Industrial Energy Profiles and Trends – 1985 to 1997 and Beyond

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ABSTRACT

The U.S. industrial sector has undergone major change in the last 20 years including major changes in the use of energy. The impact of energy cost increases in the 1970s is well known. The last 10 years have also seen great change, however. Studies of these effects are often handicapped by a lack of detailed data on specific industries or end uses. Analyses based on aggregate (overall industrial sector) data do not provide insights into the specific changes because the lumped data mask different countervailing effects. This analysis is based on a detailed database of industrial energy consumption by end use and industry for the period 1985 to 1997. This database allows the analysis of energy consumption trends in specific industries and end uses, particularly the manufacturing processes that are of primary interest but make up only a fraction of total industrial energy use.

The study uses this data resource to assess the changes in key industrial sector processes and end-uses and analyzes the factors that resulted in these changes. It also examines the role of industrial production on energy consumption and energy intensity trends. The results provide new insights into the operations of key industries and the relationships between energy use, efficiency and the various drivers. The results will be useful to industrial analysts and policy makers in addressing energy, technology and environmental issues related to the industrial sector.

Preliminary results indicate that there have been significant changes in the processes, technologies and fuel use in the U.S. industry. The process changes were primarily driven by the changes in the quality of raw materials, environmental regulations, improvements in productivity and continued expansion of industrial cogeneration. Different impacts were observed including increased energy intensity in certain industries, and successful penetration of important new technologies. The results also show the significance of the energy-intensive industries as key drivers to overall energy consumption and intensity levels.

Introduction

The U.S. industrial sector consists of establishments engaged in agriculture, mining, construction and manufacturing operations. Technically, the sector includes all industries within the Standard Industrial Classification (SIC) codes 01 through 39. The industrial sector can be divided into three categories: non-manufacturing, major process industries, and final fabrication industries. Non-manufacturing industries include agriculture, mining and construction. These industries use energy differently from the manufacturing sector, as most of its energy consumption is on off-highway transportation, asphalt pavement and natural gas lease and plant.[1] The major process industries, which include food, paper, chemical, petroleum refining, stone, clay, and glass, and primary metals, perform the initial processing of raw materials. As a result, these industries use relatively more energy than those involved in final fabrication. The final fabrication industries process the raw materials from the process industries to final products delivered to consumers. These industries are less-energy-intensive than the process industries.

The industrial sector is a very important energy-consuming sector in the U.S. In 1995 (latest data from EIA SEDS), the sector consumed 30 percent of total energy consumption in the U.S. To properly assess the current and future markets and trends in industrial energy demand, a complete and detailed characterization of energy consumption is needed. However, the development of reliable, useful, complete and detailed data related to industrial energy consumption has been problematic due to the lack of current and consistent data.

This analysis draws upon original work done by Energy and Environment Analysis, Inc. (EEA) for the Gas Research Institute (GRI). In 1994, EEA was contracted by GRI to resolve some of the data deficiencies by developing an industrial energy technology database for 1992 that contains a detailed characterization of industrial energy use. The database was made consistent with data from the Energy Information Administration (EIA). The database is designed to incorporate sufficient detail by industry group (by 2-digit SIC group with further disaggregation of the primary metals industry), by region (11 GRI regions), by fuel type (28 fuel categories), and by end-use and technology (over 500 types of processes and equipment) to be able to support GRI's R&D assessment programs and analysis of current and future trends of industrial energy use. The level of detail represented in the database follows that of the data structure used in the Industrial Sector Technology Use Model (ISTUM-2). Additionally, as part of the project, a process was also created and documented to regularly update the database. Subsequently, EEA is currently in the process of updating the database from 1993 to 1997. A complete documentation of the database is reported in the GRI topical report titled Methodology for Updating Base Year Data in the ISTUM-2 Model.

This study will use this data resource to identify the key changes in industrial sector processes and end-uses and analyze the factors, which resulted in these changes. It will assess the significance of industrial production on energy consumption and energy intensity trends, focusing on the role of energy-intensive industries. The results provide new insights into the operations of key industries and the relationships between energy use, efficiency and the various drivers. The results will be useful to industrial analysts and policy makers in addressing energy, technology and environmental issues related to the industrial sector.

1992 Industrial Energy Consumption Profile

Figures 1 and 2 summarize the industrial sector's energy consumption profile in 1992. Figure 1 presents consumption by fuel type and end-use, and Figure 2 shows consumption by industry and fuel type. In Figure 1, byproduct fuels include still gas, petroleum coke and wood. This distinction between byproduct (considered free) and purchased fuels enables a more appropriate assessment of fuel competition within end-use applications.

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[1] Natural gas lease and plant is natural gas used in well, field, and lease operations, and as fuel in natural gas processing plants.

Figure 1 shows that electricity is predominately used in machine drive, followed by process heat, space cooling, lighting and process cooling. Most of electricity used for process heat is consumed in the iron and steel industry's electric arc furnaces. Natural gas is primarily used for steam and electricity generation, followed by process heat, lease and plant, feedstocks and direct space heating. Almost all of coal is used in steam and electricity generation and as feedstocks (metallurgical coal), with a small amount used in process heat applications, mostly as cement kiln fuel. The majority of non-byproduct oil is used as feedstocks and off-road transportation fuel (diesel fuel oil and motor gasoline). The rest, which is relatively small, is used for steam and electricity generation, process heat and direct space heating. Byproduct fuels are mostly used as boiler fuel except for still gas, which is primarily used for fluid heating. Other fuels, which include non-wood-based renewables and purchased steam, are all consumed for steam and electricity generation.

Figure 2 shows that the chemical industry consumes the largest amount of energy, natural gas and petroleum. The refining sector has the second largest energy consumption, most of which is petroleum byproducts, still gas and petroleum coke. The paper industry reports the third largest consumption, with other fuel (primarily, biomass) accounting for most of it. The figure also shows how only a handful of industries can account for a significant share of a fuel source's demand level. This then provides useful insights into the importance of certain industries in the consumption levels of certain fuel types. For example, three industries (mining, chemical and refining) account for almost 65 percent of natural gas consumption. Only four industries (primary metals, chemical, paper and stone, clay and glass) consume 75 percent of total industrial coal consumption. Eighty-four percent of non-byproduct oil is consumed in only four industries, namely chemical, construction, agriculture and mining. The paper and refining industries dominate byproduct fuel consumption. Electricity is the only energy source that seems to spread across all industries. For example, the energy-intensive industries account for only 51 percent of electricity consumption.

Impacts of Industrial Production on Energy Consumption

The level and mix of industrial production critically affect the level and the mix of energy sources of industrial energy consumption. Furthermore, the production trends of the energy-intensive industries and its relation to the less-energy-intensive ones are important drivers of industrial energy consumption. The effects of industrial production on energy consumption are clearly shown during the period from 1985 to 1997.

Industrial Production Trends, 1985 to 1997

The level of industrial production in the entire industrial sector is highly dependent on the production of the energy-intensive industries. The energy-intensive industries consume 70 percent of total industrial energy consumption, over 50 percent of electricity, almost 70 percent of natural gas and petroleum and 87 percent of coal. Furthermore, they also account for 78

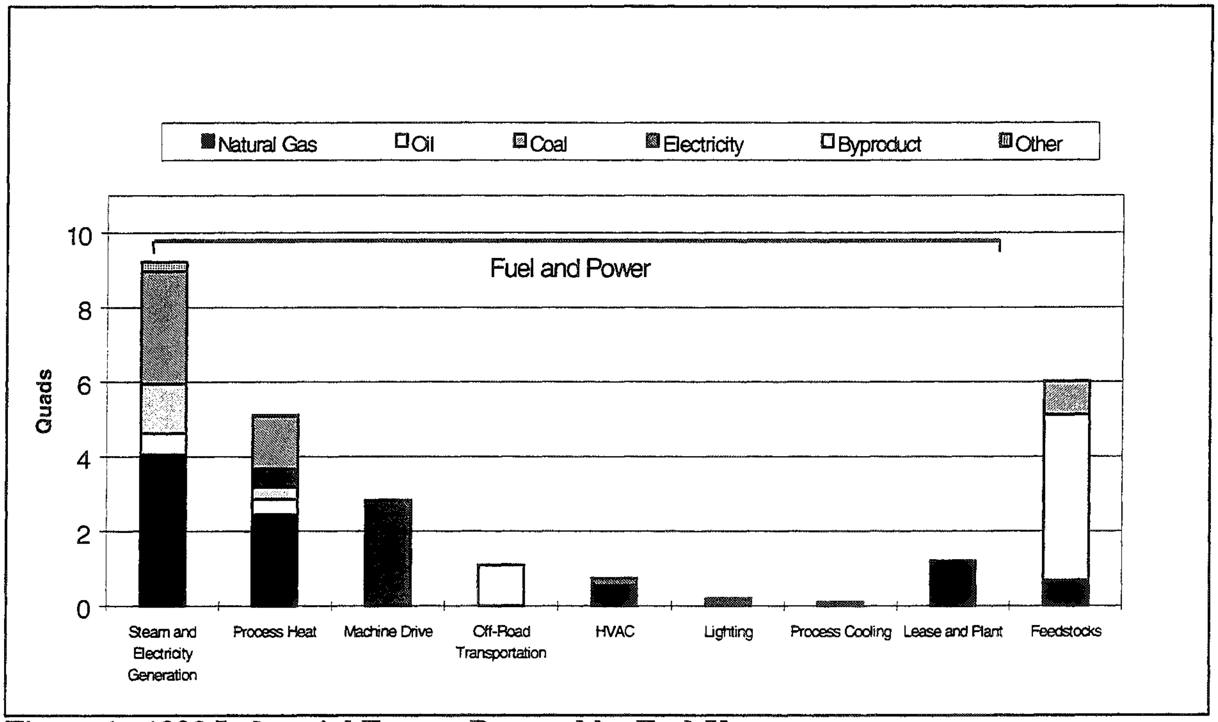

Figure 1. 1992 Industrial Energy Demand by End-Use

percent of steam consumption in the industrial sector and 82 percent of industrial cogeneration capacity. Therefore, current and future economic conditions in each of these industries are critical to the future level of industrial energy demand.

Except for a mild recession from 1989 through 1991, the period from 1985 to 1997 is characterized by tremendous growth. Table 1 shows the production trends of each industry group. During this period, the U.S. industrial sector expanded by 45 percent or 3.2 percent per year. The expansion was supported by significant growth in both the energy-intensive and less-energy intensive industries. The group of energy-intensive industries grew at an annual rate of 2.3 percent while the less-energy-intensive industries grew at a rate of 3.6 percent. However, from 1985 to 1992, the combined energy-intensive industries expanded faster (2.1 percent per year) than the combined less-energy-intensive industries (1.7 percent per year). Overall industry grew at an annual rate of 1.7 percent during this seven-year period.

The fastest growing industries from 1985 to 1997 were electronic and other electrical equipment (SIC 36), industrial machinery (SIC 35) (both in the metal durables group) and rubber and miscellaneous plastic products (SIC 30). The expansion of these industries was primarily driven by the expansion of the computer industry. Among the energy-intensive industries, the chemicals, primary metals and paper industries reported the fastest growth rates.

Overall Energy Consumption Trends, 1985 to 1997

To better understand the role of industrial production trends, we divide the analysis from 1985 to 1997 into two periods. The first period, from 1985 to 1992, is characterized by higher production growth in the energy-intensive industries than in the less-energy intensive ones.

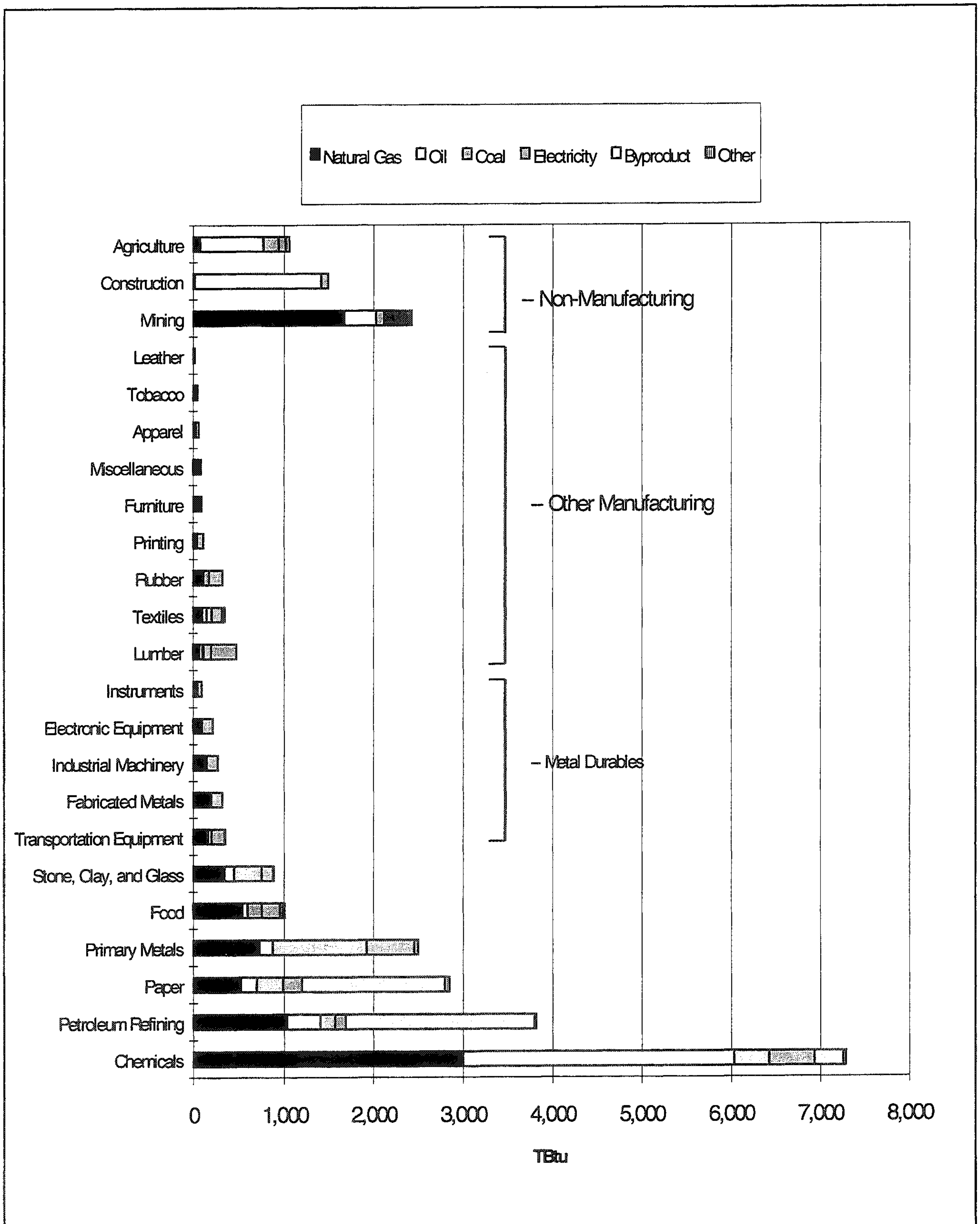

Figure 2. 1992 Energy Consumption by Industry and Fuel

Table 1. Production Trends, 1985 to 1997

Industry Group	Annual Growth Rate (%)		
	1985-1992	1992-1997	1985-1997
Energy-intensive	2.1	2.6	2.3
Food	1.7	1.8	1.8
Paper	2.5	2.5	2.5
Chemical	3.3	2.9	3.2
Petroleum refining	1.6	1.8	1.7
Stone, clay and glass	0.3	3.8	1.7
Primary metals	1.4	4.5	2.7
Less-energy intensive industries	1.7	6.4	3.6
Rubber	4.4	4.8	4.6
Metal durables	2.0	8.3	4.6
Other manufacturing	1.2	1.8	1.5
Non-manufacturing	0.6	6.3	3.0
Total industrial	1.7	5.2	3.2

Data source: Federal Reserve Board (FRB) industrial production indices.

During this period total energy consumption increased annually by 1.96 percent, purchased electricity grew at an annual rate of 2.17 percent, natural gas increased annually by 3.27 percent, coal declined at a rate of 0.56 percent per year, while petroleum increased annually by 1.45 percent. Interestingly, during this period, overall energy intensity increased slightly.

The growth rates of total consumption, natural gas and electricity are higher than the reported overall industrial production growth during this period (1.8 percent per year). The decline in coal was primarily driven by the reduction of metallurgical coal demand, combined with a slight increase in steam coal consumption (0.7 percent per year). The moderate petroleum consumption growth was the result of a significant increase in feedstocks consumption (3.6 percent per year) as well as byproduct petroleum consumption (still gas and petroleum coke) coupled with a drop in other petroleum-based fuel (e.g., distillate oil and residual oil) for heat and power use.

Over this time period, energy consumption of the energy-intensive industries increased by approximately 2.7 percent per year while the less-energy-intensive industries' consumption of energy increased only by 0.2 percent per year. More interestingly, the growth of energy consumption of the energy intensive industries was faster than production.

The second period, 1992 to 1997, is characterized by significantly higher production growth in the less-energy-intensive industries than in the energy-intensive ones. During this period, total industrial energy consumption grew at an annual rate of 1.9 percent, purchased electricity increased by 1.2 percent annually, natural gas increased at 2.5 percent per year, coal declined slightly by 0.3 percent per year, and petroleum increased by 1.5 percent per year. All of these growth rates are much lower than the overall growth rate of industrial production, thereby resulting in a significant decline in overall energy intensity in the sector.

During this period, total energy consumption of the energy-intensive industries increased by 1.8 percent per year while the less-energy-intensive industries' consumption increased by 2.0

percent per year. Although energy consumption growth of the energy-intensive industries is slightly slower than the less intensive ones, these industries combined accounted for 68 percent of the total energy consumption increase during this period. Furthermore, the extremely robust growth in the production of the less-energy-intensive industries (6.4 percent per year) did not drive energy consumption growth at any rate that was close to the production growth rate.

In summary, the level of industrial energy demand is highly dependent on the production levels of energy-intensive industries. The tremendous production growths in the less-intensive industries during the 1992-1997 period, particularly by the computer and rubber industries have not stimulated parallel energy consumption growth. Furthermore, because of the large share of energy consumption accounted for by the energy-intensive industries, growth in total energy consumption in the industrial sector continue to rely heavily on the economic health of the energy-intensive ones.

Impacts of Process Changes on Energy Consumption, 1985 to 1997

Its processes and technologies determine the energy consumption pattern of an industry. The U.S. industry underwent significant process changes from 1985 to 1997. These changes were primarily driven by the growth in secondary processes, environmental regulations, changes in the quality of raw materials, penetration of more efficient processes, and the growth of cogeneration.

Increased Use of Recycled Material

The paper, iron and steel, glass and aluminum industries are engaged in the use of recycled raw materials. In general, the processing of recycled material requires less energy and changes the industry's energy consumption patterns. For this study, the paper, iron and steel and aluminum industries were analyzed.

During this period, the paper industry reported significant growth in the consumption of recovered paper, from 23 percent of total consumption of pulp and other fibrous materials in 1985, to 32 percent in 1994. Recycled pulp has been aggressively replacing semi-chemical pulp, which it directly competes with. The use of recycled fiber requires slightly less energy but is more steam-intensive while the use of semi-chemical pulp is more electricity-intensive. Overall, the increased use of recycled fiber has contributed to the overall improvement of energy efficiency in the industry.

There also has been significant growth in the use of scrap in the iron and steel industry. From 1985 to 1997, the share of electric arc furnace (EAF) steelmaking process, which is the primary steelmaking technology that uses scrap, increased from 34 percent to 47 percent. The main competitor of EAF is the blast furnace/basic oxygen process (BF/BOP) route. The BF/BOP process is direct fuel-intensive while the EAF is primarily run with electricity. The significant growth of the EAF process has spurred the growth of electricity consumption and supported the decline in metallurgical coal use in the iron and steel industry. It is estimated that electricity consumption in this industry grew at an annual rate of 3 percent during this period. Metallurgical coal consumption dropped annually by 2.7 percent.

The aluminum industry also reported increased use of recycled material. During the same period, the share of production using recycled aluminum increased from 26 percent to 37 percent.

Primary aluminum production is one of the most electric-intensive processes in the industrial sector. Secondary aluminum production, on the other hand, requires fossil fuel, primarily natural gas. The impact of growth in the use of recycled aluminum has been the improvement of the aluminum industry's overall efficiency as well as increased natural gas consumption.

Changes in the Quality of Raw Materials

The quality of raw materials can affect the technology requirements within an industry. Thus, changes in raw material quality can result in changes in an industry's energy consumption pattern. This was clearly seen the refining and chemical industries.

In general, the quality of crude oil in the petroleum refining industry has been declining (although a slight increase is observed from 1995 to 1997), with decreasing API gravity and increasing sulfur content.[2] To enable refineries to process the lower quality crude oil, capacities for downstream operations (e.g., thermal cracking, hydrocracking) expanded during the last several years. Downstream operations in the refining industry tend to be more process heat-intensive than steam-intensive and use more electricity than the upstream processes. An important trend resulting from these factors is the significant growth in process heat energy consumption and electricity consumption in the refining industry.

The type of energy feedstocks used in the chemical industry can also affect its energy consumption level. From 1985 to 1997, petrochemical feedstocks (naphtha and other oil) demand grew significantly faster than liquefied petroleum gas (LPG). Although there is no specific documentation that explains the significant difference between LPG and petrochemical feedstocks growths, it is believed that several factors have contributed to this trend. The decline in petrochemical feedstock prices was much faster than LPG's so that the former became very competitive and desirable. Another factor is the tremendous growth in propylene production, which was faster than ethylene and butadiene. It is more desirable to use heavier feedstocks such as petrochemical feedstocks instead of LPG in the production of propylene since the heavier feedstocks produce more propylene. A significant trend resulting from this shift from lighter feedstocks (LPG) to heavier ones (petrochemical feedstocks) is the increased use of energy and steam per unit of output in the industry, as heavier feedstocks tend to require more energy and steam to process.

Response to Environmental Regulations

In certain instances, an environmental regulatory requirement forces changes in industries by requiring changes in technologies and fuel use. From 1985 to 1997, the impacts of environmental regulations were observed in the iron and steel, chemical, refining and cement industries.

The iron and steel industry's coking process has been targeted by EPA to reduce its air pollution. The industry has responded directly by reducing coke consumption in the blast furnace. Hydrocarbon injection in blast furnaces has dramatically increased, and as a result natural gas, coal and oil consumption has increased in blast furnaces, displacing coke.

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[2] Energy Information Administration. *Petroleum Supply Annual.* (various issues).

Environmental regulations can also stimulate demand for certain products, such as the case of MTBE, in which demand for this product increased significantly due to the Clean Air Act Amendment requirements. From 1985 to 1997, MTBE production grew by over 22 percent. This then spurred the growth of methanol demand and production. Subsequently, most of the growth in the demand for natural gas feedstocks was due to increased methanol production.

The EPA requirement to reduce the allowable sulfur content of diesel fuel oil has also affected the refining industry. The increased demand for diesel fuel with low sulfur content resulted in an increase in hydrotreating capacity in the petroleum refining industry. Hydrotreating capacity is also a downstream process, and has therefore also contributed to the growth of process heat and electricity consumption in this industry.

The cement industry has been indirectly affected by environmental considerations. During the last several years, there has been significant growth in the use of hazardous materials as kiln fuel. The high temperature and long residence times in the combustion system have made cement kilns a viable option for the recycle of some hazardous wastes as fuel. As a result, natural gas and coal have lost some of their share to this new fuel source.

Development of More Efficient Processes and Technologies

The U.S. industrial sector has continued to implement new and more efficient processes and technologies. From 1985 to 1997, the iron and steel industry has retired all of its open-hearth furnaces, continued its implementation of continuous casting, and introduced thin-slab casting.[3] An important result of the penetration of thin-slab casting is the further penetration of the EAF and scrap in steel markets that were confined to the integrated steelmakers. An interesting trend related to the EAF is the growth of the use and production of direct reduced iron (DRI). DRI, which is a possible supplement or substitute to scrap in EAFs, has increased the potential of the EAF process to produce steel with less impurities and overall higher quality. Like thin-slab casting, this will most likely allow the minimills to compete in markets that were originally dominated by integrated mills.

The cement industry has also experienced continued penetration of more efficient processes. The industry continues to shift from wet kiln to dry kiln processing. Also, there has been increased capacity of dry kilns with precalcining and preheating equipment. The penetration of these new processes has increased the demand for electricity in this industry.

Response to New Product Demand and Product Mix Changes

Consumer product demand changes can affect the mix of products manufactured in an industry and can therefore affect its technology and energy use. Steam demand in the food industry has declined considerably from 1985 to 1997. This trend was primarily driven by the relatively slow or declining production of the steam-intensive industries in the food sector. On the other hand, the growth in electricity demand in the industry was primarily driven by the expansion of the poultry and sausage industry, as well as the frozen specialty and ice cream sectors.

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[3] Worrel, Ernst and Curtis Moore. 1997. "Energy Efficiency and Advanced Technologies in the Iron and Steel Industry," Proceedings 1997 ACEEE Summer Study on Energy Efficiency in Industry. Saratoga Springs, New York.

The fastest growing pulping technology in the paper industry is the thermomechanical pulping process. This process has continued to displace the stoner and refiner methods. Interestingly, the thermomechanical pulping process has a higher energy requirement per unit of output than the stoner and refiner pulping processes. The successful penetration of thermomechanical pulping is largely due to its production of stronger quality paper without the addition of chemical pulp. This demonstrates that for certain decisions, product quality is provided more weight than efficiency.

PURPA and Industrial Cogeneration

In 1978, the government passed the Public Utilities Regulatory Policies Act of 1978 (PURPA) which required utilities to buy power produced by "qualified facilities." "Qualified facilities" included small power producers that use renewable energy, as well as generators that simultaneously produce electric energy and another form of energy using the same fuel source, called cogenerators.

The enactment of PURPA made industrial cogeneration opportunities more attractive for development as electric utilities were required to interconnect with cogenerators and provide backup generation at reasonable rates. Since then cogeneration has grown faster than any other industrial end-use application and formed two markets of cogeneration. Traditional cogeneration primarily provides steam for industrial processes, but also provides electricity to both the utility grid and on-site. The primary function of non-traditional cogeneration is to generate electricity to sell to the utilities. All the energy-intensive industries, except stone, clay, and glass, are heavy cogenerators and account for the majority of cogeneration capacity. The chemical industry is the largest cogenerator followed by the paper and refining industries. Natural gas is the most popular fuel of industrial cogenerators, and accounted for 137.6 million MWh in 1992. Coal and byproduct fuels are also used for cogeneration but combined account for only 77.0 million MWh in 1992.

The most important outcome of PURPA was the tremendous growth in industrial cogeneration, despite the slow growth of industrial steam demand. According to EEI, from 1985 to 1997, total industrial cogeneration capacity increased from 13.4 GW to 46.3 GW.[4] Electricity generation (from cogeneration) increased significantly from 70,402 GWh to 295,036 GWh during the same period. Natural gas and coal enjoyed the largest growth in electricity generation, each expanding at an annual rate of almost 14 percent from 1985 to 1997. Other fuel (including biomass), grew at a slightly lower rate of 13 percent per year. Fuel oil did not enjoy the growth experienced by coal, natural gas, and other fuel, increasing only by approximately 7 percent per year during the same period.

A peculiar result given the slow steam demand growth is the significant growth in fuel consumption for steam production. Cogeneration has been the source of growth in industrial natural gas and coal demand during the period analyzed. This result was created by the expansion of the non-traditional cogeneration sector. Furthermore, the growth of the non-

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[4] Because industrial cogeneration data for 1985 is not readily available, 1985 data on total cogeneration from the Electric Edison Institute are used instead. The 1985 information is useful in this analysis because in 1985 there was no real significant cogeneration activity from the other sectors (commercial and non-industrial non-utility generators).

traditional sector has shifted some of the energy consumption for electricity generation from the electric utility sector to the industrial sector. Because most of the generated electricity from these cogeneration systems is sold to the grid, the energy savings from cogeneration are not realized in the industrial sector. As such, non-traditional cogeneration has not increased energy efficiency in the sector, but rather, in some cases reduced it.

Conclusions

The results show very important trends and factors that should be taken into consideration when assessing the future of energy consumption in the U.S. industrial sector.

(1) The production levels of the energy-intensive industries are critical to the overall level of industrial energy consumption, as well as overall energy-intensity trends. Therefore, current and future economic conditions of these industries are crucial considerations when assessing future industrial energy trends. However, these industries are very mature and are not expected to experience any huge growth. On the other hand, the less-intensive ones, specifically rubber and computer industries will continue to grow. Therefore, it is expected that over the long-term, industrial energy consumption will not substantially expand and that overall energy intensity (btu/$) will continue to decline.

(2) There are several factors that prompt important process changes and technology penetration in the industrial sector. During the period analyzed, several factors promoted these changes: increased use of recycled material, raw material quality changes, environmental regulations, development of new and more efficient technologies, product demand shifts, and increased cogeneration. Most of these changes have altered energy consumption levels and patterns of many industries. Within some industries, some of these factors did not necessarily increase their energy efficiency as they were more of a response to either new production requirements (e.g., raw material change), consumer demand changes, and energy market transformation (e.g., non-traditional cogeneration). Process changes (and subsequently, changes in energy intensity and consumption) in the future will most likely continue to be driven by these same factors, especially as energy prices are expected to remain at very low levels.

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