7	12.8	12.6
Japan	1096.8	0%	1096.8	5.7	4.4	4.9	–
China	641	3.5%	1514.8	38.2	29.7	45.0	46.4
India	68.2	8%	467.1	80.5	62.6	29.2	30.6
Brazil	81.4	5%	275.6	41.0	31.9	8.8	8.1
South Africa	24.4	6%	104.7	43.5	33.8	3.5	3.4

Note: CAGR- Compound Annual Growth Rate, EI- Energy Intensity

Table 8.32 | MVA, EI, and industrial final energy estimates for 2030.

MVA (Billion $ 2000)	2000	2005	CAGR (00–05)	CAGR (05–30)	2030
World	5774.3	6536.6	2.5%	2.7%	12766
Industrialized	4369.9	4644.1	1.2%	0%	4644
Developing	1404.4	1892.5	6.1%	6%	8122
Energy Intensity (MJ/$)	**1995**	**2005**	**CAGR (95–05)**	**CAGR (05–30)**	**2030**
World	20.6	17.6	–1.6%	–1%	13.7
Industrial Final Energy in 2030 (EJ)	175				

Note: CAGR- Compound Annual Growth Rate

Source: Based on UNIDO Database, 2011; IEA Database, 2011.

Table 8.33 | Projected final energy use by country up to 2030.

		US	China	India	Brazil	SA	World
Final Energy use by Industry[1] (EJ)	2005	16.6	24.6	5.7	2.9	1.23	115
	2030 (B)	12.6	66.8	30.6	8.1	3.38	175
Industry % of Total Final Energy demand	2005	34%	51%	34%	45%	42%	30%
	2030 (B)	32%	54%	40%	38%	–	–

[1] includes feedstocks (non-energy use), see Chapter 1, Section 1.2.2.

Source: Digest of South African Energy Statistics, 2006; Brazil Ministry of Mines and Energy, 2007; IEA, 2008a; TERI, 2008; China Government Estimates, 2011.

of 20% as the retirement rate up to 2030 (approximately 1%/yr). The output in 2030 (MVA_{2030}) would be from both existing equipment and new equipment, thus:

$$MVA_{2030} = MVA(ES_{2005})*f + MVA(NS) \tag{3}$$

Hence the existing industries (from 2005) account for US$5229 billion of MVA in 2030. The remaining MVA of US$7537 billion is produced from new stock.

Table 8.37 shows the details of the frozen efficiency scenario, BAU scenario and the energy-efficient scenario. The frozen efficiency scenario is computed assuming that the same energy intensity (17.6 MJ/US$) will continue in 2030. This results in a total final energy use for industry in 2030 of 225 EJ. For the existing surviving industry we compute the potential for energy efficiency in motor drive systems, steam systems, process improvements in energy-intensive industries and SMEs, and pinch and process integration. The basis and numbers are shown in Table 8.37. A total saving of 37 EJ is possible from the existing surviving industry. For the new industry an energy intensity improvement of 40% over the existing frozen efficiency scenario is assumed (corresponding to an energy intensity of 10.6 MJ/$). This includes process improvements, pinch and process integration, and efficiency in motors and steam systems. A saving of 53 EJ in the new stock is possible compared to the frozen efficiency scenario. This results in a total final energy use of 135 EJ in the energy-efficient scenario.

Table 8.34 | Material consumption growth rates country-wise until 2030.

Material Production		US	EU	China	India	Brazil	SA	World
Crude Steel	2005	95	196	355	45	31.6	9.5	1146
	05–30 B CAGR	–0.50%		3.70%	8.60%		5.20%	
Cement	2005	99	298	1060	153	36.7	13	2310
	05–30 B CAGR	–0.50%		2.50%	8.40%			
Paper & Paperboard	2005	88	98	62	7	10	4.6	361
	05–30 B CAGR	0.00%		3.30%	8.10%		1.30%	
Ammonia	2005	8	14.5	46.3	12	0.95	0.5	151
	05–30 B CAGR	0.00%		1.80%	1.90%			
Aluminum	2005	2.5	5.2	8.5	0.9	1.4	0.85	32
	05–30 B CAGR	0.60%		3.20%	7.90%		6.90%	

Note: Total Aluminum (Primary + Secondary) growth figures.

Source: American Forest and Paper Association, 2006; IISI, 2008; TERI, 2008; IEA, 2008a; USGS, 2011.

Table 8.35 | Projected specific electricity consumption by country up to 2030.

SEC (GJ/t)		US	EU	China	India	Brazil	SA	World
Steel	2005	15.4	17.1	22.3	22.8	26.6	31.3	19.4
	2030 (B)	13.7		19.3			25.2	
Cement	2005	4.1	3.1	3.9	3.3	3.9	4.5	4.0
	2030 (B)	3.9		3.4				
Paper	2005	30.9	16.6	30.7	26.7	22	28	18.4
	2030 (B)	27.4		26.1				
Ammonia	2005	37	52	48.2	38			
	2030 (B)	36.1		40.7				
Aluminum	2005	47*	35.7	51.5*	94.7	61.6*	50*	103
	2030 (B)	46.7*		47.5*			39.5*	

Source: TERI, 2008.

Table 8.36 | World industrial CO_2 emission quantities.

Industry (Million Tonnes of CO_2)	2005	2030
Iron and steel	1992	3598
Non-metallic minerals	1770	3287
Paper, pulp and print	189	262
Non-ferrous metals	110	189
Industry total – direct and process CO2 emissions	6660	12,031
Industry total – direct and indirect CO2 emissions	9860	17,812

Source: IEA, 2008a.

If industrial output were to increase by 95% of its 2005 value in 2030, in the frozen efficiency scenario this would require an input of 225 EJ of final energy input. In the BAU scenario, due to normal efficiency improvements, the final energy input required is 175 EJ. Hence industry would require 60 EJ in 2030 more than current consumption. Under the energy-efficient scenario an additional 40 EJ can be obtained through energy efficiency. Hence it is possible to target 95% growth in industrial output by 2030 (in MVA terms) with only a 17% growth in final energy input. Figure 8.38 shows the existing, frozen efficiency, and BAU scenarios and the savings in 2030.

Total direct and indirect CO_2 emissions from the industrial sector in 2005 were about 9.9 Gt (IEA, 2008a). Assuming the same carbon intensities for the industrial sector, under the BAU scenario total CO_2 emissions would increase to 17.8 Gt, and under the energy-efficient scenario to 11.6 Gt, in 2030. It is possible to stabilize the CO_2 emissions from the industry sector at 2005 numbers by a combination of the energy-efficient scenario and an increase in the share of renewables in the industrial mix. Renewables currently account for 9% of the total or about 10 EJ of final energy supply. This needs to be increased to about 32 EJ in 2030 to account for 23% of the final energy supply to the industrial sector. This would imply a compound annual growth rate of 4.8%/yr.

Table 8.37 | Industrial energy demand estimates for 2030 in the EE scenario.

World		2005	Fraction retirement 2030 (f)	2030 (FE)	2030 (BAU)
MVA (billion US$2000)		6536.6	20%	12,766	12,766
EI (MJ/$)		17.6	-	17.6	13.7
Energy (EJ)[1]		115	-	225	175
MVA (2005 surviving in 2030)		5229	US$ billions		
MVA (New Stock)		7537	US$ billions		
Energy-Efficient Scenario (EE)					
Energy required by existing surviving stock (in FE in 2030)				92 EJ	
End-uses		**Share**	**Potential Savings**	**EJ**	
A.	Motor systems	15%	20%	2.8	
B.	Steam systems	38%	20%	7.0	
C.	Process improvements in energy-intensive industries	66%	9%	5.5	
D.	Process improvements in SMEs	34%	10%	3.1	
Total Savings (A+B+C+D)				18.3	
Energy use in existing stock after A+B+C+D				73.7	
E.	Saving through pinch	100%	25%	18.4	
F. Total savings in existing stock (A to E)				37	
New Stock energy consumption				133	
G. Reduction in New Stock vs. FE scenario (EI – 10.6 MJ/US$)			40%	53	
Total savings obtained				90	
Energy required in EE scenario				135	

[1] includes feedstocks (non-energy use), see Chapter 1, Section 1.2.2.

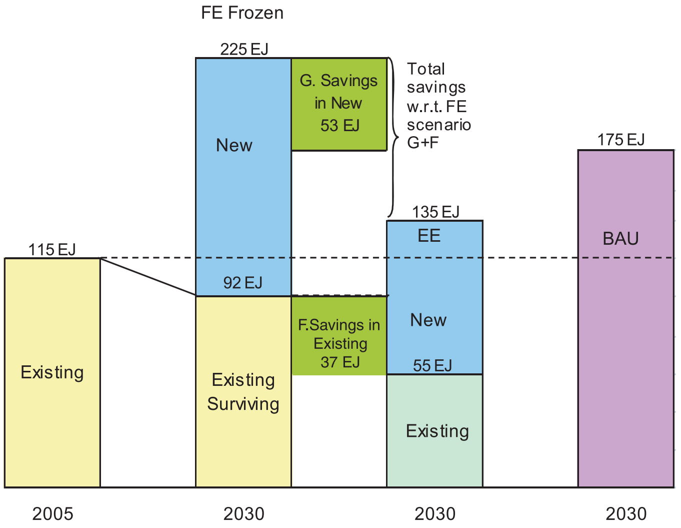

Figure 8.38 | Existing, frozen efficiency and BAU scenarios and the savings in 2030. Note: Final energy data includes feedstocks (non-energy use), see Chapter 1, Section 1.2.2.

8.10 Conclusions and Recommendations

The key messages emerging from the analysis of end-use efficiency for the industrial sector are:

- An energy-efficient scenario is possible which results in the required industrial growth till 2030 (95% increase over 2005 values) with only a 17% increase in the final energy required.
- If the energy-efficient scenario is coupled with a growth in the use of renewables for industry, it is possible to meet the growth in industrial output without any increase in the total CO_2 emissions of the industrial sector in 2030.
- Most of the growth will occur in developing countries. At present, developing countries account for 29% of industrial output; in 2030 they will account for 64%. Most investments in future industrial production capacities are likely to be in developing countries.
- Several interventions will be required if the energy-efficient scenario or the zero CO_2 growth scenario for industry are to be achieved, and the following interventions are suggested:

I. Realizing the potential for energy efficiency in existing industry:

(a) Incentivize DSM: regulatory commissions can provide incentives for motor efficiency programs and process improvements.

(b) Information gaps to be reduced: promote sharing and documentation of best practices.

(c) Develop capacity for system assessment: motors, steam, pinch, process. Recent efforts by ASME to develop System Assessment Standards for motors and steam systems in the US need to be extended to other regions of the world.

(d) Provide access to low-interest finance: investments in energy efficiency compete with investments in process improvements and enhancements in plant capacity. Separate credit lines should be provided especially for funding industrial energy efficiency in developing countries.

(e) Special efforts to focus on industry clusters of SMEs – for example, steel rolling, brick making: SMEs normally do not have the engineering capability to design and implement energy efficiency programs. Interventions that facilitate building this capability would be useful. Training workshops and energy efficiency manuals should be developed and tailor-made for different industry clusters. Sharing of best practices across industry groups is likely to result in new ideas for efficiency improvements. Multilateral agencies such as UNIDO can help facilitate this by creating regional information centers and funding dissemination workshops.

(f) National Energy Conservation Funds: governments should be encouraged to create National Energy Conservation Funds. These could be provided by a tax on all new supply (power plants, refineries). Funds should be used to provide a level playing field for energy efficiency vis-à-vis new supply.

(g) Energy management standard: industry should be encouraged to adopt the new ISO energy management standard.

(h) Benchmarking efforts: initiatives from industry organizations, such as Cement Sustainability Initiative (CSI) for cement, World Steel Association for steel, and IAI for aluminum, to draw up road maps and benchmarks for industry need to be encouraged.

(i) Risk guarantee and venture capital: there should be a mechanism to encourage commercial banks to invest in energy efficiency projects in industry. This could be in the form of guarantees for risk or special funding for venture capital.

II. New industry – Most of the new industrial growth will occur in developing countries. Under the BAU scenario, a mix of technologies would be installed with varying specific energy consumption. It is suggested that regional centers for industrial energy efficiency be set up to disseminate information related to specific energy consumption and best available technologies for different processes. There should be a (web-based) facility where any industry that is being proposed can compare its designed energy performance with the best available technologies. Consultants can be provided to undertake energy integration and efficiency improvement studies at the design stage itself. An incentive scheme should provide funding for energy performance analysis at the design stage. Financing of the incremental costs of energy-efficient technologies should be provided as low-interest loans through commercial banks.

III. Dematerialization and substitution – To encourage studies and analysis for new products, it is proposed that design challenges be announced for some important products that may result in reduced usage of material and an overall reduction of energy-intensive materials. The potential for substitution and dematerialization needs to be studied in different sectors and end-uses.

IV. Next-generation processes and technologies – Most of the energy-intensive materials produced by industry have not reached their limits for efficiency improvements. To move from the best available technologies to next-generation technologies, it is essential to facilitate R&D in new processes. Industry groups such as CSI, World Steel Association, and IAI can play a role in bringing together industry and researchers to facilitate this. Pre-competitive consortia of industries and research institutions should be facilitated by funding from government and multilateral agencies. The funding for R&D for energy-efficient processes is sub-critical and needs to be enhanced. Financing of next-generation technologies may occur from national emissions trading schemes.

V. Increased use of renewables in industry – Funding should be available for demonstration and pilot projects for innovative applications of renewables in industry. Biomass- and solar-based process heating, cogeneration, cooling and power-generation applications need to be designed, implemented, and assessed for different industrial applications. Dissemination of information related to renewable case studies in industry should be facilitated internationally. Focused attempts to bring down the costs of renewable systems would imply setting up initiatives for technology development and consortium approaches.

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