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China's Industrial Sector in an International Context

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May 2000

This work was supported by the Climate Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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I. Introduction

The industrial sector accounts for 40% of global energy use. In 1995, developing countries used an estimated 48 EJ for industrial production, over one-third of world total industrial primary energy use (Price et al., 1998). Industrial output and energy use in developing countries is dominated by China, India, and Brazil. China alone accounts for about 30 EJ (National Bureau of Statistics, 1999), or about 23% of world industrial energy use.

China's industrial sector is extremely energy-intensive and accounted for almost 75% of the country's total energy use in 1997. Industrial energy use in China grew an average of 6.6% per year, from 14 EJ in 1985 to 30 EJ in 1997 (Sinton et al., 1996; National Bureau of Statistics, 1999). This growth is more than three times faster than the average growth that took place in the world during the past two decades. The industrial sector can be divided into light and heavy industry, reflecting the relative energy-intensity of the manufacturing processes. In China, about 80% of the energy used in the industrial sector is consumed by heavy industry. Of this, the largest energy-consuming industries are chemicals, ferrous metals, and building materials (Sinton et al., 1996).

This paper presents the results of international comparisons of production levels and energy use in six energy-intensive subsectors: iron and steel, aluminum, cement, petroleum refining, ammonia, and ethylene. The sectoral analysis results indicate that energy requirements to produce a unit of raw material in China are often higher than industrialized countries for most of the products analyzed in this paper, reflecting a significant potential to continue to improve energy efficiency in heavy industry. It should be noted however, that data availability limit the ability to conduct in-depth analysis in some sectors.

The international comparisons made in this paper follow the methodological recommendations from two workshops and a handbook on international comparisons of industrial energy efficiency (Martin, 1994; Phylipsen et al., 1996; Phylipsen et al., 1998). These comparisons can be used to analyze differences in trends between countries as well as to identify opportunities for efficiency improvement. We first compare physical production levels for the six major commodities produced in the analyzed subsectors. Second, we compare the energy intensity, defined as the energy used per tonne of commodity produced. This measure, which we call the specific energy consumption (SEC), is influenced by the production processes used, the type of product produced, and the energy efficiency of the production process. For sectors for which we have adequate data (iron and steel, pulp and paper, cement), we compare the average SEC in each country to the "best practice" SEC. Best practice SEC is calculated assuming that the same mix of products are produced using existing best practice technology.

II. International Comparisons

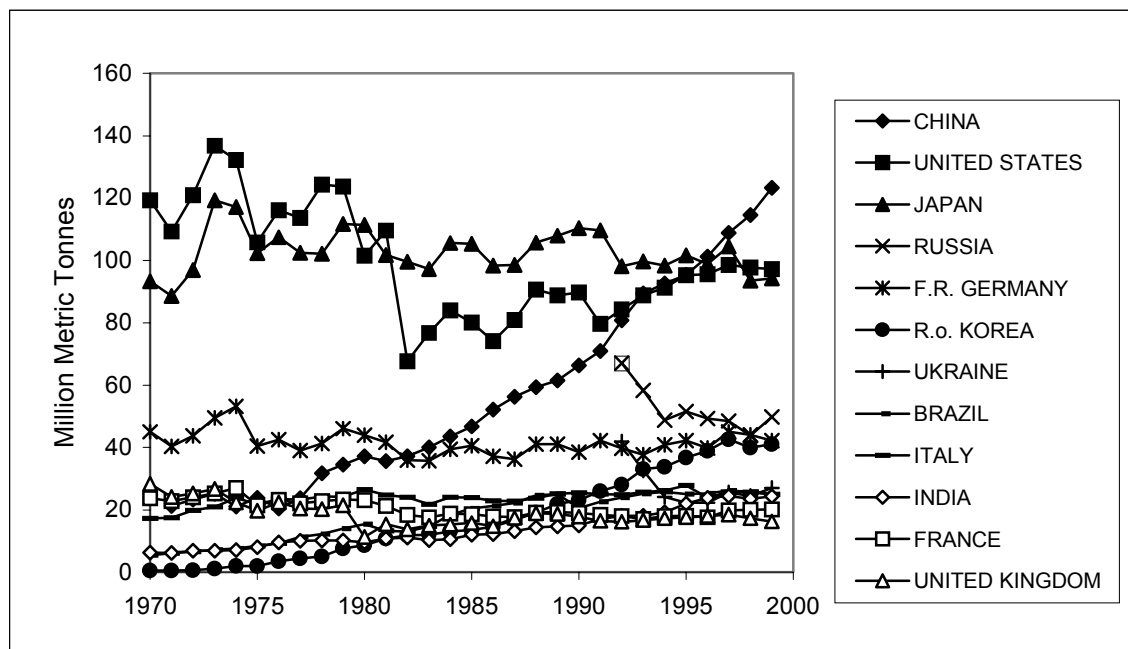
A. Iron and Steel

The iron and steel industry (ISIC category 37) is the single largest industrial energy-consuming subsector in the world, accounting for nearly 5% of the annual world primary energy demand (Worrell, 1995). Steel is used in a wide variety of applications, including automotive manufacturing, building construction, appliances, industrial equipment, high-grade alloys for oil and gas production rigs, and packaging (UNIDO, 1993).

1. Production

China clearly dominates world steel production, producing 123 Mt in 1999 (see Figure 1). The U.S., Japan, and Russia are the next largest steel makers globally. China had steady upward growth in production from 21 Mt in 1971 to 123 Mt in 1999, resulting in an annual average growth rate of 6.5%. Steel production is projected to decrease in 2000 following a recent decision to limit steel production in the large and medium-sized steel enterprises and to close all steel plants with annual production capacities of less than 100,000 tons (China Daily, 2000).

Figure 1. Crude Steel Production in Selected Countries, 1970-1999.



Source: IISI, 1992, 1994, 2000.

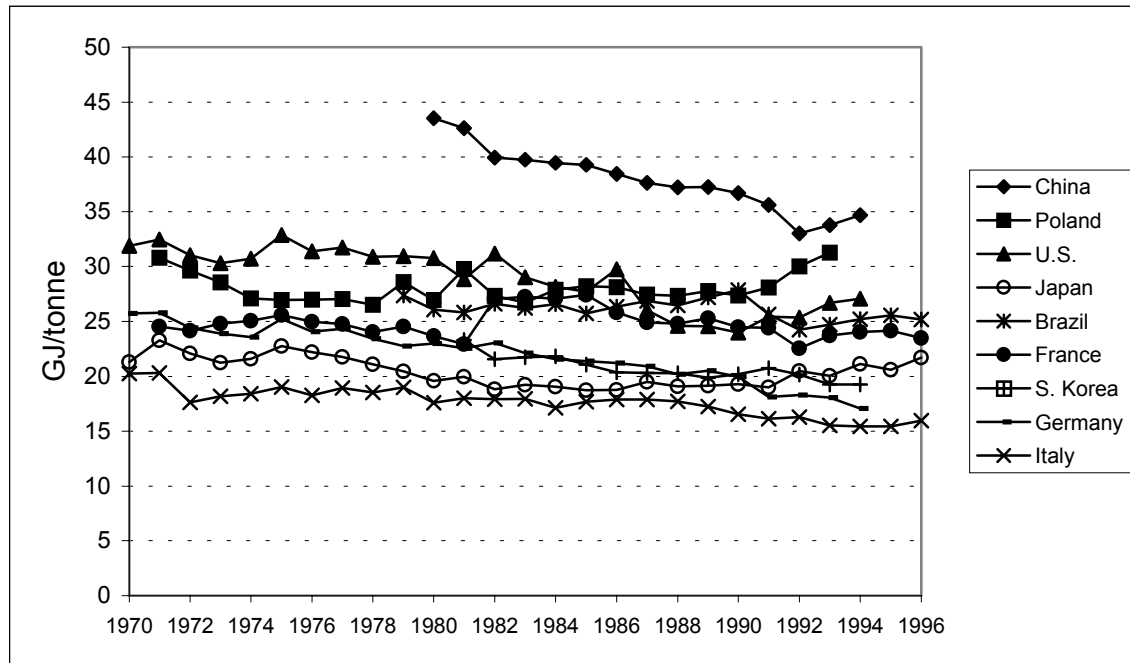
2. Energy Intensity

In 1996, China used 3.5 EJ of primary energy (using a 33% electricity conversion factor) for production of crude steel, which is approximately 9% of the country's total primary energy consumption. Primary energy use for production of steel in China grew an average of 5.0% per year since 1980.

Figure 2 compares the specific energy consumption (GJ/tonne) for China with that of eight other countries. China's SEC is significantly higher than that of all other countries during the period studied, although the decline in the SEC over the period is striking, dropping from over 52 GJ in 1980 to 40 GJ in 1993.

In comparing the efficiency of the Chinese steel industry to other countries, it is important to realize that the use of cast iron is relatively high in China and that energy is also used for so-called "non-productive use" such as residential energy use by employees and energy use for mining of raw materials. Correcting for the latter two factors may lead to 5-6% lower energy consumption in the Chinese iron and steel industry (Ross and Liu, 1991).

Figure 2. Specific Energy Consumption for Steel Production in Selected Countries, 1970-1996.



Source: INEDIS, 2000.

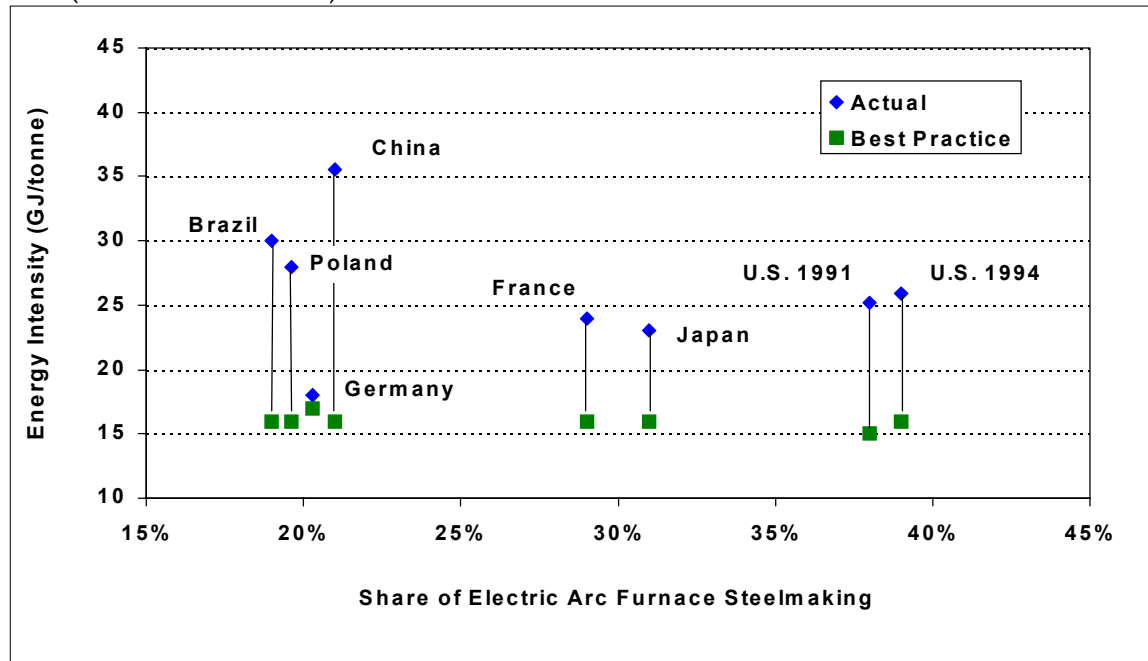
3. Best Practice Analysis

To provide an estimate of the energy efficiency improvement potential, we plot the actual specific energy consumption (SEC) and a "best practice" SEC that calculates each country's SEC based on the lowest energy use production facility in 1988. This best practice SEC accounts for the fact that product types change over time and differ by country by assigning weight factors for production of slabs and ingots by both the basic oxygen furnace (BOF) and electric arc furnace (EAF) processes, for production of hot rolled steel, and for production of cold rolled steel and is based on Worrell et al. (1997). For further details on this calculation, see Price et al. (1997).

Figure 3 depicts the actual and "best practice" SEC for China and six other countries in 1991 relative to the share of secondary (EAF) steelmaking. China has the largest potential for improvement among the countries shown, with a difference of almost 20 GJ/tonne between the actual SEC (35.6 GJ/tonne) and the "best practice" SEC (15.8 GJ/tonne). By 1996, the energy intensity of steelmaking in China had declined to 34.3 GJ/tonne. Steel production in the large and medium-sized enterprises has been estimated to consume about 30 GJ/tonne in 1998 (Li and Xu, 2000).

Recent analyses show that the energy intensity of steel production in China is 15% to 37% greater than that of other countries such as Japan, the U.S., Germany, France, and the U.K. (Li and Xu, 2000). It has been estimated that 0.64 EJ savings can be achieved in the near future by adjusting the iron to steel ratio, closing open-hearth furnaces and reducing the use of high energy-intensive processes and auxiliary processes such as ferroalloy-making (Li and Xu, 2000).

Figure 3. Comparison of Actual and Best Practice Energy Intensities for Selected Countries, 1991 (and 1994 for the U.S.).



Source: Price et al., 1997; Worrell et al., 1997.

B. Non-Ferrous Metals: Aluminum

The aluminum industry (ISIC 37202) includes alumina production as well as aluminum production. Based on volume, aluminum is the second largest produced metal, with global production of 20 Mt in 1994 (UN, 1996). Production of primary aluminum is one of the most energy-intensive industrial processes. It is estimated that global primary energy consumption for aluminum production (including alumina production) is 3-4 EJ.

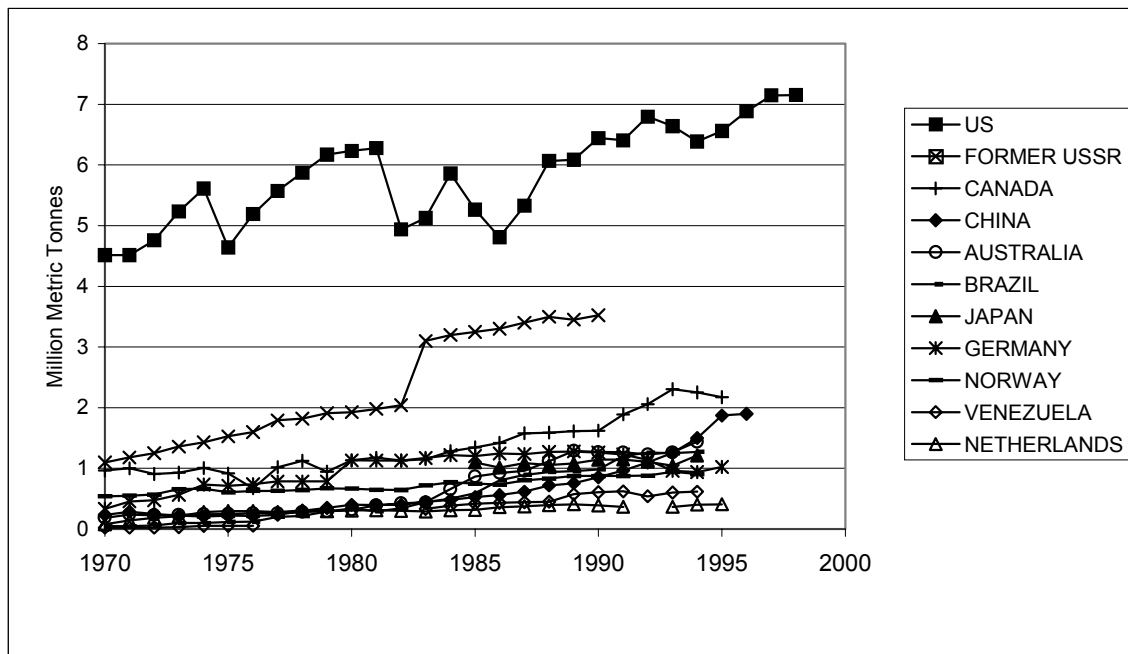
1. Production

Figure 4 shows the production of aluminum in the top 11 aluminum-producing countries in the world, which accounted for roughly 70% of total world production in 1990. In 1994, the two largest producers of aluminum were the United States and Canada, followed closely by China. (Inadequate data are available for aluminum production in Russia after the collapse of the USSR, but it is likely that it is still a large producer as well.) China's production of aluminum grew at an annual average rate of 8.4% between 1970 and 1996, from 0.24 Mt in 1970, to 1.9 Mt in 1996.

Aluminum can be produced either through the primary production method (electrolytic reduction of alumina) or by the melting and reshaping of aluminum scrap (secondary production). Table 1 lists the percentage of secondary aluminum produced in the top 10

aluminum producing countries in the world from 1970 to 1994. The growth of secondary aluminum production is a key structural factor that can influence the overall energy consumption of a country for this sector as secondary is much less energy intensive. As the table indicates, almost all China's production is primary aluminum. Until 1994, China had produced a maximum of 1% secondary aluminum each year. Countries such as Norway and Venezuela produce a similar proportion of secondary aluminum, while the proportion ranges from 40-50% for countries such as the Netherlands and the US. Japan is unique in that it has almost completely switched to secondary aluminum production.

Figure 4. Aluminum Production in Selected Countries, 1970-1998.



Source: UN, 1993; 1994; 1996; U.S.G.S., 2000; INEDIS, 2000.

Table 1. Share of Secondary Aluminum Production in Selected Countries, 1970, 1980, 1990, 1994.

	1970	1980	1990	1994
Australia	10%	12%	3%	4%
Brazil	n.a.	15%	5%	7%
Canada	0%	6%	4%	4%
China	1%	1%	1%	7%*
Germany	8%	36%	43%	44%**
Japan	31%	42%	96%	97%
Norway	3%	2%	1%	5%
US	20%	25%	37%	48%**
USSR	n.a.	9%	17%****	n.a.
Venezuela	n.a.	n.a.	2%	5%

1996 data, ** 1995 data, *** 1998 data, **** 1989 data

Sources: UN, 1993; 1994; 1996; IISI, 1993.

2. Energy Intensity

In 1994, primary aluminum production in China required 16.3 MWh/tonne of electricity (Table 2). Electricity requirements for the production of primary aluminum in a number of other countries range from 14.1 MWh/tonne to 17.9 MWh/tonne. Per unit energy requirements have tended to decrease over time, reflecting improvements in electrolytic reduction technologies. Based on these data, it appears that electricity consumption per tonne of primary aluminum produced in China is on par with other industrialized countries.

Table 2. Electricity Consumption and Primary Energy Consumption in the Production of Primary Aluminum, 1980- 1995.

	Electricity Consumption (MWh/tonne)					
	1980	1985	1988	1990	1991	1995
US		17.6	16.6		16.2	
China	20.2	21.3				16.3**
Brazil	17.9	18		17.3		16.3
Canada				17.9	16.9	17.9
EU - 12*			16.0			
Netherlands		14.1				
France		19.3	16.1*			

*1987 for France. EU-12 stands for the 12 countries of the European Union combined.

** 1994 data.

Sources: US DOE, 1988, 1991, 1994 and 1997; Vallance, 1990; State Planning Commission, 1993; Worrell and de Beer, 1992; de Beer et al., 1994; UN, 1993; UN, 1994; UN 1996; ABAL, various years; CONSIDER, 1982, 1986, 1989; ADEME, 1992.

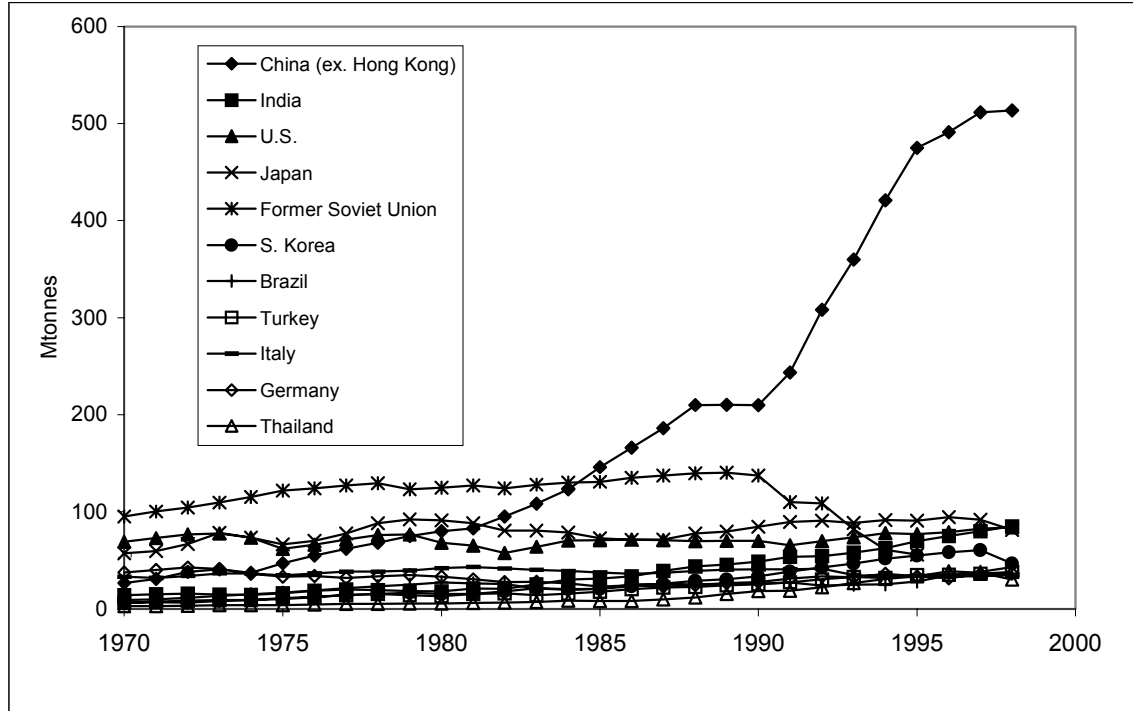
C. Building Materials: Cement

The cement industry (ISIC category 3241) is a large energy-consuming industrial sector, using 1-2% of world primary energy annually. Cement production is highly energy-intensive and involves the chemical combination of calcium carbonate (limestone), silica, alumina, iron ore, and small amounts of other materials. Cement is produced by burning limestone to make clinker, and the clinker is blended with additives and then finely ground to produce different cement types. This sector is responsible for nearly 3% of the global anthropogenic CO₂ emissions due to the use of fossil fuels and generation of non-fuel related emissions (due to the decarbonization of limestone). Cement is produced in over 80 countries with an annual global production of 1540 Mtonnes in 1997 (USGS, 2000).

1. Production

China dominates world cement production. In 1998 China's preliminary reported production of nearly 515 Mt of cement was 6 times greater than that of India, the U.S., or Japan, the next largest producing countries (see Figure 5). Between 1970 and 1998, cement production increased at an average annual growth rate of 11.2% in China. Cement production showed the most dramatic increase between 1990 and 1998, rising from 210 Mt in 1990 to 513 Mt in 1998.

Figure 5. Cement Production in Selected Countries, 1970-1998.



Source: Cembureau, 1996, USGS, 2000.

2. Energy Intensity

In 1995, China used 2.2 EJ of primary energy (using a 33% electricity conversion factor) for cement production. This consumption is over 5% of total commercial fuels and electricity used in China. Due to the dramatic increase in cement production in China, energy use for this sector has also grown significantly, increasing an average of 10.7% per year since 1980 (Sinton et al., 1996).

Table 3 provides a comparison of energy intensities for cement production in China and 12 other large cement-producing countries. China and Poland have the highest energy intensities, using 5.6 GJ for every tonne of cement produced (Van der Vleuten, 1995). China's energy intensity has declined, however, from about 6.5 GJ/tonne in 1970, indicating improvements in energy efficiency have occurred since that time (Sinton, 1996).

In most countries, average fuel intensity in the cement industry is directly correlated with the fraction of output from wet process kilns. Because China has a unique technology structure, however, it does not fit the pattern set by other countries. Although the wet process only accounted for 10% of Chinese output in 1990, the country's average fuel intensity of cement production was nearly as high as in Poland, where 60% of output came from wet process kilns, and about 40% higher than in France and Germany, where 5% of output came from wet process kilns (Sinton, 1996). The high intensity in China is due to generally high fuel intensities of rotary kilns and the high proportion of shaft kilns, which have fuel intensities higher than advanced dry process rotary kilns.

Table 3. Specific Energy Consumption for Cement Production in Selected Countries, 1990.

Country	Specific Energy Consumption (GJ/tonne)	Country	Specific Energy Consumption (GJ/tonne)
China	5.6	U.S.	4.4
Rotary kiln	5.9	Mexico	4.3
Vertical (shaft) kiln	5.2	Brazil	3.8
Poland	5.6	Italy	3.8
India	5.3	Germany	3.7
USSR	5.2	France	3.2
S. Korea	4.6	Japan	3.1

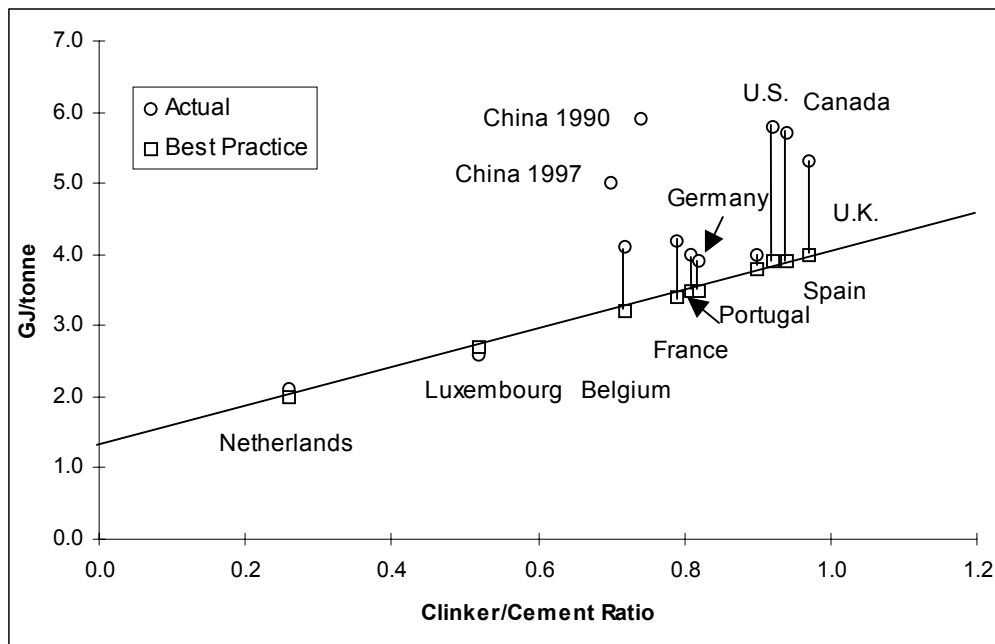
Source: Van der Vleuten, 1995. Chen, 2000.

3. Best Practice Analysis

Figure 6 depicts the actual intensity and “best practice” energy intensity for China and a number of selected countries as a function of the share of clinker produced. The distance between the upper point (the actual energy intensity) and the lower point (the “best practice” energy intensity, based on the Ash Grove Seattle plant in the U.S.) reflects the technical potential for efficiency improvement using current technology. In 1988, the potential savings in the U.S. was 33% (primary energy), compared to 21% for France, 9% for Germany, 25% for the UK and 33% for Canada (Worrell et al., 1995).

Although the “best practice” energy intensities were not calculated for China due to data limitations, the graph indicates that China’s 1990 and 1997 actual energy intensity was high compared to the sloped line drawn through the 1988 “best practice” energy intensity values for the other countries, although significant improvement in reducing the energy intensity has been made since 1990. If the “best practice” value for China fell on the sloped line, the technical potential for improvement would be close to 30%. However, a more detailed assessment based on China’s actual production practices is needed to accurately assess the actual savings potential.

Figure 6. Comparison of Actual and Best Practice Energy Intensities for Selected Countries, 1988 (and 1990 and 1997 for China).



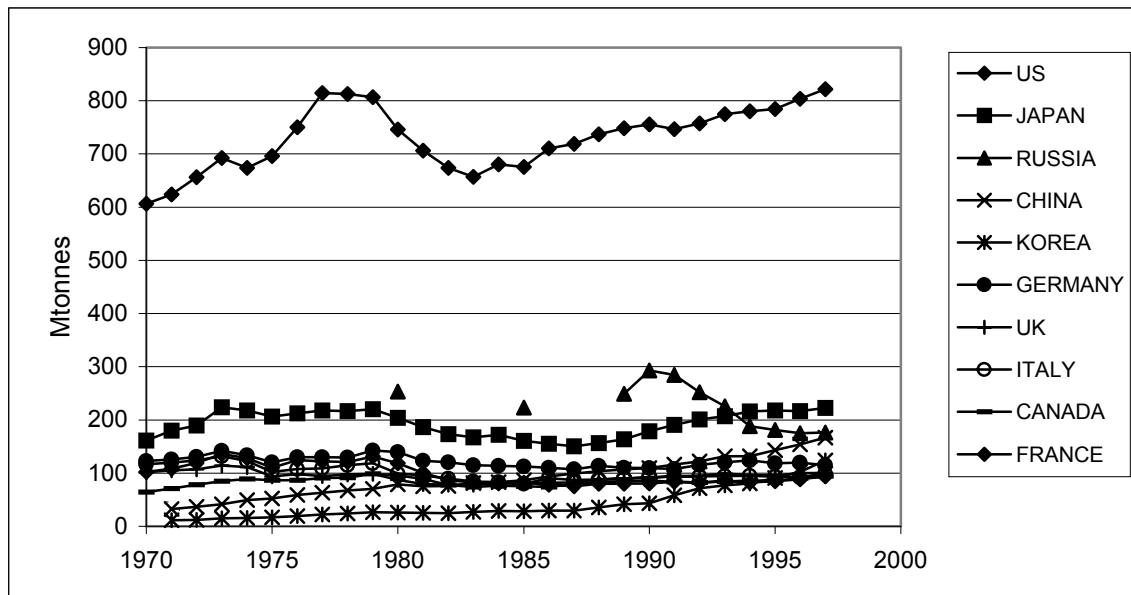
D. Petroleum Refining

Petroleum refining (ISIC 353) is the process of converting crude oil into a variety of usable petroleum products. Refining is a highly energy-intensive process using both purchased energy (gas, electricity) and refining by-products. It is estimated that energy consumption in refineries accounted for roughly 8% (12 EJ) of global industrial energy consumption in 1990.

1. Production

China is currently the fourth largest producer of petroleum products globally, with production of roughly 160 Mt in 1997 (see Figure 7). Given the increasing demand for petroleum products in China and the rapid expansion in refining output between 1971 and 1997 (an average growth of 6.5% per year in output), we can expect to see increasing growth in the production of this sector, especially given current plans by the government to upgrade and expand capacity. Refinery capacity and production of petroleum products is still dominated, however, by industrialized countries and the former USSR, with the U.S. Japan, and Russia producing roughly 35% of world total petroleum products output.

Figure 7. Production of Petroleum Products in the Top 10 Producing Countries, 1970-1997.



Source: INEDIS, 2000.

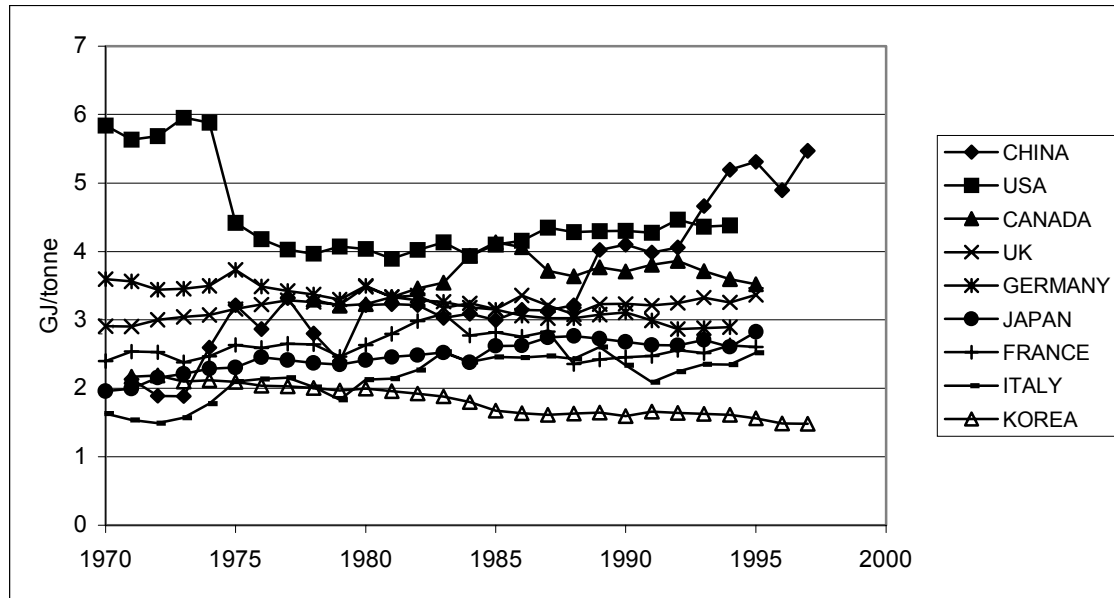
2. Energy Intensity

In 1997, China consumed 910 PJ of primary energy in the petroleum refining sector (IEA, 2000). Petroleum refining is a highly energy-intensive process, using 2 to 7 GJ/tonne of product produced. A standard complex refinery uses about 6 to 7% of intake crude (usually the gases) to process the balance of the crude into refined products while a hydrocracking based refinery can consume as much as 9% of the energy content of the intake fuel. The additional energy requirements are associated with hydrogen production and the production of a greater share of lighter distillates.

Figure 8 depicts primary energy intensities for petroleum refining between 1970 and 1997 based on data reported to the International Energy Agency (IEA, 2000). As the figure indicates,

intensities have remained relatively steady, or increased, for industrialized countries reflecting the counteracting trends between technology improvement and increasing refinery complexity. Data for China may need to be further analyzed as the significant rise in intensity since 1989 appears unusual. The data for Russia, Korea, and China may need further review.

Figure 8. Primary Energy Intensity for Petroleum Refining in Selected Countries, 1971-1994.



Source: IEA, 2000.

E. Chemicals: Ammonia

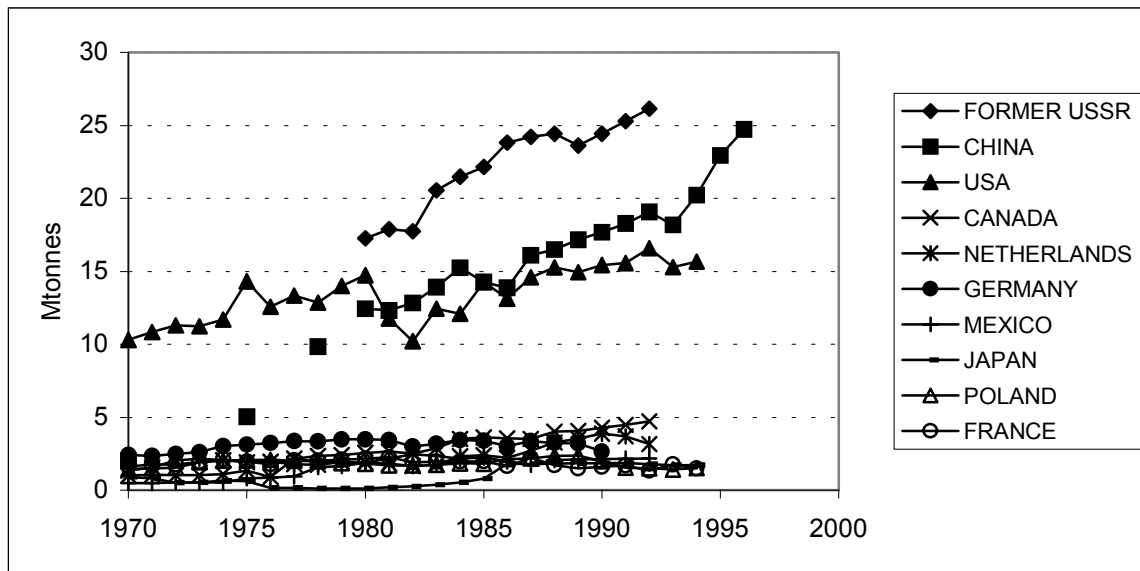
Ammonia (ISIC 351158) is the main intermediate product in the fertilizer industry. Nearly 85% of ammonia is used in the manufacture of fertilizer, although production of other applications (e.g. resins) is increasing. Current global ammonia production consumes approximately 2.6 EJ of primary energy. Per capita consumption of ammonia is stabilizing or declining in industrialized countries but growing in developing countries, reflecting the growth in fertilizer demand in these regions.

1. Production

Ammonia is produced in a large number of countries, but is concentrated in countries with access to fossil fuel (especially natural gas or coal) resources such as China, the U.S., Russia, Canada, and the European Union.

Figure 9 shows the production of total ammonia in the ten top ammonia-producing countries in the world between 1970 and 1996. In 1994 China was the largest producer of ammonia in the world, producing 20 Mt, followed by the U.S. and Canada with production levels of 15.7 Mt and 4.7 Mt, respectively. Ammonia production in China increased at an average rate of 10% per year between 1970 and 1996, hitting a high of 25 Mt in 1996. The largest growth in production and capacity has been in developing countries (particularly Asia) where production has grown at double world rates, which were about 4% per year. All planned new ammonia capacity in the near future is in developing countries while some revamping will take place in Eastern Europe (UN, 1994; Knott, 1995).

Figure 9. Ammonia Production in Selected Countries, 1970-1996.



Source: INEDIS, 2000; Sinton et al., 1996; UN, 1994 and 1996.

2. Energy Intensity

Steam reforming is the major ammonia-producing process accounting for about 80% of world capacity (90% in Western Europe) (Worrell and Blok, 1994; Chemical Intelligence Services, 1989). The theoretical minimum energy requirement to produce ammonia in the steam reforming of natural gas amounts to 19.1 GJ/tonne (Lower Heating Value, LHV), including feedstocks. Modern steam reforming plants consume 30 to 31 GJ/tonne, and recent estimates for energy use for ammonia production in Europe ranged from 33 to 44 GJ/tonne, depending on the country (Worrell et al., 1994a).

For developing countries, ammonia energy consumption and intensity can vary dramatically depending on the type of technology installed. In China, ammonia production is still dominated by small and medium-size plants, and unit energy consumption can run 20 to 25% higher than in plants of recent design. One study conducted by the government estimated that consumption per unit of output for small plants was more than 76% higher than large plants. These low efficiencies can also be partially attributed to the use of coal and coke as the primary feedstock for small ammonia production units as opposed to natural gas in large plants (Ishiguro and Akiyama, 1994). Table 4 lists physical energy intensity of ammonia production in China for small, medium, and large plants. As the table indicates, energy intensities for small and medium plants were on the order of 65% higher than those for large plants (Liu et al., 1994).

Table 4. Physical Energy Intensity of Ammonia Production in China, 1981-1990 (GJ/tonne).

Plant Size	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
small plants	85.26	78.23	72.98	69.73	69.19	68.27	71.20	70.91	68.57	65.92
medium plants	69.73	69.44	70.08	66.80	65.63	65.63	62.96	64.75	64.17	63.87
large plants	42.19	41.61	41.02	40.78	40.14	41.31	40.43	41.61	40.14	39.26

Source: Liu et al., 1994.

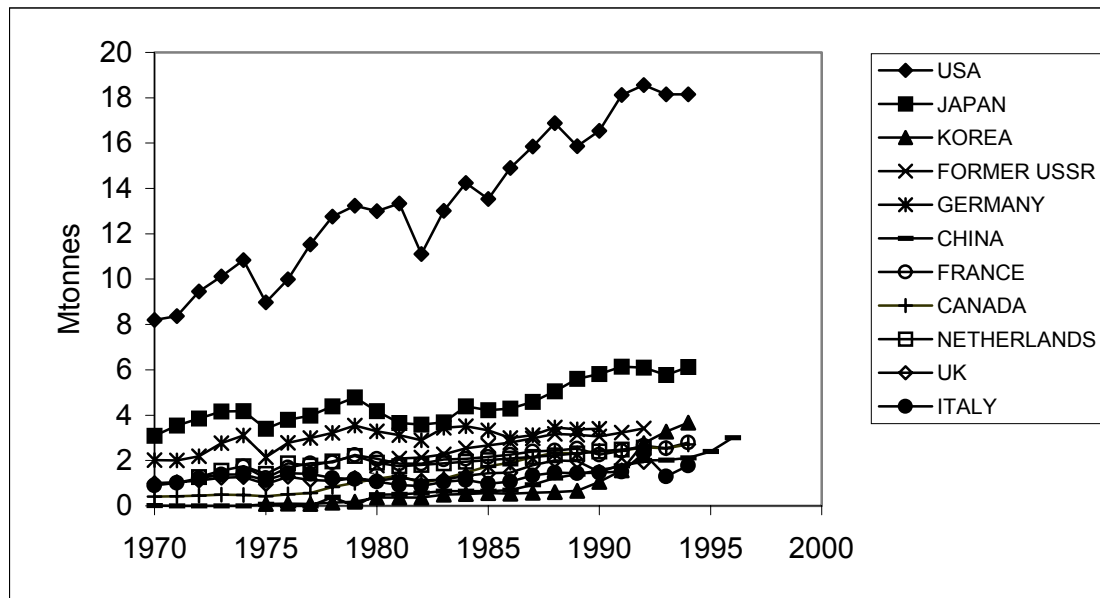
F. Chemicals: Ethylene

Ethylene (ISIC 351110) is the dominant petrochemical, accounting for about 30% of overall petrochemicals production because it is used in a wide variety of end-use applications. Nearly 75% of world production and capacity for ethylene is currently located in industrialized countries (Rhodes, 1994; UN, 1994). However, in recent years significant growth has occurred in developing countries, such as Saudi Arabia, Korea, China, and Brazil.

1. Production

Figure 10 shows the production of ethylene in the top ten ethylene-producing countries in the world from 1970 to 1996. In 1994 the top manufacturer of ethylene in the world was the U.S. (18.15 Mt). In 1994 China was the eighth largest but the fastest growing producer of ethylene. China experienced an annual average growth rate in production of almost 23% between 1970 and 1996, as production increased from 0.01 Mt in 1970 to over 3 Mt in 1996.

Figure 10. Ethylene Production in Selected Countries, 1970-1996.



Source: INEDIS, 2000; UN, 1994 and 1996.

2. Energy Intensity

The production of petrochemicals such as ethylene, propylene, and butadiene by steam cracking of hydrocarbon feedstocks is the single most energy-consuming process in the petrochemicals sector. The energy derived from feedstock is fuel for the cracking furnaces and steam generation for distillation. The ethylene yield depends strongly on the feedstock as does the energy use per tonne. For modern steam crackers the specific energy use per tonne of ethylene excluding feedstock energy varies between 13 GJ/tonne for ethane feedstock and 25 GJ/tonne for gas oil feedstock (Hydrocarbon Processing, 1995).

Including feedstock use, steam cracking plants in the U.S. consume about 68 GJ/tonne, of which a large part is feedstock (U.S. Congress, OTA, 1993). In the Netherlands the specific energy consumption for steam cracking of naphtha was estimated to be 58 GJ/tonne primary energy (including feedstocks) (Worrell et al., 1994b). Estimates for average intensities in China range

from 73 to 90 GJ/tonne using a relatively heavy feedstock mix (China Energy Research Society, 1993; Yang and Zeng, 1994).

For bulk polymers, which must undergo transformation processes that involve steam, heat, and pressure, gross energy requirements for modern plants have been estimated to be 69.8, 61.6, 81.5 and 55.7 GJ/tonne for polyethylene, polypropylene, polystyrene, and polyvinyl chloride respectively (Worrell et al., 1994b). This estimate includes the consumption of energy used to produce and transport the raw material feedstocks to the production complex.

III. Summary and Conclusions

This paper provides comparisons of industrial energy use in China with that of other countries that produce energy-intensive raw materials. The sectoral analysis results indicate that there have been significant improvements in energy efficiency in many industries in China over the last two to three decades. China's aluminum and petroleum refining sectors appear to be on par with many industrialized countries. We note, however, that in some of the energy-intensive sectors, energy requirements to produce a unit of raw material in China are still higher than in industrialized countries. Table 5 provides a brief summary of the results of the sectoral comparisons. As the table indicates, there is still potential to reduce existing average intensities in all of the sectors analyzed in China as well as in industrialized countries while striving toward energy intensity levels of the best practice plants operating today.

Table 5. Summary Comparison of Primary Energy Intensities Between China and Industrialized Countries for Selected Energy-Intensive Products.

Sector	Indicator	China	OECD Countries	Best Practice
Iron and Steel	GJ/tonne (crude steel)	36	18-26	16
Aluminum	MWh/tonne (prim. aluminum)	16.3	14.1-19.3	
Cement	GJ/tonne (cement)	5.6	3.7-4.4	3.4
Petroleum Refining	GJ/tonne (refined product)	3.5-5.0	2.9-5.0	1.3-3.8
Ammonia	GJ/tonne (ammonia)	39-65	33-44	19.1
Ethylene	GJ/tonne (ethylene incl. feedstock)	73-90	58-68	52

IV. Acknowledgments

Funding for this work was provided by the China Sustainable Energy Program of the Energy Foundation, and the Climate Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. We are deeply grateful to Hu Xiulian, Yang Hongwei, and Li Ji and (Energy Research Institute, State Development Planning Commission of China) for providing extensive data and explanatory documents regarding production and energy use in the Chinese industrial sectors. We would also like to thank Leticia Ozawa Meida (Instituto de Ingenieria, Universidad Nacional Autonoma de Mexico) for data and information on Mexico and Giovani Machado and Marcio de Costa (Federal University of Rio de Janeiro) for data and information on Brazil. We are also grateful for the assistance provided by many INEDIS network members, especially Dian Phylipsen, in collecting and organizing international data on energy use in the industrial sector.

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