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International Network for Energy Demand Analysis in the Industrial Sector

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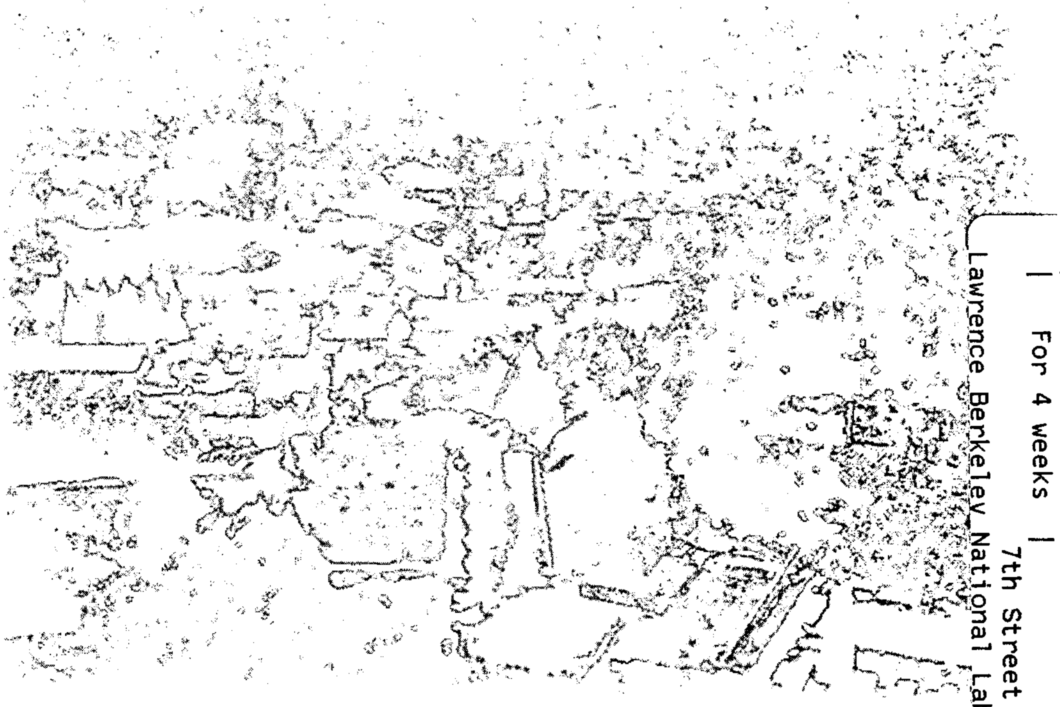

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International Network for Energy Demand Analysis in the Industrial Sector

I. Introduction

The motivation to develop an international network to collect and analyze the drivers of global industrial energy demand emerged from a joint study that Lawrence Berkeley National Laboratory and Utrecht University completed for the World Energy Council in 1995 (WEC, 1995). The study showed that while the industrial sector accounts for approximately 40% of global energy demand and carbon dioxide emissions, data relating to industrial energy use, output, processes, technologies, efficiency measures, and policies were often incomplete or non-existent.

In 1995, Lawrence Berkeley National Laboratory granted internal laboratory funds to staff of the Energy Analysis Department to expand the analysis of industrial energy use and efficiency in reducing energy use and associated greenhouse gas emissions. This funding supported the establishment of an international network of industrial sector experts, initiation of a comprehensive database on industrial energy use by key industrial subsectors, establishment of an industrial sector library, and development of a standard set of indicators and methodologies for international comparisons.

This project is based on the collaboration of an *active network of participating research institutions and organizations* involved in industrial energy demand analysis. This network, called the International Network for Energy Demand Analysis in the Industrial Sector (INEDIS), currently comprises researchers from about 20 international and national organizations and research institutes. The network held a workshop focusing on industrial sector energy efficiency policy experience in June 1998 (Martin et al., 1998).

Detailed data on industrial energy consumption are not readily available to the international research community. Such data are essential for an in-depth understanding of the driving forces of industrial energy use within countries. One of the primary tools that emerged from this project is a *comprehensive database of industrial energy demand statistics* for key industrialized and developing countries. Much of the sector-specific data in this database has been provided by members of the INEDIS network. This database is described in greater detail in this report.

In addition to the database, LBNL has established a library of articles and reports on industrial energy use, technologies, policies, greenhouse gas emissions, and other related issues. The library currently contains over 1500 articles and reports. LBNL maintains a bibliographic database of these documents that can be searched by author, title, and key words.

Establishing sound international comparisons of industrial energy consumption is becoming increasingly important as countries prepare for international agreements for reduction of greenhouse gas emissions. Members of the INEDIS network are actively involved in defining the methodology for making international comparisons in the industrial sector (Phylipsen et al., 1996; Phylipsen et al., 1998) and in using the data in the INEDIS database to analyze the data and methodologies (Worrell, et al., 1997a; Worrell et al., 1997b; Price et al., 1997; Ozawa et al., 1998; Phylipsen et al., 1999; Price et al., 1999a; Price et al., 1999b).

This report provides an overview of the INEDIS network in Section II. In section III, we describe the INEDIS database. We discuss the uses of some of the macroeconomic indicators we are developing in Section IV while Section V examines the use of sector specific indicators and section VI focuses on the use of carbon dioxide emissions indicators. The report appendices provide more detailed information on the specifics of our database use.

II. INEDIS Network

The International Network for Energy Demand Analysis in the Industrial Sector (INEDIS) is comprised of analysts from a variety of research institutions and organizations. The organizing members are Lawrence Berkeley National Laboratory (U.S), Utrecht University (The Netherlands), Fraunhofer Gesellschaft (Germany), Universidade de Coimbra (Portugal), and Lund University (Sweden). Table 1 provides information on the current members of the INEDIS network.

Network participants contribute to the project by compiling, exchanging, and analyzing data on all aspects of industrial energy use and efficiency. Members of this network have access to the data and the industrial library materials and participate in INEDIS workshops as well as collaborative industrial sector analysis efforts. We are actively seeking new network participants, especially for developing countries and countries with economies in transition.

Table 1. Current Members of the INEDIS Network.

Institution	**Country/Organization**
Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division	United States
Utrecht Univeristy, Department of Science, Technology and Society	The Netherlands
Universidade de Coimbra, Instituto de Sistemas e Robotica	Portugal
Fraunhofer Gesellschaft Institut für Systemtechnik and Innovationsforschung	Germany
Lund University, Department of Environmental and Energy Systems Studies	Sweden
Federal University of Rio de Janiero	Brazil
Canadian Industry Energy End-Use Data and Analysis Center	Canada
Department of Minerals and Energy	South Africa
Inha University	South Korea
Universidad Nacional Autonoma de Mexico (UNAM)	Mexico
Tata Energy Research Institute (TERI)	India
Institute for Energy Technology	Norway
ETH Zurich	Switzerland
Universidad Austral de Chile	Chile
AKF	Denmark
Polytechnic University Bucharest UNESCO Chair	Romania
Asia Pacific Energy Research Centre	Asia-Pacific Economic Cooperation
International Energy Agency	Organization for Economic Cooperation and Development
World Energy Efficiency Association	

III. INEDIS Database

Within the industrial sector a subset of industries exists in which the energy required to produce an additional unit of economic output is three to five times greater than the energy required for industry overall. In this subset of energy-intensive industries, raw materials are transformed or converted into intermediate and finished products, accounting for 60% to 80% of manufacturing energy use depending upon the country. Efficiency or technology improvements that can reduce energy demand in these key raw materials industries will play an important role in reducing overall global industrial energy demand.

The international energy demand database includes the data necessary to undertake international comparisons of energy efficiency in industry. We divide these data into two distinct groups: those that can be used for general comparisons of overall manufacturing energy demand among various countries, and those that can be used to focus on differences between specific industrial sub-sectors in various countries. Table 2 provides an overview of the data we collect. Currently, the INEDIS database contains data for the following industrial sectors: iron and steel, aluminum, cement, pulp and paper, petroleum refining, ammonia, and ethylene (see Appendix A for further details regarding the data collected in the specific sub-sectors; see Appendix B for a description of how to use the database).

Table 2. Data Collected by the INEDIS Network.

	Economic/Financial*	Physical Production and Technology	Energy Use and Carbon Emissions	Other
General: Country-specific	• Gross domestic product Exports -Imports • Consumption Manufacturing value added • Gross output • Manufacturing energy prices by fuel type		• Manufacturing energy consumption by fuel • Fuel inputs for electricity generation • Carbon emissions for electricity generation • Manufacturing carbon emissions	• Total population • Urban population Land area • Consumer price indices • Manufacturing price indices
Sector Specific (e.g. ISIC 371)	• Value added • Gross output • Exports-Imports (dollar basis), • Expenditure on factors of production (e.g. labor, materials, energy, capital)	• Production of intermediate and final products (e.g. pig iron and cold rolled steel) • Technology penetration (e.g. dry kiln share) • Exports -Imports (intermediate and final products)	• Sectoral energy consumption by fuel Sectoral carbon emissions	• Labor force

*Where appropriate, all economic data have been converted into 1990 dollars at purchasing power parity conversion rates.

The database contains information for 40 countries, including most countries in the Organization for Economic Cooperation and Development (OECD). These countries account for an estimated 90% of global industrial manufacturing value added. Our country selection was based on two criteria. First, we chose the top-10 producing countries for each sub-sector in the last year for which we have reliable data, usually 1994 or 1995. Second, we chose the top 10 countries in each sub-sector in terms of growth in production[1]. For these countries we also established a minimum production level to ensure selection of both high growth and relatively high production countries. Using these criteria, we have chosen the countries listed in Table 3 to be included in the database. We do not collect data on all sub-sectors for each country, but rather collect data only for those sub-sectors for which the country qualifies as either a top-10 producer or top-10 growth country (see Appendix A). We do, however, collect general data for all countries so as to enable some general international comparisons. All data are referenced in Appendix C.

[1] The selection of countries varies by subsector. See Appendix A for further detail.

Table 3. Countries Included in the International Database on Industrial Energy Demand

Australia (AUS)	Germany (DEU)	Malaysia (MAY)	South Africa (SAP0
Austria (AUT)	Greece (GRE)	Mexico (MEX)	Former Soviet Union (FSU)
Brazil (BRA)	India (IND)	Netherlands (NLD)	Spain (ESP)
Canada (CAN)	Indonesia (INS)	Norway (NOR)	Sweden (SWE)
Chile (CHI)	Iran (IRA)	Philippines (PHI)	Taiwan (TAI)
China (CHN)	Iraq (IRQ)	Poland (POL)	Thailand (THA)
Czech Republic (CZE)	Italy (ITA)	Portugal (POR)	Turkey (TUR)
Egypt (EGY)	Japan (JPN)	Romania (ROM)	United Kingdom (GBR)
France (FRA)	Korea (S) (SKO)	Saudi Arabia (SAR)	United States (USA)
Finland (FIN)	Korea (N) (NKO)	Singapore (SIN)	Venezuela (VEN)

IV. General Indicators

In addition to collecting sector specific industrial data, we are collecting more general economic and energy use information for each country as well. These general indicators help to explain the broad macroeconomic context for industrial energy efficiency changes. For example, they show whether an economy has been growing or contracting, how important trade is as a component of economic growth, or whether a country faces a higher fuel price regime relative to other countries. We normalize the economic indicators to one currency unit (using purchasing power parities) to ensure a more consistent comparison basis.

Table 4 lists some of the key general indicators that are calculated in the database for country specific analysis and country and regional energy demand forecasting.

Table 4. Key General Indicators in the INEDIS Database.

Indicators	Units
Manufacturing economic intensity	megajoule / $US manufacturing GDP
Sectoral exports / total exports	percent
Share of sectoral gross output in total manufacturing gross output	percent
Share of sectoral value added in total manufacturing value added	percent
Carbon intensity of electricity generation	g carbon / kWh
Carbon emissions/sector output	tonnes carbon / tonne output
Specific energy consumption by sector	gigajoule / tonne
Divisia disaggregation of structural and efficiency contributions to changes in energy intensity	percent
Share of expenditures on factors of production by sector	percent
R&D expenditures/unit sales (or gross output)	percent
Share of energy consumption in energy intensive sectors from total manufacturing energy consumption	percent
Capacity utilization by sector	percent
Technical potential to achieve best practice energy use	percent
Aggregation of energy consumption by sector and/or region	petajoule

Figure 1 provides an example of the use of these general indicators, depicting gross domestic product (GDP) per capita for selected countries in the database in purchasing power parity (PPP) converted to 1990 U.S. dollars.

As Figure 1 shows, GDP per capita levels are still significantly higher for fully industrialized countries (U.S., Japan, Canada, France, Germany, U.K.). Average GDP per capita for the OECD countries in Figure 1 increased from roughly $10,000 per capita in 1970 to about $16,000 per capita in 1995, showing a steady average growth of around 2% per year. GDP levels rose more dramatically in some of the rapidly industrializing economies, most notably South Korea's growth of 7.2% per year since 1970. GDP per capita in the former Soviet Union, in contrast, decreased rapidly since the early 1990s, falling 13% per year between 1990 and 1995.

Figure 1. Gross Domestic Product per Capita ('000 1990 US$/Capita) for Selected Countries: 1970-1995.

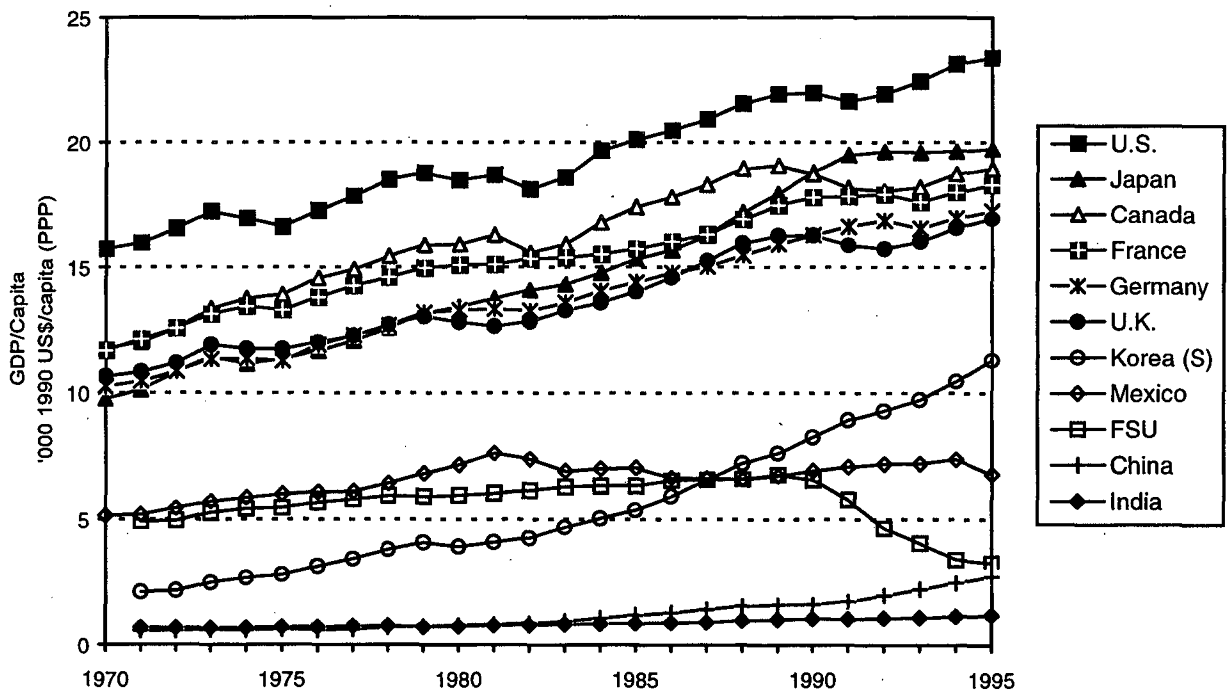


Figure 2 shows electricity prices for the industrial sector for selected countries in the database, mainly industrialized economies. As the figure shows, electricity prices have generally averaged about two times higher in Japan than in the U.S. and most European countries since the early 1980s. The historical dips and hikes in electricity prices due primarily to the oil shocks of the mid-1970s and early 1980s are apparent. Government policy also differentiates prices across consumer types. Industrial electricity prices vary widely between countries in this graph, reflecting the diverse sources used to generate power. Norway generates substantial amounts of relatively inexpensive hydropower, while Japan relies on imported fossil fuel and nuclear power to generate electricity. Overall, there has been a general downward trend in prices since the early to mid-1980s for most countries in the figure.

Figure 2. Industrial Electricity Prices (1990 US$/GJ) for Selected Countries: 1970-1995.

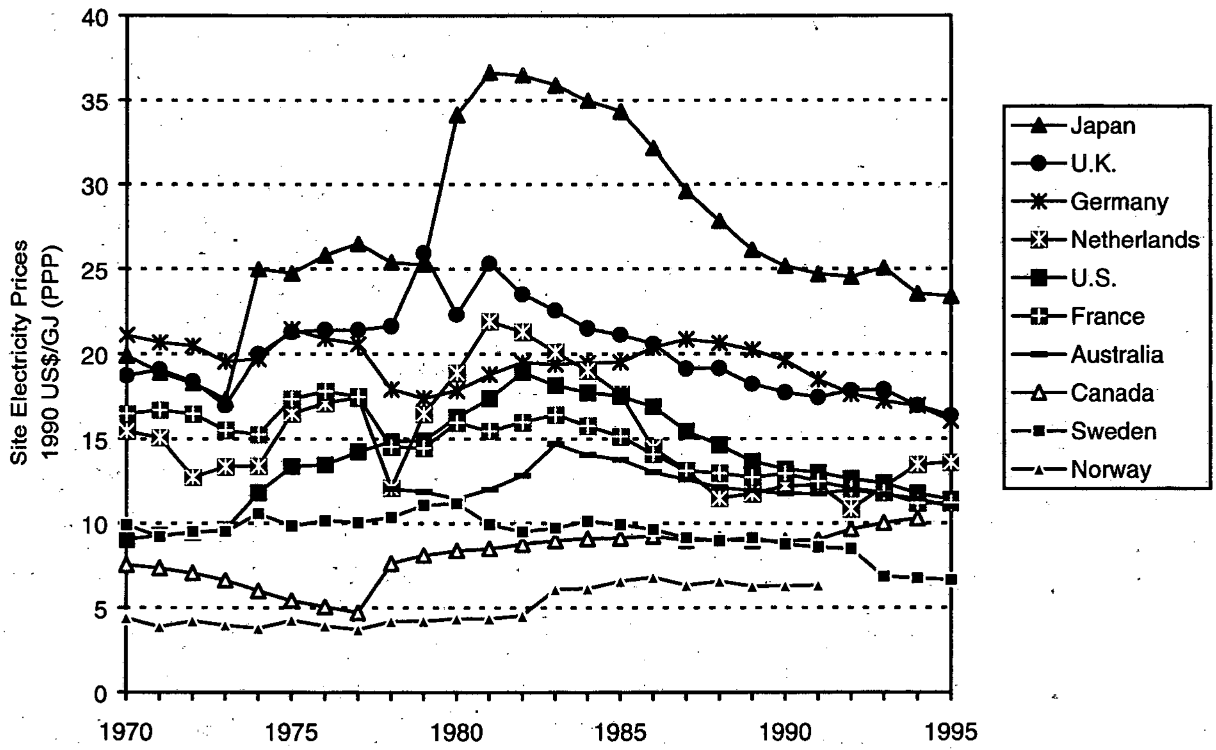


Figure 3 plots primary energy consumption in the manufacturing sector for 10 countries[2]. The U.S., China, and the former Soviet Union consume the greatest amounts of manufacturing energy, each between 15 and 20 EJ per year. The top three are followed by Japan and India's consumption of about 6 EJ per year. The highest current growth rates are found in the manufacturing sectors of southeast Asian countries. Table 3 shows the growth in manufacturing energy use for all the countries in the database.[3]

[2] A conversion factor of 33% is used for converting final to primary electricity. Actual conversion factors vary across countries. Feedstocks are not included in energy consumption unless stated. Data is presented as reported.

[3] The former Soviet Union is a group of countries which are no longer part of the Soviet Union, yet are still aggregated for the purposes of this database to keep time series comparisons valid.

Figure 3. Manufacturing Primary Energy Consumption (EJ) for Selected Countries: 1970-1994.

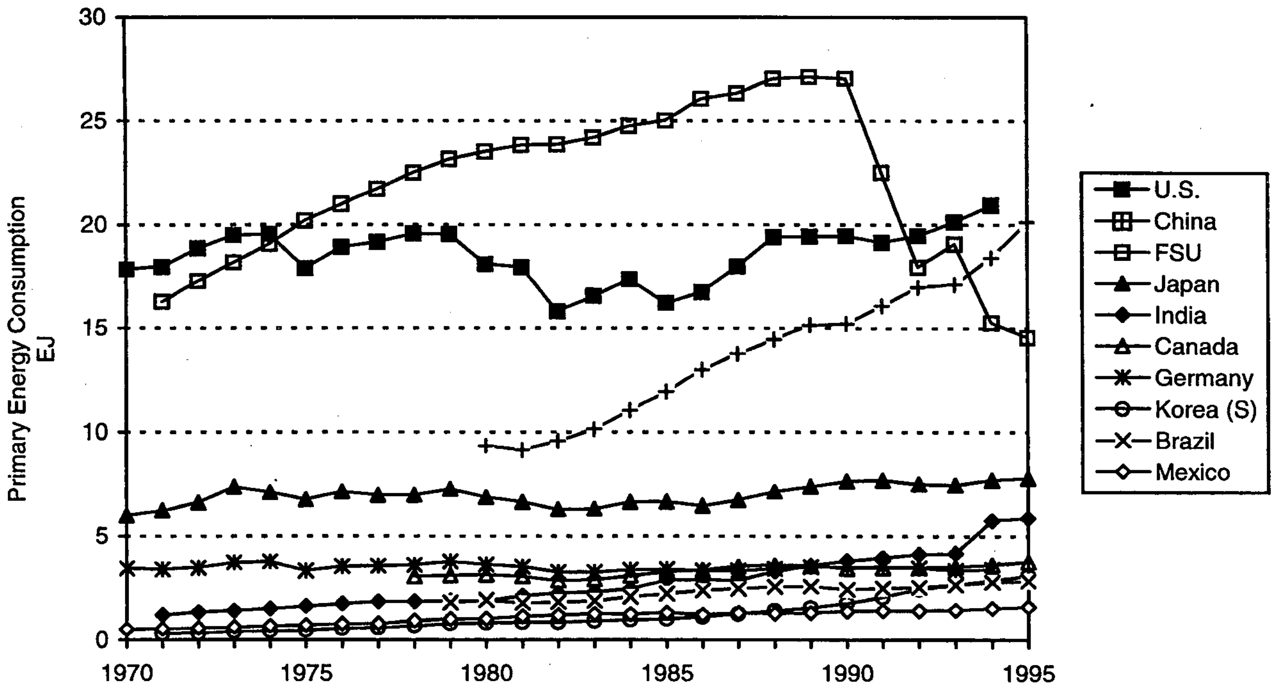


Table 5. Manufacturing Energy Consumption Average Annual Growth Rates: 1971-1994.

COUNTRY/REGION	Growth Rate	COUNTRY/REGION	Growth Rate
AUSTRALIA	2.3%	MEXICO	4.8%
AUSTRIA	0.9%	NETHERLANDS	1.7%
CANADA	1.0%	NORWAY	0.9%
FINLAND	2.4%	PORTUGAL	4.0%
FRANCE	-0.5%	SPAIN	1.8%
GERMANY	0.0%	SWEDEN	0.4%
GREECE	2.7%	TURKEY	6.9%
ITALY	0.8%	UNITED KINGDOM	-1.3%
JAPAN	0.9%	UNITED STATES	0.7%
SOUTH KOREA	10.5%		
INDUSTRIALIZED COUNTRIES	**1.2%**		
BRAZIL	2.7%	MALAYSIA	7.3%
CHILE	4.2%	PHILIPPINES	4.1%
CHINA	14.2%	SAUDI ARABIA	8.0%
EGYPT	6.6%	SINGAPORE	10.1%
INDIA	7.0%	SOUTH AFRICA	1.8%
INDONESIA	10.9%	TAIWAN	7.6%
IRAN	3.6%	THAILAND	10.0%
IRAQ	8.1%	VENEZUELA	4.1%
NORTH KOREA	-1.5%		
DEVELOPING COUNTRIES	**8.4%**		
POLAND	-0.4%	ROMANIA	-0.8%
FORMER USSR	-0.3%		
EASTERN EUROPE/FORMER SOVIET UNION	**-0.3%**		
DATABASE TOTAL	**2.2%**		

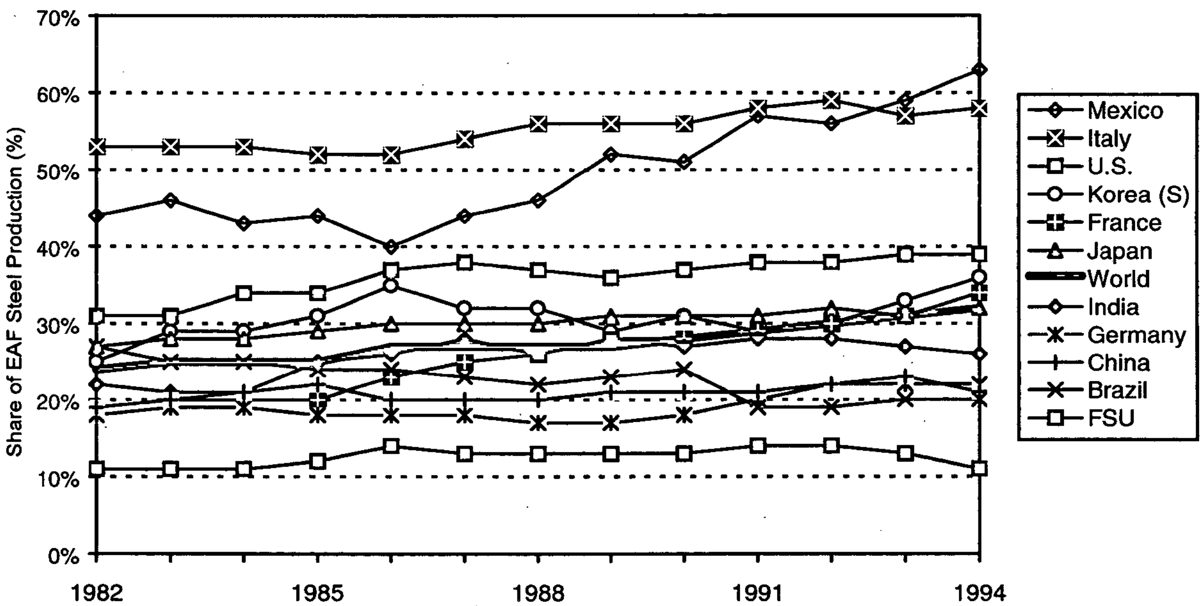
V. Sector Specific Analyses

The INEDIS database can also be used for specific industrial sub-sectoral analysis. Appendix A provides details regarding the detailed data collected for each sub-sector. The database allows comparisons of the rates of introduction of new production processes and techniques as well as the levels of production over time. Additionally, the data can be used to make detailed comparisons of changes in energy intensity over time, or to compare a country's energy consumption to energy consumption levels using a best practice plant. Analytical techniques can be used to decompose changes in energy intensity over time into structural shifts (e.g. changes in production mix) and efficiency changes (e.g. new technologies). The database also includes sub-sectoral economic data for analysis of economic changes occurring in a particular sector, such as changes in the factor costs and expenditures or improvements in the trade balance for a sector's products.

As an example of process change, Figure 4 shows the share of secondary (electric arc furnace) steel produced in selected countries, as well as the world average. Electric arc furnace steel consumes only about one-fourth as much energy as integrated steel production. Therefore, a country with a high share of EAF steel production will tend to have a lower average energy intensity than a country with a high share of integrated steel production. It is important to note, however, that both direct reduced iron (DRI) and scrap steel are used as feedstocks for EAF production. DRI needs to be manufactured, and thus requires a greater energy input than the use of scrap steel, which can be directly input to the EAF process. Thus, countries with a ready supply of scrap steel can more fully utilize the benefits of EAF production. However, EAF steel cannot be used for all steel products.

Most OECD countries produce between 30 and 40 percent EAF steel, comparable to the 1994 world average of 32%. Use of EAF production has increased steadily in most OECD countries, with Mexico increasing from 40% EAF production in the early 1980s to around 60% in 1995. The US has increased EAF production by about 8% since 1982, from 31 to 39 percent. There has been a global increase in EAF production as well, with the share of EAF steel increasing from roughly 25 to 35 percent of total steel since 1982. Many countries with developing steel production capabilities produce EAF steel more or less exclusively.

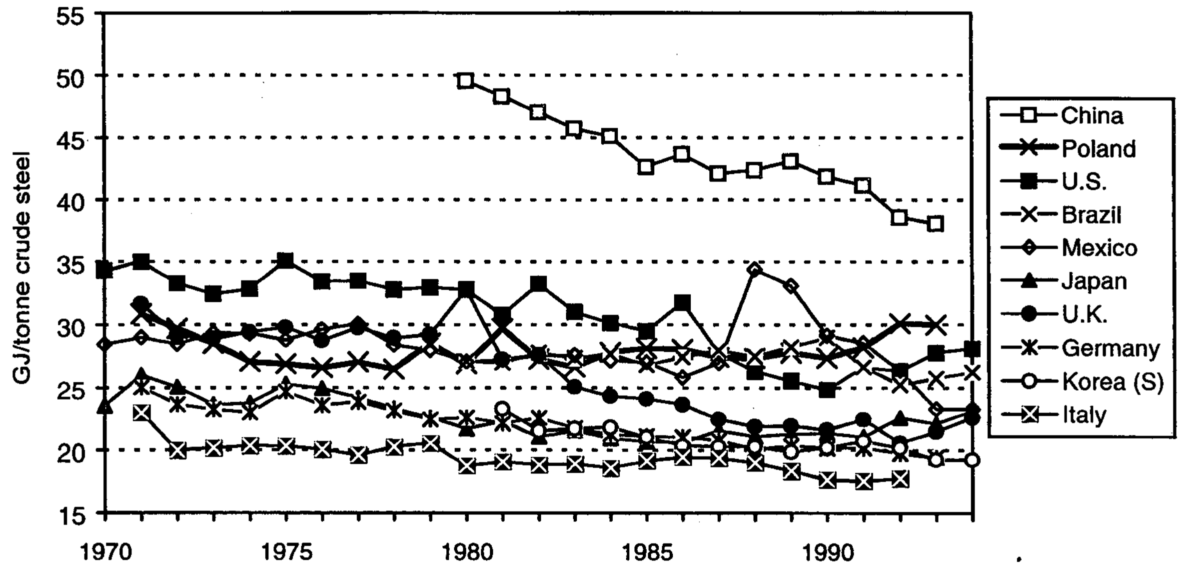
Figure 4. Share of EAF Steel Production to Total Steel Production (%) for Selected Countries and the World Average: 1982-1995.



A direct measure of energy efficiency improvement in industrial sectors is often difficult. Energy intensity represents the amount of energy required to produce a unit of product. In analyses of energy intensity in heavy industry, output indicators in physical units, as opposed to monetary units, tend to more accurately represent actual changes in the sector (Worrell et al., 1997a; Phylipsen et al., 1998).

Figure 5 shows primary energy intensity for crude steel production for selected countries in the database. Primary energy reflects the total amount of energy inputs required including the fuel inputs for electricity generation. As the figure indicates, primary energy intensity has decreased over time on average by 0.5% per year since 1970 for the countries studied. This decline is due to a combination of improved energy efficiency and structural changes toward the use of less energy-intensive processes.

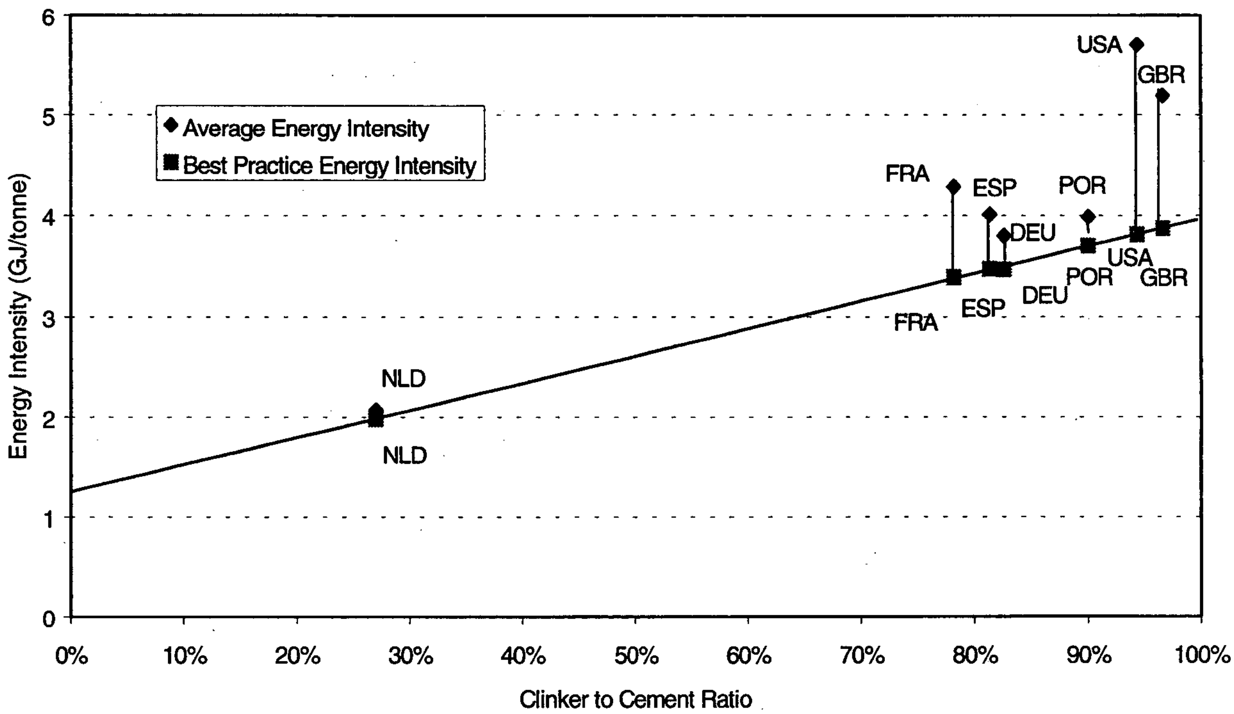
Figure 5. Primary Energy Intensity of Crude Steel Production (GJ/t) for Selected Countries: 1970-1994.



Best practice comparisons can be used to account for structural differences between countries. These types of comparisons require more data than energy intensity comparisons and show a country's energy use for a specific year compared to a reference energy consumption of a best practice plant (Worrell, 1994; Phylipsen et al., 1998).

Figure 6 shows a comparison of average to best practice energy consumption for selected countries in our database. Because clinker production is the most energy-intensive step in cement production, the share of clinker to total cement is used as the key structural indicator to normalize the international comparison. In other words, a country with a high share of clinker to cement is not necessarily inefficient; however, the country's average primary energy intensity will tend to be higher than a country with a low clinker to cement ratio. As the figure indicates, the potential for technical energy efficiency improvement is much greater for countries such as the United States or the United Kingdom as compared to France, Germany, or Spain.

Figure 6. Cement Best Practice Comparison (GJ/t) for Selected Countries: 1988/1989.

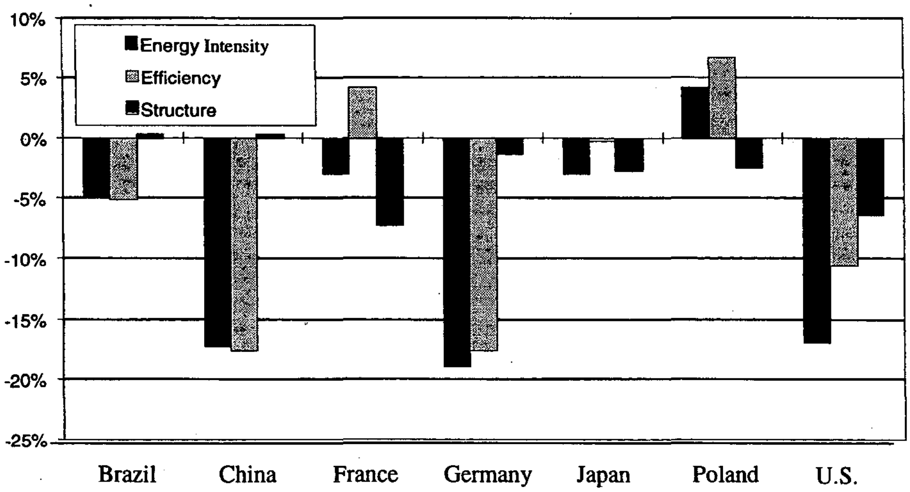


Accounting for the impact of sectoral structure and efficiency changes can be done using Laspeyres or Divisia decomposition methods. These methods decompose changes in overall intensity in a sector into the effect of efficiency versus structure. In the case of iron and steel production, for example, we represent the overall reduction in energy intensity as a product of changes in energy efficiency (e.g. new and better process technology) and changes in the structure of the sector (e.g. more EAF steel, a different product mix). Mathematically this can be shown as:

$$\Sigma E = \Sigma P * PPI/\Sigma P * \Sigma E/PPI$$

where ΣE denotes the change in energy intensity over the period, ΣP is the production of steel products, $PPI/\Sigma P$ reflects structure, and $\Sigma E/PPI$ reflects energy efficiency (Worrell et al., 1997). The results of a decomposition analysis using the database for the iron and steel sector are shown in Figure 7. In Brazil, China, and Germany, virtually all improvements in energy intensity were due to changes in energy efficiency of process equipment. In the Unites States, however, roughly two-thirds of energy intensity improvements were attributable to the improved efficiency of new technologies, while the remaining third were due to structural changes in the U.S. steel industry. The U.S. increased production of EAF steel between 1980 and 1991 (Fig. 7).

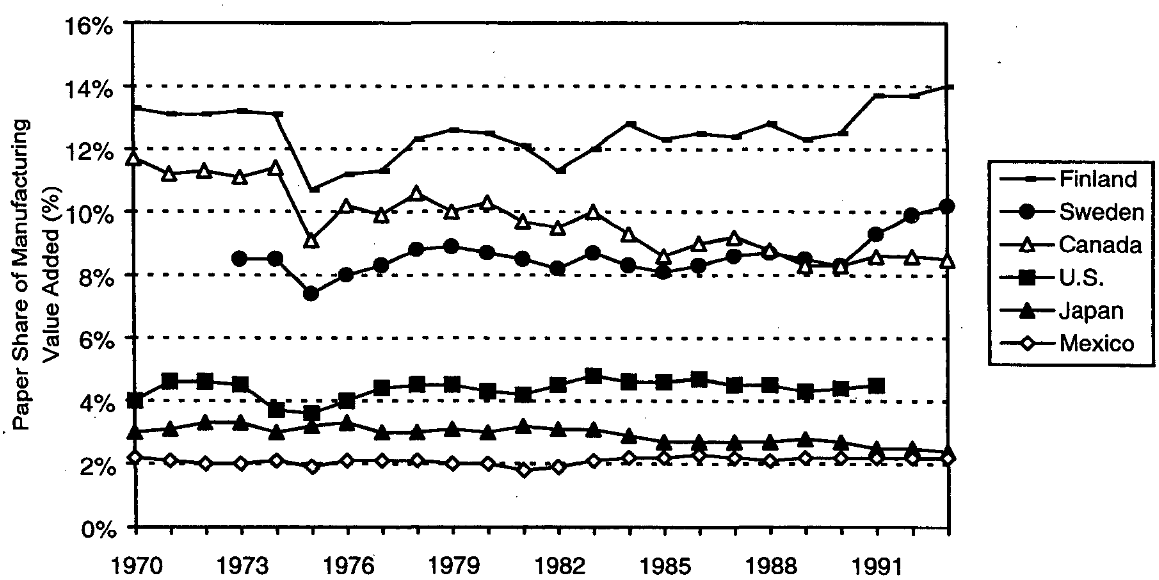
Figure 7. Relative Changes in Energy Intensity and the Contribution of Structure and Efficiency Changes (%) for Selected Countries, 1980-1991.



Source: Worrell et al., 1997.

In addition to detailed sectoral energy efficiency data, the database includes a variety of sectoral economic data to provide a better context for understanding changes in a particular sector. Sector specific economic information aids in understanding the factors driving the markets for the production of energy-intensive products. Figure 8 compares the share of value added from the pulp and paper sector to total manufacturing value added, providing an indication of the relative economic importance of this sector. Finland, Sweden, and Canada's paper production makes up about 10% of each country's national manufacturing value added total, or roughly 10% of industrial production. Conversely, the paper industry in Japan, the U.S., and Mexico averages only 3% per year of total manufacturing value added.

Figure 8. Pulp and Paper Sector Value Added as a Share of Total Manufacturing Value Added (%) for Selected Countries: 1970-1993.

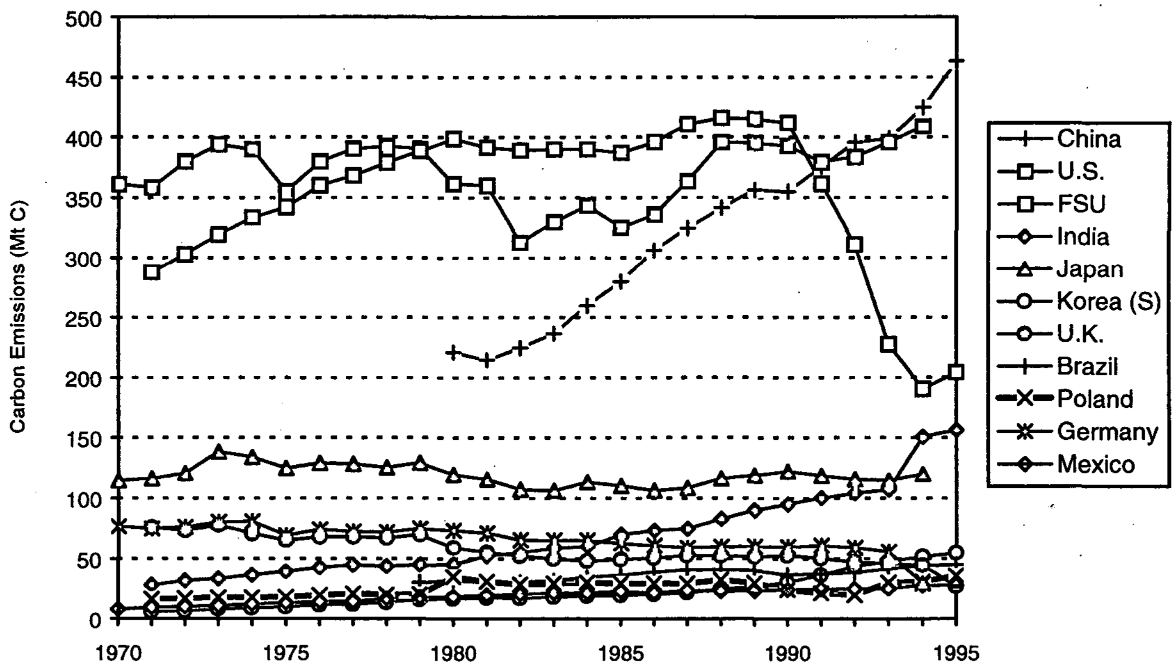


VI. Carbon Dioxide Emissions from Industry

Our database has been set up to calculate carbon dioxide emissions (in million tonnes of carbon) from energy use. We use the emission factors established by the Intergovernmental Panel on Climate Change (IPCC, 19XX). Providing reliable information on carbon emissions from energy use is increasingly important given international concern about global warming. The database can be used to calculate carbon emissions from energy for total manufacturing as well as for specific sectors.

Figure 9 shows total manufacturing carbon dioxide emissions from energy use for selected countries in our database[4]. As expected, the three dominant manufacturing energy-consuming countries are also the manufacturing carbon emissions leaders. The U.S., China, and the former Soviet Union accounted for about 57% of manufacturing carbon emissions in 1990. The total emissions for database countries has increased by roughly 0.6% per year since 1980, with substantial yearly increases seen in South Korea (8.5%), India (7%) and China (4.5%). The U.S. (0.5%) and Japan (0.2%) have kept emissions levels relatively constant, while Germany (-4%) and the UK (-2%) have decreased carbon emissions, through fuel shifts and reduced industrial energy use.

Figure 9. Manufacturing Carbon Dioxide Emissions (Mt C) for Selected Countries: 1970-1995.



The nature of a country's electricity sector also affects its total carbon dioxide emissions. A country that produces electricity chiefly from renewable sources such as hydropower (e.g. Norway) will have relatively low emissions per kWh of electricity produced. However, a country whose electricity generation is fossil fuel based will have much higher emissions for the same kWh produced. Figure 10 shows carbon intensities (ktC/PJ) for electricity production for several countries in our database. Depending on the fuel mix, intensities can vary by a factor of 3, as shown in Figure 10.

[4] Self-generated and purchased electricity are both accounted for. Purchased electricity is assigned a carbon factor, as are the fuels used to generate electricity on-site.

Carbon dioxide emissions from the chemicals sector for the leading petrochemical-producing countries are shown in figure 11. As the figure indicates, the largest chemicals producers--the U.S., Germany, and the former Soviet Union--account for about 65% of the total carbon emissions for the 20 database countries. Emissions have increased for the group on average by about 1.5%/year. The U.S. and Japan have maintained almost constant emissions since 1971, U.S. emissions increasing by about 1% per year, Japan's decreasing by 1% per year. More dramatic fluctuations are evident in Germany and South Korea, where Germany has managed to decrease emissions by about 4.5% per year, while South Korea's emissions have increased at a remarkable 15% per year.

Figure 10. Carbon Intensity of Electricity Production (Kt C/PJ) for Selected Countries: 1971-1995.

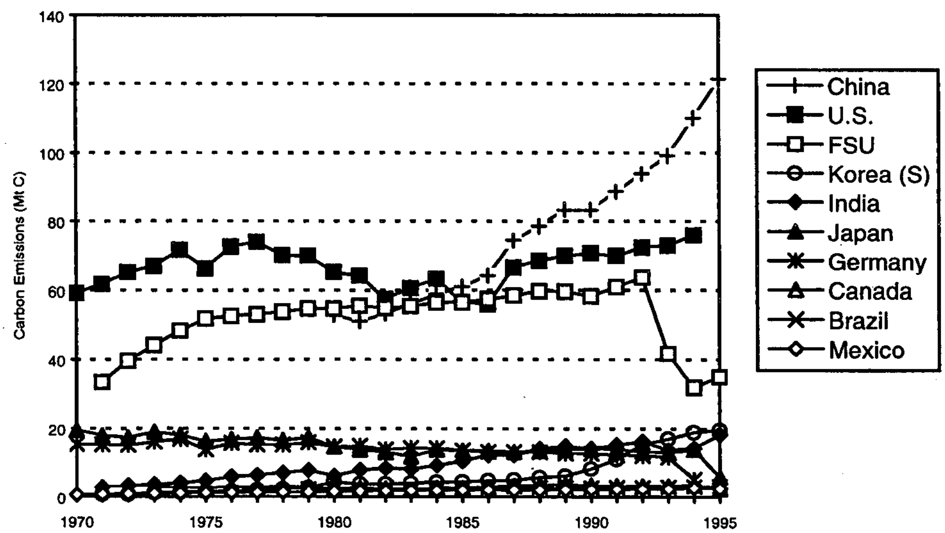
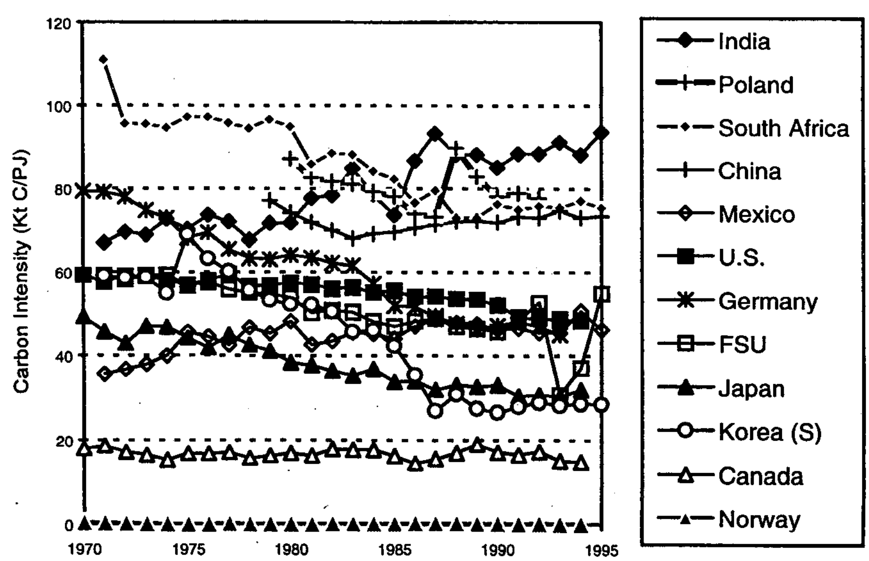


Figure 11. Carbon Emissions from Energy Use in the Chemical Industry (Mt C) for Selected Countries: 1970-1995.



Appendix A. INEDIS Sector-Specific Data Collection

Iron and Steel

Background

The basic metals sector produces a wide variety of metals, including iron and steel (and alloys) and non-ferrous metals like aluminium, zinc, copper and lead. We concentrate on the iron and steel industry and the aluminium industry because these are responsible for the largest part of the production and energy consumption in this sector. The metals industry consumes nearly 25-30 EJ (1990) primary energy.

Iron and Steel

The iron and steel industry consumes approximately 19 EJ or 10-15% of global industrial energy use. Steel is used for a wide variety of applications. Per capita consumption is now stabilizing or declining in the industrialized countries, but strongly growing in developing countries. Steel production is largely concentrated in a few countries, e.g. Japan, United States, China, Russia, and the EU.

Table A-1. Crude Steel Production Levels (Million Tonnes) and Average Annual Growth Rates (percent) for the Top 10 Producing and Top 10 Growth Countries

Country	1982	1993	AAGR (1982-1993)
Japan	99.5	99.6	0.0
former USSR	147.2	95.7	-3.8
China	37.1	89.4	8.3
United States	67.7	87.0	2.3
Germany	35.9	37.6	0.4
South Korea	11.8	33.0	9.8
Italy	24.0	25.7	0.7
Brazil	13.0	25.2	6.2
India	11.0	18.6	4.8
France	18.4	17.1	-0.7
Saudi Arabia	0.3	2.4	20.8
Iran	0.6	3.7	18.0
Indonesia	0.7	3.8	14.1
Turkey	3.2	11.4	12.2
Taiwan	4.2	11.9	9.9
Egypt	1.1	2.8	8.9
Venezuela	2.2	3.4	4.0
Netherlands	4.4	6.0	2.9
Mexico	7.1	9.0	2.2
UK	13.7	16.7	1.8
Canada	11.9	14.4	1.8
World	**645.0**	**725.3**	**1.1**

International Iron and Steel Institute, annual. *Steel Statistical Yearbook.* Brussels, Belgium: IISI.

Sector and Process Definitions

To ensure consistency and comparability of results from the network, we have chosen to define the coverage of the iron and steel industry and aluminium industry according to the international standard industrial classification (ISIC) system. According to this classification, iron and steel industry falls within the three digit ISIC code 371. The products can be further subdivided to iron and various steel products (including pipes). The figure on the next page identifies the main processes and product-types in the iron and steel industry. This industry includes ore agglomeration (on site, e.g. sintering and pelletizing), production of iron (pig iron from blast furnaces, DRI/HBI from direct reduction and others like iron carbide), the production of steel (open hearth, basic oxygen, electric arc and others like energy optimizing furnace) and the casting (ingots and slabs), shaping and finishing stages.

Figure A-1. Flow Diagram of Iron and Steel Production Process Routes

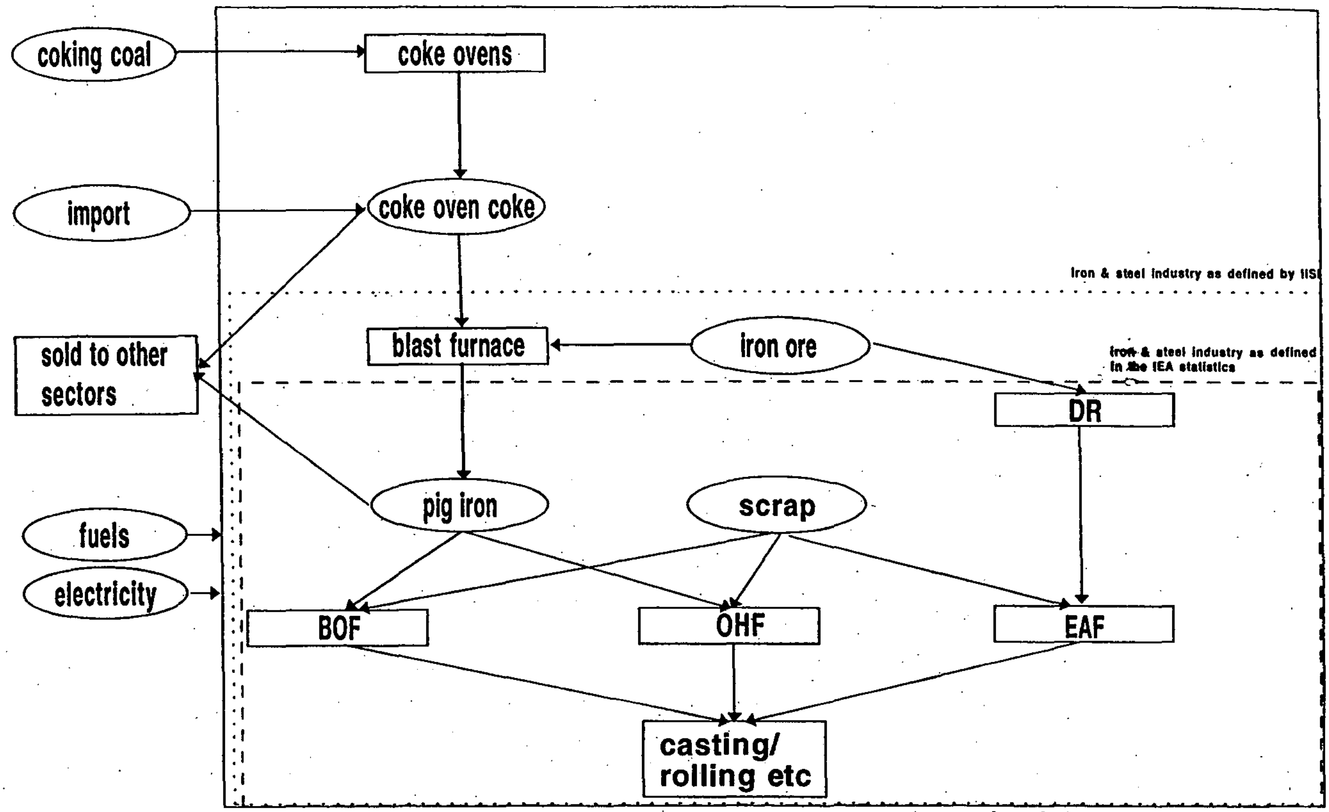


Table A-2. Iron and Steel Data (ISIC 371)

CATEGORY	UNITS	CATEGORY	UNITS
IRON AND STEEL (ISIC 371)			
PHYSICAL DATA		ECONOMIC DATA	
Output		Iron & Steel deflator	1990=100
Ore Agglomeration		Iron & Steel Labor Force	10^3 pers
Sinter	Mtonne	Sales of Iron and Steel products	currency
Pellets	Mtonne	**Output**	
Total Ore	Mtonne	Gross output total steel production	currency
Coke Making		Value added total steel production	currency
Coke production	Mtonne	**Expenditures**	
Iron Making		Energy	currency
Pig Iron (blast furnaces, Corex)	Mtonne	Labor	currency
DRI/HBI (direct reduction)	Mtonne	Gross Capital Formation	currency
Others (iron carbide)	Mtonne	Total operating Expenditures	currency
Total iron	Mtonne	Research and development expenditures	currency
Steelmaking		**Exports and Imports**	
Open hearth furnace output	Mtonne	Agglomerated Ore exports	Mtonne
Basic Oxygen Furnace output	Mtonne	Agglomerated Ore imports	Mtonne
Electric arc furnace output	Mtonne	Agglomerated Ore exports	currency
Other	Mtonne	Agglomerated Ore imports	currency
Total steel	Mtonne	Coke exports	Mtonne
Casting		Coke imports	Mtonne
Continuous casting (including strip casting)	Mtonne	Coke exports	currency
Ingot casting	Mtonne	Coke imports	currency
Shaping		Iron exports	Mtonne
Hot rolling (plate, strip, profiles)	Mtonne	Iron imports	Mtonne
Cold rolling (sheets)	Mtonne	Iron exports	currency
Wire	Mtonne	Iron imports	currency
Others	Mtonne	Steel exports	Mtonne
Total shaped steel products	Mtonne	Steel imports	Mtonne
Technologies		Steel exports	currency
Share of ladle treatment steel	Mtonne	Steel imports	currency
[Technology 2]	Mtonne	Scrap exports	Mtonne
[Technology 3]	Mtonne	Scrap imports	Mtonne
Structural Data		Scrap exports	currency
Number of Plants: Integrated (Prim.)	Mtonne/yr	Scrap imports	currency
Number of Plants: Other (Scnd.)	Mtonne/yr		
Total capacity of integrated plants	Mtonne/yr		
Total capacity of other plants	Mtonne/yr		
Average age of BF plants	Years		
Average age of EAF plants	Years		
Material losses (total crude steel -sum of all products)	%		
Scrap input primary steelmaking	%		
Purchased sinter	Mtonne		
Purchased pellets	Mtonne		

Aluminium

Background
The basic metals sector produces a wide variety of metals, including iron and steel (and alloys) and non-ferrous metals like aluminium, zinc, copper and lead. We concentrate on the iron and steel industry and the aluminium industry because these are responsible for the largest part of the production and energy consumption in this sector. The metals industry consumes nearly 25-30 EJ (1990) energy, expressed as primary fuels.

Aluminium
Aluminium is the second largest produced metal, expressed in volume, with an estimated global production volume of 20.5 Mtonnes (1994). Aluminium is one of the most abundant materials but the reduction of aluminium is very electricity intensive and production is concentrated in countries or areas with inexpensive electricity sources. The total primary energy consumption for aluminium production (including alumina production) is estimated at 3-4 EJ. Aluminium demand and per capita consumption is still growing worldwide.

Table A-3. Crude Aluminium Production (Million Tonnes) and Average Annual Growth Rates (percent) for the Top 10 Producing and Top 10 Growth Countries

Country	1985	1994	AAGR (1985-1994)
USA	5.3	5.8	1.1
former-SU	1.1	2.8 (1990)	0.7
Canada	1.0	2.3	6.3
Australia	0.2	1.4	5.8
Brazil	0.0	1.3	8.9
Japan	1.0	1.2	1.1
China	0.1	1.5	15.5
Norway	0.5	0.9	2.3
Germany (E&W)	0.4	0.7	3.0
Venezuela	0.0	0.6	17.0
New Zealand	0.0 (1971)	0.3	13.1
South Africa	0.0 (1971)	0.2	9.2
Netherlands	0.1	0.4	7.9
Egypt	0.0 (1976)	0.1	6.0
India	0.1	0.5	5.6
Mexico	0.0	0.1	5.6
Spain	0.2	0.5	4.8
Greece	0.1	0.1	3.2
Italy	0.3	0.6	3.1
Romania	0.1	0.2	2.4
Austria	0.1	0.2	2.2
Ghana	0.1	0.2	2.1
World	**11.3**	**20.1**	**2.8**

UN Statistical Yearbook, UN Industrial Commodity Statistics Yearbook: Production and Consumption Statistics, 1996

Sector and Process Definitions
The aluminium industry falls under the five digit ISIC code 37202, and includes alumina production as well as aluminium production (including alloys). The aluminium industry includes the Bayer process to produce alumina from bauxite, the primary smelting of aluminium by electrolysis (Hall-Heroult process), the secondary melting and refining of aluminium, and the casting (ingots). Shaping of aluminium most often occurs outside the basic aluminium industry, however care should be taken with the analysis, as national sector classifications are not always completely equivalent to the ISIC. We exclude the shaping (other than ingots in the primary and secondary aluminium industry and direct castings in the secondary steel industry) from the basic aluminium industry. The figure on the next page shows the process routes and system boundaries in aluminum production.

Figure A-2. Flow Diagram of Aluminum Production Process Routes

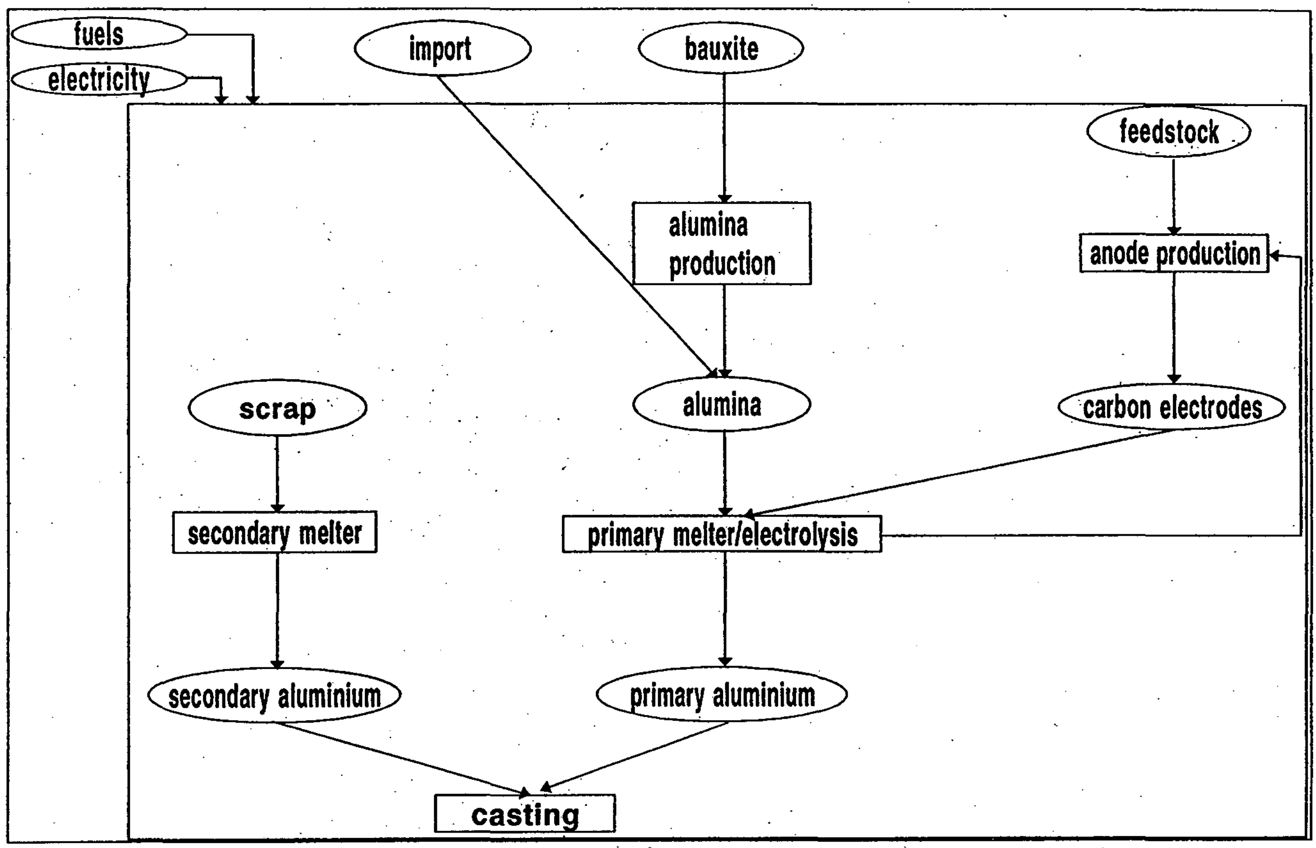


Table A-4. Aluminum and Non-Ferrous Metals Data (ISIC 372/372022)

CATEGORY	UNITS	CATEGORY	UNITS
ALUMINUM (ISIC 372022)		NON-FERROUS METALS (ISIC 372)	
PHYSICAL DATA		PHYSICAL DATA	
Output		**Output**	
Alumina production		Zinc (ISIC 372043-046)	Mtonne
Alumina production	Mtonne	Lead (ISIC 372037)	Mtonne
Electrode Production (if part of aluminium industry)	Mtonne	Copper (ISIC 37200)	Mtonne
Soderberg (in-situ)	Mtonne	Tin (ISIC 372049)	Mtonne
Pre-baked anodes	Mtonne	ECONOMIC DATA	
Aluminum Making		**Output**	
Primary Smelting: Hall-Heroult	Mtonne	Gross output total non-ferrous metals production	Currency
Primary Smelting: Soderberg	Mtonne	Value added total non-ferrous metals production	currency
Secondary smelting (refining)	Mtonne	Non-ferrous metals Deflator	1990=100
Total Aluminum Production	Mtonne	Non-ferrous metals Labor Force	10^3 pers
Casting (ingot, direct castings)	Mtonne	Sales of Non-ferrous metals Prod.	currency
Fabrication of semis	Mtonne		
Technologies			
Technology 1	Mtonne		
Technology 2	Mtonne		
Structural Data			
Number of plants: Primary			
Number of plants: Second.			
Total capacity: Primary	Mtonne		
Total capacity: Secondary	Mtonne		
Average age of plant: Prim.	Yrs		
Average age of plant: Sec.	Yrs		
Aluminum Labor Force	10^3 pers		
Output			
Gross output total aluminium production	currency		
Value added total aluminium production	currency		
Expenditures			
Energy	currency		
Labor	currency		
Gross Capital Formation	currency		
Total operating expenditures	currency		
Research & Development Expenditures	currency		
Exports and Imports			
Aluminium exports	Mtonne		
Aluminium imports	Mtonne		
Aluminium exports	currency		
Aluminium imports	currency		
Alumina exports	Mtonne		
Alumina imports	Mtonne		
Alumina exports	currency		
Alumina imports	currency		

Cement

Background

The processes used to produce building materials (cement, glass, bricks and tiles, ceramics, etc.) use significant amounts of energy. This workplan focuses on cement production which is by far the largest energy-consuming commodity in the subsector. Cement production accounted for an estimated 2% of annual world primary energy, or 148 Mtoe (6.2 EJ) in 1992. The cement industry accounts for about 1 to 6% of total commercial energy consumption in most countries.

The table below provides cement production levels and average annual growth rates for the top 20 cement producing countries and the world between 1970 and 1994. During this period, world cement production more than doubled. China alone produces one-third of the world's cement and is by far the world's largest producer. Worldwide, cement production increased an average of 3.6% annually between 1970 and 1994.

Table A-5. Cement Production Levels (Million Tonnes) and Average Annual Growth Rates (percent) for the Top 10 Producing and Top 10 Growth Countries

Country	1970	1994	AAGR (1970-1994)
China	10	421	12.4
Japan	57	92	2.0
United States	68	79	0.7
India	14	60	6.3
Korea (S)	6	51	9.5
Germany (1970 = W. Germany)	38	40	0.2
Russia (1970 = USSR)	95	37	-4.3
Italy	33	33	0.0
Mexico	7	30	6.0
Turkey	6	29	6.6
Indonesia	0.5	19	16.2
Saudi Arabia	0.7	16	14.2
Thailand	3	28	10.4
Malaysia	1	10	10.0
Iraq	1.5	15	9.9
Iran	2.6	16	7.9
Egypt	4	16	6.3
Korea (N)	4	17	6.2
Brazil	9	25	4.4
Greece	5	13	4.1
World	**579**	**1348**	**3.6**

Source: United Nations, annual. *U.N. Statistical Annual.* New York: United Nations; U.S. Geological Service website, http//minerals.er.usgs.gov/minerals/pubs/commodity/cement.

Sector and Process Definitions

To ensure consistency and comparability of results from the network, we have chosen to define the coverage of the building materials sector according to the international standard industrial classification (ISIC) system. Building materials fall under ISIC code 36 (Stone, Clay, and Glass). Cement production is defined as ISIC code 369204. We include energy use for raw material preparation at the cement or clinker production site (e.g. breaking, grinding), for production of clinker, for mixing, and for finish grinding in the analysis. Mining, raw material preparation at the mining site, and transporting raw materials is not included (see figure on next page). Limestone is crushed and mixed with other constituents to produce the raw meal. The raw meal is burnt in a kiln, where the material is calcined and fused into pellets called clinker. The clinker is then ground and mixed with additives to produce various types of cement, varying in the clinker content. Clinker manufacture is the most energy intensive production step. Grinding and drying of additives (e.g. blast furnace slags) are included in the cement industry.

Figure A-3. Flow Diagram of Cement Production Process Routes

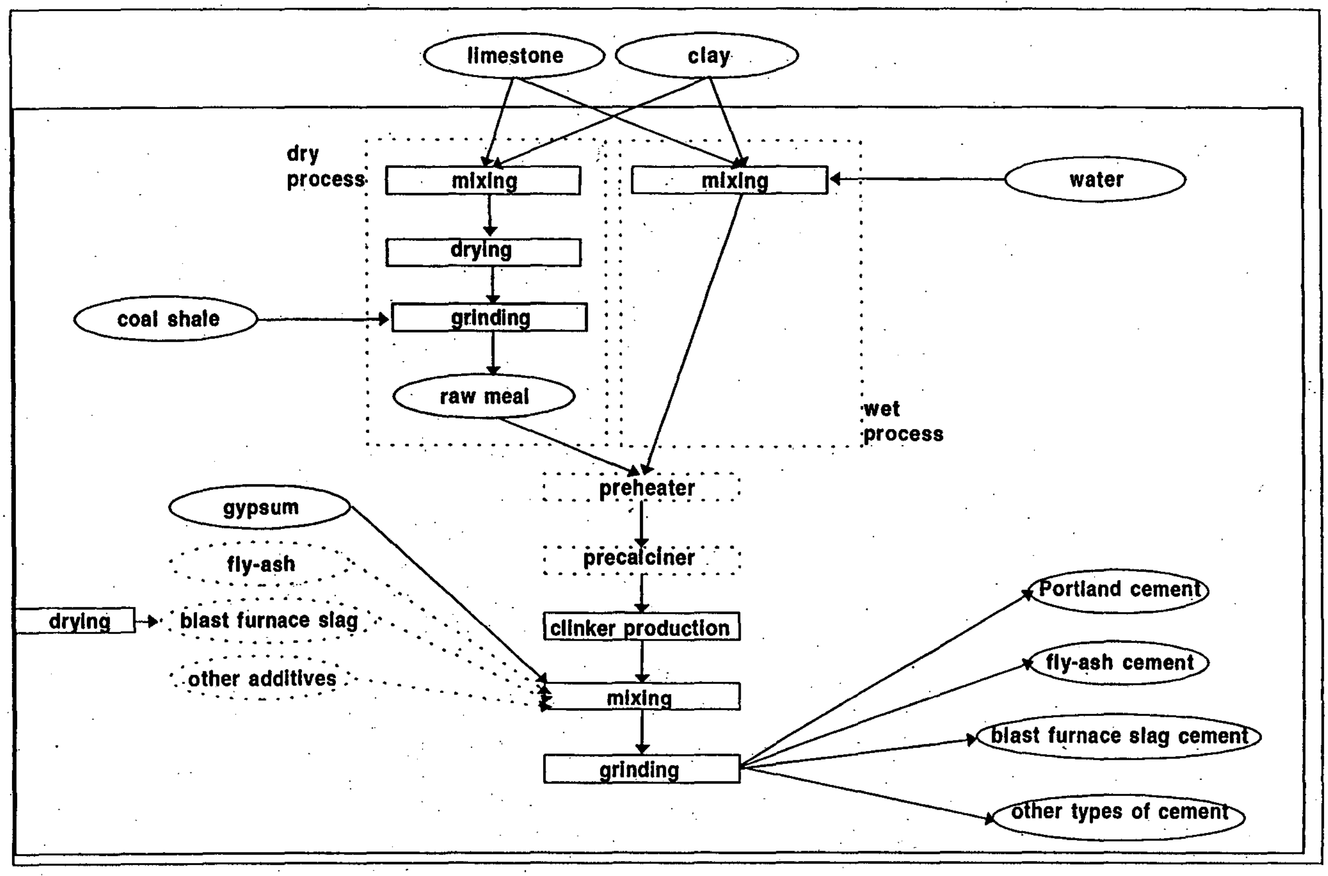


Table A-6. Cement and Building Materials Data (ISIC 369/3692)

CATEGORY	UNITS	CATEGORY	UNITS
CEMENT (ISIC 3692)		BUILDING MATERIALS (ISIC 36)	
PHYSICAL DATA		PHYSICAL PRODUCTION	
Output		**Output**	
Clinker	Mtonne	Bricks and tiles (ISIC 3691)	Mtonne
Portland Cement	Mtonne	Lime (ISIC 369201)	Mtonne
Blast furnace slag cement	Mtonne	Glass (ISIC 3620)	Mtonne
Fly ash cement	Mtonne	Ceramic (ISIC 3610)	Mtonne
Other cement types (Incl. white cem.)	Mtonne		
Cement total	Mtonne	ECONOMIC DATA	
Technologies		**Output**	
Wet cement production (rotary)	Mtonne	Gross output total building materials production	currency
Dry cement production (rotary)	Mtonne	Value added total building materials production	currency
Cement production (shaft)	Mtonne	Building Materials Deflator	1990=100
Installed capcity of dry kilns with multi stage preheaters	Mtonne	Building Materials Labor Force	10^3 pers
Installed capacity of dry kilns with precalcinaters	Mtonne	Sales of Building Materials Prod.	currency
Structural Data			
Consumption of limestone in cement production	Mtonne		
Consumption of blast furnace slag in cement production	Mtonne		
Consumption of coal fly-ash in cement production	Mtonne		
Consumption of natural pozzolanes in cement production	Mtonne		
Consumption of other materials in cement production (e.g. gypsum)	Mtonne		
Total consumption of materials	Mtonne		
Number of clinker plants			
Number of cement plants			
Total capacity of of clinker production	Mtonne/yr		
Total capacity of cement production	Mtonne/yr		
Average age of clinker kiln	Years		
ECONOMIC DATA			
Cement Labor Force	10^3 pers		
Output			
Gross output total cement production	currency		
Value added total cement production	currency		
Expenditures			
Energy	currency		
Labor	currency		
Gross Capital Formation	currency		
Total operating expenditures	currency		
Research and development expenditures	currency		
Exports and Imports			
Cement exports	Mtonne		
Cement imports	Mtonne		
Cement exports	currency		
Cement imports	currency		
Clinker exports	Mtonne		
Clinker imports	Mtonne		
Clinker exports	currency		
Clinker imports	currency		

Pulp and Paper

Background

The process of pulp production and papermaking uses significant amounts of energy (20-30 GJ/tonne of product). Our current estimates suggest that the pulp and paper sector consumed about 7% of global industrial purchased energy in 1990 (5.7 EJ). If one were to include the use of biomass fuels, energy use would be much greater. And unlike other raw materials sectors such as steel and cement which have experienced a drop in per-capita consumption in industrialized countries, the per-capita demand for paper products continues to increase in both industrialized and developing countries at a significant rate (2-5% annually).

The table below provides pulp and paperboard production levels and average annual growth rates for the top 20 paper and paperboard producing countries and the world between 1970 and 1995. While over 60% of the world's production is concentrated in five countries, growth has been highest in many Asian countries including Indonesia, Thailand, S. Korea, and China.

Table A-7. Paper and Paperboard Production Levels (Million Tonnes) and Average Annual Growth Rates (percent) for the Top 10 Producing and Top 10 Growth Countries

Country	1970	1995	AAGR (1970-1995)
United States	45.8	89.3	2.7
Japan	13.0	29.7	3.4
China	3.0	28.2	9.4
Canada	11.3	18.7	2.1
Germany (1970 = W. Germany)	6.7	14.8	3.3
Finland	4.3	10.9	3.8
Sweden	4.4	9.2	3.0
France	4.1	8.6	3.0
Korea (S)	0.3	6.9	12.9
Italy	3.5	6.8	2.6
Indonesia	0.0	3.9	23.7
Thailand	0.7	2.0	14.2
Brazil	1.1	5.9	6.9
Austria	1.0	3.6	5.2
Mexico	0.9	3.0	5.0
South Africa	0.6	1.9	4.6
Spain	1.3	3.7	4.3
Australia	1.1	2.2	3.0
Netherlands	1.6	3.0	2.5
Norway	1.4	2.3	1.9
World	**128.7**	**285.6**	**3.2**

Source: United Nations, Food and Agriculture Organization, annual. *Yearbook of Forest Products*, Rome: United Nations Food and Agriculture Organization, FAO Forestry Series. Pulp & Paper International, 1995. *North American Pulp and Paper Fact Book*, J. C. Riley, Stacy; Tsai, Karen, San Francisco: Miller Freeman, Inc.

Sector and Process Definitions

To ensure consistency and comparability of results from the network, we have chosen to define the coverage of the pulp and paper sector according to the international standard industrial classification (ISIC) system. According to this classification, pulp and paper products fall within the three digit ISIC code of 341. These products are then further subdivided according to intermediate pulp products versus finished paper products as well as according to the type of process (e.g. thermomechanical pulp versus chemical pulp). Energy used for transport of wood from the logging site to the pulp production site, for collecting and transporting waste paper, and for transporting pulp from the pulp production site to the paper production site are not included. The figure on the next page shows the process routes in pulp and paper production.

Figure A-4. Flow Diagram of Pulp and Paper Production Process Routes

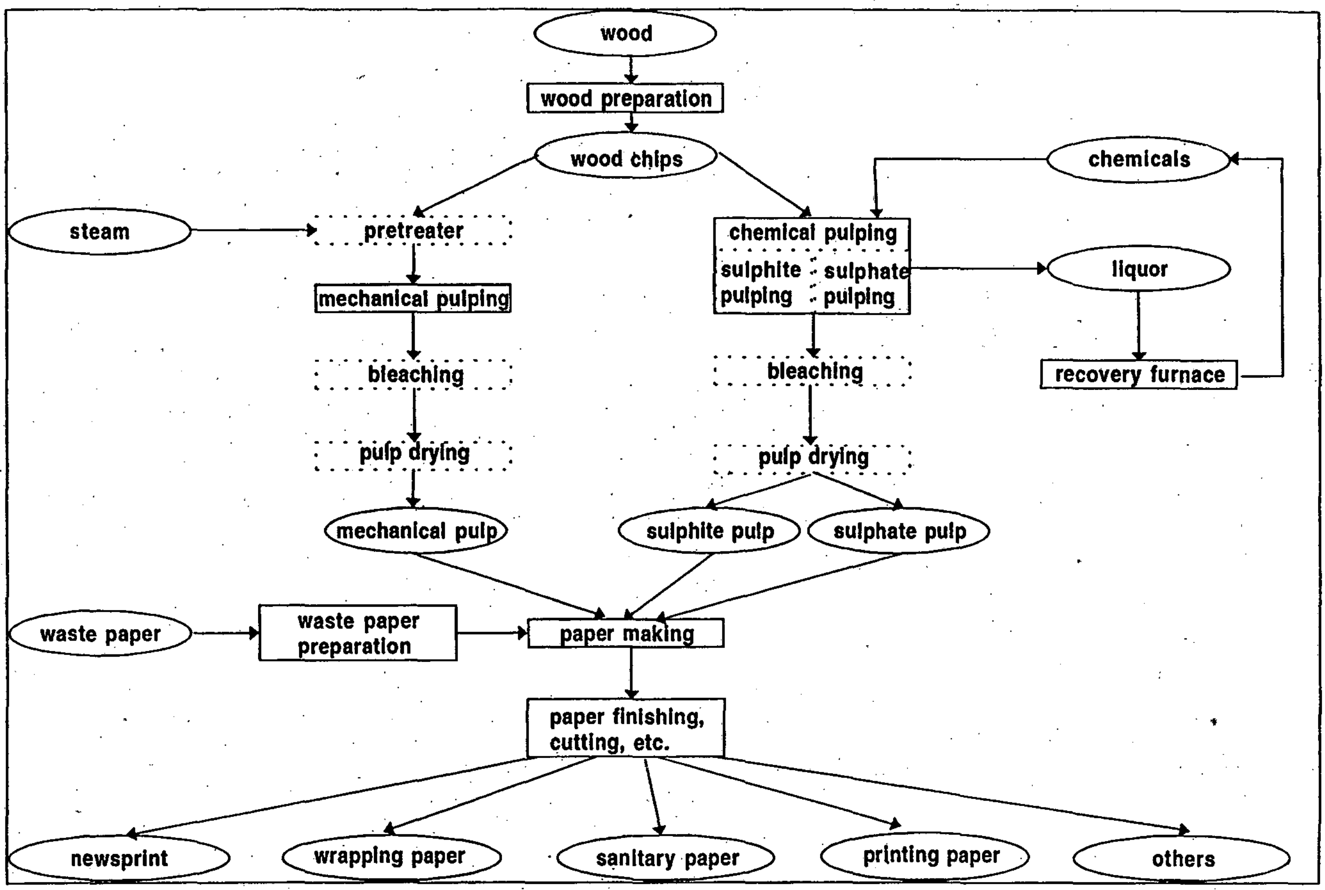


Table A-8. Pulp and Paper Data (ISIC 341)

CATEGORY	UNITS	CATEGORY	UNITS
PULP AND PAPER (ISC 341)			
ECONOMIC DATA		PHYSICAL DATA	
Pulp & Paper deflator	1990=100	**Output**	
Pulp & Paper Labor Force	10^3 pers	**Pulp**	
Sales of Pulp & Paper Products	currency	*Mechanical pulp*	
Output		Mechanical pulp - groundwood	Mtonne
Pulp		Mechanical pulp - thermomechanical	Mtonne
Gross output pulp production	currency	Mechanical pulp - total	Mtonne
Value added total pulp production	currency	*Chemical pulp*	
Paper		Sulphate pulp - bleached	Mtonne
Gross output total paper	currency	Sulphate pulp - unbleached	Mtonne
Value added total paper	currency	Sulphite pulp - bleached	Mtonne
Total		Sulphite pulp - unbleached	Mtonne
Total gross output paper and pulp production	1e9 Current US$	Other chemcial pulp	Mtonne
Total value added paper and pulp production	1e9 1990 US$	Chemical pulp total	Mtonne
Expenditures		*Other pulp*	
Energy	currency	Other pulp	Mtonne
Labor	1e9 Current US$	**Paper**	
Gross Capital Formation	1e9 Current US$	Newsprint	Mtonne
Total operating expenditures	currency	Printing and writing paper	Mtonne
Research and development expenditures	currency	Wrapping and packaging	Mtonne
Exports and Imports		Sanitary and household	Mtonne
Mechanical pulp exports	Mtonne	Other paper and paperboard	Mtonne
Chemical pulp exports	Mtonne	Total paper	Mtonne
Total pulp exports	Mtonne	**Technologies**	
Mechanical pulp imports	Mtonne	Share of biomass waste in cogeneration/electricity production	Mtonne
Chemical pulp imports	Mtonne	Share of Long Nip press in papermaking	Mtonne
Total pulp imports	Mtonne	Technology 3	Mtonne
Paper Exports	Mtonne	**Structural Data**	
Paper Imports	Mtonne	Number of integrated mills	
Mechanical pulp exports	1e9 1990 US$	Number of paper-only mills	
Chemical pulp exports	1e9 1990 US$	Average capacity of integrated mills	Mtonne/yr
Total pulp exports	1e9 1990 US$	Average capacity of paper-only mills	Mtonne/yr
Mechanical pulp imports	1e9 1990 US$	Average age of paper machines	Years
Chemical pulp imports	1e9 1990 US$	Use of wastepaper in paper production	Mtonne
Total pulp imports	1e9 1990 US$	of which Post Consumer Waste	%
Paper Exports	1e9 1990 US$	Use of Virgin pulp in paper production	Mtonne
Paper Imports	1e9 1990 US$		

Petroleum Refining

Background

Petroleum refining, the process of converting crude oil into a variety of usable petroleum products, is a highly energy-intensive process (3-6 GJ/tonne of product) with energy consumption in refineries accounting for roughly 8% (12 EJ) of global industrial energy consumption in 1990. The sector is also economically significant.

Although developing countries account for a significant portion of world oil production, refining capacity is concentrated in EE/FSU and OECD countries, which account for over 60% of the total output (Table 1). However, capacity expansion (and hence the opportunity to improve refining energy efficiency) has occurred most rapidly in developing countries, especially in Asia (China, Korea, Indonesia, India), and the Middle East (Iran, Saudi Arabia) where rapid increases in product demand have occurred.

Table A-9. Output of Refined Petroleum Products (Thousand Tonnes) and Average Annual Growth Rates (percent) for the Top 10 Producing and Top 10 Growth Countries

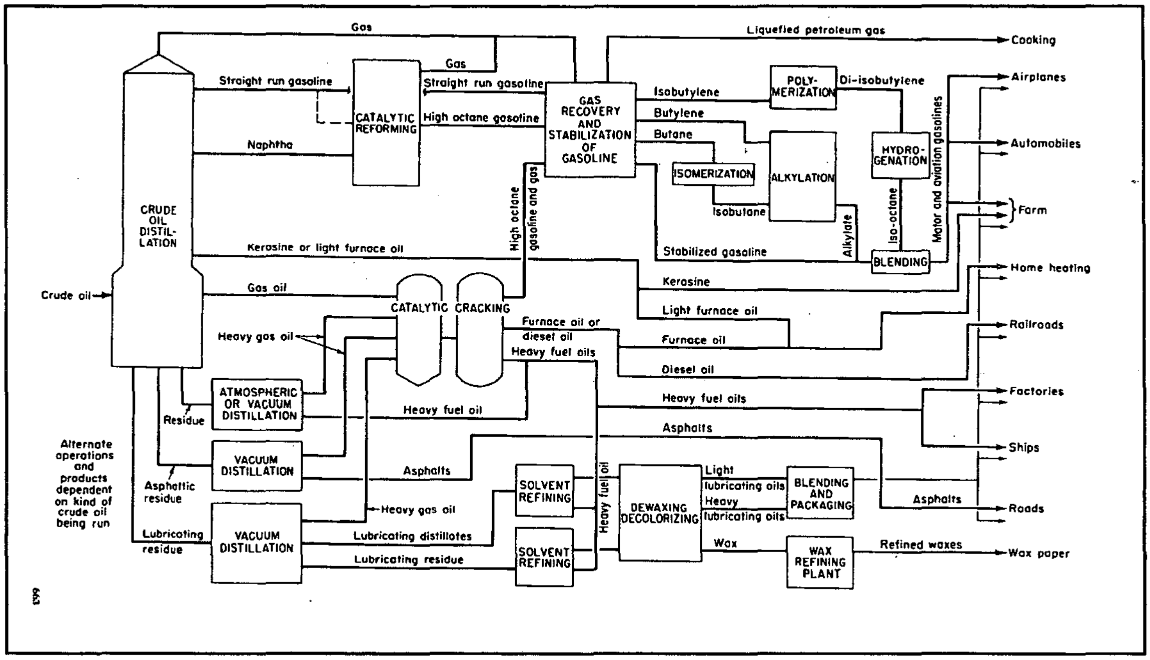
Country	1971	1994	AAGR (1971-1994)
US	598453	753943	1.0%
USSR	289600	254471	-0.6%
Japan	179039	209870	0.7%
China	31500	126581	6.2%
Germany	123737	119583	-0.1%
Italy	104425	93014	-0.5%
UK	118722	91912	-1.1%
France	68786	83810	0.9%
Canada	106371	80247	-1.2%
South Korea	11478	76362	8.6%
Portugal	4036	13760	5.5%
Mexico	21776	71808	5.3%
Greece	5309	16283	5.0%
Turkey	8589	24849	4.7%
Saudi Arabia	27514	75231	4.5%
Norway	5695	14632	4.2%
Sweden	11500	19089	2.2%
Spain	34528	55512	2.1%
Australia	21847	34017	1.9%
Finland	8642	11953	1.4%

Source: International Energy Agency, *Basic Energy Statistics, 1995.*

Sector and Process Definitions

We define the coverage of petroleum refining as encompassing products produced under ISIC code 353. Refining processes involve crude distillation processes where the crude oil is separated into various distillate products, conversion where heavier distillates are converted into lighter compounds, reforming processes where hydrocarbon molecules are reorganized to produce chemical feedstocks and high octane products, and finishing processes that involve the removal of sulfur and other impurities from the product (see figure on next page). While crude distillation and conversion processes account for the largest share of energy use, on a per-unit basis reforming and finishing processes can be more energy intensive. Complex, modern refinery systems (those which produce lighter and higher octane products) tend to have much higher intensities than more simple distillation units, mainly because of additional energy requirements associated with conversion and finishing processes. The product mix of a particular refinery depends both on market conditions and the feedstock or crude oil type being processed.

Figure A-5. Flow Diagram of Petroleum Refining Process Routes



Source: Austin, 1984

Table A-10. Petroleum Refining Data (ISIC 353)

CATEGORY	UNITS
PETROLEUM REFINING (ISIC 353)	
PHYSICAL DATA	
Physical Output Data	
Refined Petroelum Products	
Gasoline (aviation, motor)	Mtonne
Diesel	Mtonne
Kerojet (kerosine, jet fuel)	Mtonne
Residual fuel oil	Mtonne
Naphtha	Mtonne
Liquified Petroleum Gas	Mtonne
Lubricants	Mtonne
Refinery gas	Mtonne
Other/losses	Mtonne
Petroleum Products Total	Mtonne
Technologies	
Crude distillation (input cap.)	Mtonne/yr
Vacuum distillation (input cap.)	Mtonne/yr
Thermal cracking (input cap.)	Mtonne/yr
Coking (input cap.)	Mtonne/yr
Catalytic cracking (input cap.)	Mtonne/yr
Catalytic reforming (input cap.)	Mtonne/yr
Catalytic hydrocracking (input cap.)	Mtonne/yr
Hydrotreating (input cap.)	Mtonne/yr
Hydrorefining (hydrofinishing) (input cap.)	Mtonne/yr
Polymerization (alkylation) (output cap.)	Mtonne/yr
Aromatics (output cap)	Mtonne/yr
Lubricants (output cap.)	Mtonne/yr
Oxygenates (MTBE, ETBE) (output cap.)	Mtonne/yr
Hydrogen production	10^6 cu. m output cap
Structural Data	
Number of plants	%
Total capacity	Mtonne
Total crude intake	Mtonne
Total refining throughput	Mtonne
ECONOMIC DATA	
Petroleum Refining deflator	1990=100
Petroleum Refining Labor Force	10^3 pers
Sales of Petroleum Refining Prod.	currency
Output	
Gross output	currency
Value added	currency
Expenditures	
Energy	currency
Labor	currency
Gross Capital Formation	currency
Total operating expenditures	currency
Research & Development Expenditures	currency
Exports and Imports	
Exports	currency
Imports	currency

Ammonia

Background
The chemicals sector produces a wide variety of products, estimated at over 50,000 various compounds. The industry consumes over 5% of global energy, expressed as primary fuels, and generates 7% of global income. Given the wide variety in products and processes the working group will track developments for the sector as a whole as well as concentrating on specific energy intensive products. Our initial focus is on the production of ammonia (for fertilizers) and ethylene. (The list of chemicals covered is expected to expand as the network develops

Ammonia is the main intermediate (energy intensive) product in the fertilizer industry. Ammonia is the most produced chemical besides sulfuric acid. Current global ammonia production consumes approximately 2.6 EJ. Nearly 85% of ammonia is used in fertilizer manufacture, while other applications are increasing (e.g. resins). Consumption levels vary widely over the world. Per capita consumption is now stabilizing or declining in the industrialized countries, but still growing in developing countries, i.e. Asia. Ammonia is produced in a large number of countries, but is concentrated in a few countries, especially those with access to natural gas resources such as the United States, China, Russia, Canada and the European Union (see table below). The figure on the next page provides a simplified schematic of ammonia production.

Table A-11. Ammonia Production (in Million Tonnes) and Average Annual Growth Rates (percent) in the Major Producing Countries and the World

Country	1970	1992	AAGR (1970-1992) unless ()
China	11.8 (1978)	24.4 (1994)	4.6
USSR*	17.2 (1978)	23.6 (1989)	1.7
USA	10.3	15.7 (1994)	1.8
Canada	1.0	4.0 (1989)	7.6
Netherlands	1.3	3.1	4.0
Germany	1.8	2.2 (1994)	0.8
Japan	0.9	1.7 (1994)	2.7
France	1.6	1.5 (1994)	-0.3
Romania	0.9	1.4 (1994)	1.9
Italy	1.5	0.6 (1994)	-3.7
Mexico	0.5	2.2	7.0
Poland	0.1	1.5	13.1
Brazil	0.2 (1976)	1.1	11.2
Venezuela	0.1 (1973)	0.5	8.8
Turkey	<0.1	0.4	11.0
Norway	0.5	0.4	-1.0
South Korea	0.5	0.4	-1.0
Spain	0.6	0.4	-1.8
Greece	0.2	0.3	1.9
Portugal	0.3 (1971)	0.3	0.0

United Nations. *United Nations Commodity Statistics*. New York: UN.
* Production in the Former Soviet Union has declined significantly since 1989, but UN data are not available

Figure A-6. Flow Diagram of Ammonia Production Process Routes

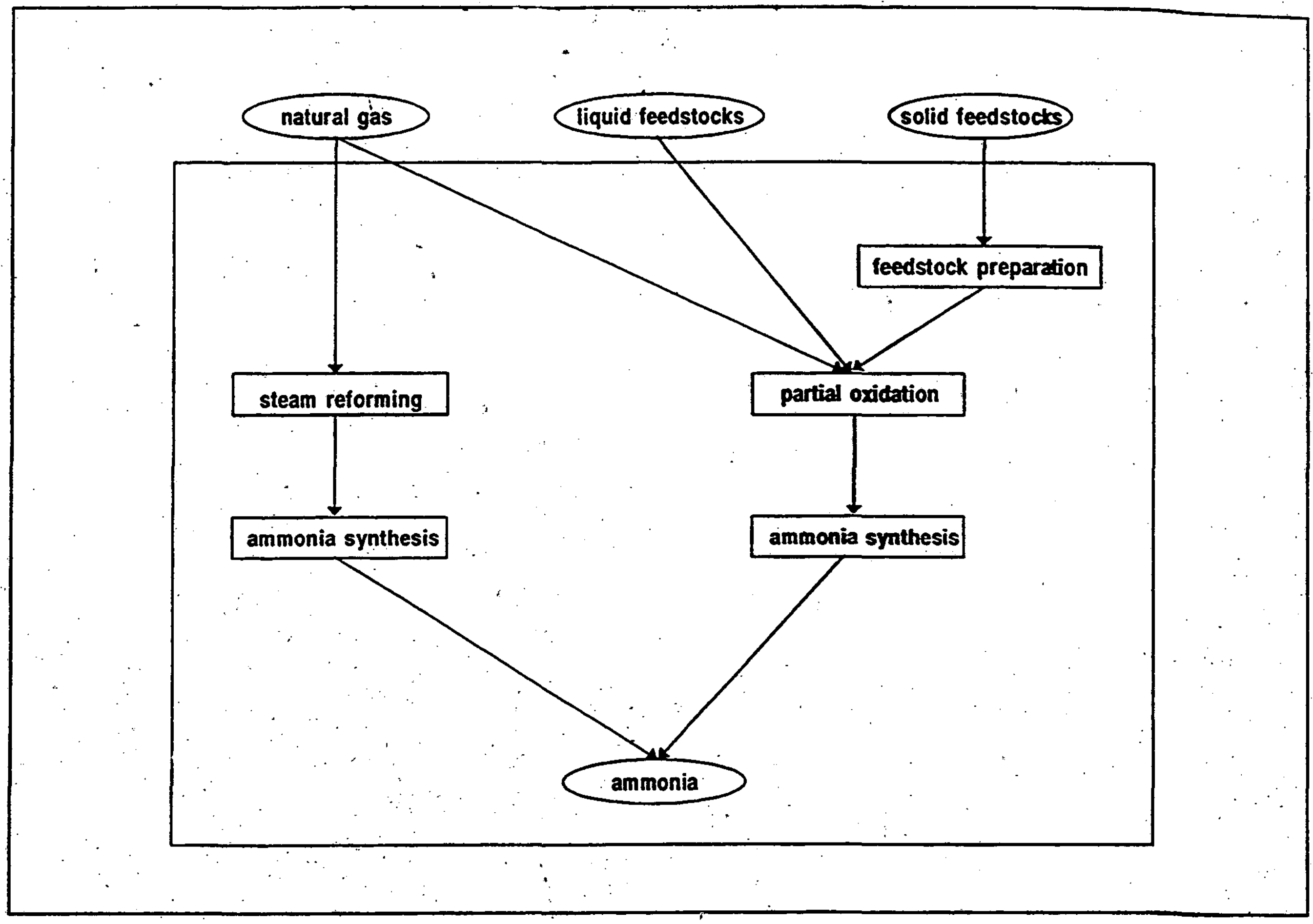


Table A-12. Ammonia and Chemicals Data (ISIC 351-352/351158)

CATEGORY	UNITS	CATEGORY	UNITS
AMMONIA (ISIC 351158)		CHEMICALS (ISIC 351-352)	
PHYSICAL DATA		ECONOMIC DATA	
Output		**Output**	
Ammonia production (including intermediate)	Mtonne N	Gross output total chemicals production	currency
Fertilizer Production		Value added total chemicals production	
Nitric acid	Mtonne N	Chemicals Deflator	1990=100
Ammonia nitrate	Mtonne N	Chemicals Labor Force	10^3 pers
CAN/PAN	Mtonne N	Sales of Chemicals Products	currency
Urea	Mtonne N		
Compound Fertilizer	Mtonne N		
Other	Mtonne N		
Total nitrogenous fertilizers	Mtonne N		
Technologies			
Share of steam reforming	Mtonne		
Share of partial oxydation	Mtonne		
Technology 3	Mtonne		
Technology 4	Mtonne		
Structural Data			
Number of plants			
Total capacity	Mtonne/Yr		
Average plant age	Years		
Total feedstock	Mtonne		
Share natural gas	%		
Share hydrocarbon residues	%		
Share coal (direct coal use, i.e. gasification)	%		
Share coke (production from coke gases)	%		
Other (including electrolysis)	%		
ECONOMIC DATA			
Chemicals Labor Force	10^3 pers		
Output			
Gross output total ammonia production	currency		
Value added total ammonia production	currency		
Expenditures			
Energy	currency		
Labor	currency		
Gross Capital Formation	currency		
Total operating expenditures	currency		
Research and development expenditures	currency		
Exports and Imports			
Nitrogen fertilizer exports	Mtonne N		
Nitrogen fertilizer imports	Mtonne N		
Nitrogen fertilizer exports	currency		
Nitrogen fertilizer imports	currency		

Ethylene and Other Petrochemicals

Petrochemicals production is the second largest energy consumer in the chemicals industry. The most energy-intensive step is the production of the intermediate materials from refinery oil products (naphtha, heavy and light fuel oil, natural gas and refinery gas (including ethane rich natural gas)). The petroleum refineries are often integrated, or closely connected through pipeline with petrochemical production facilities. The major intermediate petrochemical products are ethylene (the "market leader"), propylene, butadiene and aromatics (mainly benzene, as toluene and xylenes are mainly produced by refineries). Ethylene is still seen as the most important product given its wide variety of used (especially in plastics, solvents, cleaning agent), as well as the significant energy requirements involved in its production. The table below provides data on recent trends in ethylene output. The figure on the next page provides a simplified schematic for ethylene and plastics production.

Table A-13. Ethylene Production (in Million Tonnes) and Average Annual Growth Rates (percent) in the Major Producing Countries and the World.

Country	1985	1994	AAGR (1985-1994)
USA	13.5	18.2	3.3%
Japan	4.2	6.1	4.2%
Germany	3.0	4.2	3.7%
former USSR	2.7	1.4	-6.9%
France	2.2	2.8	2.9%
Korea	0.6	3.7	23.2%
Canada	1.7	2.7	5.0%
Italy	1.0	1.8	6.9%
UK ***	1.2	1.9	5.9%
Netherlands ***	1.3	1.7	3.7%
	1983	**1992**	**AAGR (1983-1992)**
Turkey	0.1	0.4	24.2%
Portugal	0.1	0.3	19.2%
China	0.7	2.0	13.2%
Mexico	0.6	1.5	10.2%
Finland	0.2	0.3	8.1%
Austria	0.2	0.3	4.2%
Poland	0.2	0.3	4.1%
Spain	0.8	1.0	2.4%
Brazil	1.3	1.5	1.7%
India	0.2	0.2	1.2%

United Nations. *United Nations Commodity Statistics*. New York: UN.

Sector and Process Definitions

To ensure consistency and comparability of results from the network, we have chosen to define the coverage of the chemical industries according to the international standard industrial classification (ISIC) system. According to this classification, the manufacture of ammonia (and products) falls within ISIC 351158 and the fertilizer manufacture under 3512. The sector includes the production of ammonia from several resources, including natural gas, hydrocarbon residues, coal, coke and electrolysis. It also includes the processing of ammonia to fertilizers, e.g. urea, ammonia nitrate, nitric acid and compound fertilizers, but excludes the use of ammonia for other purposes, e.g. resins. The production of ammonia sulphate is excluded when it is produced as a waste product of nylon manufacture. The production data should preferably be reported in nitrogen content (N-content).

The manufacture of petrochemicals falls within the four digit-ISIC 3511. The main products are ethylene (351110), propylene (351113), butadienes (351109), and benzene (351107). The sector includes the production of petrochemicals from several resources, including ethane-rich natural gas, hydrocarbons (LPG, fuel oil and naphtha). It excludes the further processing of the raw materials (e.g. polymerization, styrene production, oxidation). For analysis it is desirable to collect production on all major products, however ethylene production data are good first indicators. Energy use is often expressed as function of function of ethylene produced, as ethylene is the price leader of the major products. Energy use will often be difficult to quantify, as ethylene production is often part of large petrochemical production sites that produce a variety of products simultaneously.

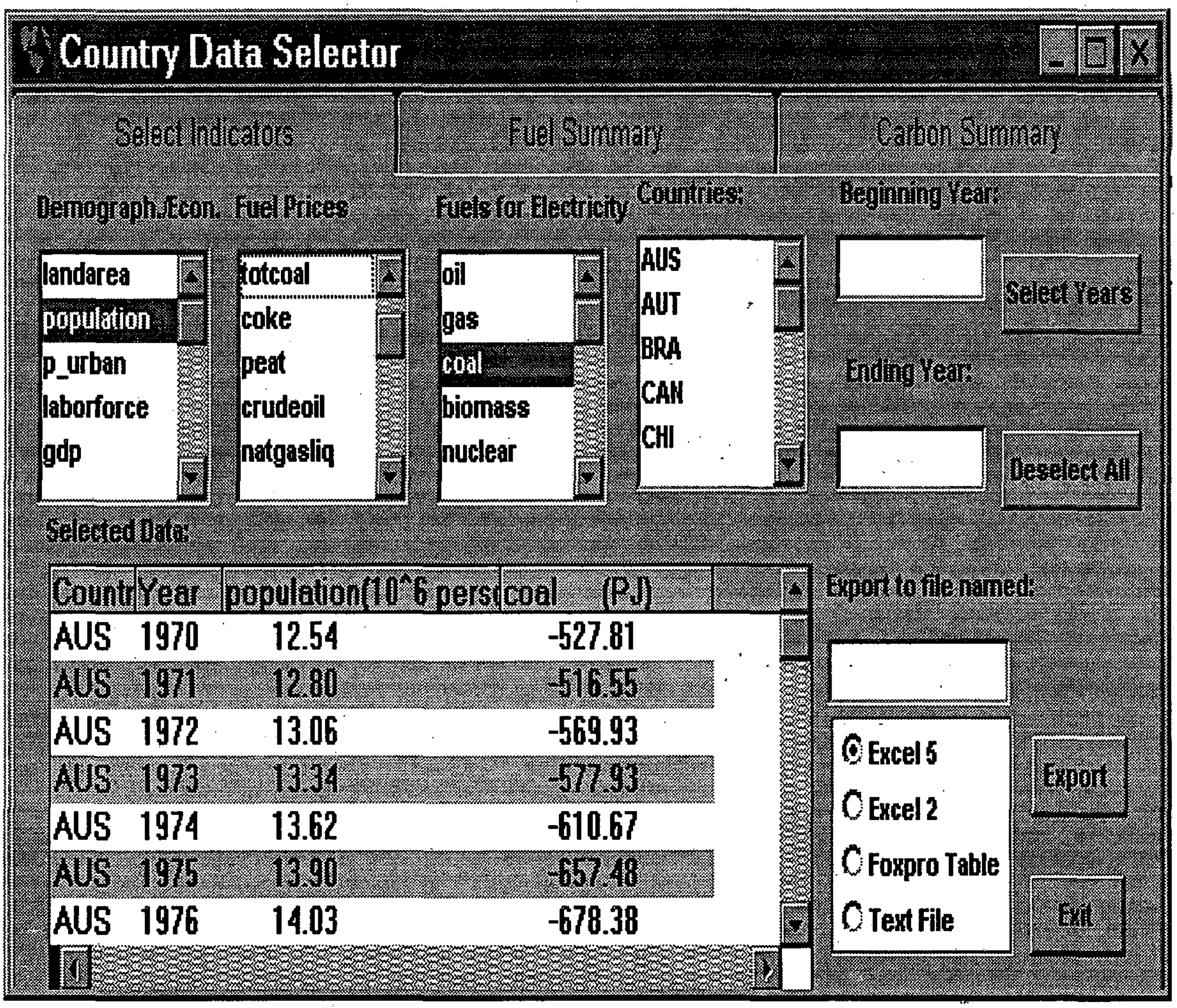
Table A-14. Ethylene Data (ISIC 351110)

CATEGORY	UNITS
ETHYLENE (ISIC 351110)	
PHYSICAL DATA	
Output	
Ethylene	Mtonne
Propylene	Mtonne
Butadiene	Mtonne
Benzene	Mtonne
Technologies	
Technology 1	Mtonne
Technology 2	Mtonne
Technology 3	Mtonne
Structural Data	
Number of plants	
Total capacity	Mtonne/yr
Average plant age	Years
Total feedstock	Mtonne/yr
Share ethane-rich natural gas	%
Share LPG	%
Share naphtha	%
Share fuel oil	%
Other (specify)	%
ECONOMIC DATA	
Petroleum Labor Force	10^3 pers
Output	
Gross output total ethylene production	currency
Value added total ethylene production	currency
associated products	
Gross output total propylene production	currency
Value added total propylene production	currency
Gross output total butadiene production	currency
Value added total butadiene production	currency
Gross output total benzene production	currency
Value added total benzene production	currency
Expenditures	
Energy	currency
Labor	currency
Gross Capital Formation	currency
Total operating expenditures	currency
Research and development expenditures	currency
Exports and Imports	
Petrochemical exports	Mtonne
Petrochemical imports	Mtonne
Petrochemical exports	currency
Petrochemical imports	currency

Appendix B. How to Use the Database

Our industrial data has been organized in a Microsoft FoxPro database that can be used by a standard PC computer. We chose FoxPro because it is widely available and also has adequate capabilities to handle the data and calculations we use for our analysis. The database is set up with a screen for accessing general indicators, a screen for accessing sector data, and a screen for accessing carbon emissions by country. In the "indicators" section, one selects an indicator (tons of crude steel, gross value added, Petajoules of fuel oil), a country or countries, and the time series desired. In the "fuel summary" section, sectoral energy consumption is displayed by fuel in Petajoules, and includes calculated values for total final and total primary energy consumption. The final section, "carbon summary", displays sectoral carbon emissions by fuel in kilotonnes carbon, and includes final and primary carbon intensities of fuel mix. Once the desired values have been specified the screen immediately displays the output values. These values can be exported as either text or excel tables for further manipulation by the researcher. Our goal is to put the database on the world-wide-web to ease access. A sample of the indicators screen for the country data sector is shown in Figure 12.

Figure B-1. Country Data Selector Form



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Appendix D. Carbon Factors for Selected Fuels

Table D-1. Carbon Factors for Selected Fuels (Tons Carbon per Terajoule (ktC/PJ))

Fuel Type	Tons Carbon per Terajoule
Hard Coal	25.8
Brown Coal	26.85
Coking Coal	25.8
Other Bituminous Coal and Anthracite	25.8
Sub-Bituminous Coal	26.2
Lignite	27.6
Peat	28.9
Patent Fuel	25.8
Coke Oven Coke	29.5
Gas Coke	29.5
BKB	25.8
Gas Works Gas	15.3
Coke Oven Gas	13
Blast Furnace Gas	66
Oxygen Steel Furnace Gas	66
Natural Gas	15.3
Crude\NGL\Feedstocks\Non-Crude	20
Crude Oil	20
Natural Gas Liquids	17.2
Refinery Feedstocks	20
Additives\Blending Components	20
Input of Origin not Crude or NGL	20
Refinery Gas	18.2
Ethane	16.8
Liquified Petroleum Gas	17.2
Motor Gasoline	18.9
Aviation Gasoline	18.9
Gasoline Type Jet Fuel	18.9
Kerosene Type Jet Fuel	19.5
Other Kerosene	19.6
Gas\Diesel Oil	20.2
Residual Fuel Oil	21.1
Naptha	20
White Spirit	20
Lubricants	20
Bitumen	22
Paraffin Waxes	20
Petroleum Coke	27.5
Non-Specified Petroleum Products	20
Non-Specified Fuels for Heat Production	20
Combustible Renewables and Waste	29.9
Solid Biomass and Animal Products	29.9
Industrial Waste	29.9
Municipal Waste	29.9
Gas\Liquids from Biomass and Waste	25.3
Non-Specified Renewables and Waste	29.9

Appendix E. Physical to Energy Conversion Factors for Selected Fuels

Table E-1. Conversion Factors for OECD Countries.

	AUS	AUT	CAN	DEU	ESP	FIN	FRA	GBR	GRE	ITA	JPN	MEX	NLD	NOR	POR	SKO	SWE	TUR	USA
Anthracite				8.4			27.2	20.1	26.0	26.0	27.2			20.1	26.0		26.4	33.8	30.6
Lignite			15.0	8.4			5.3	9.6	8.4	17.6	8.4			8.4	17.6		8.4		
Coking coal				26.0			29.3	20.1	26.0	26.0	27.2	24.7		20.1	26.0		26.4	31.2	31.2
Steam coal			29.3	26.0			28.3	20.1	26.0	26.0	27.2	19.2		20.1	26.0		26.4		25.6
Total Bit. coal																			
Total Coal					26.0								28.1			27.2		26.5	
Coke			28.8	27.2	28.0		29.3	27.2	27.2	27.2	27.2		28.5	27.2	27.2	28.1	27.2	28.1	28.8
Peat				8.4			8.4	8.4	8.4	8.4	8.4			8.4	8.4		8.4		
Other Solid Fuels				20.1			15.3	20.1	20.1	20.1	20.1			20.1	20.1		20.1	27.9	
Crude oil				42.7	42.0		42.7	42.7	42.7	42.3	42.7	50.1	43.0	42.7	42.3		42.7	45.9	
Natural gas liquids				42.7			45.2	43.1	42.7	42.7	42.7			41.9	42.7		42.7		
Diesel (gas oil)			46.2	43.5			43.3	43.5	43.5	43.5	43.5	45.9	43.1	43.5	43.5	42.5	43.5	45.8	46.2
Fuel oil			41.3		42.0								43.1			38.0		42.7	
Kerosene			40.2	44.0			43.8	44.0	44.0	44.0	44.0	46.5	43.1	44.0	44.0	42.6	44.0	47.6	
LPG			50.1	47.3	46.0		47.3	47.3	47.3	47.3	47.3			47.3	47.3	46.1	47.3	49.6	44.2
Motor gasoline			46.7	44.8	44.0		44.8	44.8	44.8	44.8	44.8		46.1	44.8	44.8	42.3	44.8	47.4	
Naphtha				45.2			45.0	45.2	45.2	45.2	45.2			45.2	45.2		45.2		
Residual Fuel Oil			44.5	40.2	40.0		40.2	40.2	40.2	40.2	40.2		40.6	40.2	40.2	41.6	40.2	42.7	44.5
Other Liquid Fuels				44.8	42.0		42.5	44.8	44.8	44.8	44.8			44.8	44.8		44.0		
Total Fossil Liquids					42.0													45.9	
Natural gas			37.8									46.1	40.9			38.9		39.6	38.8
Ethane				47.3			47.3	47.3	47.3	47.3	47.3			47.3	47.3		47.3	52.3	
Coke oven gas			18.6													16.7		31.3	
Blast furnace gas													10.0					42.2	
Gas works (town gas)																16.7			
Refinery gas			41.7	48.2			48.2	48.2	48.2	48.2	48.2			48.2	48.2		48.2		
Other gases			50.1										50.2					49.2	
Total Fossil Gases																			
Charcoal																4.5			
Wood			18.0										8.4			4.5		11.9	
Non-commercial fuels(industrial waste)													10.5					16.0	
Black liquor			14.0										14.0						
Wood, vegetal material, or waste													16.8					39.0	

All data are net calorific value unless noted * (gross calorific value). Solid fuels: GJ/tonne, LHV; Liquids: GJ/m3, LHV; Gas: GJ/1000m3, LHV.

Table E-2. Conversion Factors for Non-OECD Countries

	BRA*	CHI	CHN	EGY	IND	INS	IRA	IRQ	MAY	NKO	PHI	POL	ROM	SAF	SAR	SIN	TAI	THA	USS	VEN
Anthracite		28.5	23.0		26.0	26.0			26.0		27.2	27.2	26.0	26.0	22.6	27.0	26.4	30.0	18.4	26.0
Lignite		17.2	8.4		8.4	8.4	10.5	17.2	8.4		8.8	8.8	8.4	8.4	8.4	8.8	18.4	11.7	14.7	8.4
Coking coal	28.5	28.5	23.0		26.0	26.0		32.2	26.0		27.2	27.2	26.0	26.0	22.6	30.0	26.4	32.9	18.4	26.0
Steam coal		28.5	23.0		26.0	26.0		24.3	26.0		28.1	28.1	26.0	26.0	22.6	24.5	26.4	27.4	18.4	26.0
Total Bit. Coal																				
Total Coal							31.0													
Coke	30.6	28.5	28.5		27.2	27.2	29.3	30.1	27.2		27.6	27.6	27.2	27.2	28.1	30.1	27.2	29.3	25.1	27.2
Peat		8.4	8.4		8.4	8.4			8.4		8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Other Solid Fuels	18.8	20.1	18.0		20.1	20.1			20.1		18.0	18.0	20.1	20.1	20.1	20.2	20.1	20.9	20.1	20.1
Crude oil		43.1	41.9	41.4	42.7	42.7		49.3	43.1	42.7	41.5	41.5	42.7	42.7	38.1	42.7	42.7	42.8	42.3	41.9
Natural gas liquids		42.7			42.7	42.7		43.1	43.1		45.2	45.2	42.7	42.7	42.7	45.2	46.9	45.2	41.9	41.9
Diesel (gas oil)	45.0	43.5	43.5	42.5	43.5	43.5	42.7	46.1	43.5	42.7	43.5	43.5	43.5	43.5	43.5	43.3	43.5	43.3	43.5	43.5
Fuel oil	45.6			42.3			41.0	41.6		44.0										
Kerosene	46.4	44.0	44.0	43.1	44.0	44.0		46.3	44.0	43.6	44.0	44.0	44.0	44.0	44.0	43.8	44.0	43.8	44.0	44.0
LPG	49.2	47.3	47.3	45.6	47.3	47.3		50.2	47.3	31.7	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3
Motor gasoline	47.0	44.8	44.8	43.1	44.8	44.8		47.4	44.8		44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8	44.8
Naphtha	47.4	45.2	45.2	44.4	45.2	45.2		42.6	45.2	44.0	45.2	45.2	45.2	45.2	45.2	45.0	45.2	45.0	45.2	45.2
Residual Fuel Oil		40.2	40.2	40.6	40.2	40.2		43.8	40.2		40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2
Other Liquid Fuels		44.8	44.8		44.8	44.8	42.7	42.3	42.7		44.8	44.8	44.8	44.8	44.8	42.5	44.8	42.5	44.8	43.5
Total Fossil Liquids	45.6		41.9																	
Natural gas	43.8							41.0												
Ethane		47.3	47.3		47.3	47.3			47.3		47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3
Coke oven gas										31.7										
Blast furnace gas																				
Gas works (town gas)	16.3							41.9												
Refinery gas	36.8	48.2	48.2	51.9	48.2	48.2			48.2	31.7	48.2	48.2	48.2	48.2	48.2	48.2	48.2	48.2	48.2	48.2
Other gases	38.8																			
Total Fossil Gases			39.0				34.5													
Charcoal	28.5																			
Wood	13.8																			
Non-commercial fuels (industrial waste)																				
Black liquor	12.7																			
Wood, vegetal material, or waste																				

All data are net calorific value unless noted * (gross calorific value). Solid fuels: GJ/tonne, LHV; Liquids: GJ/m3, LHV; Gas: GJ/1000m3, LHV.

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