

**FINAL SUMMARY REPORT FOR EMF 8:  
INDUSTRIAL ENERGY DEMAND**

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## EMF 8

### INDUSTRIAL ENERGY DEMAND, CONSERVATION, AND INTERFUEL SUBSTITUTION EXECUTIVE SUMMARY

This report documents the results of a project on future trends in U.S. industrial energy demand. Central in the work of the EMF 8 working group was the use of a group of public models of industrial energy demand to project fuel demands for a base case. In addition, a variety of alternative scenarios were examined to investigate the possible effects of the key uncertainties affecting industrial energy demand. Complementing this investigation were analyses of the data upon which the models are based and comparisons of industry practice with the models' operation and projections. Through this process, insights were gained about the strengths and limitations of the specific modeling efforts included in the study and, perhaps more importantly, about the likely level and composition of industrial energy demand in the years ahead.

Industrial energy demand is affected by a large number of factors, most of which are not controllable by any one individual or group. Energy prices have been erratic since the 1973-1974 Arab oil embargo. The economy has been marred by several recessions in recent years. Consumer tastes for industry's output are constantly changing and foreign competition provides challenges in world markets once dominated by American products. Technological innovations in the production of all types of commodities constantly appear. OPEC production policies are the major determinant of crude oil prices, but changes in U.S. industrial demand strongly influence the complicated and lengthy adjustment of oil product, gas and electricity prices to major changes in crude prices. Moreover, these demand adjustments ultimately feed back to OPEC production and pricing policies.

An examination of industrial energy demand is important because nearly 40 percent of total energy consumption in the United States takes place in the industrial sector. Many studies of industrial energy consumption have focused exclusively on purchased energy used for heat and power in manufacturing. However, these uses account for less than half of total industrial use; the balance is used as materials and feedstocks (about 30%), in the agricultural, construction, and mining industries (about 15%), and as self-generated refinery fuels (about 10%).

Each Energy Modeling Forum study focuses on a set of policy and analysis issues. A study of these issues enables the working group to assess the capabilities of the models included in the study in relation to one another and to real-world evidence. Three issue areas were particularly prominent in the work of the EMF 8 working group: sectoral shift, technology trends, and fuel choice. Before discussing results in these issue areas, however, we note several general trends that emerge from the application of the models to the study scenarios:

- The models project that energy use per unit of industrial output will continue to decline through 2010. This trend is apparent in the results from all the models for all scenarios. Energy use per unit of output is projected to decline by .5 to 1.5 percent per annum from 1985 to 2010. The explanations for this trend are a shift towards the production of less energy-intensive goods, the further penetration of new technologies that are more productive in the use of all inputs, and a continuation of the gradual adjustment to the rapid energy price increases of the past 15 years. The much lower energy prices that emerged in 1986 may retard the last trend, but will not significantly slow the other two.
- Despite this trend towards reduced energy consumption per unit of output, growth in industrial output over the next two decades is expected to result in a modest increase in total industrial energy demand over that time period. Energy use for heat and power in by industry is projected to grow by 1 to 2 percent per year from 1985 to 2010, or by about 40 to 80 percent of the rate of growth of industrial output.
- The rate of growth of industrial energy demand in the future depends as much on the projected level of total industry output and the projected mix of energy-intensive and non energy-intensive goods produced as on projected energy prices. The adjustment in total energy use per unit of output to changes in energy prices tends to evolve over a long period of time. In addition, long-term trends towards less energy intensive products and towards more efficient use of all inputs in producing those products continue somewhat independently of changes in energy prices, up or down.

- Data and analysis on the use of energy by the agriculture, construction, and mining industries, and for feedstocks in the manufacturing industries is very sketchy. This leads to great uncertainty concerning future trends in the demands for fuels for these purposes. Since a great deal of feedstock consumption occurs in the chemicals industry where literally thousands of products are produced, different assumptions about the growth rates of the demand for these individual products can lead to dramatically different projections of feedstock requirements. In the recent past the depletion of oil and gas reserves has led to more energy use per unit of output for mining, and electricity use for irrigation in the agricultural sector has grown dramatically. In the future, events in the mining and minerals, agriculture and chemicals industries may change these trends in one direction or the other.

In addition to these general trends in model results, conclusions were drawn in each of the three specific issue areas.

#### SECTORAL SHIFT

- Compositional changes in economic output (sectoral shift) from more energy-intensive to less energy-intensive industries have been important contributors to reductions in energy use per dollar of output in the post-embargo period. Alternative methods for measuring the sectoral shift effect lead to somewhat different results regarding its importance. However, application of the generally preferred methods indicate that even at the 2-digit level of industrial classification this effect accounts for about one-third of the change in the energy-output ratio and well over one-half of the change in the electricity-output ratio since 1973. The more disaggregation, by industry or product, the more the change in energy use is explained by compositional changes.
- It is not known how much of this sectoral shift was caused by higher energy prices or to what extent it will continue in the future.
  - The Wharton sectoral output projections used in the EMF 8 study design show a continuing sectoral shift trend towards less energy-intensive industries that does not appear to be very

sensitive to alternative energy prices, when GNP and interest rates are held constant. Results from the Wharton model and a recent EIA study both show industrial mix considerably more sensitive to changes in GNP growth rate than to changes in oil prices.

--This result regarding the effects of gradual increases in energy price on the structure of the U.S. economy is consistent with the strong correlation observed during the 1970s. During that decade the effect of sudden increases in energy prices may well have had significant indirect effects on the structure of the economy through the rise in interest rates and accompanying slowdown in capital accumulation that they initiated.

## TECHNOLOGY TRENDS

- Electricity use by industry is projected to increase more rapidly than its use of fossil fuels. However, the engineering process models project a gradual decrease in electricity use per unit of economic output (about -1% per year), while the econometric models show a gradual increase (about +1% per year). The econometric models assume that post-embargo trends in the dependency of electricity use on fuel prices and output growth will continue into the future. The process models explicitly represent individual electricity-using technologies; thus, they can account for saturation effects which could keep electricity growth rates below historical levels, but they may not represent all future electricity-consuming technologies or subtle process/product shifts towards greater or less electricity use.
- Further penetration of cogeneration in the industrial sector would result in more electricity used than purchased by the industrial sector. While such penetration depends on a host of regulatory, institutional, and business strategy issues, scenarios involving increased cogeneration are possible. Thus, purchased electricity per unit of industrial output will, in fact, be less than electricity consumption in industrial processes. Similarly, if some cogenerated electricity is sold to utilities, this extra source of electricity could also augment central electric generation in the decades to come.

- There appear to be important differences between models in the projected decline in the energy-output ratio within major industrial sectors (intrasectoral adjustments). Changes in energy intensity within each industry group can be further disaggregated into changes in the mix of products produced, changes in the processes employed to produce those products, and changes in the equipment and maintenance procedures employed to implement those processes. In general, equipment selection and maintenance procedures are more sensitive to energy price changes than product mix and process selection.
- The penetration of new technologies can be important for explaining the decline in the energy-output ratio. Several individual technologies can be identified as being important contributors to this result: cogeneration has already been mentioned; in addition, the introduction of new electricity-based technologies in the metals industries and advanced process technologies in the paper and chemicals industries appear to be important.
- Computers (part of the durable goods industry) provide a vivid example of new products which provide greater value relative to all costs of production, including energy. The historical reduction in energy intensity has been greatest precisely in those industries (durable goods and chemicals) known for this type of innovation.

## FUEL CHOICE

- In the near term, the most intense interfuel competition is between oil and gas.
  - Most existing dual-fired capacity is oil-gas, with relatively low associated capital costs. Currently, gas is in standard use.
  - There is a potential for greatly increased oil use in the industrial sector in the medium-to-longer term if relative oil prices are low, although there are indications that many users may not switch from gas to oil as rapidly as aggregate fuel price data indicates.

- In the longer term, oil/gas compete with coal and electricity, depending on the application. Several general trends in long-term fuel shares emerge from the model results:
  - All the models show a trend toward greater use of electricity by industry due to electrification automation etc.
  - There is a gradual shift away from natural gas due, in part, to the high relative price of gas assumed in the Reference case, and to the tendency of gas to compete well in industries that are projected to grow less rapidly than the industry average, e.g., chemicals, steel and refining. In many industries emerging electric technologies are projected to replace gas-fired processes.
  - The engineering process models show significant market penetration for coal, which is sensitive to assumptions about cogeneration economics and the evolution of clean coal-burning technologies. The other models show slower growth in coal shares, limited by economies of scale and a slow buildup of experience using coal.
  
- The models included in this EMF study cannot be used to study dramatic jumps in energy prices without external information/analysis regarding the effects of these shocks on the overall economy.
  - The most important effects of energy price shocks may be their impacts on savings rates, inflation, and economic output, which are not explicitly represented in these models.
  - Some of the models use 5-year time periods which does not allow for a detailed representation of the macrodynamics of energy shocks.

## DATA ISSUES

The Data Issues Group included experts on data availability and quality from industry, government, and academia. The Group recommends that serious consideration be given to collecting the following industrial energy-related data.

- An annual establishment-level database on energy consumption and expenditures for the manufacturing sector. This data should be integrated into the Census Longitudinal Establishment Data file (LED), as it was for 1972-1981, and be made available to analysts under the

Census LED-usage procedures. The Energy Information Administration (EIA) should be encouraged to expand the establishment-level Manufacturing Energy Consumption Survey (MECS) so that it has a coverage level and periodicity similar to the data contained in the discontinued Annual Survey of Manufactures "Fuels and Electric Energy Consumed" survey. The sample should be broad enough to allow the data to be published at the 4-digit Standard Industrial Classification (SIC) level by state and Standard Metropolitan Statistical Area (SMSA) and at more aggregate levels.

- The MECS should also be extended to include data on costs, operating characteristics, and the utilization of other energy-related technologies. This extension should be along the lines of the 1980 EIA combustor survey, modified to reflect the concerns that led to the study's termination.
- A study should be undertaken on the appropriate industrial energy-related data to be collected by the public sector, with the remaining data being collected by the private sector. At a minimum, the public sector should provide benchmark data on industrial production and energy consumption.
- Private groups that collect micro-level data on manufacturing production, energy consumption, etc. should be encouraged to provide public-use sets of their information for specified research projects.
- Public-use files of government micro data bases should be developed.
- EIA and other agencies (e.g., the National Research Council, the National Academy of Engineering) should develop two additional sets of information.
  - Develop a source book on the costs, operating characteristics, and standards to evaluate new energy-related technologies likely to have a significant effect upon energy use over the next 25-50 years.
  - Develop or expand existing surveys of energy consumption and technology data for the nonmanufacturing portion of the industrial sector (agriculture, construction and mining).

## USERS PERSPECTIVE

The Energy Users Group included representatives of large industrial energy consumers: Chemical, paper, steel, refiners and electric utilities. Based upon a review of the results produced during the EMF 8 study and a better understanding of the models' behavior, the Energy Users Group concluded:

- o The energy-consuming industry uses various models to gain insights as part of corporate planning forecasts.
- o The specific models reviewed in EMF 8 cannot be used to make management decisions on capital expenditures, conservation steps, or fuel switching.
- o The EMF 8 models can provide useful insights to be considered along with labor, capital cost, and other factors.
- o The differences noted in the results projected by the EMF 8 models using the same input parameters indicate the vulnerability in using any one model to project industrial energy demand.
- o Energy models are only as realistic as the underlying assumptions, structure, and data.
- o To be viable energy data must be collected on a consistent basis over a number of years, focus on consumption rather than method of use, and the collection method must guarantee confidentiality.
- o In contrast to the members of the Data Issues Group most members of this group are opposed to sweeping data collection surveys by multiple governmental agencies.
- o Nearly all industrial users and industrial trade associations have opposed the MECS survey and would certainly oppose any expansion of that survey. Trade association opposition has included the chemical, iron and steel, paper, glass, textile, petroleum, automotive and cement and rubber industries. The cost of preparation, the proprietary nature of energy data and the lack of

offsetting benefits to the companies involved are the key reasons for industrial opposition.

- The personal contacts established during the EMF 8 working sessions among the modelers, model users, energy users, energy producers, and EMF staff should provide a network for the informal exchange of information which should lead to improved results in future modeling efforts.

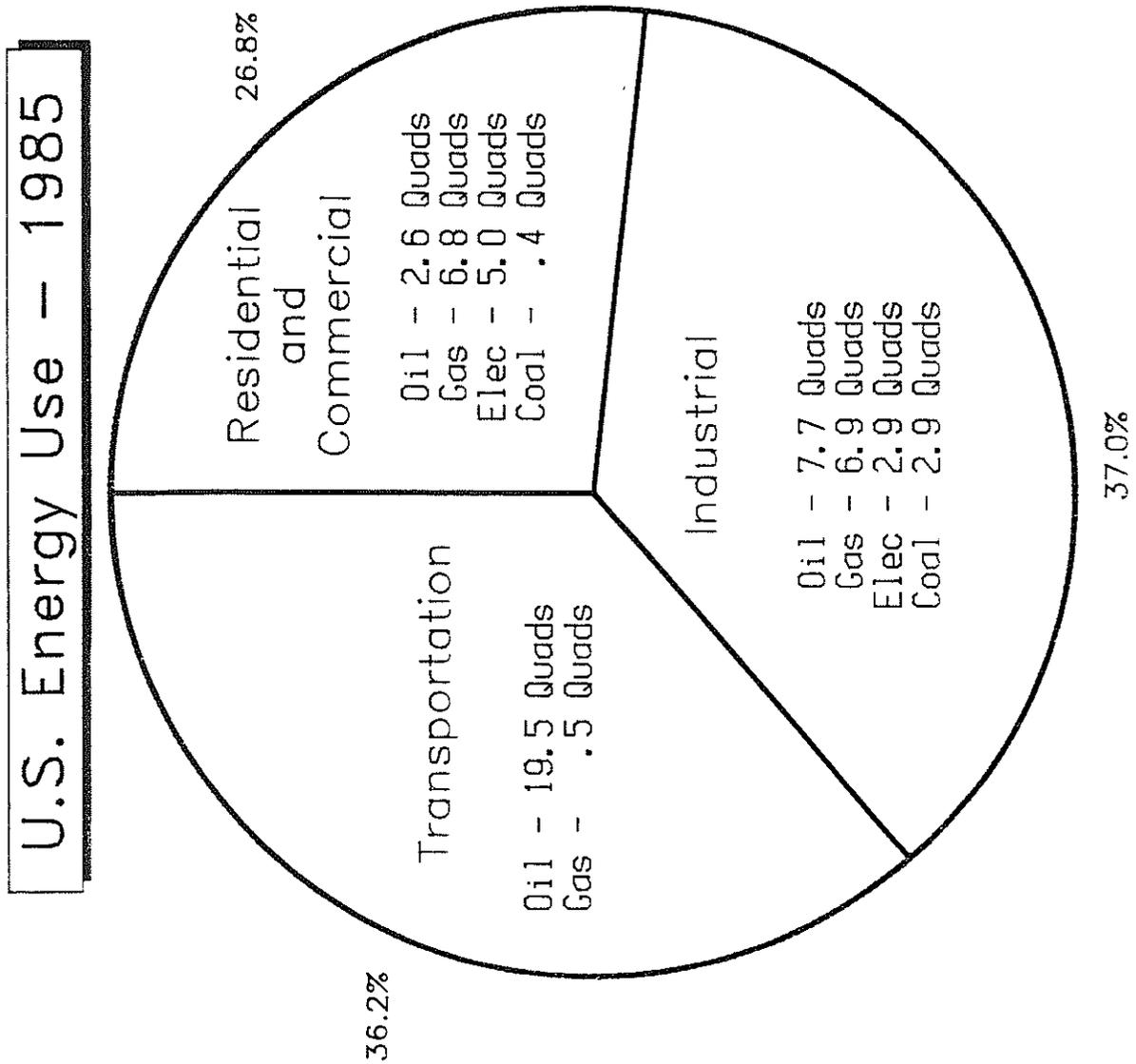
## INTRODUCTION

The demand for energy by U.S. industry plays a critical role in determining fuel prices in oil, gas, and electricity markets. OPEC oil production policies are the single most important determinant of crude oil prices. However, changes in world oil demand have been significant unexpected sources of change in OPEC's capacity utilization, a major determinant of its production and pricing policies. Moreover, changes in fuel consumption patterns by U.S. industry drive the fluctuations in the prices of other fuels that occur over their long adjustment to changes in crude oil prices. The oil price collapse of 1986 has again lead to dramatic changes in all fuel markets, making it even more important to reexamine trends in industrial energy use.

Industrial energy demand projections are of great interest to a variety of planners. Capital investment decisions are often based in part on energy prices which in turn are affected by total energy demands. Energy suppliers choose production and pricing strategies by considering customers' demands. Government energy policies depend on estimates of future energy demands and the impacts that regulations will have on the economy.

Although making accurate industrial energy demand projections is important, it is not easy. Industrial energy demand is affected by a large number of factors, most of which are not controllable by any one individual or group. Decisions on energy-related investments - like any other corporate investment decisions - can depend as much on financing considerations and the state of the economy as on expected energy prices. However, the sheer magnitude of the industrial sector's energy consumption

Figure 1: U.S. Energy Consumption by End Use Sector - 1985



insures its central role in determining future fuel prices, even if energy prices are not the most critical determinant of its energy use. In 1985 the industrial sector used approximately 20 quadrillion Btus of direct fuel, electricity, and fossil fuel feedstock, nearly 40 percent of all energy consumed in the United States (see Figure 1). And this 40 percent figure significantly understates the role of the industrial sector in U.S. energy demand because a large part of the commercial sector provides services to industry, and a significant share of the transportation sector is devoted to the transportation of industrial supplies and products.

Both energy prices and economic growth have been erratic since the 1973-1974 Arab oil embargo. Fundamental innovations in the production of all types of commodities appear literally overnight in this era of high technology and increased international competitiveness. Foreign competition provides challenges in world markets once dominated by American products. These and other factors are important determinants of U.S. industrial energy demand. Uncertainties in these areas make projecting industrial energy demand a difficult challenge.

The EMF 8 project examined these issues and their implications for industrial energy demand through a study of models of industrial demand currently in use. These models represent the state of the art in aggregate projections of future energy demand. The methodologies employed in these models include econometrics, input-output analysis, and process analysis. Projections derived from a standardized base case and a variety of alternative scenarios were used to examine the possible effects of the key uncertainties affecting industrial energy demand. Through this process, insights were gained about the strengths and limitations of the specific

modeling efforts included in the study and, perhaps more importantly, about the likely level and composition of industrial energy demand in the years ahead. A range of possible energy/technology futures was examined by dealing explicitly with the uncertainty about factors affecting future industrial energy demand. Contingency planning is facilitated when these uncertainties are recognized and allowance is made for them in making investment decisions. Ultimately, this process can lead to a better appreciation of the forces governing industrial energy demand and to better energy policies.

In addition to the standardized model comparisons, this EMF working group pursued three topics related to the use of analysis in the study of industrial energy use trends: (1) the appropriate use of models by corporations involved in producing or consuming energy; (2) the availability and appropriate use of data on industrial energy use; and (3) the impact of the changing structure of the U.S. economy on the use of energy by U.S. industry.

## OVERVIEW OF U.S. INDUSTRIAL ENERGY USE

In 1985 U.S. industry purchased 9.6 quadrillion Btus (quads) of fuels for heat and power in manufacturing out of a total of 20.4 quads of industrial energy use; the difference being comprised of 2.8 quads of energy use in agriculture, construction, and mining, 6.1 quads in raw materials and feedstocks, and about 1.9 quads of self-generated fuels used in refineries. Figure 2 shows the breakdown of total industrial energy use according to these basic functional use categories.

Most data collection and modeling efforts concerning energy use in the industrial sector have focused on the analysis of energy purchased for heat and power in manufacturing. The manufacturing heat-and-power sector tends to dominate the use of gas and electricity in industry and it is here that the competition amongst oil, gas, coal, and electricity is most intense; in recent years, however, oil consumption has been concentrated outside of this sector. Table 1 shows the breakdown of fuel use in 1985 within each of the four aggregate fuel use categories identified in Figure 2. EIA's Annual Energy Review 1985 shows 6.6 quadrillion Btu of oil use in industry in 1985, of which only 1.0 was for purchased heat and power in manufacturing and only 0.4 of that for residual oil (i.e., boiler fuel and the like). Thus, to project oil demand and oil market conditions, it is especially important to focus on the demand for energy in the agriculture, construction, and mining industries, as well as on the demand for chemical feedstocks.

Primary data from the Census Bureau, the Department of Agriculture, the Energy Information Administration, and the Bureau of Mines shows a trend towards increasing use of energy per unit of output for agriculture,

Figure 2: Industrial Energy Use - 1985

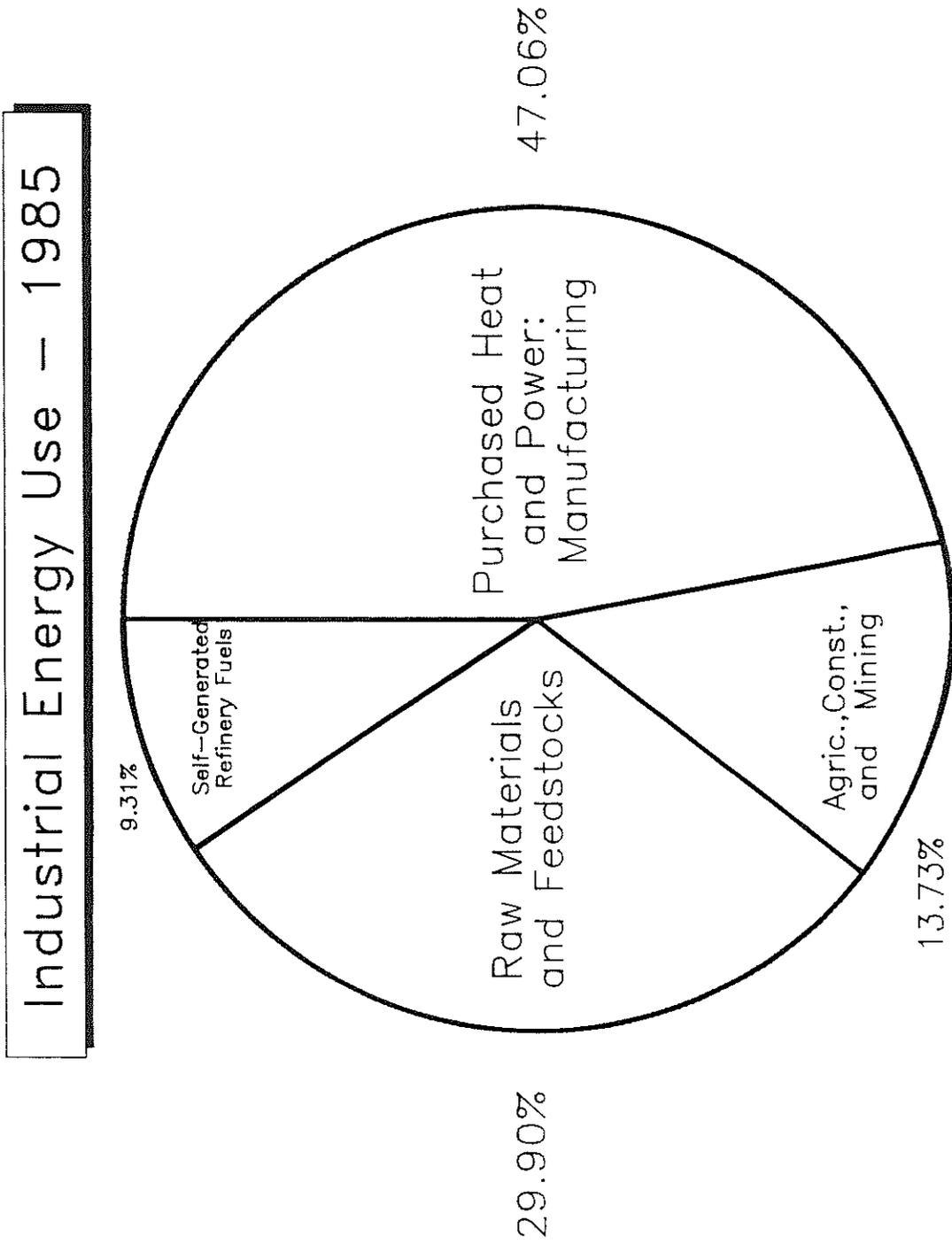


Table 1  
 Industrial Fuel Demands - 1985\*  
 (Quadrillion Btus)

	<u>Petroleum Products</u>	<u>Natural Gas</u>	<u>Coal</u>	<u>Purchased Electricity</u>	<u>Self- Generated Fuels</u>	<u>Total</u>
Heat and Power Manufacturing	1.0	4.5	1.7	2.4	1.9	11.5
Feedstocks	4.4	.6	1.1	-		6.1
Agriculture, Construction, and Mining	1.2	1.0	.1	.5		2.8
TOTAL	<u>6.6</u>	<u>6.1</u>	<u>2.9</u>	<u>2.9</u>	<u>1.9</u>	<u>20.4</u>

\* Preliminary estimates.

construction, and mining over the last decade. The energy-output ratio has been constant in two areas, crop drying and quarrying. This is what one might expect, since there has been little depletion of stone and gravel, and no diminishing returns problems with crop drying. On the other hand, in oil and gas production--an important part of the mining sector--the need for more and deeper drilling to sustain existing production has lead to an increase in fuels used by drill rigs and related equipment. In addition, electricity use in irrigation has been growing exponentially.

Fuel use for raw materials is also important. A quad is used for metallurgical coal. This is generally expected to decrease, because of the switch to electric-based technologies in the steel industry. Most of the rest is for oil and natural gas liquids, including about 3.0 quadrillion Btus of petrochemical feedstocks in 1985.

About two quads of self-generated fuels (mostly still gas) were used in U.S. refineries in 1985. In addition to these self generated fossil fuels, a significant quantity of biomass and waste products were used as fuels. In the paper industry (SIC 26), a very energy intensive industry, about half of the energy consumed was waste pulping liquor and biomass, both of which are by-products of the raw materials (mostly wood) processed in the industry. These non-fossil fuels are omitted in Figure 2 and Table 1.

## HISTORICAL TRENDS IN INDUSTRIAL ENERGY USE

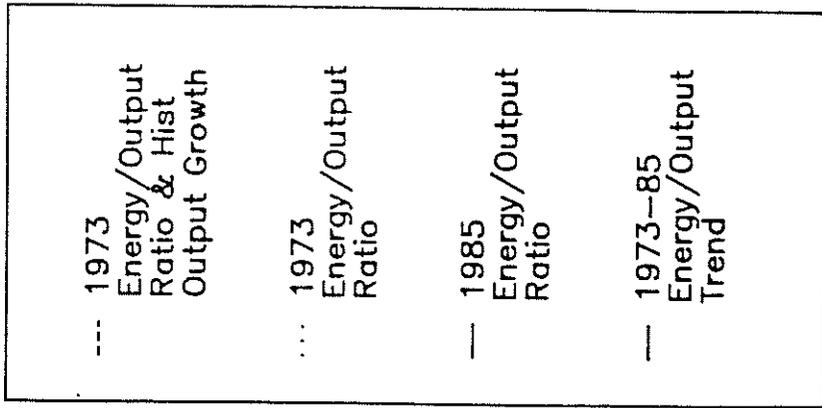
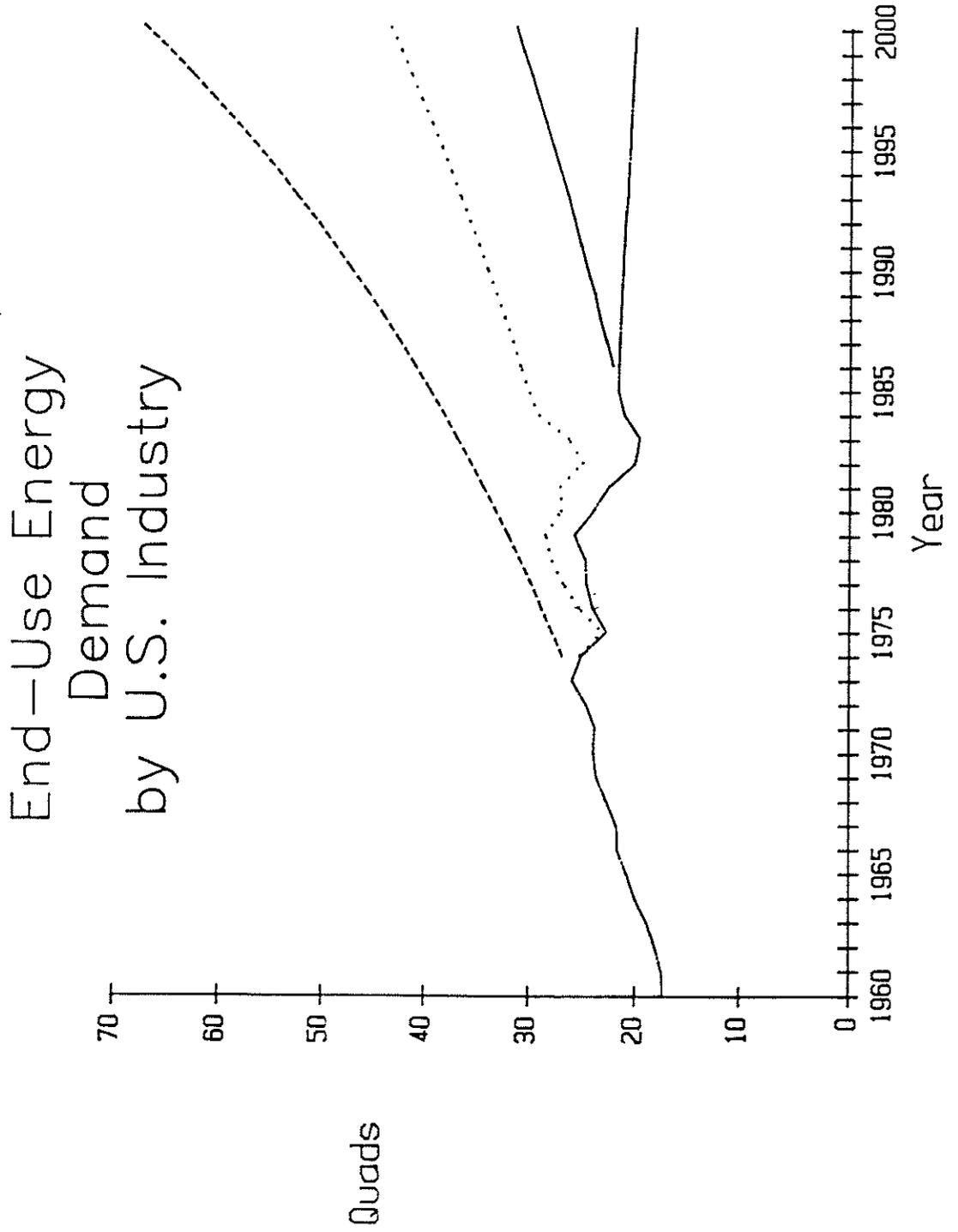
Past trends in energy use by U.S. industry provide a useful benchmark for any attempt to project future trends. Figure 3 shows actual end-use energy demand by U.S. industry from 1960 to 1985 as well as four trend extrapolations through the year 2000.

Industrial end-use energy demand grew from 17 quadrillion Btus in 1960 to 26 quadrillion Btus in 1973, an average annual growth rate of 3.1 percent. During this period real industrial output grew at an average annual rate of 3.6 percent per year, so end-use energy per unit of output was declining very slowly at about .5 percent per year. Had these trends continued end-use energy demand by industry would have reached nearly 40 quadrillion Btus by 1985 and over 60 quadrillion Btus by the year 2000.

Part of the reason that actual energy demand growth slowed between 1973 and 1985 was that industrial output grew much slower during that period than during the sixties and early seventies. In fact, real output grew at only 1.4 percent per year from 1973 to 1985 compared to its 3.6 percent annual growth rate between 1960 and 1973. Figure 3 shows that with actual output growth and the energy output ratio fixed at its 1973 level, industrial demand for end-use energy demand would have reached approximately 30 quadrillion Btus by 1985. In addition, if real output grew at 2.5 percent per year from 1985 to 2000 after reaching 30 quadrillion Btus in 1985, demand would reach 44 quadrillion Btus by 2000.

As shown in Figure 3, actual end-use energy demand by U.S. industry fell from 26 quadrillion in 1973 to 20.4 quadrillion Btus in 1985, an average annual decline of 2.0 percent per year. With output growth at 1.4

Figure 3: Industrial Energy Use Trends



percent per year, this implies a 3.4 percent reduction in the energy-output ratio during the post-embargo period.

Two additional trend extrapolations based on a 2.5 percent growth in real output between 1985 and 2000 are shown on Figure 3. In one, the 1973 to 1985 reduction in energy output ratio of 2.9 percent per year continues yielding a further reduction in energy use to 20 quadrillion Btus by 2000. In the other extrapolation, the energy-output ratio is fixed at its 1985 level so energy demand grows at 2.5 percent per year reaching 31 quads by 2000.

None of the four trend extrapolations shown in Figure 3 represents a forecast of the future. They do, however, provide a useful perspective on future energy use. If energy use per unit of output continues its 1973-85 trend despite much lower energy prices, industrial energy demand will decline gradually between now and the end of the century unless output growth is 3 percent or greater. Alternatively, if the energy-output ratio of the average piece of energy-using equipment installed between now and 2000 is equal to the average energy-output ratio of all equipment in use in 1985, end-use energy by industry will grow at the same rate as real output; if real output growth is 2.5 percent, end-use energy demand will grow at 2.5 percent as well.

The two extrapolations on the top of Figure 3 provide additional benchmarks. First, if the energy-output ratio returns to its 1973 level (and real output grows at 2.5 percent), then end-use energy demand would grow at 4.8 percent per year. This is a projection that is consistent with prices returning permanently to their pre-1973 level and an assumption of full symmetry of the response of energy demand to lower prices with respect

to its response to higher prices. In other words, this trend would result if prices return to their pre-1973 level for a long period of time and all technology and product mix decisions revert to those made in that year. Finally, the top line shows that if the economy were able to achieve its old long run potential growth rate, if there were full symmetry in price responsiveness and if prices fell to their pre-1973 level, then a 6.9 percent annual growth rate in end-use energy demand would result. To a significant degree, the analysis of industrial energy use centers on determining which of these historical trend extrapolations will prevail in the future.

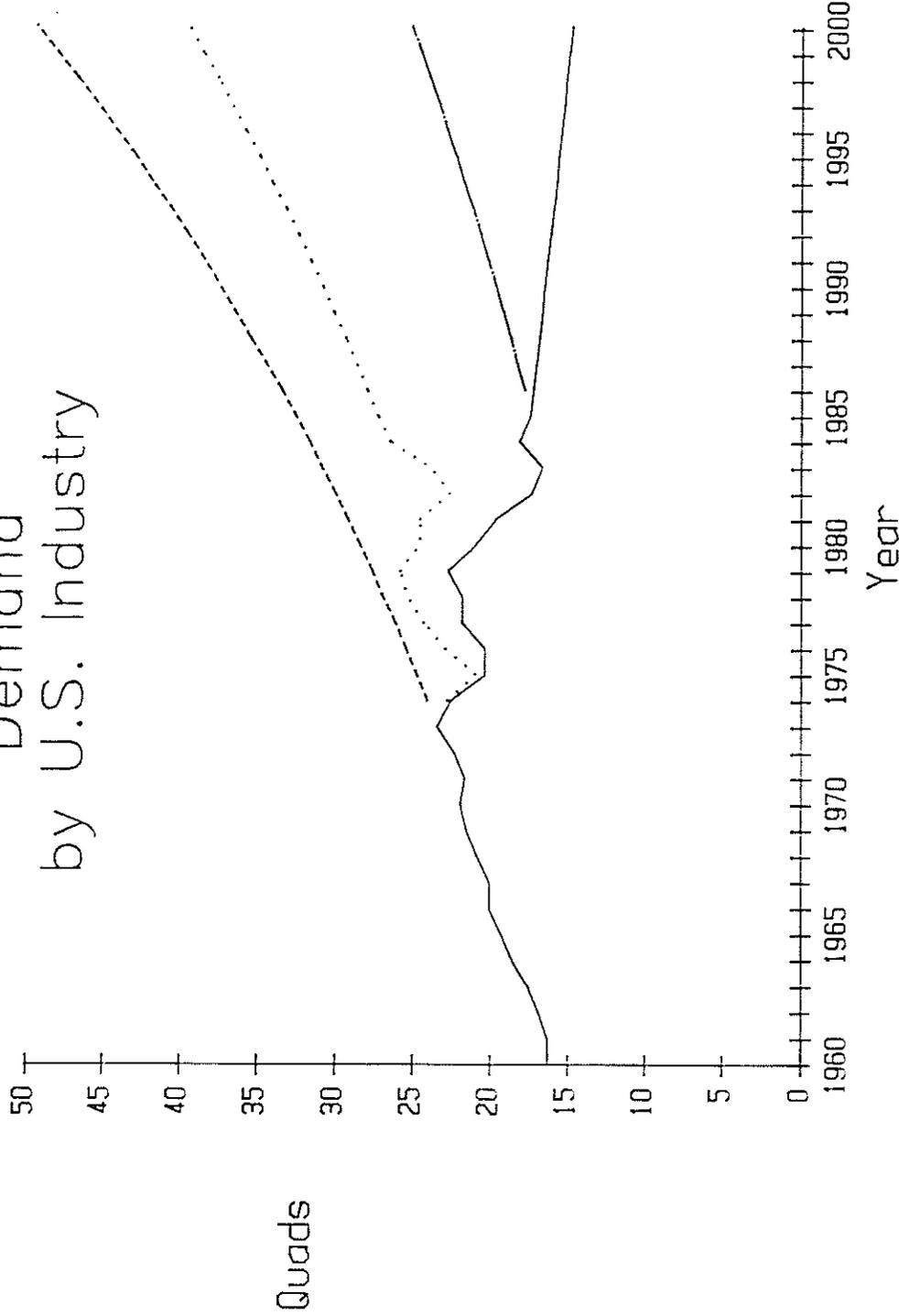
Although the aggregate trends shown in Figure 3 are interesting, differential trends in the use of the individual energy fuels--oil, gas, coal, and electricity--can lead to some distortion in their interpretation. Part of the reduction in energy use over time represents shifts from lower to higher valued fuels like shifts from coal to oil and gas, or oil and gas to electricity. Higher valued fuels have a higher value because they are worth more in producing products that consumers value; if they were not worth more in production, no one would pay a higher price for them. One solution to this problem is the use of economic indices for energy prices and quantities, where the quantity of each fuel is weighted by its relative value in computing an adjusted aggregate quantity measure. Despite its theoretical attractiveness, results derived using this method can be difficult to grasp. Furthermore, since the most important trend to capture in analyzing industrial energy use is the trend from fossil fuel to electricity use, trends in these two types of fuels can be examined separately as a compromise between straight Btu aggregation and economic indexation.

Figures 4 and 5 repeat the framework developed in Figure 3 for fossil fuel and electricity use, respectively. Fossil fuel use grew at 2.8 percent from 1960 to 1973, implying a decline in the fossil fuel-output ratio of .8 percent per year. From 1973 to 1985, fossil fuel use declined at an average rate of 2.2 percent per year, implying a 3.6 percent per year reduction in the fossil fuel to output ratio. These trends are similar to, but more pronounced than, the total end-use energy demand trends.

The historical trend in electricity use departs significantly from the total energy and fossil fuel use trends. As shown in Figure 5, electricity demand grew at 5.9 percent from 1960 to 1973, implying an increase of over 2.0 percent per year in the electricity-output ratio. And from 1973 to 1985, electricity demand grew by an average of 1.7 percent per year, implying a .3 percent per year increase in the electricity-output ratio. A comparison of the historical trends in Figure 4 for fossil fuels with that in Figure 5 for electricity reflects the steady increase in the market share of electricity in total energy use that has taken place over both the pre- and post- embargo periods. This comparison suggests that future trends in energy use can be usefully disaggregated into trends in electric and nonelectric energy consumption.

Figure 4: Industrial Fossil Fuel Use Trends

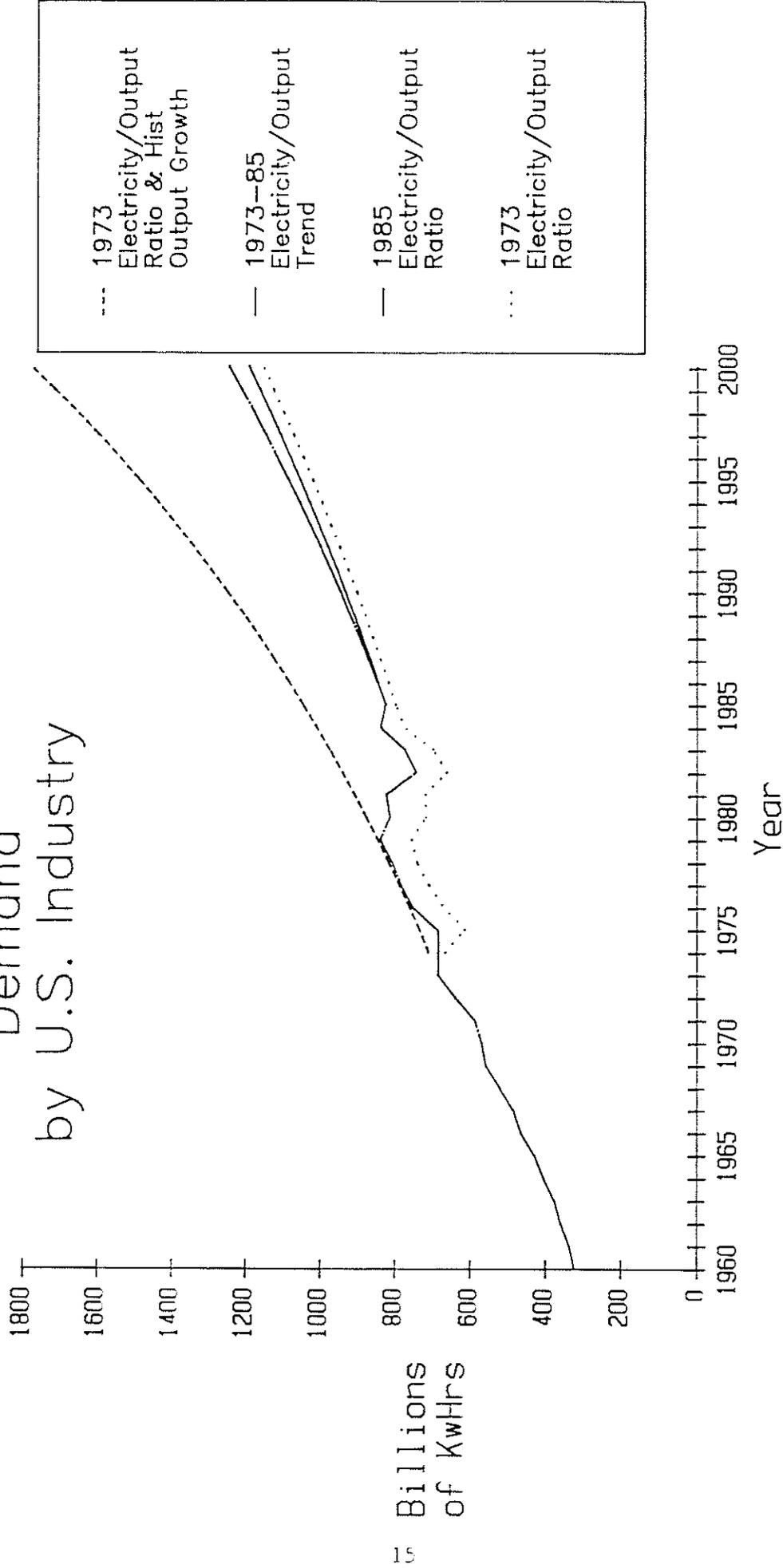
# Fossil Energy Demand by U.S. Industry



--- 1973 Fossil Energy/Output Ratio & Hist Output Growth  
... 1973 Fossil Energy/Output Ratio  
— 1985 Fossil Energy/Output Ratio  
— 1973-85 Fossil Energy/Output Trend

Figure 5: Industrial Electricity Use Trends

# Electricity Demand by U.S. Industry



## ISSUES IN INDUSTRIAL ENERGY DEMAND ANALYSIS

Each Energy Modeling Forum study focuses on a set of policy and analysis issues. By studying these issues, the working group can assess the capabilities of models and other methods of analysis in relation to one another and to real-world evidence.

The specification of a reference case for the model comparisons is an important task in the design of the study. Equally important is the choice of the most important uncertainties to examine via alternative model runs. The issues that cannot be credibly examined with the existing set of analytical tools must also be identified. In this study, the most important uncertainties were felt to be:

### Fuel Prices

Considerable uncertainties on the supply and demand sides of the markets for individual energy fuels makes fuel price forecasting a precarious occupation at best. Yet industrial energy demand does seem to be influenced by total energy costs as well as relative fuel prices. This makes it imperative to study the sensitivity of industrial energy demand to changes in fuel prices.

### Fuel-Switching Capability

In both the short and long run the ability of a particular industry to use alternative fuels will exert a significant influence on how the demands for individual energy fuels respond to changes in their relative prices. In the short-run, the degree of switching will be dictated by the characteristics of the equipment in place. In the long term more flexibility is generally available as industries may switch processes.

### Cost of Capital

The role of the prices of other inputs (i.e., capital, labor, materials) in energy investment and use decisions represents another dimension to the problem of understanding past trends in industrial energy demand and projecting future ones. Many decisions on investments in energy-consuming capital equipment depend as much on the cost of capital as on the price of energy. Thus, it is important to determine the sensitivity of projections of energy consumption by industry to variations in the cost of capital.

### GNP and Economic Growth

The rate of growth of the economy can have a significant impact on future fuel demand trends. On the one hand, if the economy is growing rapidly there will be more demand for investment goods, which are generally more energy intensive. On the other hand, in a rapidly growing economy there is a larger fraction of the total stock of energy-using equipment that is new. As a result, there is a more rapid adjustment of average energy use per unit of equipment to changing conditions in energy or capital markets. If the marginal rate of energy use per unit of output is falling (because of higher prices or technological advances), then rapid growth will lower the average rate of energy use per unit of output within each industry faster than slower growth. It is particularly important to capture such counterbalancing effects when economic growth rates and energy prices are changing as dramatically as they have over the past fifteen years.

### Product Mix

Recent research has shown that a significant amount of the reduction in energy use per dollar of output produced by industry can be attributed to shifts in the mix of products produced rather than reductions in the amount of energy used to produce each product. Furthermore, shifts in the production of energy-intensive products between the United States and foreign producers have had a large influence on domestic industrial energy consumption. This effect has been particularly evident in the cement and steel industries.

### Technological Change

Changes in technology can significantly influence fuel use by providing alternative ways to combine inputs in the production of a particular product. The potential effects of these changes must be assessed in any attempt to understand the future of industrial energy demand. Technological changes which allow substitution of solid fuels (low cost) for oil and gas (higher cost), such as gasification and fluidized-bed combustion are an issue for modeling.

### Utility Boiler Emissions Restrictions

Restrictions on electric utility and industrial boiler emissions motivated by environmental concerns like acid deposition can have a major impact on industrial fuel use. From the point of view of major industrial energy users, such regulations can lead to higher electricity rates and to a higher cost for the direct combustion of coal. Thus, both electricity and coal consumption by industry, as well as the consumption of alternative fuels, can be significantly affected by environmental regulations

## MODELING INDUSTRIAL ENERGY USE

The diversity of U.S. industries and the variety of uses of energy by each industry complicates the task of analyzing industrial energy demand. Several approaches for dealing with this complexity have been developed over the past decade or so, but they all fit into a single framework drawn from modern microeconomics.

Each approach starts with a breakdown of the industrial sector by industry group. This choice is generally dictated by the availability of data, the computational constraints inherent in the chosen methodology, and the model designer's judgement about how much disaggregation is required for a particular set of applications of interest.

Once an appropriate level of disaggregation of the industrial sector has been chosen, a way of determining the output of each "industry" must be developed. Generally, the demand for the output of each industry is supposed to depend on some measure(s) of economic activity (e.g., population, income, the outputs of other industries) and on the price of the output of the industry. In addition, changes in the composition of overall industrial output have had major impacts on the amount of energy consumed per unit of aggregate output, as will be argued later in this report.

Once output by each industry is projected, the level of output that can and should be produced from each vintage of capacity must be estimated, together with the amount and type of the new production capacity.

In terms of analyzing energy (and other input factors, e.g., capital, labor, and materials) demands by industry, the choice of equipment in new production capacity is central. The long life and high cost of energy using equipment (particularly by the most energy-intensive industries) generally means that it is easier to change the mix of factors (including energy) used to produce a particular product "ex-ante" before new equipment is installed than "ex-post" when it has already been put in place. Subsequent investments can be made after the new equipment has been installed, but these tend to be costly relative to buying new equipment with the same factor use characteristics. In fact, when factor prices change dramatically enough, it is sometimes better to shut down old capacity before it is physically obsolescent because of the unfavorable economics (economic obsolescence).

The key to a model's representation of the new capacity investment decision is the specification of the technological menu it includes, and how that menu changes over time due to advances in technology. Also important is the way the model represents the choice of technologies from those available. This is sometimes done in a way to simply minimize the cost of providing output, but other factors (e.g., experience with this type of technology, flexibility in adjusting inputs in response to sudden changes in factor prices, etc.) can be incorporated.

Once the new production capacity has been selected and the output from all vintages of equipment (capacity utilization) determined, total factor use (including energy) by the industry is obtained by adding together the factor requirements of all equipment vintages in operation. In reality, decisions on input factors, technology choice, and output supplied are made

simultaneously, but in a modeling approach equilibrium solutions are often obtained iteratively by sequentially updating input demands until the implied output prices clear their markets.

All of these steps (and more) are carried out by industrial energy consumers. Consequently, they must be dealt with in some way (explicitly or implicitly) in any attempt to analyze industrial energy demand. In the present study, projections of industry outputs at the 2-digit Standard Industrial Classification (SIC) level from a single model are employed (although these are put in broad historical perspective and alternative cases are considered). Thus, most of the model comparisons discussed here focus on different ways of representing the effect of product choices, technological change, and technology choices on energy demand within each industry group.

## **MODELING METHODOLOGIES**

A number of different methodologies have been employed by the architects of the models represented in EMF 8. Four different types of models have been developed: process models, econometric models, input-output models, and hybrid models.

### Process Models

Since future energy demands are strongly influenced by the choice of available technologies, the main feature of a process model is a competition, based on cost minimization, between technologies for market share. The main inputs for each model run are projections of the gross output for each industrial sector and fuel prices. The model contains within it specific descriptions of all relevant technologies.

In addition to providing energy demand forecasts by fuel and industry, the detailed nature of the technological specifications within process models (including options for co- and self-generation of electricity) makes them useful for addressing specific questions about energy conservation, market penetration rates, and for allocating resources to an R&D program. Process models can be sensitive to changes in policy constraints or significant new technologies.

### Econometric Models

Econometric models use historical time series and geographical cross-sectional data together with economic theory to determine an analytical relationship between prices and quantities demanded. The fundamental tool to describe this relationship is a set of elasticities (the percentage change in quantity demanded for each percentage change in a particular price). Using statistical analysis, these elasticities can be calculated from the historical data for all relevant input prices (and, usually, output levels). Using assumptions about fuel prices and industrial output, future consumption trends are projected on the basis of these historical elasticities. This approach is useful for projecting baseline forecasts and the response of demand to changes in output or prices. If there is reason to suspect that elasticities may change (due to changes in external factors such as policy constraints), the modeler must make exogenous adjustments in these parameters. Technological change is often incorporated by a time trend that determines changes in energy intensity (the ratio of industry output to energy use) not associated with energy price changes.

### Input-Output Models

The main feature of input-output models is a matrix of intersectoral flows of goods and services. The elements of the matrix represent the share of the output of each industry that is sold to each other industry. Similarly, the input requirements for each industry determine the demand for the output of other industries. Supply and demand are determined by the simultaneous solution of these equations. The appropriate values for the matrix's elements can be fixed constants or functions derived judgmentally or econometrically. These models are particularly helpful in assessing the causes of sectoral shifts in output and interactions amongst the energy demands of the different sectors.

### Hybrid Models

Typically, models will not incorporate strictly one methodology. For example, the data requirements of a process model that includes every industrial process would be overwhelming. For this reason, most process models use external economic analyses and input-output calculations to estimate demand in those sectors that are not energy intensive or where available data is inadequate. In addition, historical trend factors are sometimes employed to capture aggregate trends in the structure of industrial energy demand. Process models also use behavioral lags to adjust for the many factors that prevent a firm from responding immediately to changes in business conditions. Likewise, disaggregation to the process level can be incorporated into an econometric model for significant processes. This tendency toward hybridization is becoming increasingly common.

The 6 models included in the study were: the Wharton Annual model; the Industrial Sector Technology Use Model - 2 (ISTUM2) developed by Energy and Environmental Analysis, Inc. (EEA); the AES/ISTUM1 model maintained by Applied Energy Services, Inc.; the Purchased Heat and Power (PURHAPS) model developed by the Energy Information Administration; the Oak Ridge Industrial Model (ORIM); and the INFORUM model developed at the University of Maryland.

Each of these models has been refined and enhanced over a number of years and by now includes elements of all three approaches to energy demand modeling. Each has a specific methodology at its foundation. PURHAPS relies dominantly on econometric concepts and data-estimation techniques; ISTUM2 and AES/ISTUM1 on the process analysis methodology; ORIM combines the econometric and process analysis approaches; and Wharton and INFORUM rely on input-output analysis, with econometric estimation of values for parameters that reflect the adjustment of input-output coefficients, the composition of final demand, and the adjustment of the level of final demand to changes in the prices of inputs.

#### **REFERENCE CASE ASSUMPTIONS**

This section presents a standard set of assumptions for key input variables defining the Reference case. These assumptions were input to as many of the models included in the study as possible, providing the degree of standardization necessary for comparison of model results. This standardization permits the projections of industrial energy demand produced by a variety of models to be analyzed with respect to one another. In addition, an individual model's projections may be compared across different scenarios.

In the design of the Reference case and alternative scenarios a two-step procedure was followed. First, assumptions were specified for primary energy prices over the next 25 years. Second, these primary energy price assumptions were input to the Wharton Annual macroeconomic model. This produced projections of delivered fuel prices, economic output, and capital, labor, and materials prices that were used as inputs to the other models. The other models produced detailed projections of fuel demands by industry that were used to focus the working group's deliberations. Some of the models included in the study (e.g., PURHAPS) were designed to be operated as part of fuel market analysis systems that project fuel prices as well as fuel demands, but the linkages between supply and demand included in those larger systems were not employed in the present study in order to focus the model comparisons exclusively on energy demand behavior. The sequential process for standardizing input assumptions for EMF 8 is summarized schematically in Figure 6.

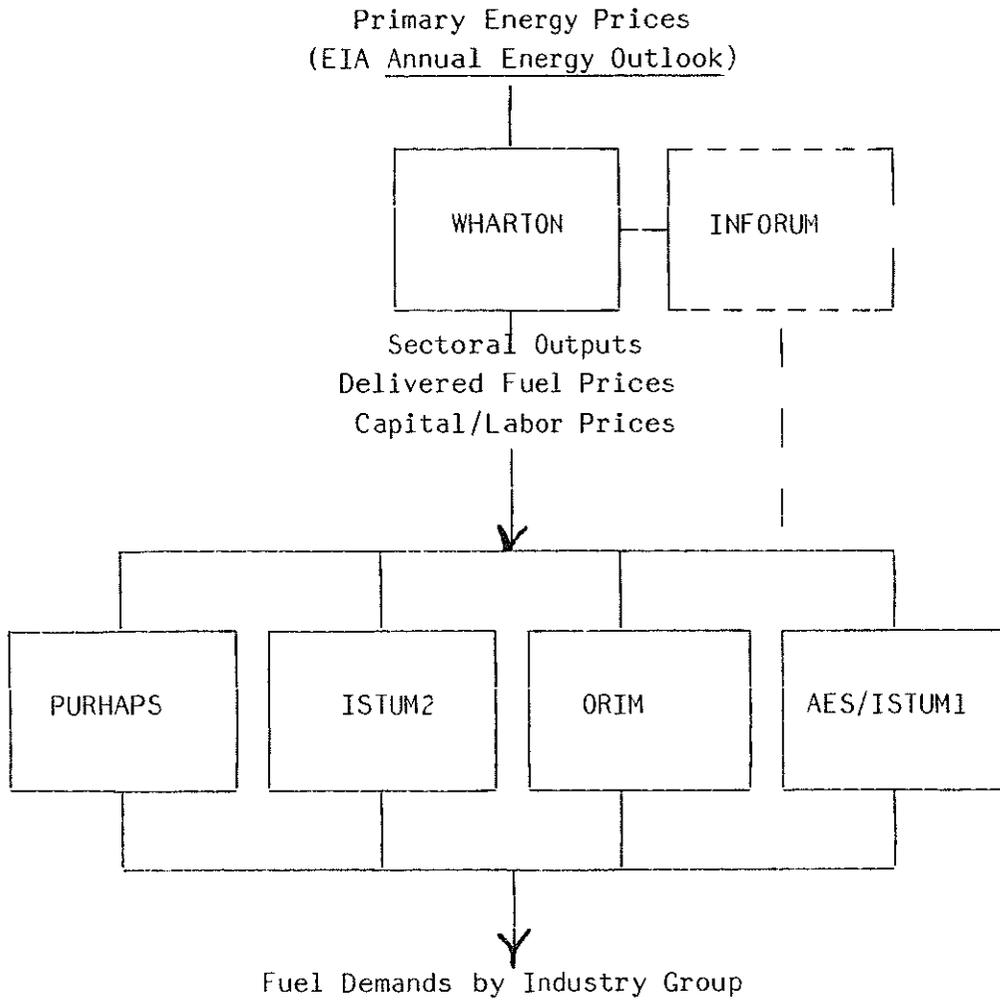
The Reference case represents a reasonable reference path for comparing the scenario results, rather than a consensus on the most likely forecast of industrial energy demand.

### Primary Energy Prices

The input assumptions for world oil price in the Reference case are consistent with the reference projections of the EIA 1984 Annual Energy Outlook through 1995, and crude oil price growth rates from the base case projections of the National Energy Policy Plan from 1995-2000. The world oil price follows the EIA reference projection through 1995 and the growth rate of the NEPP crude price projections from 1995 to 2010. In this case, refiner crude oil acquisition costs, in inflation-adjusted terms,

FIGURE 6

EMF 8 INPUT ASSUMPTION DEPENDENCIES



continue to decrease through 1987, then increase at three to four percent per year throughout the remainder of the study's time horizon. The 3.6 percent real growth rate in crude costs from 1984 to 2010 implied by these assumptions seems very high by current thinking. Prices for natural gas and coal are also fit to Annual Energy Outlook assumptions. Table A-1 in the Appendix contains the primary energy price assumptions for the EMF 8 Reference case.

### Delivered Energy Prices

The real delivered prices for coal, natural gas, fuel oil, and electricity for the years 1984-2010 were provided from Wharton model output. These prices provide a set of delivered energy prices consistent with the primary energy price assumptions. For example, delivered fuel oil prices are projected to increase by about 2.9 percent per year over the study's time horizon.

### Economic Activity

Values for the real GNP level, adjusted for inflation, and price deflator were also Wharton model outputs and reflect a continuation of current economic trends consistent with the primary energy price projections. GNP is projected to grow at 2.6 percent per year from 1984 to 2010 in inflation-adjusted terms.

### Industrial Output Mix

Gross output for each industry was taken from the Wharton model output and represents the composition of industrial activity consistent

with the projected level of overall U.S. economic activity and primary energy prices. Output in the pulp and paper industry grows by 2.6 percent per year, in the chemicals industry by 2.5 percent, no growth is projected for oil refining, output in the primary metals industry grows by 1.2 percent, in the durable manufacturing industry by 3.5 per cent, in agriculture, construction, and mining by 2.0 percent, and in other manufacturing industries by 2.1 percent.

#### Other Prices

Real wage, real cost of materials, and consumer prices were to be calibrated to the values provided by the Wharton model. In inflation-adjusted terms, wage rates grow at 1.3 percent per year, while materials costs show no escalation. The long-term corporate bond rate (again relative to inflation) is projected to be 7.1 percent in 1990, 5.6 percent in 2000, and 4.3 percent in 2010. The cost of capital varies widely in definition and use and was therefore to be calculated individually for each model. The modelers chose values consistent with the interest rates reported by the Wharton model.

#### Technology Options

In the reference case it was assumed that technology choices remain conservative with a "business as usual" menu of processes through 2010. The modelers used process options consistent with technologies currently available or widely believed to be in use in the near future.

### Environmental Regulations

The Reference case is based on the status quo in federal environmental policy. It assumes that no proposals for further constraints on emissions, regulations for air or water quality controls, or acid rain legislation will be passed during the projection period. In addition, Fuel Use Act restrictions were assumed to be nonbinding on energy-use decisions.

### Governmental Regulations/Taxes

No change in federal fiscal policy is projected for the Reference case. Current tax regulations, measures for encouraging developing cogeneration capability, and foreign trade policies will remain in effect over the reference period. Cogeneration prices were set at less than the full "avoided cost" buy-back rate.

## **ALTERNATIVE SCENARIOS**

Alternative scenarios were specified to represent higher and lower world oil prices, higher and lower economic growth, lower natural gas prices, lower capital costs, an international oil price shock, higher electricity prices, lower coal prices, and a large decrease in the price of all energy fuels.

### Higher and Lower World Oil Prices

The refiner crude oil acquisition cost for these scenarios through 1995 are from the 1984 Annual Energy Outlook. The growth rates after 1995 are taken from the new National Energy Policy Plan reference projection (the world oil price paths from 1985 to 1995 in the two documents are roughly comparable). In the Low World Oil Price scenario refiner acquisition costs

decline through 1990 in inflation-adjusted terms and then grow at between three and four percent per year between 1990 and 2010, implying a compound annual growth rate between 1984 and 2010 of 2.4 percent. In the High World Oil Price case, inflation-adjusted crude oil acquisition costs increase continually from 1984 to 2010 at a compound annual growth rate of 4.9 percent per year.

Delivered fuel oil prices, GNP growth rates, sectoral output levels, labor costs, materials costs, and interest rates for these primary energy price assumptions were again produced by the Wharton model. All other assumptions (including gas, coal, and electricity prices) were as in the Reference Case.

#### High and Low GNP Growth Scenarios

The High and Low GNP Growth scenarios were those projected by Wharton, modified to incorporate the EMF 8 Reference case energy price assumptions. In the High Growth scenario, real GNP grows at 3.4 percent per year from 1984 to 2010; in the Low Growth scenario at 2 percent per year.

#### Low Natural Gas Prices

In this scenario gas prices are depressed over the remainder of the 1980s due to longer than expected persistence of the gas bubble and heightened gas-to-gas competition. Canadian imports and special marketing programs (SMPs) are instrumental in depressing gas prices in this scenario. Wellhead gas prices decline through 1987 in inflation-adjusted terms and then start increasing slowly. By 1990 the average wellhead gas price reaches 80 percent of the Reference case level. Thereafter, the

average wellhead gas price rises at the same rate as the average refiner crude oil acquisition cost. All other assumptions are as in the Reference case.

#### Lower Costs of Capital

A 10 percent (in some models, e.g., ORIM, approximately two percentage points) reduction in real annual costs of capital (however measured in the individual models) relative to the Reference case. All other assumptions as in the Reference case. Because of differences in capital cost accounting conventions it was difficult to maintain comparability between the individual models in this case.

#### High Electricity Prices

An increase of 9 percent (that is the biggest national average impact we could find) in electricity prices in each year caused by more stringent emissions standards for coal-fired electricity utility boilers or by any other set of financial or regulatory sources. All other assumptions as in the Reference case.

#### Oil Price Shock

In this scenario oil prices follow the Low Oil Price trajectory until 1994. Then a sudden anticipated increase (doubling) in world oil prices occurs in 1995. Finally, crude oil prices return to the Low Oil Price trajectory by 1998. All other assumptions as in the Low Oil Price scenario.

### Low Coal Costs

Constant delivered real coal costs (at \$19.51 per ton in 1972 dollars - \$43.70 in 1984 dollars) from 1984 through 2010. All other assumptions as in the Reference case.

### Low Energy Prices

A simultaneous reduction in all energy prices with respect to the reference case; oil and gas prices are reduced 30 percent, coal prices 20 percent, and electricity prices 10 percent from 1990 on. Between 1984 and 1990 prices ramp from Reference levels to the Low Price levels. In this scenario refiner crude acquisition costs decline to about \$19 a barrel in 1990 in inflation-adjusted terms, and then increase at 3.6 percent per annum from 1990 to 2010. This trajectory implies about a 1.5 percent annual growth rate in inflation-adjusted crude acquisition costs over the study's 1984-2010 time horizon. This price trajectory seemed quite low when it was initially proposed (in May 1985), but the oil price collapse of February 1986 has actually resulted in prices 25 percent or more below those postulated in this scenario. Whether prices will remain at this low level for long is an open and hotly debated question.

## GENERAL TRENDS IN MODEL RESULTS

Each Energy Modeling Forum study focuses on a set of policy and analysis issues. A study of these issues enables the working group to assess the capabilities of the models included in the study in relation to one another and to real-world evidence. Three issue areas were particularly prominent in the use of the models by the EMF 8 working group: sectoral shift, technology trends, and fuel choice. Before discussing results in these specific issue areas, however, we note several general trends that emerge from the application of the models included in the study to the study scenarios.

First, energy use per unit of industrial output in the United States will continue to decline through 2010. This trend is apparent in the results from all the models for all scenarios. For example, Figure 7(a) shows the projected decline in total energy use for heat and power in manufacturing per unit of industrial output for the Reference case price assumptions where fuel oil prices increase in real terms by 2.9% and real GNP grows by 2.6 percent per year over the study's time horizon. Depending on the model, energy use for heat and power in manufacturing per unit of output is projected to decline by from 1.5 to 1.7 percent per annum from 1985 to 2010, compared with the 2.9 percent decline experienced from 1960 to 1973. As shown in Figure 7(b), this trend is revealed even in the Low Energy Price scenario (where oil and gas prices drop to 30 percent below their Reference case levels), and energy use for heat and power in manufacturing is projected to decline by from 1.2 to 1.5 percent per year over the study's time horizon.

Reference Case  
 Manufacturing  
 Purchased End-Use Energy Div. by Gross Econ. Output  
 Indexed to 1985

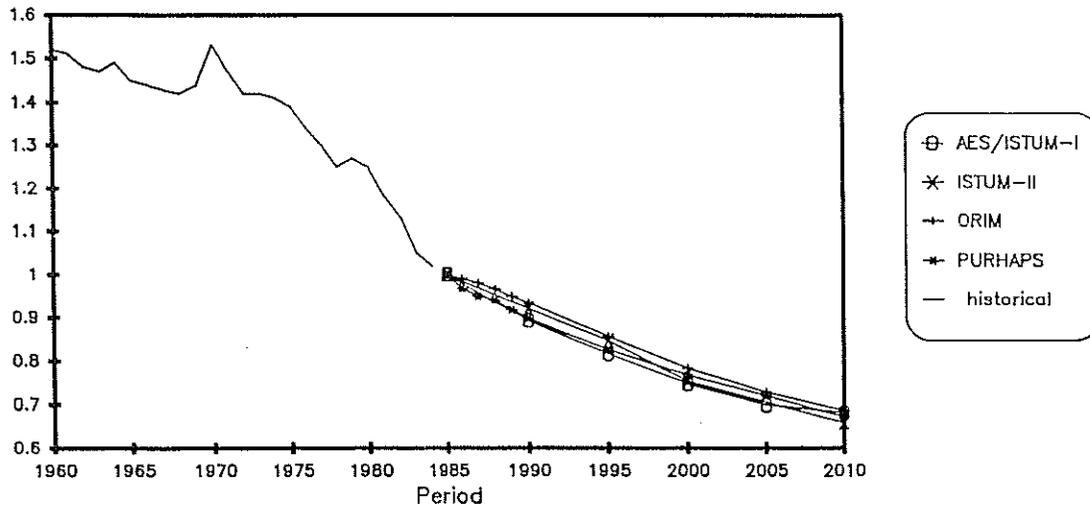


Figure 7A: Energy Use per Unit of Output in Manufacturing

Low Energy Prices  
 Manufacturing  
 Purchased End-Use Energy Div. by Gross Econ. Output  
 Indexed to 1985

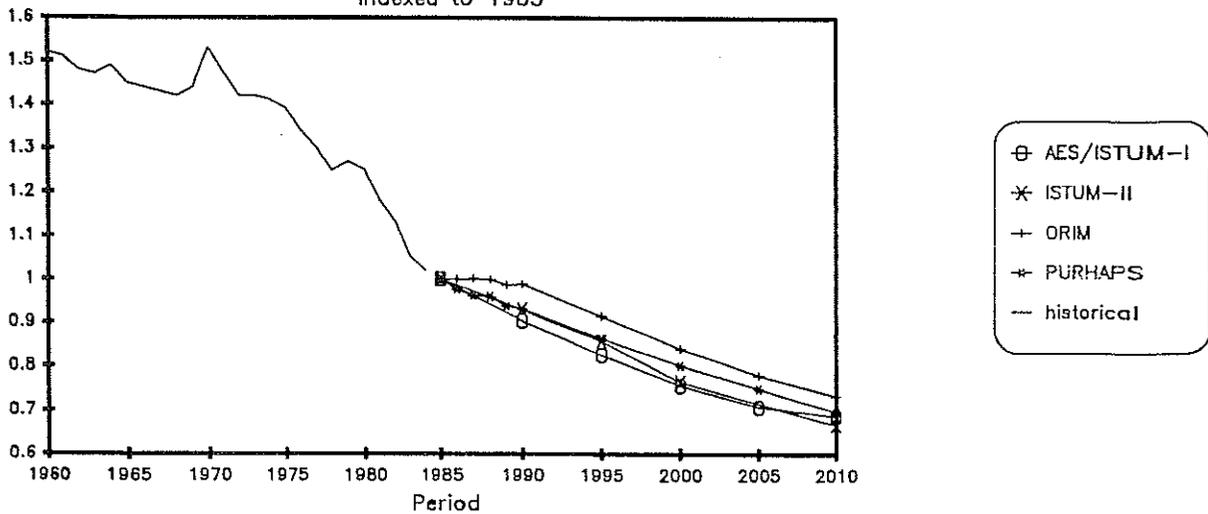


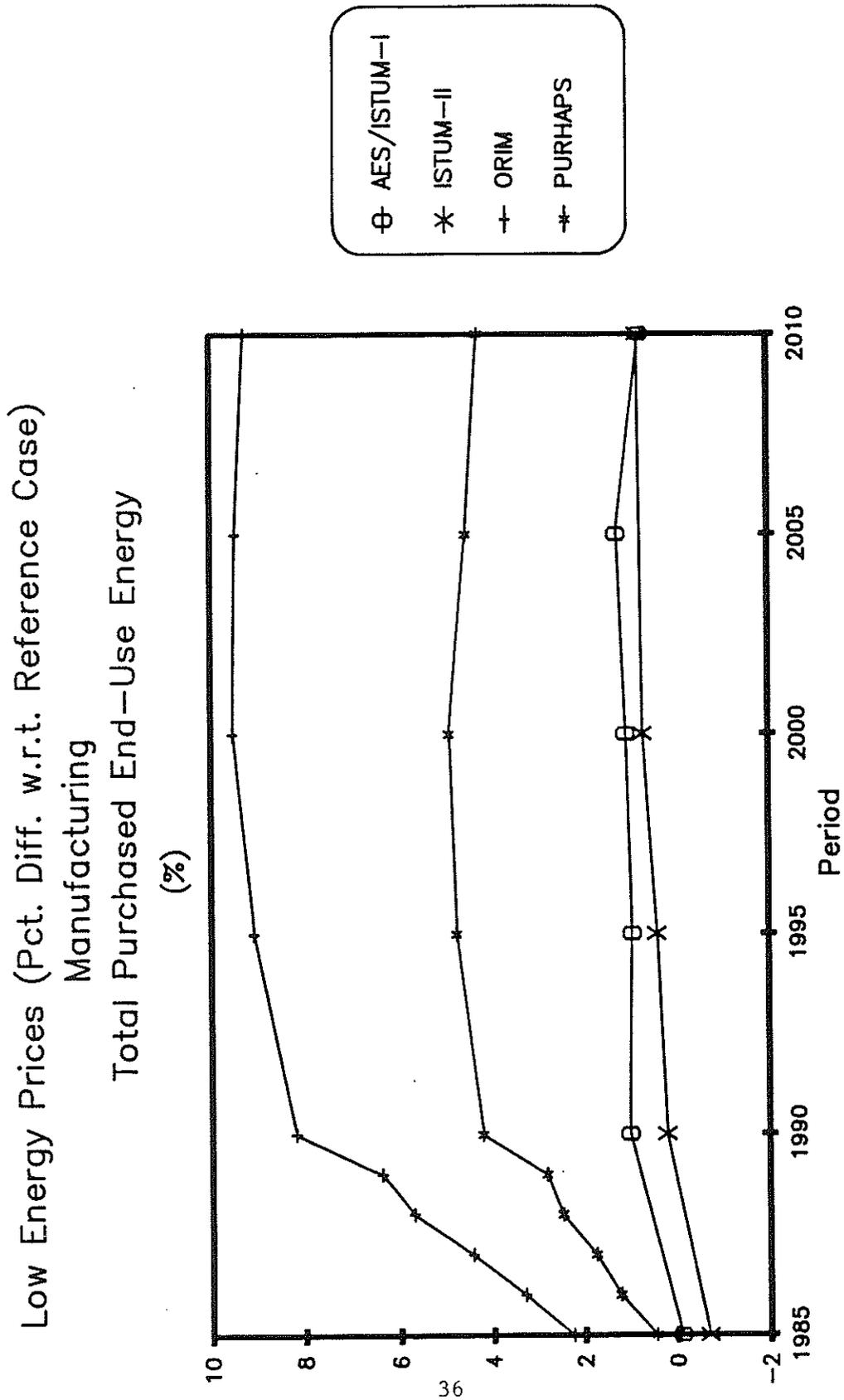
Figure 7B: Energy Use per Unit of Output in Manufacturing

The lower energy prices of 1986 may slow this trend still further, but will probably not reverse it. As shown in Figure 8, the demand for purchased fuels is sensitive to fuel price changes, with an increase of one to ten percent resulting from the approximately 20% composite price decrease considered in the Low Energy Prices Scenario with respect to the Reference Case. Energy prices today appear to be (at least temporarily) on a path about 20 percent below that in the Low Energy Prices scenario; thus, the energy-output ratio can be expected to be up to 10 percent higher than projected in that scenario as long as prices stay at their current level.

Over the next decade the explanation for this trend towards less energy use per unit of output is: (1) the continued shift away from the production of energy intensive products, (2) the continued shift towards processes and equipment that can produce the required industrial products with less energy than older technologies, and (3) the gradual adjustment to the energy price increases of the past 15 years. Although the last adjustment may be slowed considerably by the much lower energy prices that have emerged in 1986, the first two adjustments are likely to continue as they have over the last 30 years.

The overall shift towards the production of less energy intensive goods has been well documented as discussed in the next section. Changes in energy prices may be part of the explanation for this trend, but changes in interest rates, economic performance, consumer tastes, and foreign competition have probably been at least as important. While the first two trends may or may not continue, the last two almost surely will.

Figure 8: Response of Energy Use in Manufacturing to Price Changes



New technologies are more productive in their use of inputs, and consequently employed in many large-scale energy-intensive applications. These new technologies are discussed on an industry-by-industry basis later in this report. Again, higher energy prices have been a factor behind this trend, but some of the new technologies and processes that have come into widespread use (particularly in the chemicals and durable goods industries) have been adopted because they make more productive use of all inputs (capital, labor, materials, and energy), or because they lead to higher quality products.

Although oil prices have declined over the past 6 years and may continue to do so over the next several years, they are still higher than they were when some of the energy-using capital stock now in operation was installed. Gas, coal, and electricity prices are also higher, in inflation-adjusted terms, than they were during the pre-embargo era. Although the level of energy use in new equipment may tend to increase as prices decrease on a year-to-year basis, the average energy consumption by all equipment in operation may continue to decrease.

As mentioned previously, the aggregation of all energy fuels by Btu content into a single aggregate total can conceal fundamental shifts in the structure of energy demand. Disaggregation between the trends in fossil fuel and electricity use is particularly important. Figure 9 shows the historical trend and model projections for fossil fuels used for heat in manufacturing for the Reference Case and Low Energy Prices scenario. Recall that fossil fuel use per unit of output declined at an average annual rate of .8 percent from 1960 to 1973, and at 3.6 percent per year between 1973 and 1985. The models project further declines of from 1.7 to 2.8 percent per year in the Reference case and from 1.5 to 2.3 percent in

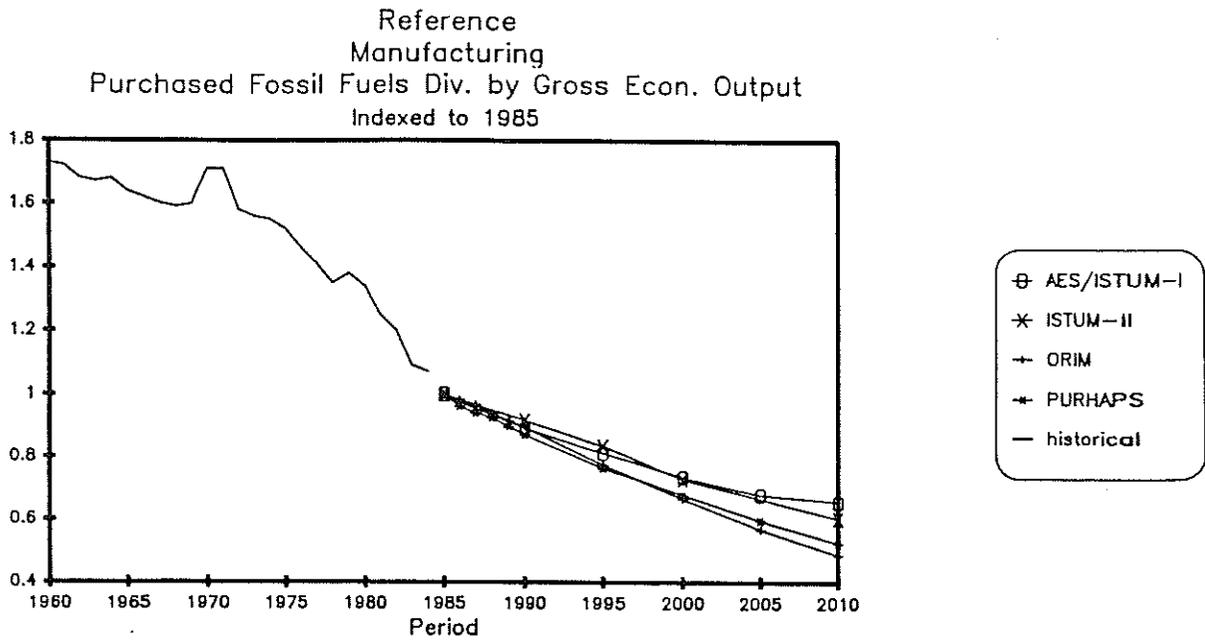


Figure 9A: Fossil Fuel Use per Unit of Output in Manufacturing

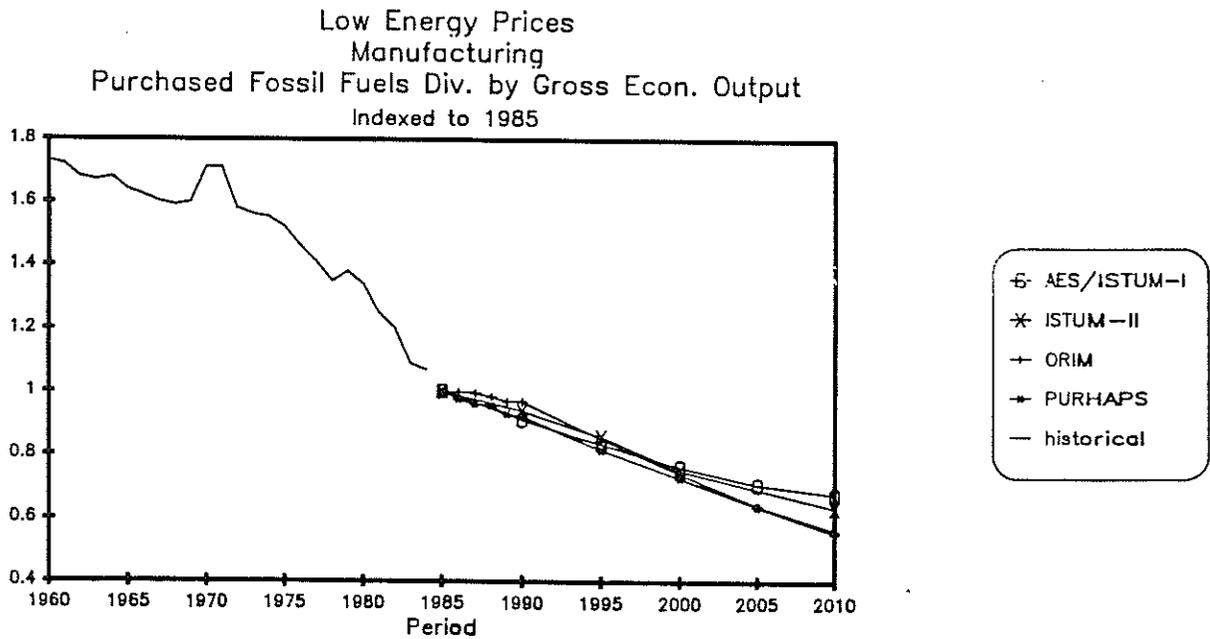


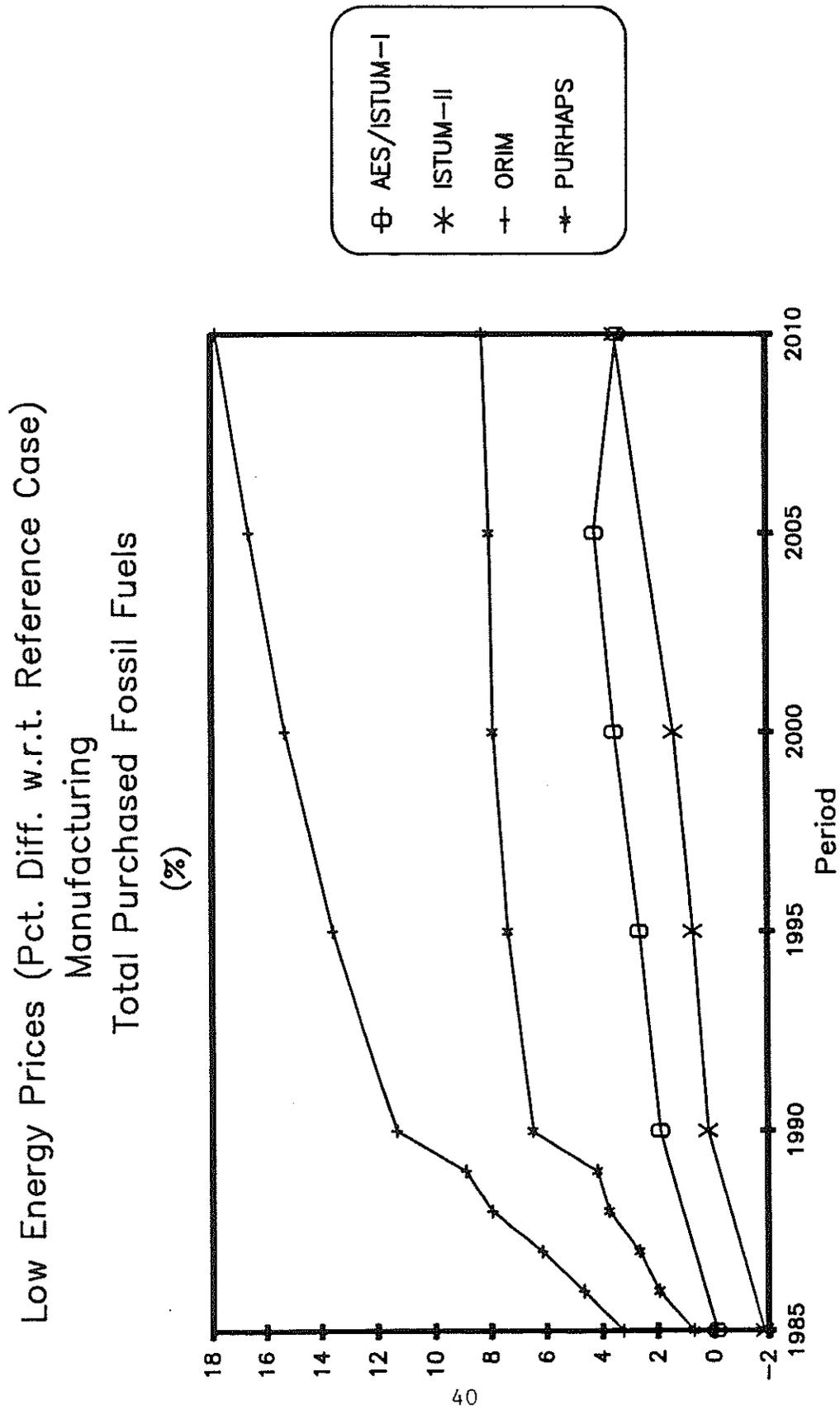
Figure 9B: Fossil Fuel Use per Unit of Output in Manufacturing

the Low Energy Prices scenario. Figure 10 shows the price sensitivity implied by the results from these two scenarios. The pattern is quite similar to that shown in Figure 8 for total end-use energy consumption.

Figure 11 shows historical trend and model projections of purchased electricity use in manufacturing per unit of output. Recall that electricity use per unit of output grew at 2.0 percent on average between 1960 and 1973 and at .3 percent per year on average between 1973 and 1985. The models differ in the sign of the projected rate of change of the electricity-to-output ratio. ORIM and PURHAPS show about a one percent increase on average over the next twenty-five years, while AES/ISTUM-I and ISTUM-II show about a one percent per year decline. Even the latter two models, though, show a slower decline in electricity use than fossil fuel use implying an increase in electricity's market share. This trend is partly the result of assumed decreases in the price of electricity relative to that of fossil fuels and partly the result of technological trends represented in the models.

The sensitivity of these trends to alternative price assumptions is shown in Figure 12 which compares electricity use in the Low Energy Prices Scenario with those for the Reference Case. Recall that the Low Energy Prices Scenario includes a thirty percent reduction in oil and gas prices, a twenty percent reduction in coal prices and a ten percent reduction in electricity prices. These changes lead to increased electricity demand in the late 1980s according to the ISTUM-II model and less purchased electricity over the whole projection period according to the AES/ISTUM-I model owing to greater self- and co-generation.

Figure 10: Response of Fossil Fuel Use in Manufacturing to Price Changes



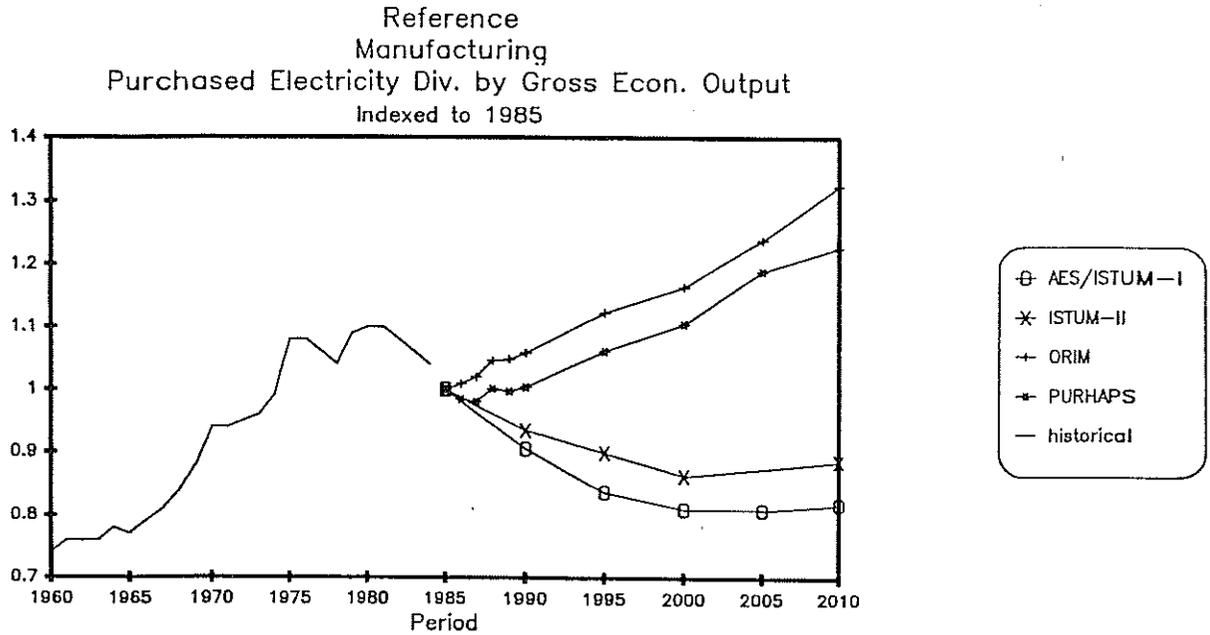


Figure 11A: Electricity Use per Unit of Output in Manufacturing

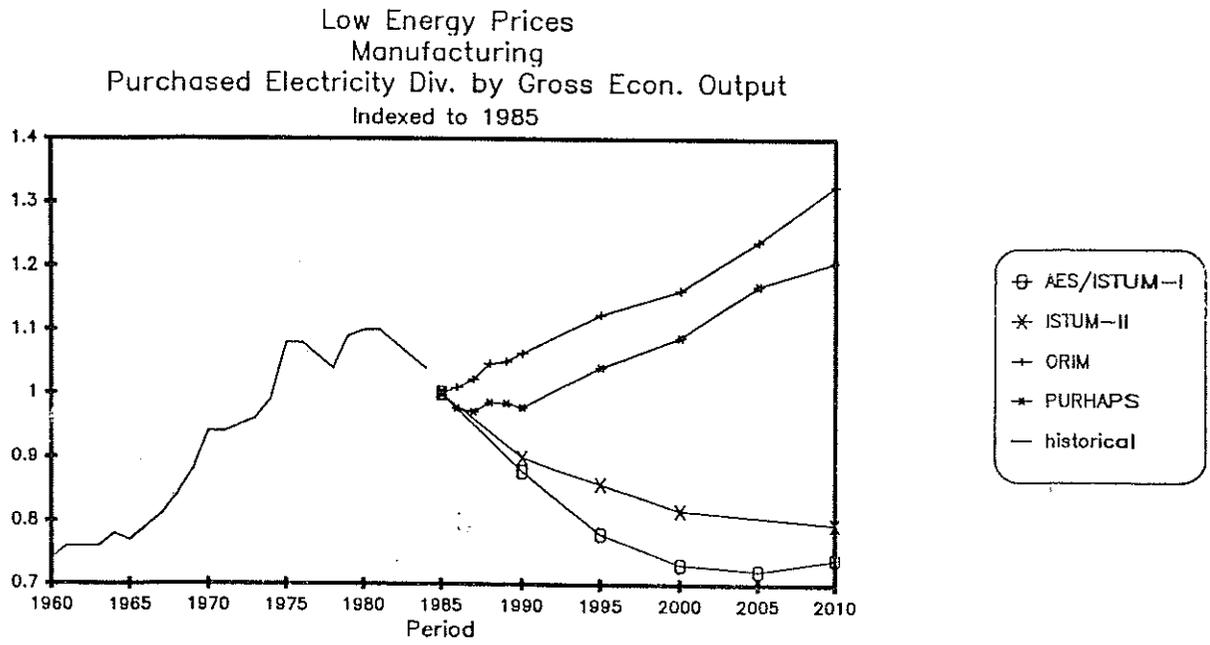
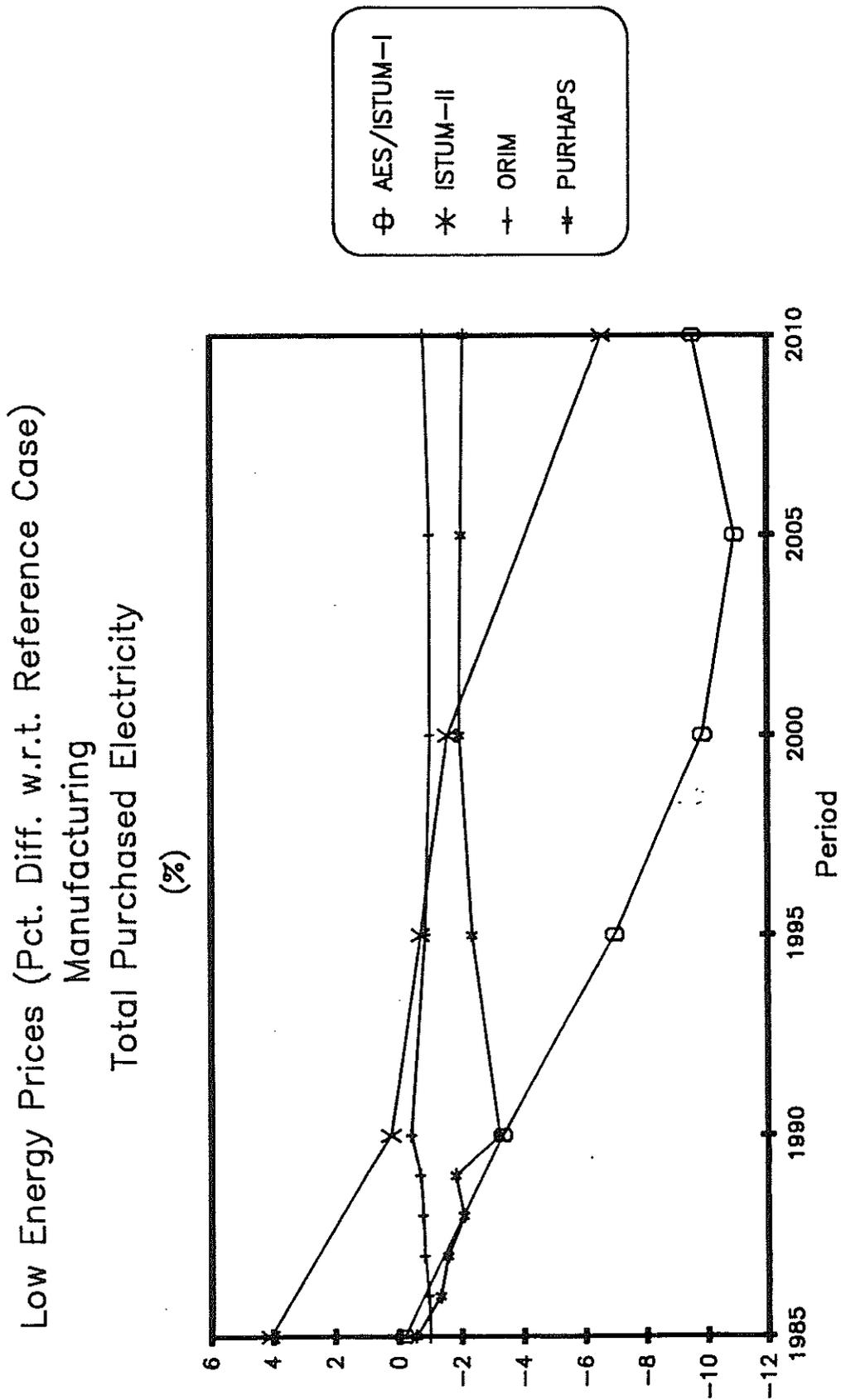


Figure 11B: Electricity Use per Unit of Output in Manufacturing

Figure 12: Response of Electricity Use in Manufacturing to Price Changes

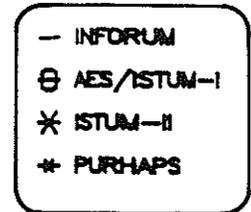
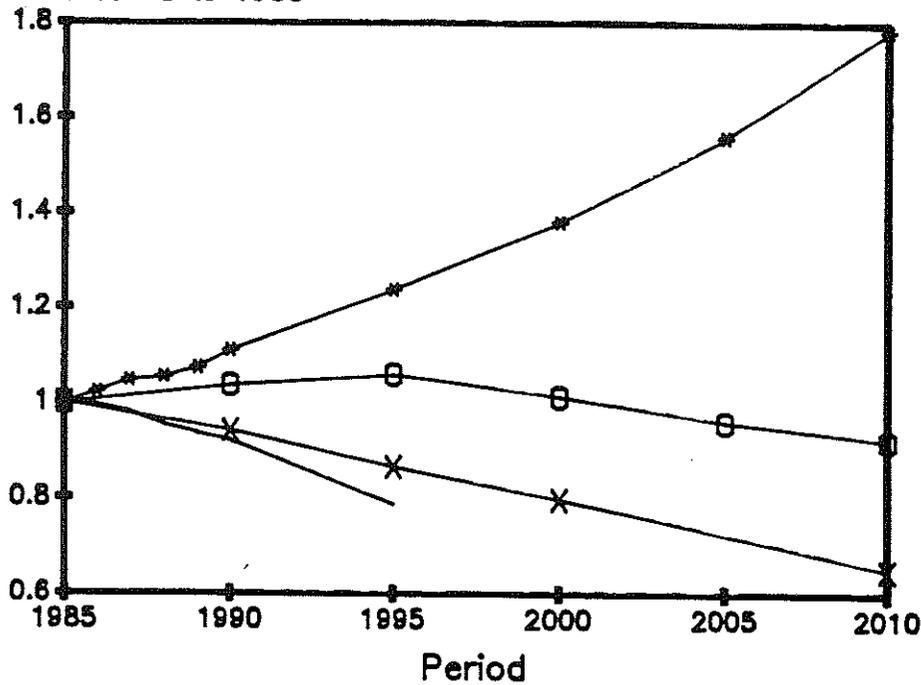


The projections of energy use by the agriculture, construction, and mining industries vary dramatically. As shown in Figure 13 for the Reference case, the projections of energy use per unit of agriculture, construction and mining output range from -1.7 to +2.4 percent per year over the period from 1985 to 2010. To a large extent these differences reflect the paucity of research on energy use outside of the manufacturing industries. This lack of research makes the identification of historical trends in energy use difficult, and the estimation of causal relationships linking energy demands to energy prices and industry output levels precarious. Thus, great uncertainty must be attached to any projection of energy use by the agriculture, construction, and mining industries. Interestingly, projections from the PURHAPS system, which uses the most recent and comprehensive data on non-manufacturing energy use, show much more growth than those from any of the other models. In fact, this difference leads to a much slower rate of decline in energy use for heat and power per unit of total industrial output for PURHAPS than from any other model. This is all the more striking given the similarity in projections of energy use per unit of output within the manufacturing industries noted in Figure 7.

The projections of energy use as material feedstocks also show a significant degree of variation. As shown in Figure 14 for the Reference case, the projections of energy use per unit of manufacturing output range from -.7 to 2.2 percent per year over the period from 1984 to 2010. As in the case of energy used in agriculture, construction, and mining, a paucity of research makes analyses of past trends in feedstock use and projections of future ones very difficult. To a significant extent the demand for

Figure 13: Energy Use per Unit of Output in Agriculture, Construction and Mining

(a). **Reference Case**  
**Agric., Const. & Mining**  
**Total Energy Cons. (Div. by Gross Econ. Output)**  
**Indexed to 1985**



(b). **Low Energy Prices**  
**Agric., Const. & Mining**  
**Total Energy Cons. (Div. by Gross Econ. Output)**  
**Indexed to 1985**

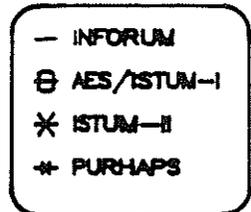
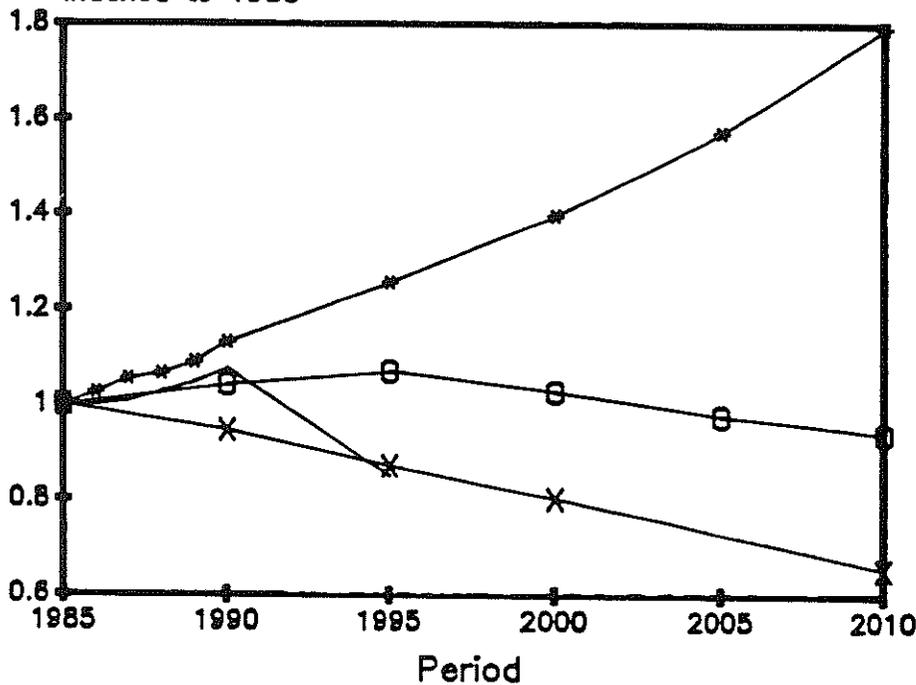


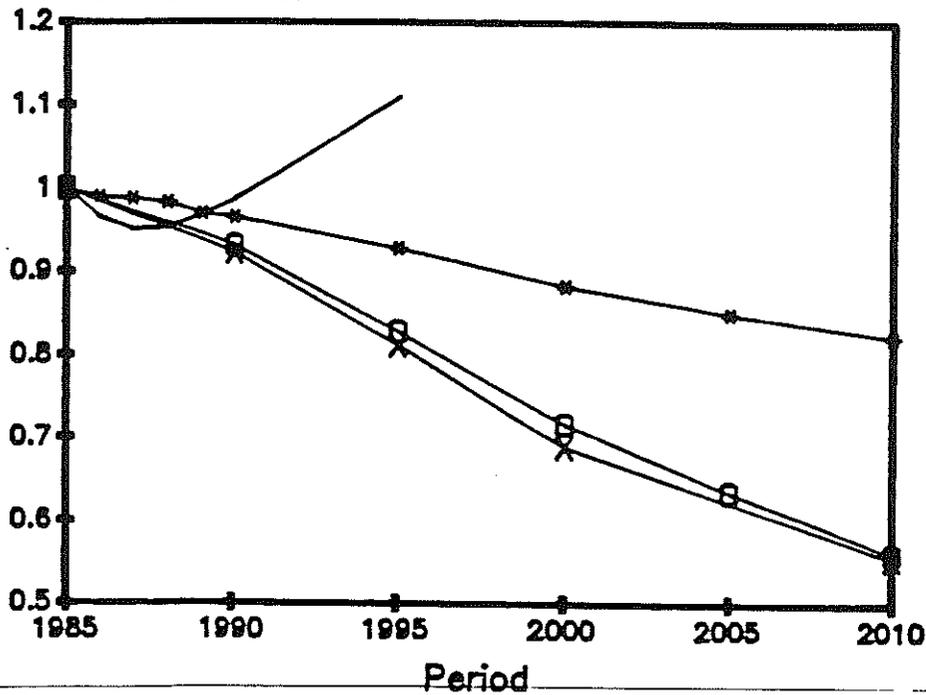
Figure 14

Reference Case

Feedstocks

Total Energy Cons. (Div. by Gross Econ. Output)

Indexed to 1985

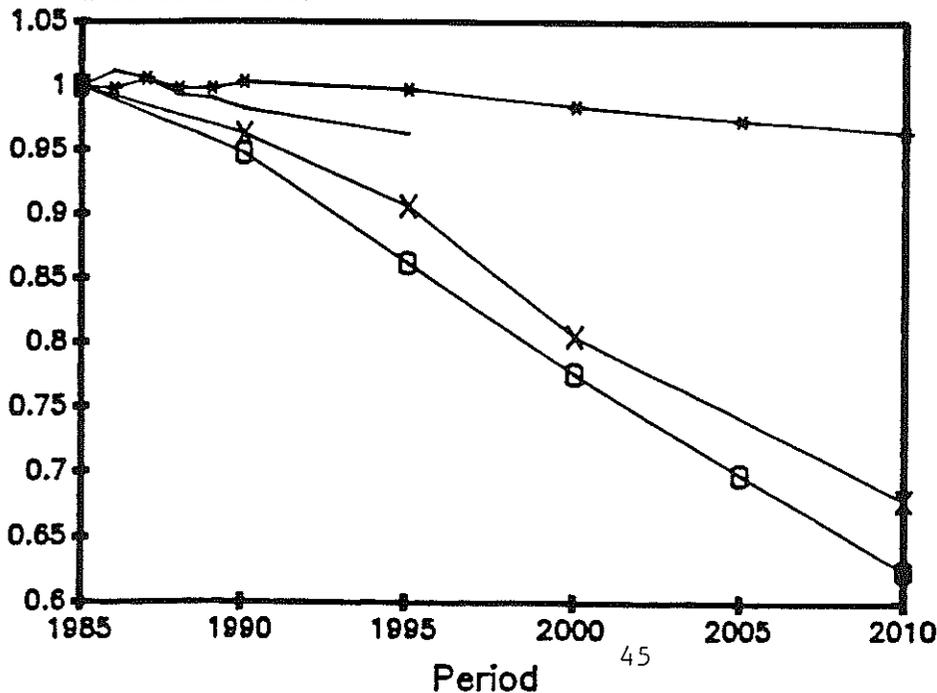


Reference Case

Feedstocks

Oil Cons. (Div. by Gross Econ. Output)

Indexed to 1985

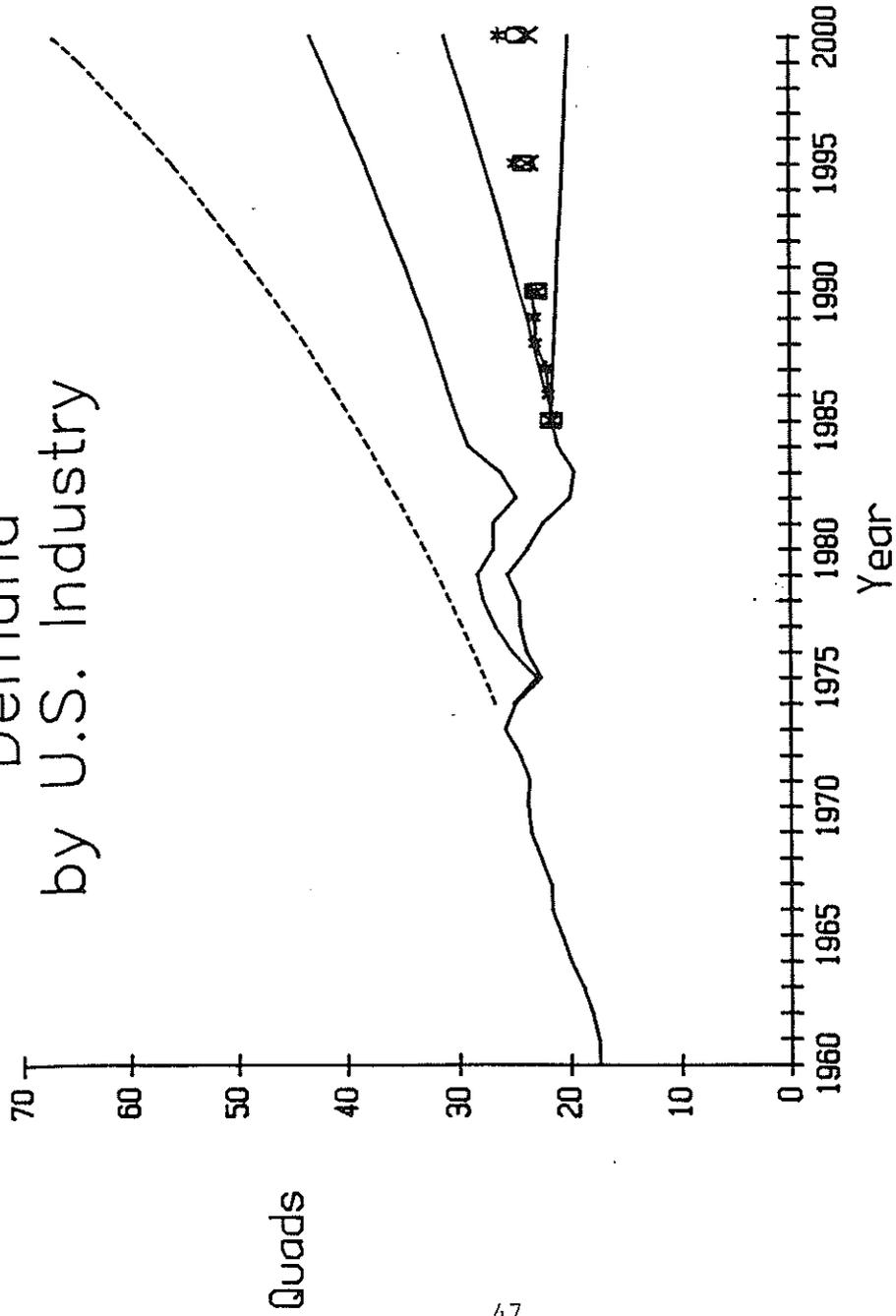


chemical feedstocks (mostly oil) depends on the types of products produced, and the demand for metallurgical coal depends on the further penetration of electric arc based mini-mills into the steel making industry. These trends have been significant historically, but it has been difficult to ascertain why they have occurred at one rate rather than another.

In Figure 15, the model projections of total industrial energy demand for the Low Energy Prices Scenario are superimposed on the historical trends framework developed in Figure 3. The model projections include: (1) fuel used for heat and power in manufacturing; (2) fuel used in agriculture, construction and mining; and (3) feedstocks. The model projections all show greater energy demand growth than would result from an extrapolation of the 1973-85 trend in the energy-output ratio, but less than the assumed rate of output growth. Industrial energy demand is projected to grow at between 1.0 and 2.1 percent per year, implying a .5 to 1.6 percent per year decline in total energy demand per unit of output. At current prices (recall these are lower than those assumed in the early years of the Low Energy Prices Scenario) energy demand would be projected to grow at a more rapid rate, perhaps as much as one half of a percentage point faster per year.

Total fossil fuel and electricity demand projections for the Low Energy Prices Scenario are put in historical perspective in Figures 16 and 17, respectively. Fossil fuel demand by industry is projected to grow at between .8 and 1.5 percent per year and electricity demand at 1.8 to 3.8 percent per year.

# End-Use Energy Demand by U.S. Industry



- ✦ PURHAPS
- ✧ ISTUM-II
- ⊖ AES/ISTUM-I
- 1973 Energy/Output Ratio
- 1985 Energy/Output Ratio
- 1973-85 Energy/Output Trend

Figure 15: Model Projections of Energy Use by U.S. Industry

Figure 16: Model Projections of Fossil Fuel Use by U.S. Industry

# Fossil Energy Demand by U.S. Industry

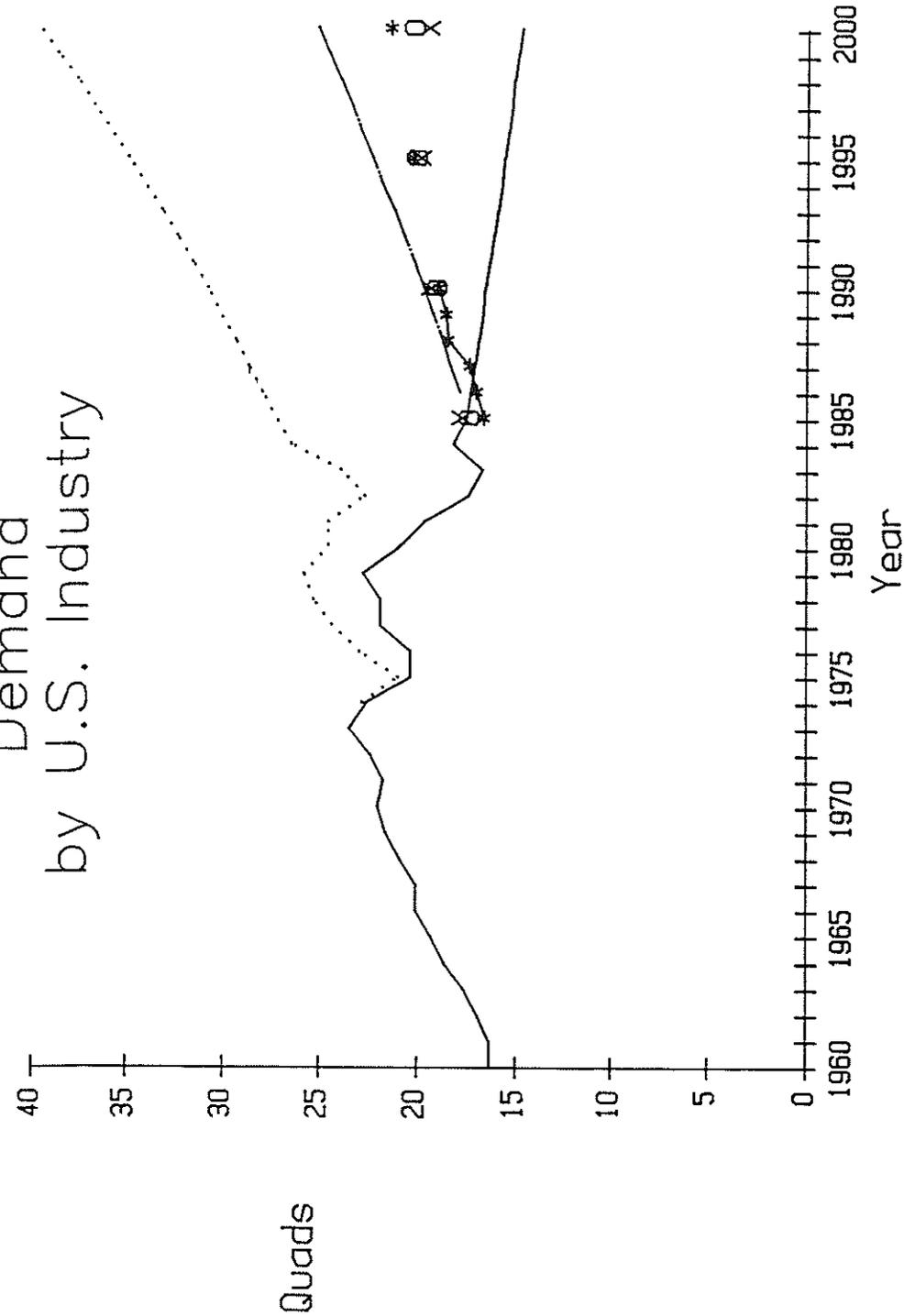
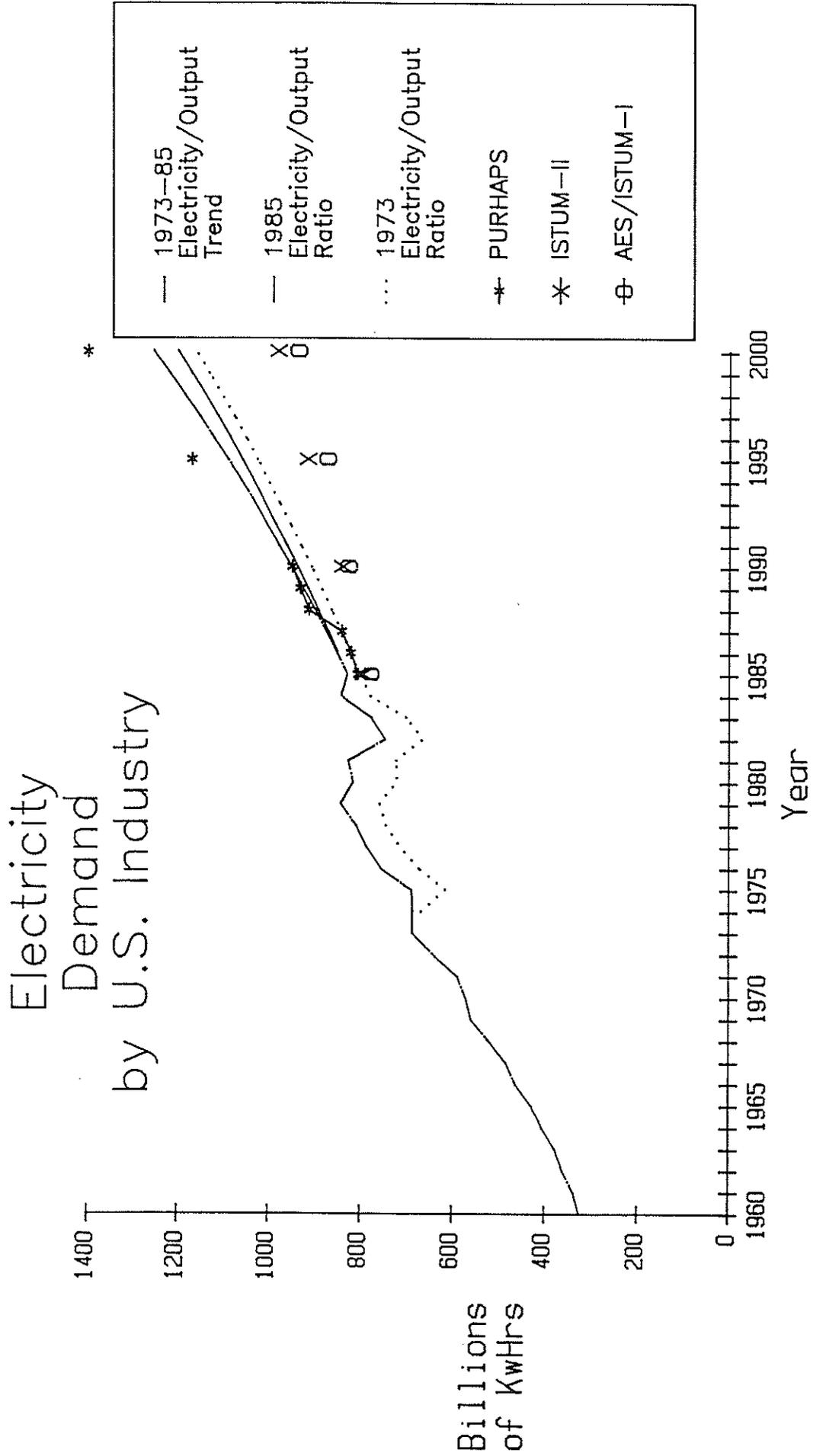


Figure 17: Model Projections of Electricity Use by U.S. Industry



## SECTORAL SHIFT

Energy use per unit of output in manufacturing has fallen substantially since the 1973 oil embargo. This trend holds for total energy, for fossil fuels, and for electricity. In the case of fossil fuels, this decrease represented an acceleration of the pre-embargo trend of declining fuel intensity. For electricity, on the other hand, the post-embargo trend represented a reversal of the growing electricity use observed before 1973.

A significant portion of this decline was due to shifts among sectors of the economy, among industries (measured at various levels of disaggregation), and among products. At a minimum, these changes in the composition of economic output, or product mix, account for at least one-third of the decline in purchased energy use for heat and power per unit of output in manufacturing since the embargo. The relative importance of this effect appears to be greater than one-half when the period examined includes the early 1980s. We will refer to such shifts among sectors within manufacturing as the sectoral shift effect.

In addition, energy use per unit of output within each sector has also decreased because firms have adopted new processes (e.g., the electric-arc furnace in steel) or have improved their operation and maintenance of existing facilities. We will refer to trends in the intensity of energy use within sectors as the change in sectoral energy intensity. Together these two effects determine the trend in the energy-output ratio in manufacturing as a whole, or aggregate energy intensity.

While a consensus has not yet developed on the causes of the decline in major energy-using sectors, it appears clear that future energy demand will be strongly influenced by trends relating to the transformation of the

economy. It is important to recognize sectoral shift's distinct role in shaping aggregate energy intensity. If current economic trends remain intact, shifts within industry will tend to keep growth in energy demand low. However, low energy prices, reduced capital costs, and more rapid growth, if they occurred together, could improve the prospects for important energy-using industries, partially countering the energy trends observed during the previous decades. Moreover, changes in the mix of goods produced can alter energy use relatively rapidly, compared with the slower process of replacing the capital stock within individual industries.

#### Defining the Sectoral Shift Effect

Sectoral shift is a change in the relative economic importance of the individual sectors that constitute industry in the aggregate. Importance here is measured by the value of output after adjusting for increases in prices over time (i.e., output measured in constant prices). For example, within the aggregate "manufacturing" sector, the rising importance of electrical machinery has been accompanied by the waning importance of primary metals in terms of output produced in each industry.

In general, the finer the decomposition of an aggregate, the larger the fraction of the decline in the energy-output ratio that can be attributed to sectoral shift. Thus, a study that disaggregates all industry into many sectors or even individual products can generally be expected to show a larger industrial shift effect because more of the shift away from energy-intensive goods is being incorporated in the sectoral shift measure. However, even if one decomposes all industry into only two sectors, a group of materials industries producing raw materials for other industries and all remaining sectors, this effect remains important.

Shifts between sectors can raise as well as lower the aggregate energy-output ratio in manufacturing. While this effect has reduced the energy-output ratio in the post-embargo period, new conditions could emerge that would reverse these effects over time. Thus, it is inappropriate to consider these trends as permanent structural shifts in our economy that cannot be reversed. We have avoided the term, "structural change", precisely for this reason.

#### The Sectoral Shift Effect During the Post-Embargo Period

All past studies investigating this issue have concluded that the sectoral shift effect has been important in determining the observed energy-output ratio during the post-embargo period. Table 2 summarizes the studies' findings regarding the importance of shifts in the composition of output as a determinant of the decline in the ratio. It should be emphasized that no two studies are strictly comparable with each other because they frequently are based upon different methodologies, data bases, etc. Studies can differ from each other by employing different levels of industrial aggregation, different indices for aggregating the sectors, or different time periods. In addition, some studies analyzed fuels and electricity separately while others combined them.

Table 2

RELATIVE IMPORTANCE OF COMPOSITION EFFECT (SECTORAL SHIFT)<sup>1</sup>  
IN PREVIOUS STUDIES OF POST-EMBARGO PERIOD

<u>Study</u>	<u>No. of Sectors</u>	<u>Decline in Energy Intensity (% change)</u> [1]	<u>Composition Effect (% change)</u> [2]	<u>Relative Importance of Composition Effect (%)</u> [3]=[2]/[1]
Myers & Nakamura	2			
Energy 1967-76		10.8	0.6	6
Energy 1974-76		4.2	1.4	33
Samuels, Vogt & Evans	448			
Energy, 1975-80		18.8	4.4	23
Fuels, "		20.9	5.1	24
Electricity, "		8.6	0.7	8
Marlay	475			
Energy, 1972-80		16.5	5.9	36
Energy, 1972-84		34.4	18.5	53
Fuels, 1972-84		42.4	21.2	50
Electricity, 1972-84		15.0	10.0	67
Werbos	18			
Energy, 1974-81		17.2	5.7	33
Energy, 1974-82 <sup>2</sup>		14.4	10.8	75
Jenne & Cattell				
U.K. Energy, 1973-78	9	12.5	4.2	34
	104	12.5	6.8	54
Boyd et al	20			
Fuels, 1974-81		20.5	7.0	34
Roop & Belzer	N.A.			
Energy, 1972-77		21.0	9.7	45
Fuels, 1972-77		21.4	9.6	45
Fujime	N.A.			
Japanese Energy, 1974-83		N.A.	N.A.	33

Source: See Boyd et al (1985) for all estimates except Marlay (1985), Roop and Belzer (1986), and Fujime (1985).

N.A. Not available.

<sup>1</sup>Based upon sectoral shifts and energy intensity changes within manufacturing. Additional shifts may occur between manufacturing and other sectors.

<sup>2</sup>Differs from preceding Werbos study in that estimates are for all industry (including agriculture, construction, and mining) and incorporate feedstocks and primary energy content of electricity.

### Trends in Energy Intensity

Despite these fundamental differences in approach, there appears to be a consensus on the approximate magnitude of the effect. Given the results reported in Table 2, many of the studies suggest that perhaps one-third of the decline in the energy-output ratio can be attributed to this effect. And under certain conditions, the relative importance of this effect is considerably larger.

The sectoral shift effect was relatively minor during the few years just prior to the embargo, as revealed by the first entry for Myers and Nakamura (1978) in Table 2. In recent years, however, the role of sectoral shift in energy-output trends has increased dramatically especially since 1980. This trend is observable for the Marlay (1983, 1984, 1985) results, which are based upon a very detailed disaggregation of industry, as well as for several studies conducted by Werbos (1984, 1985).

The estimates in Table 2 refer to the relative importance of shifts between sectors within manufacturing. In addition, there will be compositional shifts between manufacturing and the rest of the economy. Werbos (1984, 1985) has found this latter shift to be important. When it is included, his estimate of the sectoral shift effect increases to 59% of the total decline in energy intensity between 1974 and 1981. Moreover, its relative importance increases to 75 percent when 1982 is added and feedstocks are included.

### Changes in the Trend for Fuel Intensity

Sectoral shift accounts for an even larger proportion of the change in the trend of the electricity- and fossil fuel- output ratio from just before to after the embargo. Since not all studies reported estimates of both pre- and post-embargo trends, we will discuss this point with reference to only one of the studies, that by Boyd et al (1985). This effort was conducted at Argonne National Laboratory concurrently with the EMF effort on comparing industrial energy models. It represents one of the more recent attempts to decompose the sectoral shift and sectoral intensity change effects. It used an energy-weighted index of production, similar in spirit to that of Marlay and EIA but based on moving averages. Its conclusions are similar in character to many of the other studies.

The fossil fuel-output ratio was already falling by about 1 percent per year during the years immediately preceding the embargo (1967-74). Table 3 shows that this decline incorporates a 1.9 percent per year decline due to the change in sectoral intensity but that this effect was offset partially by a 0.9 percent per year increase in aggregate energy intensity due to the output shift among 2-digit SIC industries. During the post-embargo period (1974-81), the decline due to the change in sectoral intensity became more pronounced (2.9 percent per year), which was reinforced by a 1.0 percent decline due to sectoral shift. Aggregate fuel intensity, the sum of these two effects, declined by 3.9 percent per year during this period.

Table 3

TRENDS IN SPECIFIC ENERGY INTENSITY  
AND PRODUCT MIX (PERCENT PER YEAR)

(Industry disaggregated at two-digit SIC level)

	Fuel	Electricity
Specific Energy Intensity		
Pre-embargo <sup>a</sup>	-1.9	+2.0
Post-embargo <sup>b</sup>	-2.9	0
difference	-1.0	<0 <sup>c</sup>
Sectoral Shift		
Pre-embargo <sup>a</sup>	+0.9	+0.8
Post-embargo <sup>b</sup>	-1.0	-1.3
difference	-1.9	-2.1

Source: Boyd et al., (1985).

<sup>a</sup>1967-74

<sup>b</sup>1974-1981

<sup>c</sup>No precise estimate is available but the effect is negative.

Comparing the two periods, aggregate fuel intensity declined by 2.9 percent per year more during the post-embargo period than in the pre-embargo period. Sectoral shift accounted for about 66 percent (1.9 percentage points) of this difference in energy-output ratios between periods, as its contribution to aggregate intensity moved from being positive to negative. This result contrasts with trends for the post-embargo period (not the change between periods), during which sectoral shift represented about 26 percent (1.0 percentage points) of the annual decline of 3.9 percent in the aggregate energy-output ratio.

#### Changes in the Trend for Electricity Intensity

The trends in electricity per dollar of output in Table 2 are somewhat different. Both effects together were causing aggregate electricity intensity within manufacturing to increase by a total of 2.8 percent per year during the pre-embargo period. Sectoral shift accounted for a yearly increase of 0.8 percent per year, while the remaining 2 percent was attributable to changes in sectoral intensity. After the embargo, aggregate electricity intensity reversed directions. The sectoral shift effect became negative, contributing a decline of 1.3 percent per year. The effect of the change in sectoral intensity was about neutral, causing little additional change in the aggregate electricity-output ratio for this period. Thus, virtually all of the decline in aggregate electricity intensity during the post-embargo period was attributable to sectoral shift.

In comparing the two periods, sectoral shift alone was causing the electricity intensity within manufacturing after the embargo to fall 2.1 percentage points per year below its pre-embargo trend. Changes in sectoral intensity within individual industries were also contributing to a slower growth in electricity intensity for all manufacturing, although the Argonne researchers were reluctant to estimate the magnitude of this effect because the estimates fluctuated widely from year to year. However, if one assigns the 2 percent implied in Table 1 to the sectoral intensity effect, the sectoral shift effect would account for at least 50 percent of the 4.1 percentage point decline in the aggregate ratio between periods.

#### A Two-Sector Decomposition

The Argonne study also concluded that for fossil fuels, about 80 percent of the composition effect was attributed to shifts between two major manufacturing sectors. Five industries (paper, chemicals, petroleum refining, primary metals, and stone, clay, and glass) share the common features of being highly energy-intensive as well as producers of raw materials for other industries. These five materials industries were separated from the rest of manufacturing in a two-sector analysis of the decline in aggregate fuel and electricity intensities. This finding suggests that detailed disaggregation of manufacturing may not be necessary to incorporate much of the sectoral shift effect for fossil fuels.

With regard to aggregate electricity intensity, the disaggregation into materials-producing and all other industries accounted for substantially less than the full sectoral shift effect at the two-digit level. This result once again emphasizes the difference between the energy intensity trends for electricity and fossil fuels.

## TECHNOLOGY TRENDS

There appear to be important differences between models in the projected decline in the energy-output ratio within major industrial sectors (adjustments in sectoral intensities). Changes in energy intensity within each industry group can be further disaggregated into changes in the mix of products produced by the group, changes in the processes employed to produce those products, and changes in the equipment and maintenance procedures employed to implement those processes (Figure 18). The penetration of new technologies can be important for explaining the decline in the energy-output ratio. Several individual technologies (see Table 4) can be identified as being important contributors to this result. The role of new technologies, changes in product mix, and changes in equipment and maintenance procedures in reducing energy use per dollar of industrial output can best be described on an industry-by-industry basis.

### Pulp and Paper

Historical trends and model projections of fossil fuel and electricity use per unit of output by the pulp and paper industry (SIC 26) are shown in Figure 19. Paper production consists of three major steps: pulping, bleaching, and papermaking. All three steps in this process are energy intensive. Energy conservation improvements in the pulp and paper industry over the past decade have come about through improved housekeeping measures and increased capability to recover energy from waste. The industry moved from supplying 41 percent of its energy needs from self generated sources in 1972 to 50 percent by 1981. By 1984, 55% of the estimated energy use in the paper industry (according to American Paper Institute statistics) was

Figure 18-a

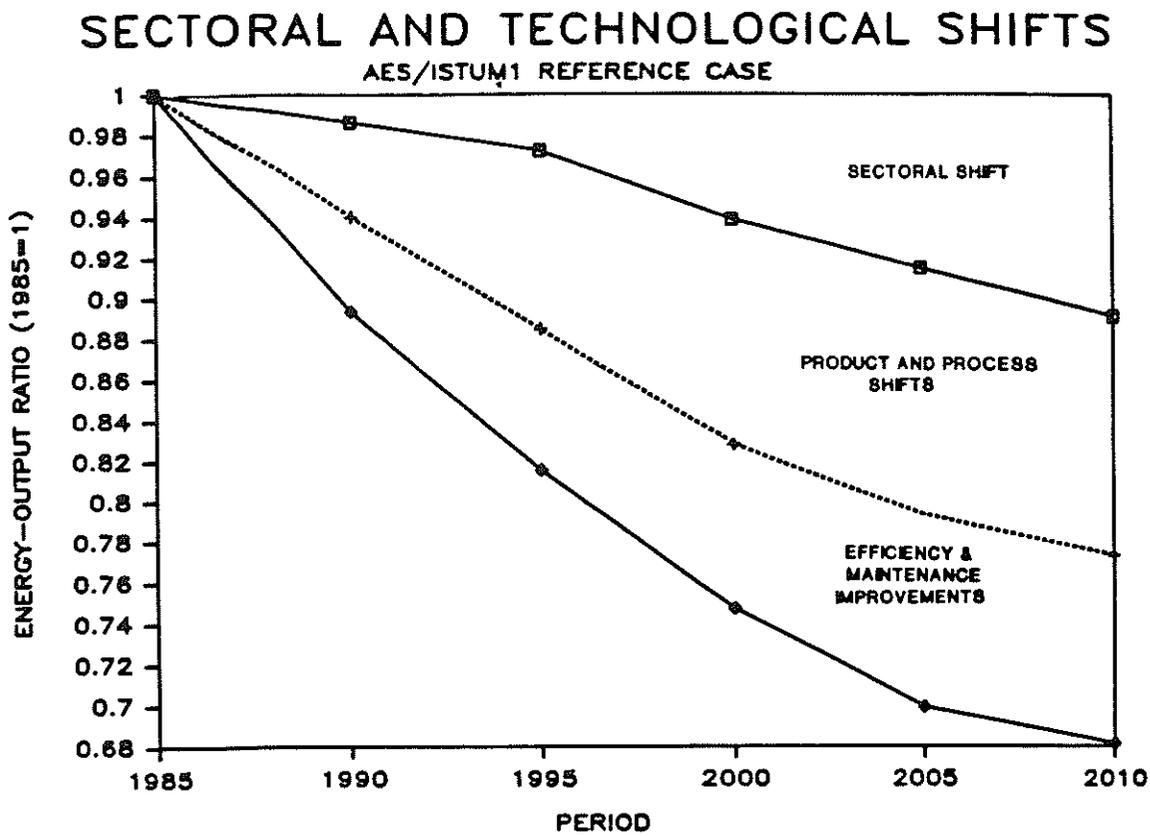


Figure 18-b (Preliminary)

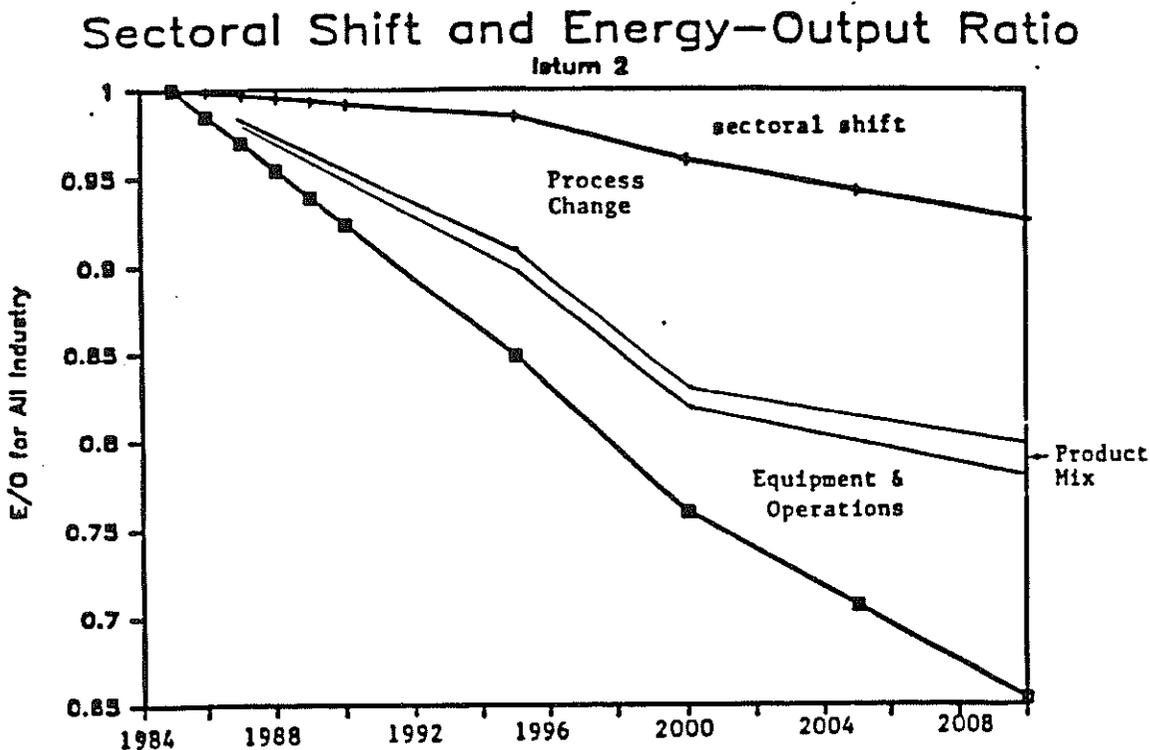


Figure 7: Decomposition of Aggregate Intensity Changes Into Sectoral Shift (between 7 sectors), Product and Process Shifts, and Efficiency and Maintenance Improvements

Table 4  
New Technologies That Capture Significant Market Shares  
in AES/ISTUM 1 and ISTUM 2 Reference Cases

AES/ISTUM 1

Atmospheric Fluidized Bed Coal Boiler  
Atmospheric Fluidized Bed Coal Boiler with Topping Cycle  
Coal Boiler with Topping Cycle  
Gas Turbine with Waste Heat Boiler  
Biomass Boiler with Topping Cycle  
High Efficiency Gas Boiler  
High Efficiency Oil Boiler  
High Efficiency Biomass Boiler  
High Efficiency Gas Direct Heaters  
Clean Coal Direct Heaters  
High Efficiency Gas Indirect Heaters  
Heat Pumps for Space Heating  
High Efficiency Direct Coal Calcining  
High Efficiency Gas Glass Melting  
New Waste Gas Steel Reheating

ISTUM 2

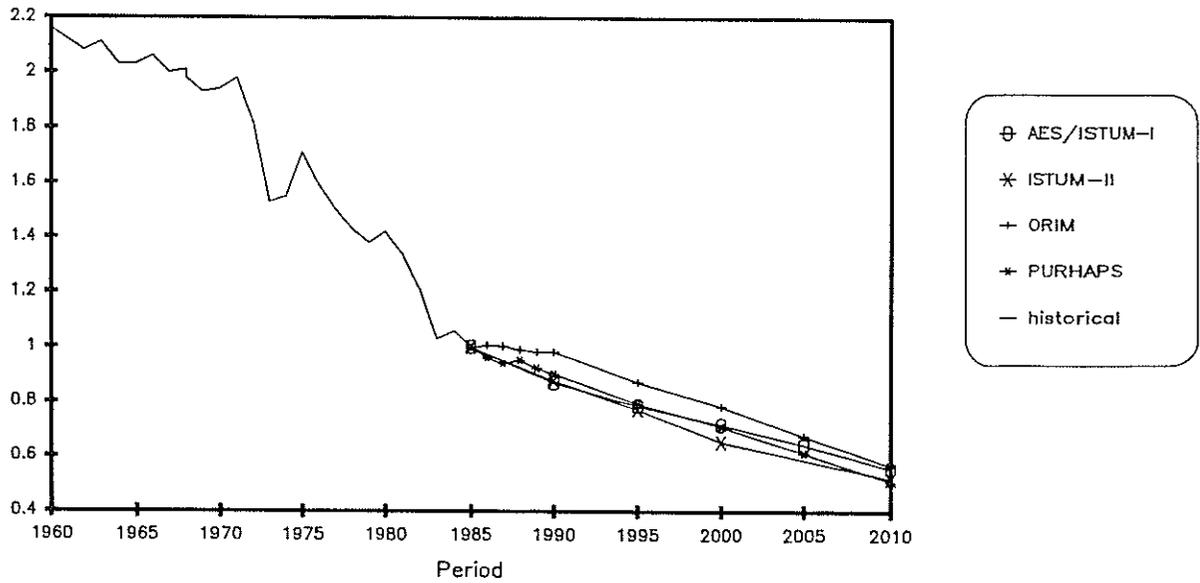
Microwave Drying of Pasta Products  
Displacement Bleaching (ODE) of Kraft Pulp  
Combined-Cycle Gas Cogeneration in Chemicals Industry  
Atmospheric Fluidized Bed Boiler in Chemicals Industry  
Advanced (MHD) Container Glass Melter  
Continuous Casting of Steel  
High Temperature Recuperator on Steel Reheat Furnaces  
Batch Preheater with Heat Exchanger on Scrap Aluminum Remelters  
Rotary Hearth Forging Furnace with Recuperator (Used in Metals Fabrication)

Figure 19: Trends in Paper Industry Energy Consumption

Pulp & Paper

Fossil Fuels (Div. by Gross Econ. Output)

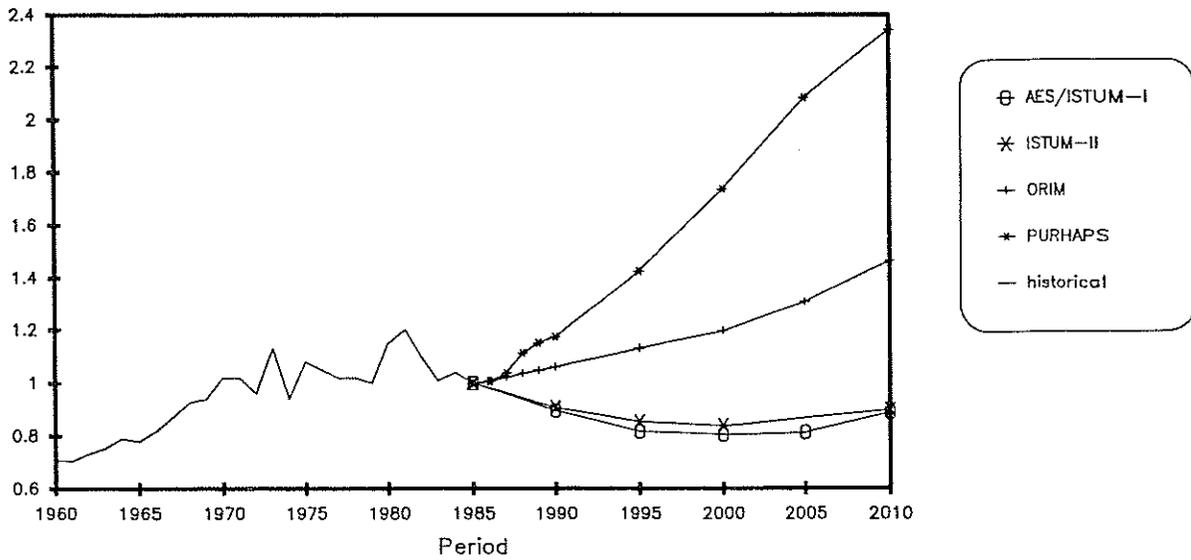
Indexed to 1985



Pulp & Paper

Purchased Electricity Div. by Gross Econ. Output

Indexed to 1985



for self-generated and residue fuels, 38% of that being for black liquor - a by-product of the Kraft pulping process. Since the passage of stricter environmental laws governing the disposal of red liquor produced in the sulfite pulping process in the early 1970s, the Kraft process has displaced the sulfite process to a significant extent. At some point one might expect to see diminishing returns from residue fuel use if new material must be bought or cut just for energy purposes; indeed, changes in wood supply markets might even reduce the fraction of usable waste. Thus, the rate of reduction in energy use due to greater waste utilization may be slowing down. On the other hand, product mix effects probably led to more energy use per unit of output during the 1970s than would have otherwise occurred. These shifts may continue into the future.

Increasing electricity demand in the pulp and paper industry has been driven largely by an increase in the use of Thermomechanical Pulping (TMP), and in the use of pollution control equipment. Other electric-intensive technologies such as oxygen-based bleaching and delignification may extend the trend. In the longer-term, the papermaking stage may offer some opportunities for electricity use as well.

The paper industry is perhaps the biggest user of cogeneration. The American Paper Institute reports that cogeneration has increased 40% in the past seven years and that another 40% increase is foreseen.

PURHAPS. According to the projections from PURHAPS the trend in energy use per unit of output here is projected to be about the same on net through 1995, as over the past ten years or so. As in the recent past, substantial investment in Thermomechanical Pulping is expected to come on line over the next few years. This leads to an increase in electricity

consumption. Canada picked up market share from the U.S. with improved technology a few years ago, but with a falling dollar U.S. firms may be able to regain market share (assuming access to cheap electricity as in the past and as in the EMF projections).

AES/ISTUM1. A large portion (roughly 40 percent) of the drop in purchased fuel per unit of output in the paper industry can be attributed to product and process shifts--primarily continued growth in Kraft pulping, greater use of continuous versus batch Kraft digestors and use of displacement bleaching. A small increase in mechanical pulping and increased use of electric vapor recompression systems leads to a slight increase in demand for electrical energy services over time.

Technology efficiency improvements contribute roughly 15 percent of the total decrease in purchased energy per unit of output. Most of this is due to more efficient boilers, in both new and replacement applications. New efficient motors and variable speed drives provide savings in machine drive.

The growth in Kraft pulping (which provides greater amounts of black liquor) and trends toward greater use of chips and wood in boilers lead to greater use of nonpurchased fuel. This displacement accounts for roughly 40 percent of the drop in purchased energy. Only a small portion of the total purchased energy per unit output decrease is due to increased use of cogenerated electricity. Cogeneration provides a large portion of electricity demand in 1985, and is not projected to gain any further significant market share.

ISTUM2. Due to more efficient processes and energy recovery options, overall intensity drops 27 percent by 2000. In the short-term, the

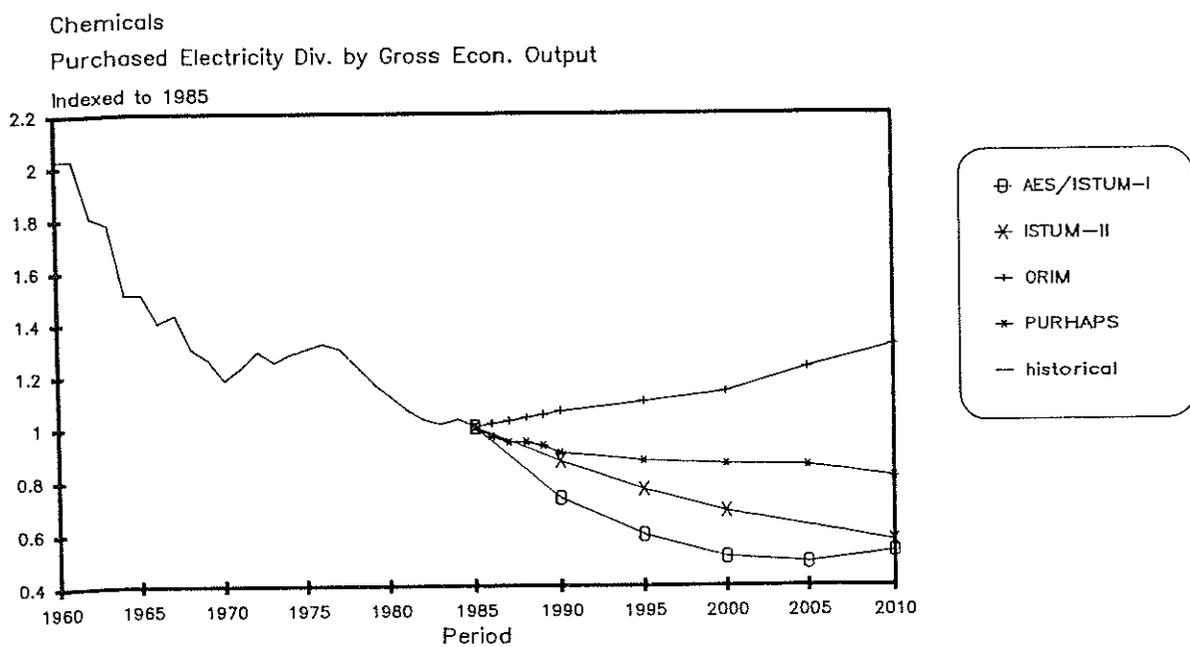
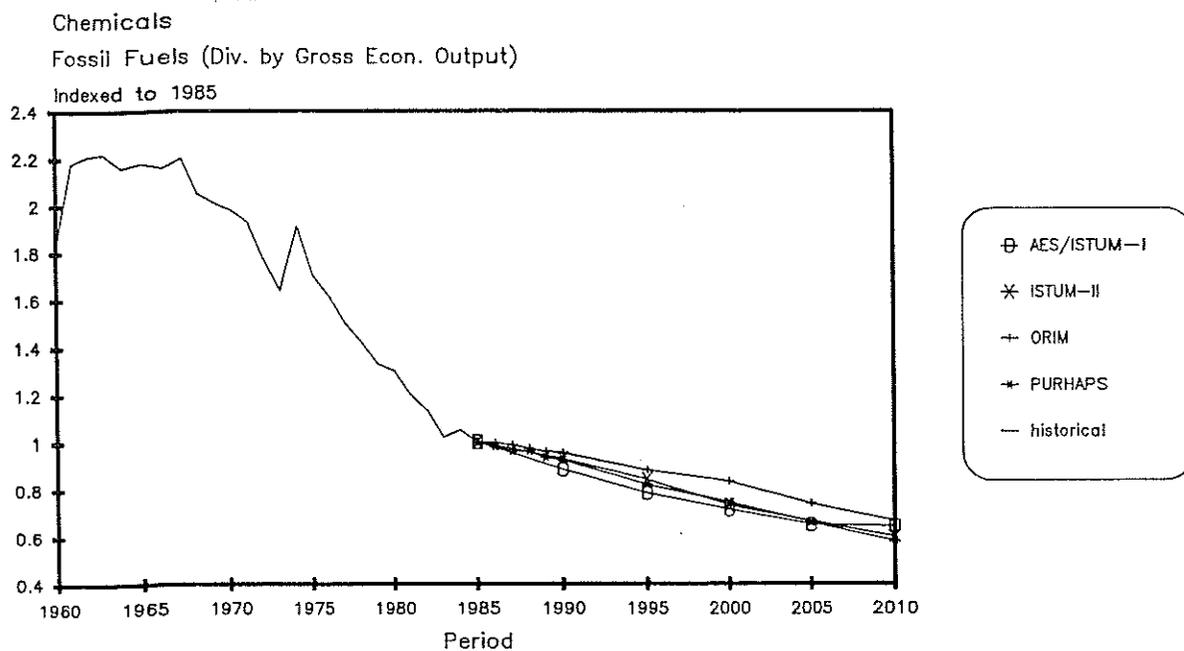
intensity of self-generated fuels (e.g., black liquor, hogged fuels and wood waste) increases as they replace purchased fuel. Longer-term process shifts to such options as continuous digesters, displacement bleaching (ODE) of Kraft pulp, extended nip pressing, and vapor recompression help bring down purchased fuel intensity substantially and that of self-generated fuels by a lesser degree.

### Chemicals

Historical trends and model projections of fossil fuel and electricity use per unit of output by the chemicals industry (SIC 26) are shown in Figure 20. The chemicals industry is the most dynamic of the four industries singled out here. It makes the most diverse set of products, far too complex for any of the EMF 8 models to analyze in detail. The greatest portion of its energy use occurs in the production of commodity chemicals such as ethylene, polyethylene, methanol, ammonia, benzene, chlorine, caustic soda, elemental phosphorous, and the like. The proportion of energy use per unit of value is less in intermediate and final consumption chemicals, such as pharmaceuticals and agricultural pesticides where the value added content is much greater than for commodity chemicals. The chemicals industry is also a significant user of cogeneration technologies.

The chemical industry has seen a tremendous reduction (of over 30 %) in energy use per unit of real output over the past decade due to improved processes, equipment, and housekeeping. There has been an additional effect through a shift to higher value-added products that use less energy per unit of production value. This subtle product mix shift has led to lower energy consumption for total industry output than can be accounted for by the from more energy-efficient technologies and practices for producing individual products.

Figure 20: Trends in Energy Use in the Chemicals Industry



PURHAPS. The PURHAPS projections for heat and power used in manufacturing chemicals show some slowing of the historical trend towards less energy consumption per dollar of output. However, significant reductions are projected to continue because of the on going shift towards the production of less energy intensive, higher value-added products. The historical trends in chemical feedstocks (including primarily oil, including natural gas liquids) were adjusted in PURHAPS. According to historical data, this feedstock consumption grew 2% faster than SIC 28 (chemicals) and 30 (rubber) output from 1963 to 1982 (the most recent EIA data). It grew 1.3% faster than production in SIC 282, Plastic Materials and Synthetic Fibers. EIA believes that this increase was due to the relative grow of simple, energy intensive plastics in the recent past; for example, historical datashows rapid growth for ethylene in this period.

In the PURHAPS projections for EMF 8, it was assumed that plastics will continue to grow 0.7% faster than chemical production as a whole. However, it is also assumed that feedstocks per unit of plastic output will decline at .7% per year instead of growing at 1.3%, because of a shift to more specialized plastics; counterbalancing this, the energy used for heat and power is adjusted upwards by 2% per year, due to the need for more downstream processing. The net effect is that feedstocks grow exactly in proportion to chemical output.

The PURHAPS projections exhibit no electrification trend in the chemical industry, based on recent trends. Two declining trends cancel each other out -- a trend away from self-generated electricity and a trend towards less electricity use in uranium enrichment; also, the trend towards higher value-added products should be relatively favorable to electricity, offsetting a modest growth in cogeneration.

AES/ISTUM1. Most (over 60 percent) of the decline in purchased energy use per unit of economic output for the chemical industry in this model is the result of product and process shifts. Because economic output is measured in dollars, growth in high-valued products, which are generally lower energy consumers per unit of output, is overstated in relation to the more energy-intensive products, when projecting energy service demands. In addition, there is an assumed future trend away from production of the more energy-intensive basic chemicals to more capital-intensive products. Demand for electric services per unit output is projected to decrease roughly 10 percent by 2010 due to reduced use of electric arc furnaces in the production of phosphoric acid and a continued historical trend of improvements in electrode technology in the chlor-alkali industry.

Reductions in energy intensity due to improved equipment are much smaller for chemicals than for paper, and explain only 6 percent of the total decrease in 2010. The gains from improved equipment for indirect heat and steam are partially offset by an increase in cogeneration. When energy is measured on an end-use basis for industry alone, cogeneration increases energy consumption because the losses associated with electricity production are now attributed to industry rather than the electric utility. Increased cogeneration also reduces the demand for purchased electricity and thus total purchased energy as well. More than a third of the 37 percent drop in purchased electricity per unit output by 2010 is due to decreased purchases from electric utilities resulting from onsite cogeneration. Roughly 40 percent of the total drop is due to increased self-generation replacing electricity demand, primarily through the use of non-purchased fuels, such as mixed fuel gas. The increased use of

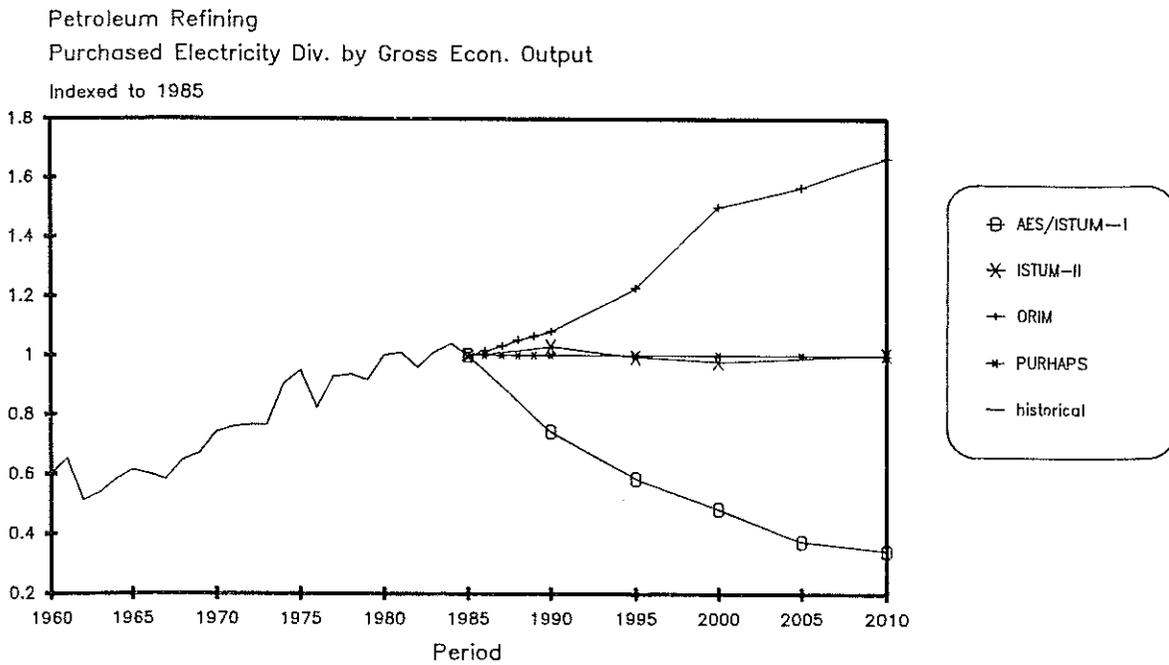
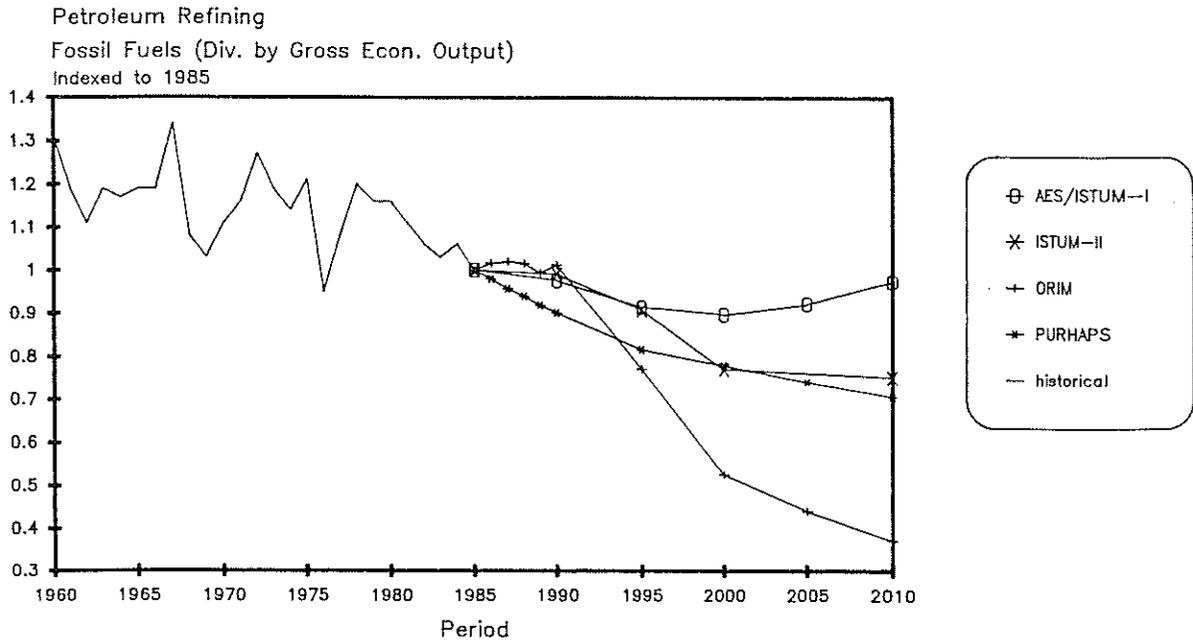
non-purchased fuels is also evident in total energy use projections where it plays a significant role in reducing demand for purchased energy. This trend may be overstated in AES/ISTUM1 since a decline in basic chemicals production should reduce the availability of non-purchased fuels.

ISTUM2. The range of uncertainty about new products and processes is much wider here than in any other industry. The ISTUM-2 projections, which are based on a limited slate of products and processes, indicate little change in the intensity for feedstock fuels and significant reduction in other fuels for process heating, and steam and power generation. The use of combined-cycle gas boilers and atmospheric fluidized-bed boilers are expected to grow rapidly in this industry, especially as the current surplus boiler capacity evaporates. Overall energy intensity is projected to drop by about 20 percent from its 1972 level by 2000 due to process shifts, improved heat recovery and better energy housekeeping. The further penetration of cogeneration probably explains the lower level of purchased electricity in ISTUM2 than in PURHAPS.

### Petroleum Refining

Historical trends and model projections of fossil fuel and electricity use per unit of output by the petroleum refining industry (SIC 29) are shown in Figure 21. The scale of the domestic refining industry has declined over the past decade because of the reduction in demand caused by the rising prices of petroleum-based fuels relative to prices of other fuels and other goods and services in general. This situation has led to the substitution of other products for petroleum products and hence has reduced the demand for refinery outputs. In 1981, the refinery utilization rate was only 65 percent of capacity. At the same time, the refinery slate

Figure 21: Trends in Energy Use by the Oil Refining Industry



was shifting away from regular, leaded gasolines to unleaded, high octane products and to a steadily declining fraction of residual fuel oil. Also, there was a shift in crude oil away from the more easily refined light, low-sulfur crude oils toward heavier, high-sulfur crude oils.

PURHAPS. The total energy number projected with PURHAPS exhibits a 2% per year reduction in energy consumed per unit of output, as in 1974-84 data from EIA's Energy Conservation Indicators. (Actually, it was 3% until 1981, when it froze.) Likewise, the electricity ratio is flat, based on inspecting the same data.

ORIM. The petroleum industry uses a large amount of process heat to crack crude oil and produce refined products. In ORIM, electricity can compete with fossil fuels in 50% of the process heat market. ORIM uses life-cycle costs to estimate market penetration for each vintage of capital stock. If current year costs rather than life-cycle costs are used to perform a back-of-the-envelope estimate, the market share for electricity in its potential market increases from 10% in 1985 to 90% in 2010; since electricity is limited to 50% of total process heat, the market share for new electric furnaces increases from 5% to 45%.

AES/ISTUM1. Projected product mix shifts away from gasoline production to more middle distillate lead to reduced total energy service demand per unit of economic output. However, the use of heavier crudes partially offsets this decline. Electric service demands per unit of output are projected to increase slightly in this industry with greater use of electric vapor compressors. As in the chemicals industry, efficiency improvements in new boilers, furnaces, and motors combined with greater use of cogeneration lead to only a 2 to 3 percent decline in energy use per unit of output. Also self-generation for machine drive, much of it fueled

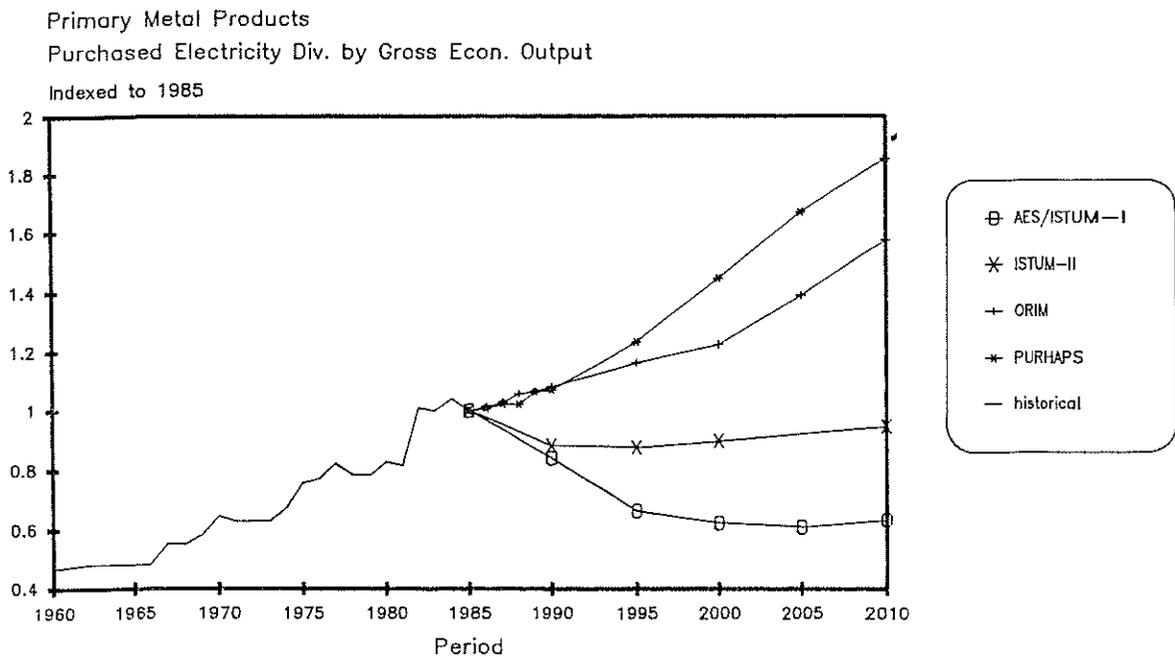
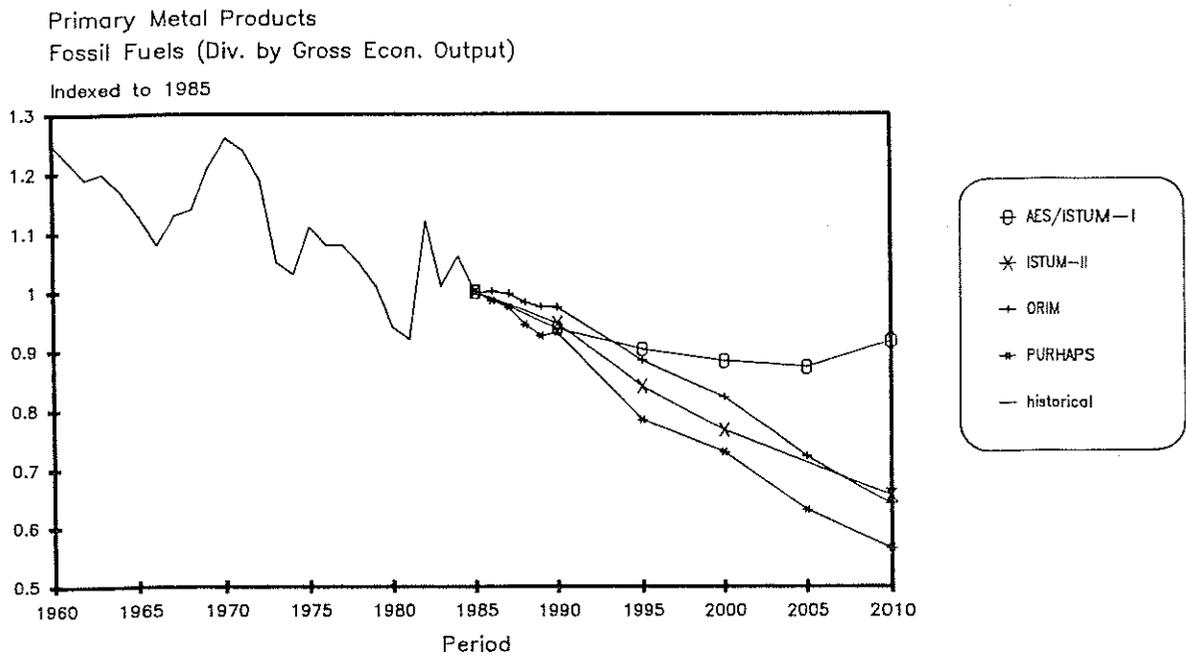
by still gas (non-purchased), causes a decline in electricity use. Post-1995 the use of still gas is projected to decline due to reduced utilization of fluid catalytic cracking and isomerization units as heavier oils are used. In these later years purchased energy actually increases per unit of output although total energy use remains fairly constant.

ISTUM2. Significant reductions in the short term are expected for the intensity of total energy, self-generated fuels (e.g., still gas, gas oils, residuum oil) and purchased fuels. This is due primarily to better process and intra-process flow control, improved heat recovery and more housekeeping activities. Additional intensity reductions in the longer term are harder to realize due to deterioration in raw material (heavier and higher sulfur crudes) and the lack of significant new capacity additions because of low projected product demand growth.

### Primary Metals

Historical trends and model projections of fossil fuel and electricity use per unit of output by the primary metals industry (SIC 33) are shown in Figure 22. Among the four key energy-using industries, primary metals now suffers the most from declining domestic sales. In addition, older, large-scale, integrated iron and steel producing firms also suffer from competition from domestic minimills that can produce steel at a much lower costs. Investment strategies vary a great deal between the older, integrated firms, and the newer minimills. The former have been forced into triage, sacrificing older mills to husband resources for their most efficient and highest profit operations. Even for the latter, many energy-related projects can not be undertaken because of abnormally low use

Figure 22: Trends in Energy Use by the Primary Metals Industry



of existing capacity. At minimills, capital availability does not now appear to constrain investments in energy efficient equipment or for any other objective as long as target hurdle rates for returns on investment are achieved.

During the 1970s a slight trend towards more energy intensity occurred in this industry. Since 1981, some more efficient new units have come on line; however, the share of metallurgical coal has fallen a great deal, and the share of electric-based plants has increased, suggesting counterbalancing changes. Data from the American Iron and Steel Industry show a continuing decline in self-generated electricity, due to the closure of older integrated plants which are more likely to use cogeneration.

PURHAPS. Through 1995 at least, the share of electric arc furnaces versus blast furnaces increases to maintain the historical trend; again, the most recent data suggest an acceleration of the trend, if anything. Electric reheat furnaces have just begun to come on line, as well. Recently, a major manufacturer was quoted as saying that electric plasma reduction is already cost-competitive; this would allow a more rapid electrification than projected here, even through 2010. More generally, shifts towards more complex alloys and intermetallics will be important after 1995.

AES/ISTUM1. Process trends here include retirement of open hearth furnaces which are replaced with electric-arc furnaces, decreased use of coke and greater hydrocarbon injection in blast furnaces, and declining demand for electricity due to continuous casting in primary finishing replacing ingot casting. The net result of these trends leads to a 5 percent drop in the total energy service demand per unit output and a 7 percent drop in electric service demand per unit output by 2010.

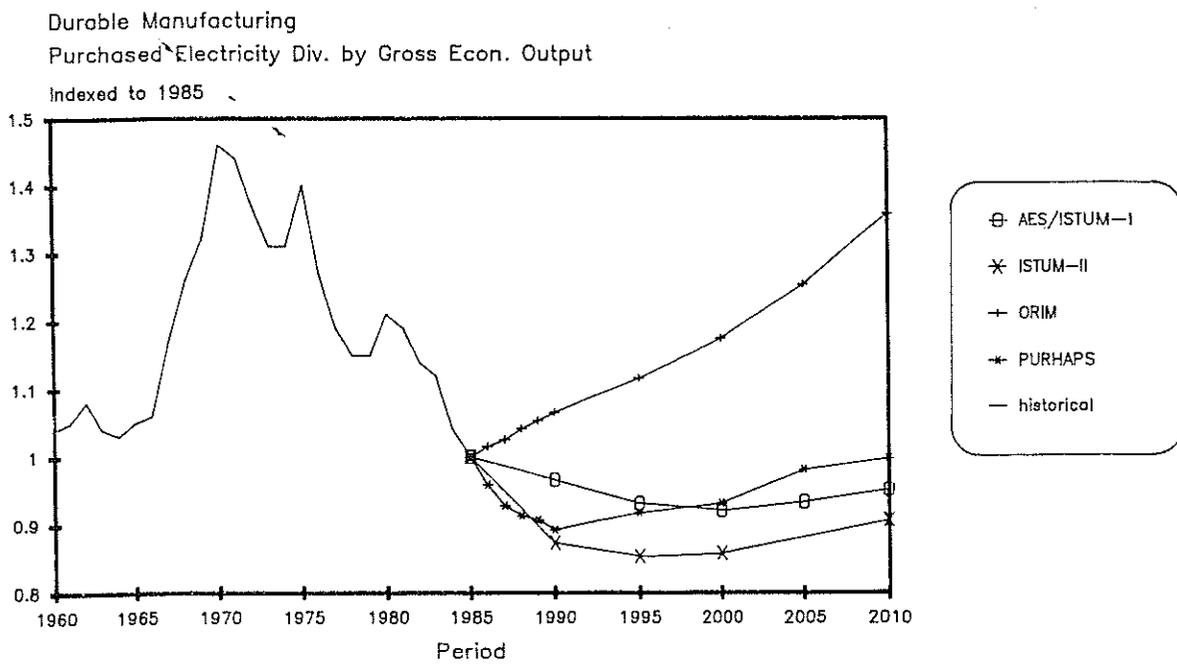
Technology improvements include higher efficiency boilers, furnaces and motors and high temperature recuperators. These trends lead to a further 13 percent drop in energy use by 2000. As in the paper industry, cogeneration is not projected to gain much additional market share and therefore has little effect on indices of total energy use or purchased electricity. Non-purchased fuels such as blast furnace gas, are projected to maintain a fairly constant overall market share. Coal and gas-fired self generation are projected to gain some market share, which leads to lower electricity use per unit output.

ISTUM2. Due to reductions in the coking rate for blast furnaces and the increased use of electric-arc furnaces and continuous casters, the steel industry trends exhibit significant reductions in energy intensities. The most substantial reductions are in metallurgical coal use due to environmental constraints on coking capacity, adequate scrap supply and investments in direct-reduction iron facilities. The drop in the intensity of fuels other than metallurgical coal is due to a higher fraction of electric arc furnaces, increased continuous casting, improved heat recovery (primarily via high temperature recuperators on steel reheat furnaces, batch preheaters with heat exchangers on scrap aluminum remelters, and recuperators on rotary hearth forging furnaces) and housekeeping.

#### Durable Manufacturing

Historical trends and model projections of fossil fuel and electricity use per unit of output by the durable manufacturing industries (SICs 34-38) are shown in Figure 23. The trends here are an important reason for the overall agreement between the process models and econometric models in forecasting total energy use by the manufacturing industries. Here the

Figure 23: Trends in Energy Use by the Durable Manufacturing Industries



econometric models project far less energy use than the process models, mainly because of product shift. In the Wharton forecasts, the big growth is in machinery and electrical machinery. With computers and programmable machine tools, value-added can grow without big growth in the tonnage of the product. (With automobiles, PURHAPS projects a bit less reduction in energy use.) This value-added effect leads to strong growth in the market share of electricity relative to that for other fuels, but not to a dramatic increase in the absolute level of electricity demand.

#### Role of Cogeneration

One technology that appears in one form or another in each of the energy intensive industries discussed above is cogeneration. The two process models (AES/ISTUM1 and ISTUM2) explicitly represent a number of different cogeneration options. In the aggregate these models project a modest increase in the market share of electricity requirements met with cogenerated, as opposed to purchased, electricity between 1980 and 1995, with much less growth after 1995 (see Figure 24). The Primary Metals Industry already derives a significant share of its electricity requirements from cogeneration and that share is not projected to increase very much. However, moderate growth in the use of cogeneration is expected to take place in the chemicals, paper, and oil refining industries over the next ten years.

# Electricity Growth Rates: 1985-1995

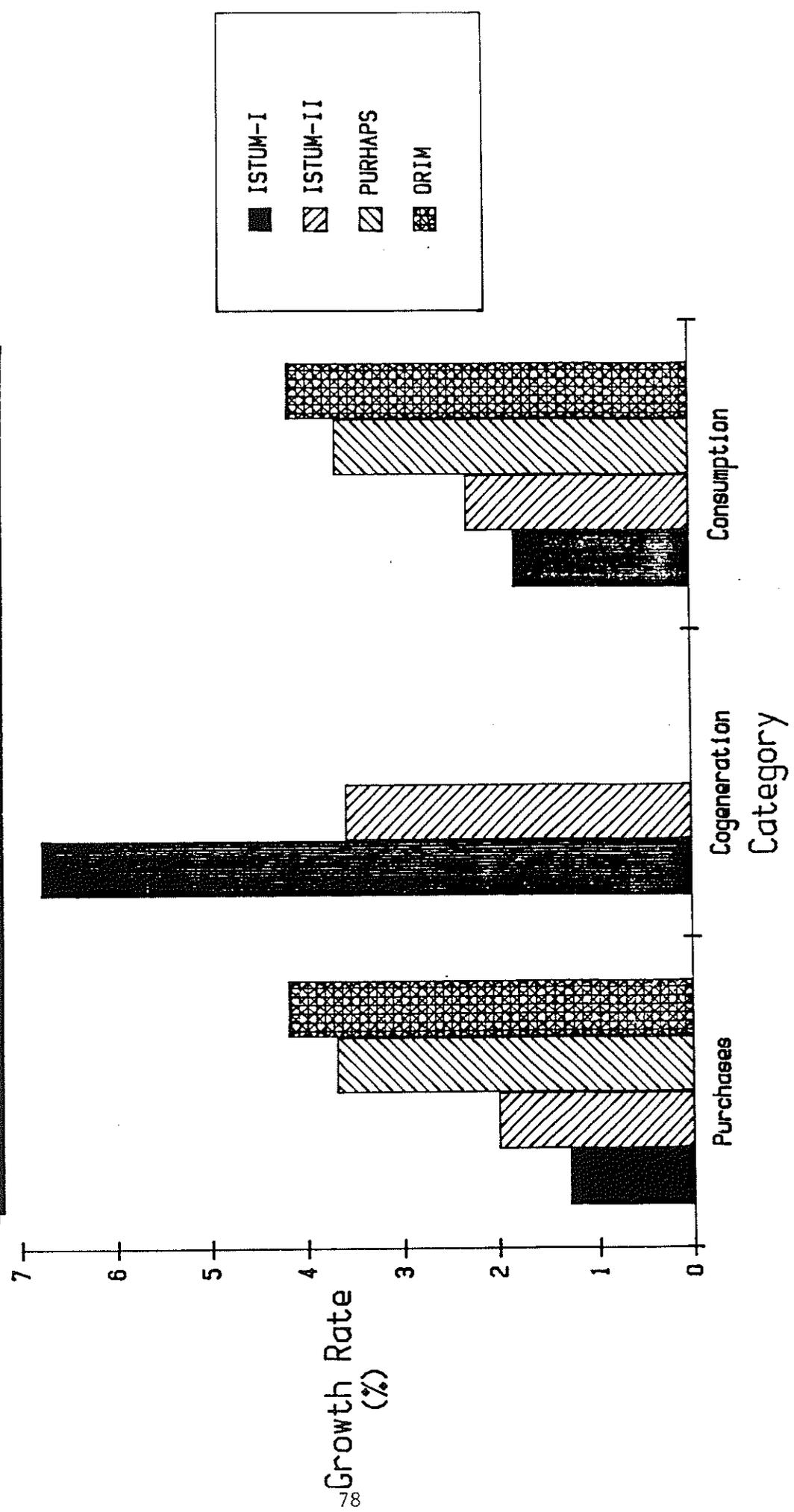


Figure 24: Trends in Use of Cogeneration by U.S. Industry

## FUEL SWITCHING/CHOICE

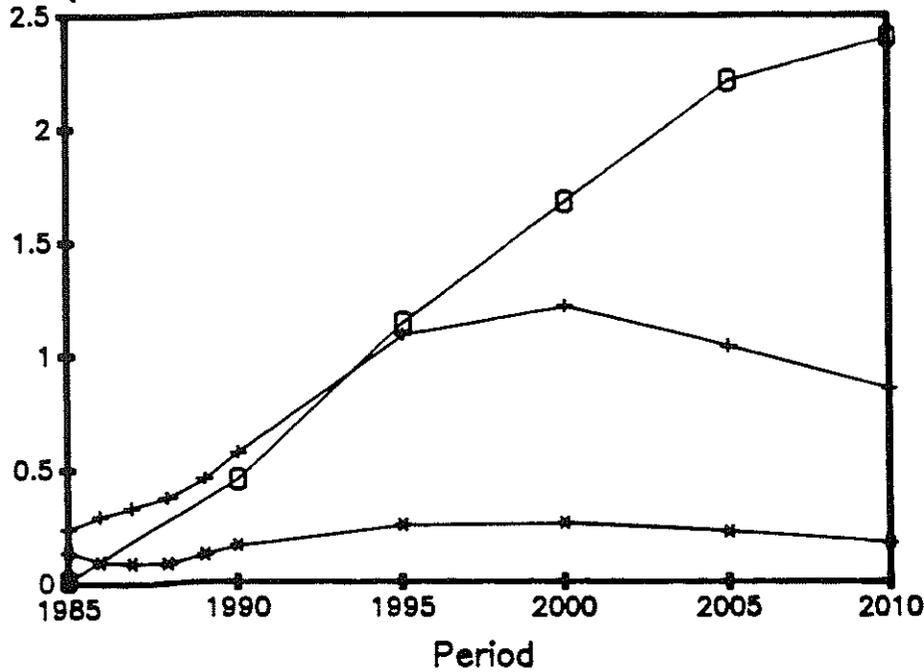
In this study a distinction was made between short-term fuel switching using existing equipment, and longer term fuel choice including equipment purchase options.

### Short Term Fuel Switching

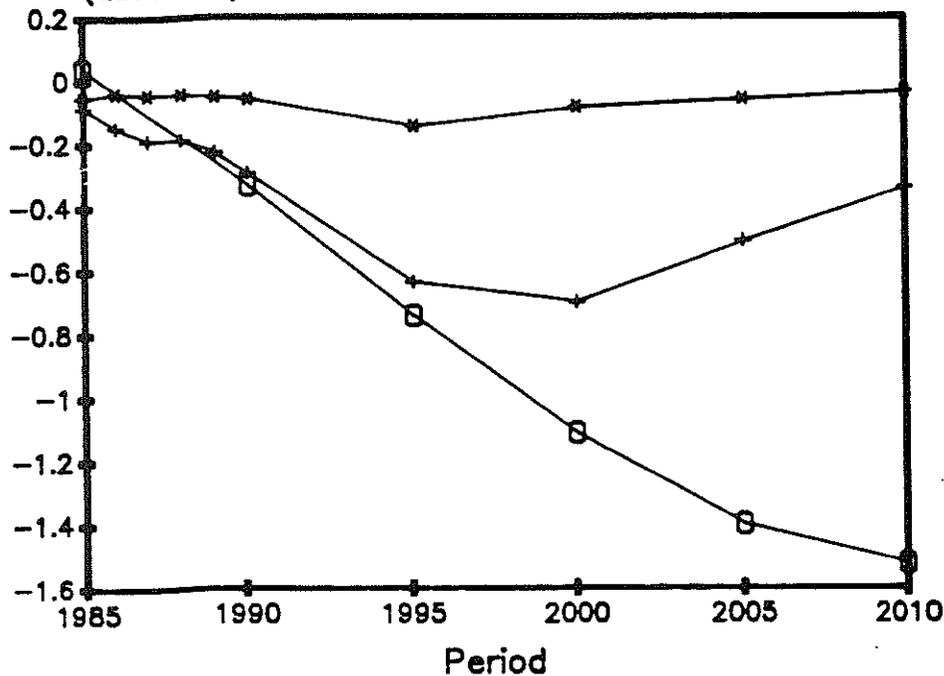
In the near term, the most intense interfuel competition is between oil and gas because most existing dual-fired capacity is oil-gas and the capital costs associated with dual-firing are relatively low. During 1985 gas was in standard use in dual-fired boilers, with approximately .4 quads of residual oil and 5.5 quads of natural gas being used annually. As shown in Figure 25, the models show varying degrees of response to changes in the relative prices of oil and gas. In the econometric models, a reluctance to switch fuels reflects low historical levels of fuel switching. Industrial users do not all have dual-fired capacity and even those who do may not switch between gas and oil as much or as rapidly as aggregate fuel price data would seem to indicate due to (1) high unit costs of switching faced by some smaller classes of users, (2) extra--albeit small--handling, storage, and heating costs associated with using oil, (3) long-term contractual obligations, (4) seasonal factors, (5) the clean-burning capability of gas, and (6) the ability of larger industrial users to negotiate attractive gas prices, at least on incremental volumes. These factors are not all explicitly incorporated in the models used in this study. Nonetheless, the low relative oil price scenarios do indicate, at least for the process models, the potential for greatly increased oil use in the industrial sector in the medium to longer term.

Figure 25: Responsiveness of Oil and Gas Use to Changes in the Relative Prices of Oil and Gas

Low Oil Price (Abs. Diff. w.r.t. Reference Case)  
 Manufacturing  
 Oil Cons.  
 (Quad Btu)



Low Oil Price (Abs. Diff. w.r.t. Reference Case)  
 Manufacturing  
 Gas Cons.  
 (Quad Btu)



### Longer Term Fuel Choice

In the longer-term, oil and gas compete with coal and electricity depending on the application. Heat and process power are often available from several sources, and costs must be balanced against the risks and benefits of a particular technology selection. There is also competition between purchased electricity and cogeneration supplied by a variety of fuel sources. Several general trends in long-term fuel shares emerge from the model results.

The models consistently project steady penetration of purchased electricity in industrial energy markets over the long term, as shown in Figure 26. A portion of this penetration is related to the continuing automation of the U.S. industrial sector. The majority of current and projected industrial electricity demand is electricity-specific processes (e.g., electrolysis, process control, lighting, and many motor applications). Direct competition with fossil fuels may be a lesser issue, except in the case of cogeneration. However, the models do demonstrate that the pace of electrification is sensitive to future electricity prices, especially relative to capital and labor costs. In general, the models do not anticipate any significant saturation of electricity technologies in the industrial sector, although ISTUM-I does incorporate such a potential. In the very long term, most scenarios include declining relative electricity prices which prompt more direct competition between electricity and fossil fuels in non-electricity specific applications such as process heat.

All the models show declining market share for gas for industrial heat in the Reference case and for almost all alternative scenarios, (see Figure 27 and Table 5). This tendency to substitute electricity, coal, and oil for gas reflects the facts that the price of gas is relatively high in most

Figure 26: Projections of Electricity's Share of the Manufacturing Fuel Use Market

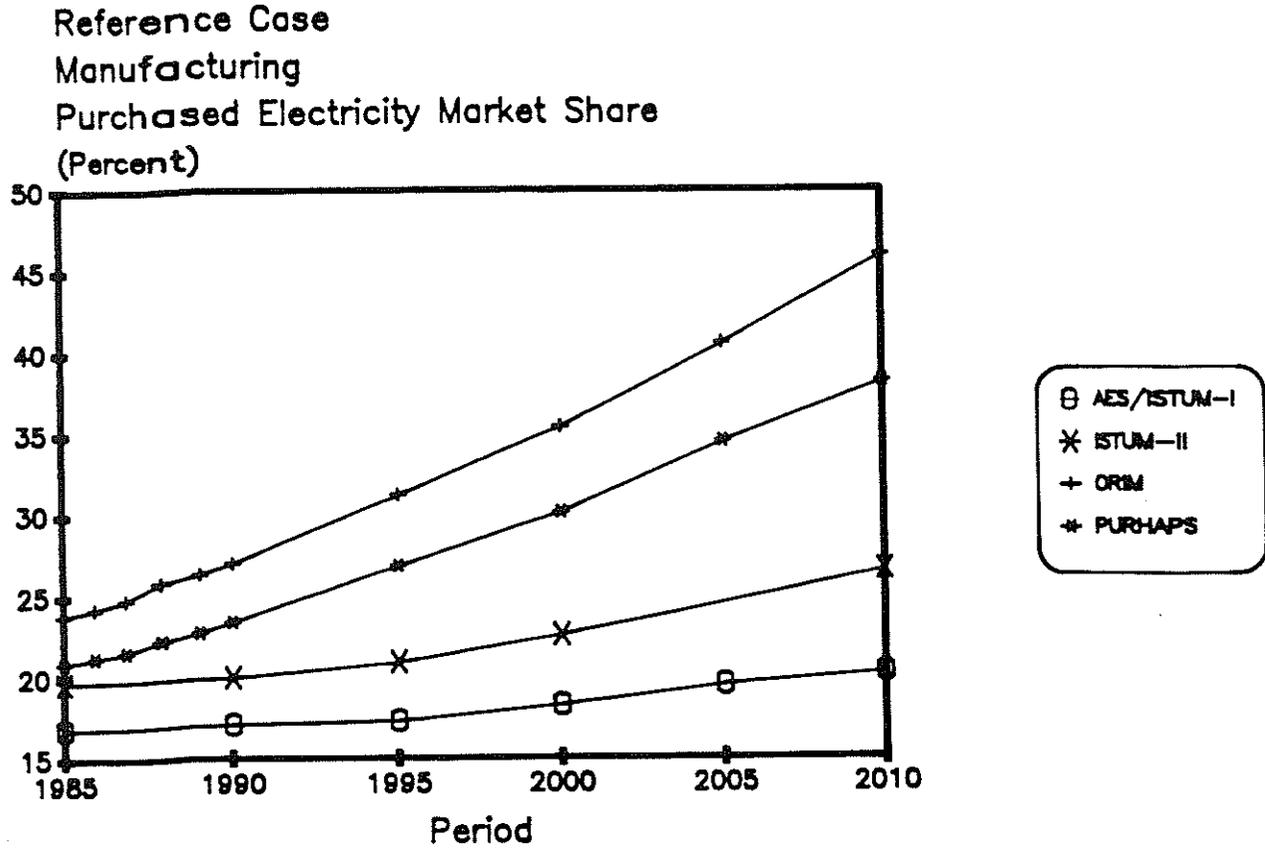


Figure 27: Projections of Market Share of Natural Gas in Manufacturing Fuel Use

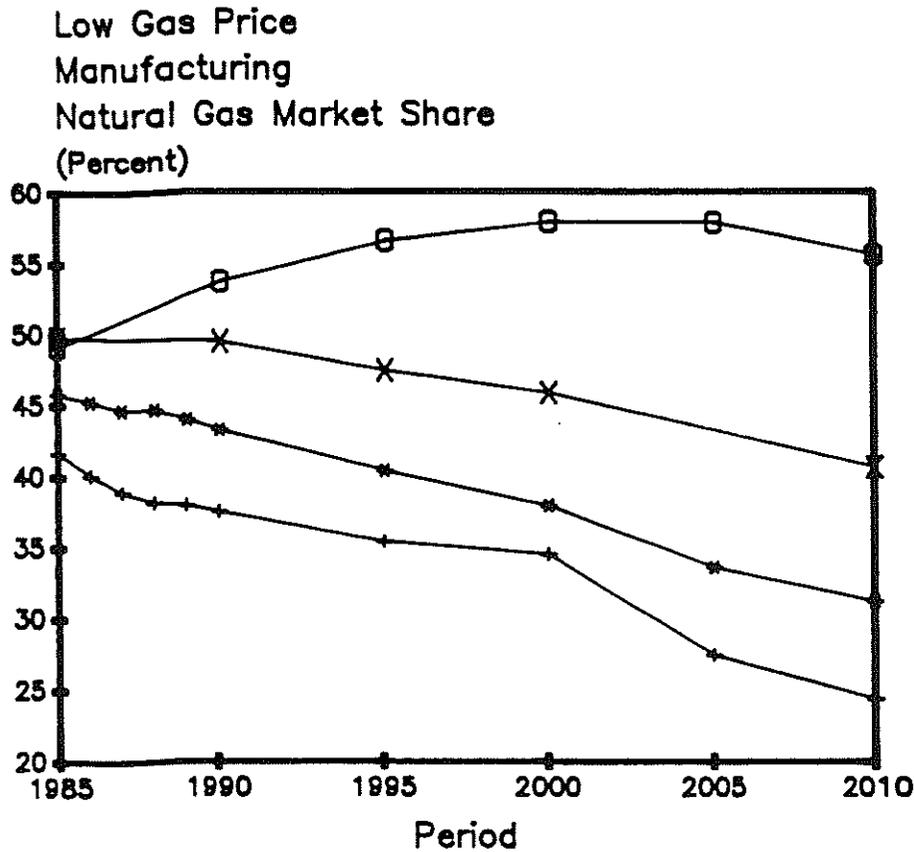
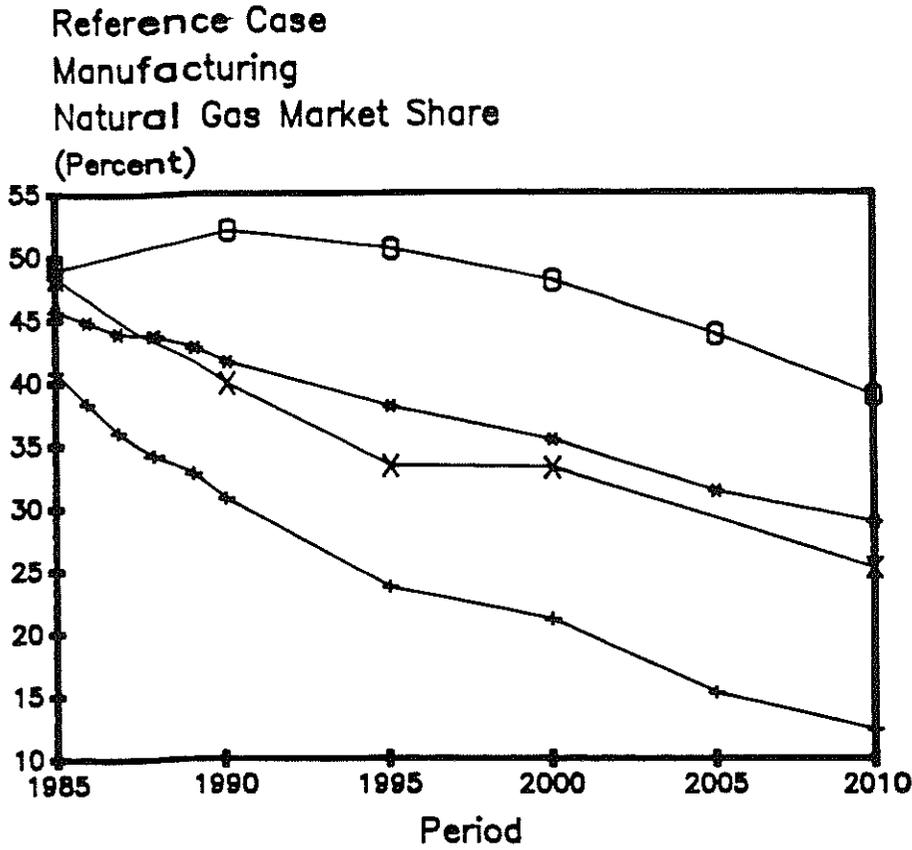


Table 5  
 Manufacturing  
 Natural Gas Market Shares  
 (Percent)

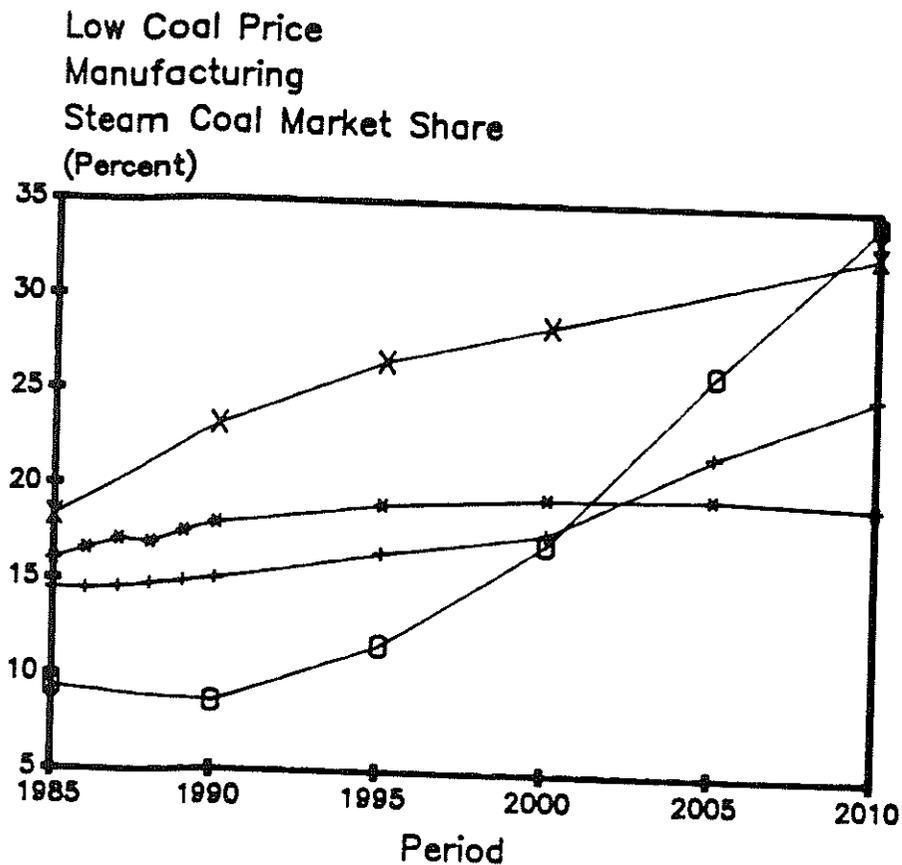
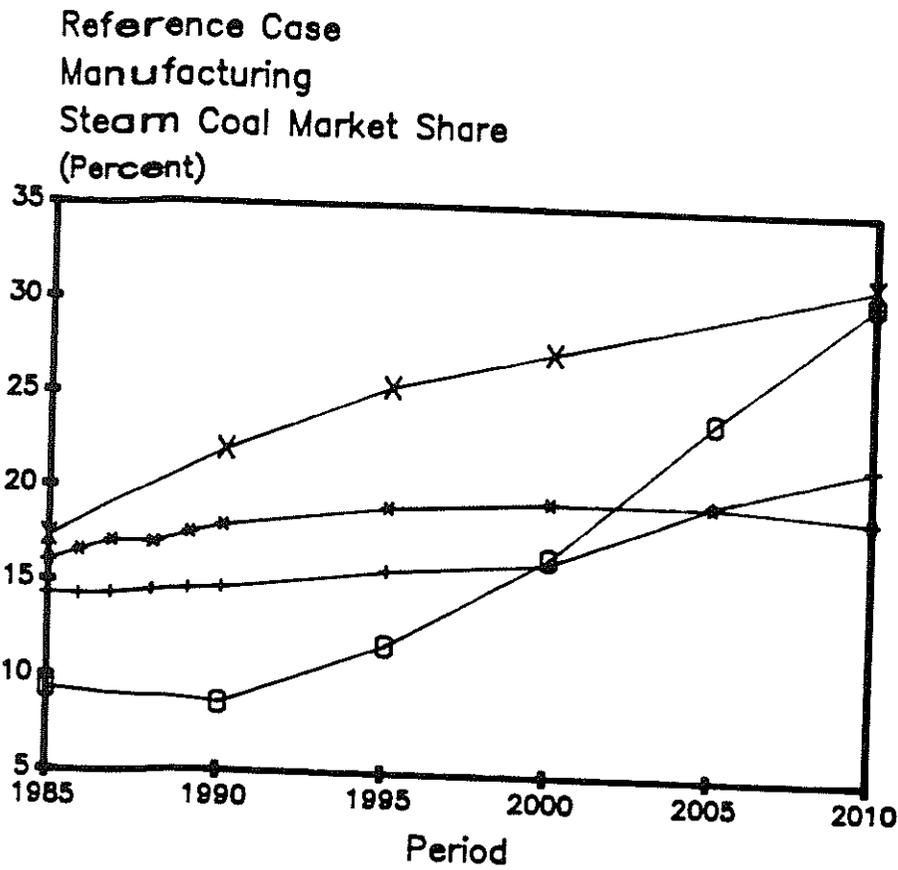
	<u>1985</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>	<u>2005</u>	<u>2010</u>
<u>High Oil Price</u>						
ISTUM-II	50.54	48.82	45.76	43.54	---	35.02
ORIM	41.19	37.62	32.39	29.70	22.58	18.25
PURHAPS	46.13	43.09	39.45	36.58	32.37	29.76
<u>Low Oil Price</u>						
AES/ISTUM-I	49.05	49.23	44.65	39.64	33.95	29.32
ORIM	39.40	27.45	17.42	14.42	10.57	9.33
PURHAPS	44.88	40.74	36.69	34.22	30.46	28.31
<u>Low Gas Price</u>						
AES/ISTUM-I	49.12	53.73	56.60	57.92	57.85	55.56
ISTUM-II	49.77	49.47	47.42	45.81	---	40.60
ORIM	41.67	37.52	35.40	34.49	27.42	24.35
PURHAPS	45.78	43.24	40.37	37.88	33.57	31.19
<u>Low Coal Price</u>						
AES/ISTUM-I	49.25	53.16	52.35	49.74	45.96	40.78
ISTUM-II	48.66	40.99	34.36	34.26	---	26.40
ORIM	41.36	31.59	24.62	22.18	16.23	13.29
PURHAPS	46.18	42.07	38.53	35.86	31.77	29.32
<u>High Electricity Price</u>						
AES/ISTUM-I	48.97	52.04	50.57	47.58	42.22	36.50
ISTUM-II	46.19	37.93	31.55	31.56	---	23.90
ORIM	40.71	30.59	23.38	20.65	14.63	11.52
PURHAPS	45.74	41.62	38.09	35.49	31.45	29.03

of the scenarios examined and that most industrial users who may choose between oil and gas are currently using gas. Gas use is also reduced by the potential for conservation and efficiency improvements in selected gas-intensive industries such as chemicals. In addition, gas competes well in industries that are projected to grow less rapidly than the industry average as do chemicals and steel. However, AES/ISTUM-I does show a potential for gas to gain market share when the relative price of gas is reduced.

Natural gas faces particularly difficult long-term competition with purchased electricity. Several important emerging electricity technologies, such as electric furnaces for metals reduction and microwaves for drying, compete most directly with processes that are currently gas-fired. In addition, the potential for cogeneration creates additional competition between gas and purchased electricity. The economics of many current cogeneration opportunities hinge on the relative prices of gas and electricity. Natural gas is used to fuel many cogeneration facilities. The decision to cogenerate electricity thus depends on the cost of using gas to produce electricity, the cost of purchased electricity, and the tax incentives and electricity buy-back rates allowed by law. Focusing on energy costs, if a consumer's anticipated future cost of using natural gas to produce electricity is less than the expected cost of purchasing electricity, the consumer will invest in electricity generation equipment, buy gas rather than electricity, and produce his own electric power.

Projected penetration of industrial markets by steam coal varies significantly across models, as shown in Figure 28. Econometric models tend to project relatively slow growth for coal, based at least in part upon its lackluster historical performance in industrial markets. Some

Figure 28: Projections of the Market Share of Coal in Manufacturing Fuel Use



process models, on the other hand, show scope for significant coal penetration. That rate of penetration is sensitive to assumptions regarding cogeneration economics and the evolution of clean coal-burning technologies, especially fluidized-bed combustors. Industrial coal use is somewhat less sensitive to fuel prices than the use of oil and gas because much of the cost of using coal is associated with capital costs, storage, handling, and environmental control (see Table 6). For all models, overall coal penetration is sensitive to the economics of its use by the small to mid-sized industrial user whose scale of operation currently discourages conversion to coal or investment in new coal capable capacity.

As indicated in Figure 29, fuel choice in agriculture, construction, and mining is much less sensitive to energy prices than in manufacturing. A number of factors lead to the implied reluctance to change fuel consumption in response to fuel price changes. Energy demand in mining and agriculture is dominated in the long term by depletion effects, which means that more energy is required to produce the same output. Also, substantial amounts of motor fuel and diesel generator requirements which do not face significant interfuel competition are included in this sector's energy demand. Historical data on the mining sector are poor, so the price response shown here may simply be understated.

#### Energy Price Shock Analysis

The models included in this EMF study cannot be used to study dramatic jumps in energy prices without external information/analysis regarding the effects of these shocks on the overall economy. The most important effects of energy price shocks may be their impacts on savings rates, inflation, and economic output, which are not explicitly represented in these models.

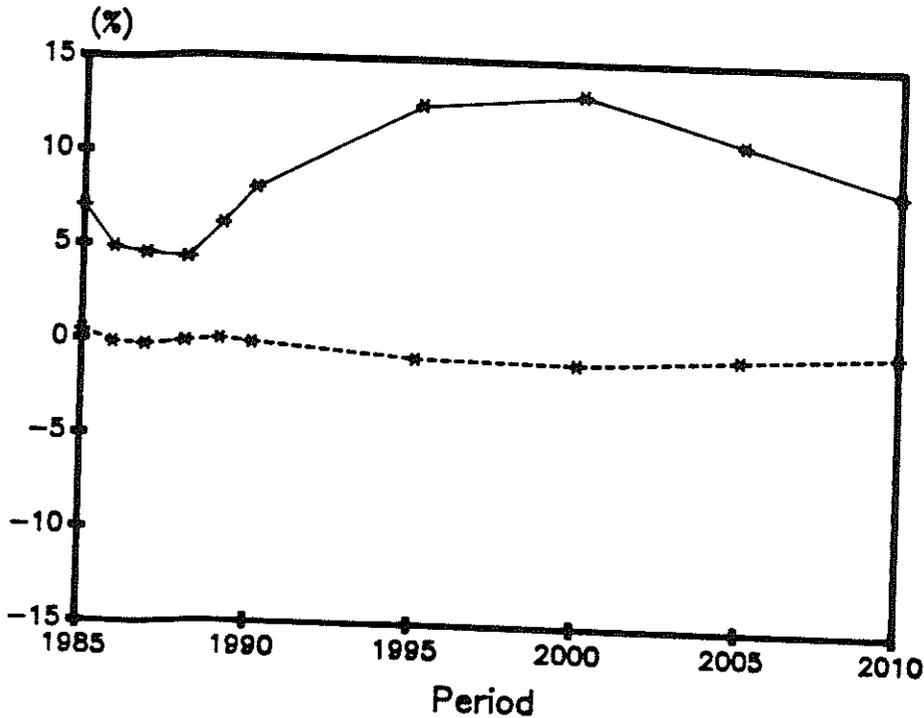
Table 6  
 Manufacturing  
 Steam Coal Market Share  
 (Percent)

	<u>1985</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>	<u>2005</u>	<u>2010</u>
<u>High Oil Price</u>						
AEA/ISTUM-I						
ISTUM-II	17.36	22.17	25.57	27.53	---	31.24
ORIM	14.64	15.56	16.64	17.28	20.72	22.96
PURHAPS	16.06	18.04	19.19	19.57	19.49	18.84
<u>Low Oil Price</u>						
AES/ISTUM-I	9.29	8.19	9.77	13.34	19.01	25.28
ORIM	13.95	14.07	14.84	15.41	18.54	20.56
PURHAPS	15.95	17.86	18.96	19.35	19.35	18.74
<u>Low Gas Price</u>						
AES/ISTUM-I	9.31	8.15	9.34	11.53	14.90	18.69
ISTUM-II	17.24	20.84	24.20	26.19	---	30.39
ORIM	13.45	12.83	12.88	12.75	15.17	16.62
PURHAPS	16.02	17.96	19.06	19.51	19.52	18.94
<u>Low Coal Price</u>						
AES/ISTUM-I	9.31	8.68	11.70	16.97	23.95	30.42
ISTUM-II	17.17	21.57	25.02	27.06	---	31.15
ORIM	14.24	14.56	15.49	16.03	19.29	21.40
PURHAPS	16.01	18.04	19.17	19.60	19.67	19.09
<u>High Electricity Price</u>						
AES/ISTUM-I	9.33	8.58	11.61	17.08	26.14	34.29
ISTUM-II	18.34	23.16	26.57	28.57	---	32.65
ORIM	14.48	15.05	16.46	17.63	21.85	25.08
PURHAPS	16.02	17.97	19.02	19.48	19.63	19.29

Figure 29: Comparison of Responsiveness of Oil Use in Manufacturing to Changes In Oil Price With Responsiveness of Oil Use in Agriculture, Construction and Mining to Changing in Oil Price

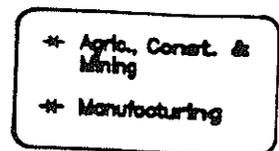
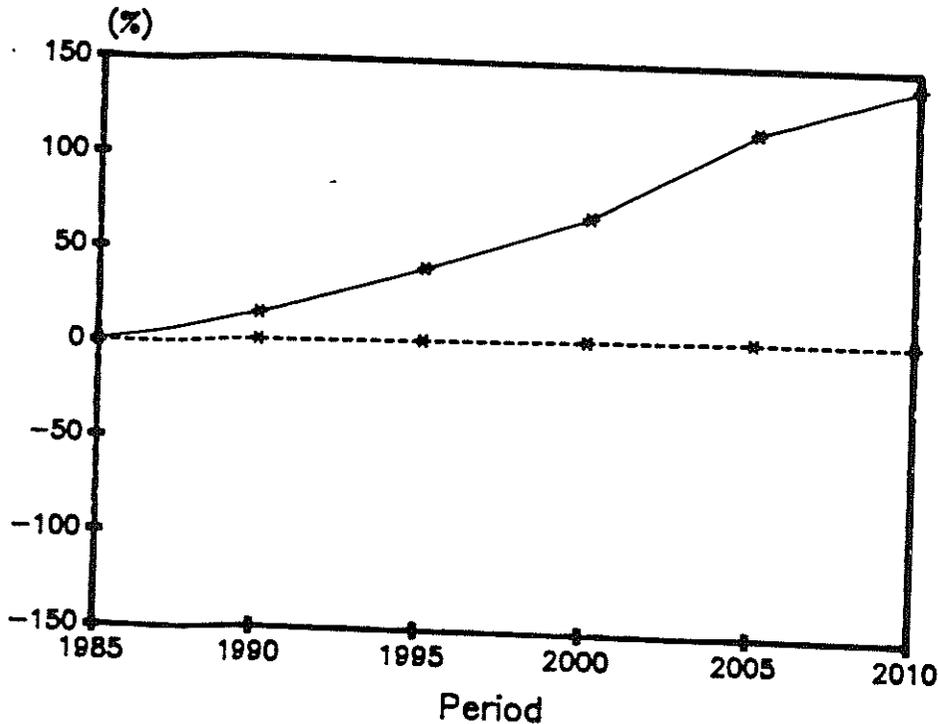
PURHAPS

Low Oil Price (Pct. Diff. w.r.t. Reference Case)  
Oil Cons.



AES/ISTUM-1

Low Oil Price (Pct. Diff. w.r.t. Reference Case)  
Oil Cons.



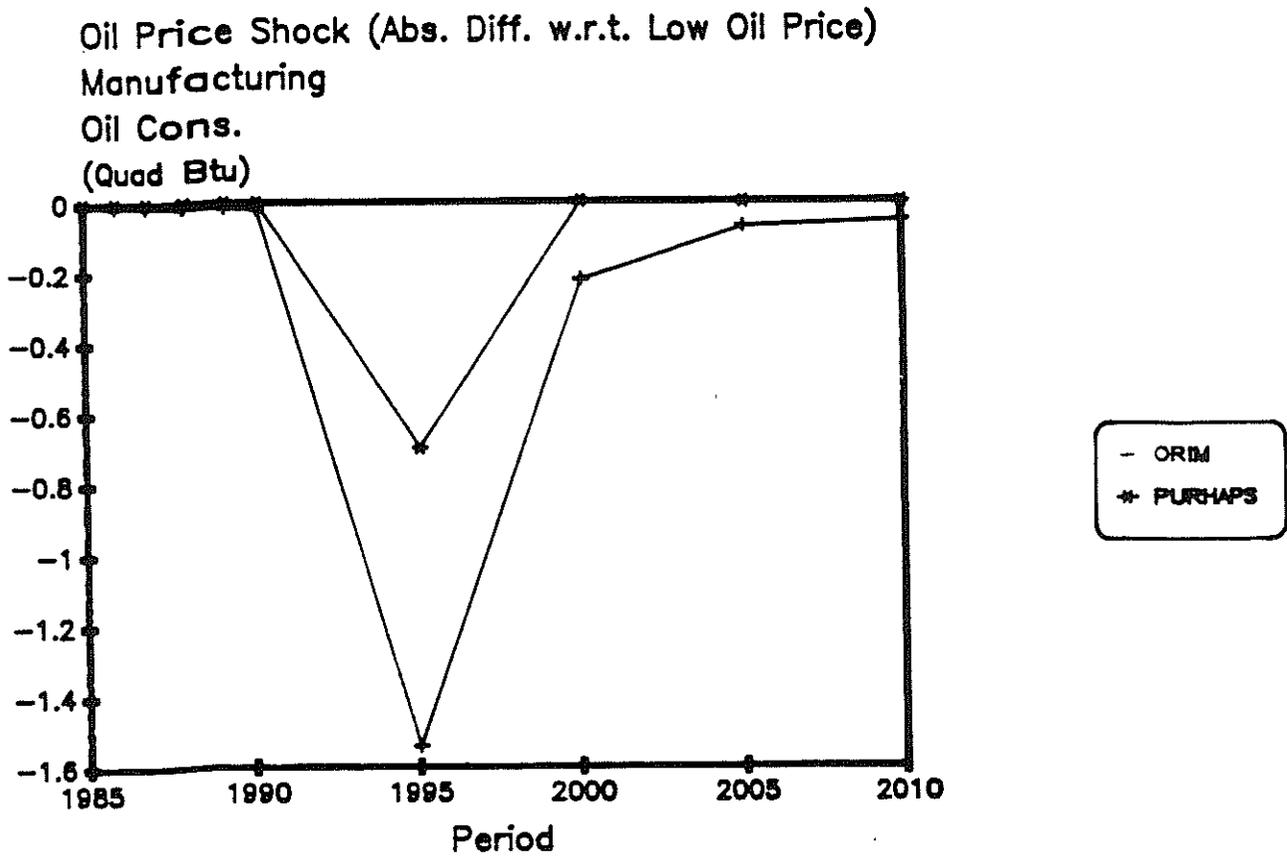
In addition, some of the models use 5-year time periods which do not allow for a detailed representation of the macrodynamics of energy shocks. None of the models in the study were intended to simulate a phenomenon with such sudden, drastic changes to economic conditions. However, PURHAPS and ORIM do reveal a strong sensitivity of industrial energy use to a sudden change in oil prices in one scenario. As shown in Figure 30, oil use fell by from .6 to 1.6 Quadrillion Btus when the price of oil was suddenly doubled in one year. The use of multi-fuel boilers provides an important mechanism for industrial consumers to respond quickly to sudden changes in the relative prices of gas and oil. The tendency toward fuel flexibility in industry is growing.

#### **DATA ISSUES**

The complexity of energy use in the industrial sector and the proprietary nature of much of the data on energy use by particular major energy-consuming facilities limits the data available to the modelers and other analysts seeking to study aggregate industrial energy-use trends.

To a considerable extent, the longer-term and more aggregate structures of the EMF 8 models reflect the data available at the time of their development. Because of this, several important issues that can only be analyzed at the plant level, such as short-term fuel switching, were inadequately considered. In addition, to analyze many other major industrial energy-use issues, such as cogeneration and technological change, plant-level data at the combustor level similar to the information collected on electric utilities is preferred. Examples of such data collection efforts include the 1980 Manufacturing Industries Energy Consumption Study and Survey of Large Combustors ((EIA-463) which

Figure 30: Responsiveness of Oil Use in Manufacturing to an Oil Price Shock



was terminated before the completion of its data collection phase), or Dun & Bradstreet's Major Industrial Plant Database (MIPD). Since the models considered in EMF 8 have longer-term more-aggregated structures, their usefulness in making business decisions has also been limited.

Although a complete cost-benefit analysis on data collection was beyond the scope of this study, the collection of both aggregate benchmarks as well as microeconomic plant-level or combustor-level data on the U.S. industrial sector is required to perform high-level analyses. The following recommendations on industrial energy data collection cover what the Data Issues Group considers necessary to perform such analyses. Admittedly, because of time and cost constraints, not all of this data can be collected. Nevertheless, the Group feels that serious consideration should be given to collecting the following industrial energy-related data.

- o Maintain an annual establishment-level database on energy consumption and expenditures for the manufacturing sector. The establishment-level data should be integrated into the Census Longitudinal Establishment Data file (LED), as it was for 1972-1981, and be made available to analysts under the Census LED-usage procedures. The Energy Information Administration (EIA) should be encouraged to expand the Manufacturing Energy Consumption Survey (MECS) so that it has a coverage level and periodicity similar to the data contained in the discontinued Annual Survey of Manufactures "Fuels and Electric Energy Consumed" survey. The sample should be broad enough to allow the data to be published at the 4-digit Standard Industrial Classification (SIC) level by state and Standard Metropolitan Statistical Area (SMSA) and at more aggregate levels.

- o The MECS should also be extended to include data on costs, operating characteristics, and the utilization of other energy-related technologies. This extension should be along the lines of the 1980 EIA combustor survey, modified to reflect the concerns that led to that survey's termination.
  
- o A study should be undertaken on the appropriate industrial energy-related data to be collected by the public sector, with the remaining data being collected by the private sector. At a minimum, the public sector should provide benchmark data on industrial production and energy consumption.
  
- o Private groups that collect micro-level data on manufacturing production, energy consumption, etc. should be encouraged to provide public-use sets of their information for specified research projects. As examples:
  1. Dun & Bradstreet Technical Economic Services has offered to make its MIPD available to research institutions under certain disclosure restrictions.
  
  2. Since both the LED and MIPD are establishment-level data files, their integration should be explored as a method of making micro-level data available for research through Census usage procedures.
  
- o Public-use files of government micro data bases should be developed.

o EIA and other agencies (e.g., the National Research Council, the National Academy of Engineering) should develop two additional sets of information.

--Develop a source book on the costs, operating characteristics, and standards to evaluate new energy-related technologies likely to have a significant effect upon energy use over the next 25-50 years.

--Develop or expand existing surveys of energy consumption and technology data for the nonmanufacturing portion of the industrial sector (agriculture, construction and mining).

#### USERS PERSPECTIVE

During the study, a group of participants from major energy consuming industries, as well as energy producing and transporting industries, considered the study's objectives and results from their own individual perspectives.

#### Energy Decision Making in Industry

Energy considerations are important, but may not be the determining factor in industrial decisions on capital investments, new facilities, operating levels, and fuel switching.

Decisions on energy use are primarily based on site specific data. Many factors must be considered in establishing the services needed and in determining the best solution to meet the need. There are also important corporate level inputs such as assigned product mix, fuel price forecasts, capital costs and capital availability. All factors must be analyzed to develop service demands, burner tip prices and required capital.

Usually energy decisions start by defining energy "needs" and then determining how the "needs" can be met at minimum cost. This definition starts with the range of product volumes and mix to be produced. This is translated into energy need specifications including factors such as steam pressure levels, continuity requirements (i.e., is the demand base load or peaking, can interruptible electricity be used, can steam flow be interrupted, can backup capacity or dual fuel capability be used if needed?), the balance of electric-shaft horsepower and thermal needs, and future energy conservation expected. This is required in fuel and facilities planning for either a new site, existing site expansion, boiler replacement or fuel switching.

In planning to meet an energy need, fuel price is a key consideration. Oil price is usually the starting point and this involves worldwide supply-demand and political factors. Natural gas prices are linked in a complex way to residual oil prices because both compete directly for the boiler fuel market. Coal pricing is related to the cost of production at the mine. Electricity pricing is utility specific depending on fuel mix, facilities investment and regulatory rate policies. Oil, natural gas and coal prices must be made site specific by including transportation costs which can approach or exceed the price of the fuel.

Once the "needs" and delivered fuel costs are known many other factors are involved. These are site specific and include:

- o Timing (how soon must the need be met).
- o Existing facilities that can be used in common.
- o Physical space (a coal-fired boiler needs more space than gas turbine cogeneration).

- o Electric-shaft horsepower and steam balance (suitability for cogeneration).
- o Local environmental regulations for air and water.
- o Current laws and regulations (such as the FUA and PURPA).
- o Site generated by-products usable as fuel.
- o Capital investments required by fuel type.
- o Operating costs by fuel type.

Superimposed on these factors is the cost and availability of capital. For example, a coal-fired boiler requires far more investment than a gas-fired unit.

In summary, fuel decisions require detailed knowledge of a site's fuel needs and the site and regional factors that determine the availability and cost of various supply options. These factors, combined with capital costs and capital constraints, lead to the fuel source decision.

#### Industry's Use of Energy Models

All industry uses some form of energy models. They may be mental models or multi-dimensional computer-based models. Questions asked can be as straight forward as next month's electricity price, or part of a complex analysis of potential plant locations. Some type of model is used if energy cost, availability, or policy is part of the solution. In the case of a user's mental model, there is both understanding and "buy-in" (defined as comprehension and acceptance) on the part of the user. In the case of a multi-dimensional computer-based model, the modeler must present the results so that the user understands and can choose to "buy-in" if he is convinced the interactions depicted are sound. In both commercial decision-making and policy evaluation, the value of the modeling

enterprise is the ability to gain insights that it provides. A user must be able to understand cause and effect and "buy-in" to the reality of the interaction. Results from complex computer-based model results are often not communicated to the user in a form that he can comprehend. The user becomes frustrated and is forced to resort to his mental model. The modeler also becomes frustrated and proceeds to make his model more complex and less understandable. This dilemma will persist until both user and modeler put sufficient effort into breaking down communication barriers.

Energy Intensive Companies. The integrated energy company may be the most sophisticated user of energy models. They are producers, sellers, users, processors, and transporters of energy so all aspects of the energy business environment impact their activities. Looking at one segment of the energy business environment in isolation, such as the U.S. industrial sector, is not very useful.

The need is to gain insights in specific areas without losing the integration of the total system. Industries that are involved with only one piece of the energy arena have less complex needs but also attempt to gain insights relative to their specific needs within the overall system. A partial list of factors indicates the complexity of the system.

- o For a producer and seller of energy, factors are:
  - Current and future availability by type of energy (volume/price/sectoral end-use market/location).
  - Availability and price of competing fuels.
  - Existing infrastructure to utilize different energy fuels.
  - Potential for modifying or expanding the infrastructure.
  - Technology that can change use and availability.

- o For a user of energy, factors are:
  - Current and future availability of a particular type of energy (volume/price/location).
  - Competing users for the energy source.
  - Available and potential transportation.
  - Current and future availability of alternate fuels.
  - Technology that can alter need and skew availability.
- o For a processor of energy, factors are:
  - Current and future product need (volume/price/sectoral end-use market/location).
  - Competing sources of product.
  - Technology that can change use pattern or competing source economies or energy type.
- o For a transporter of energy, factors are:
  - Current and future availability and need for a specific fuel (volume/end-use market/location).
  - Competing logistics systems.
  - Technology that might alter availability, need, and logistic conditions.

The above describes how models might be used with a fixed set of governmental policy constraints. Evaluation of a proposed governmental policy change that impacts energy is also important. Models that can be used for this purpose need not be as specific as those needed for individual business decisions. As with other models, policy evaluation models can only provide insights.

Corporate Planning. In the industrial corporate planning process the nationwide industrial energy demand measures which the EMF 8 models generate can provide useful insights. These corporate staff groups generally provide forecasts to other staff groups and operating companies on questions involving the energy industry as a whole. Their role is to provide a consistent view of the world to the rest of the Corporation. In some corporate planning cycles, an assessment of the economic environment is prepared from which specific project plans are later derived. This usually includes a general economic picture for the United States and the world, political trends, short and long-term oil supply, demand and price forecasts. To assist planners likely alternative scenarios are provided to illustrate the range of possibilities and risks.

Energy Utilities. Industrial sector energy forecasting is very important to most energy utilities. Industrial customers frequently represent 30 to 40 percent of a utility's gas or electric sales. A variety of industrial sector energy forecasts are used for both short and long term planning. Short term (5 year) forecasts are needed for financial planning and rate making and for targeting conservation and load management programs. Long term (20 years) forecasts are needed for demand-side management, electric and gas supply, transmission, and distribution capacity planning and capital budgeting.

Both short and long term planning include such issues as fuel switching, cogeneration, efficiency improvement, automation and electrification. All these issues can be investigated using industrial sector energy models.

The models and forecasts used in this study are not useful for industrial decision making because the models do not forecast fuel prices faced by individual firms and may not accurately reflect other decision variables specific to a particular firm. Utilities recognize this inherent limitation in their own models and do not attempt to use them to forecast the behavior of individual firms. Models are used to forecast aggregate trends and tendencies of all firms in their service areas. Personal contacts with customers are used to forecast the short term behavior of specific firms.

#### Model Applications and Limitations.

EMF 8 Models have limitations as well as applications depending upon the user's needs. A classification of "micro" process models vs. "macro" trend models would be appropriate to distinguish generic applications. Most industrial users tend to focus on regional or micro demand considerations while government policymakers are more inclined to favor macro energy trend outlooks.

The nature of the process models in EMF 8 (e.g., ISTUM 1, ISTUM 2) permits some degree of physical process characterization of energy demands at a macro level. What potential industrial model users would need is a process engineering characterization of energy demands at a micro level. Currently no EMF model provides this combination of structure and coverage. The policymaker is not focusing on the bottom line but rather on the longer term socioeconomic, demographic, and political results of future energy demand patterns and the implications for policy design and implementation. These two schools of thought have different primary objectives. There are important consistency considerations that must be

bridged for these tools to be useful.

Either a model can address the user's needs or it can't. There may be little flexibility for analytical compromise. This is perhaps where many of the models in EMF 8 fall. For instance, an industrial user would have to enhance the level of disaggregation of the ISTUM framework and adapt structural market characteristics to capture behavioral factors not considered in the engineering economic framework of ISTUM.

Ideally, process models can be adapted to fit the needs of the policymaker but it is doubtful that the macro trend models could be modified for an industrial user's needs. Specification of fundamental causality at a building block level is essential to the industrial user. This is generally not the perception of the policymaker. This may be due to considerations of comparative expertise, data, and fundamental understanding of the basic mechanics and dynamics of energy use.

A viable candidate for the industrial user and the policymaker, barring confidentiality of micro energy consumption and energy capital stock data, is a process model framework adapted to market/region level demographics. Specifically, micro data that can be aggregated to manageable levels and yet preserve the basic physics of energy use should be a basic paradigm for energy models. Data and technical expertise are probably the two major factors constraining realization of this format on a widespread scale.

#### Energy Users Study Group Comments and Conclusions

EMF 8 has provided a forum where energy users have been able to interface with the modelers and with the individual and institutional users of the models. It has provided information on the construction of

various models and how they respond to various inputs. The insights gained from EMF 8 have helped the Energy Users Group members to better understand the models and the comparison of results obtained in the framework of EMF 8. Any comments by the Energy Users Study Group on suitable uses for the EMF 8 models and their results, will reflect the members' bias towards their management-oriented approach to energy and its forecasting.

Energy consuming industries only use the EMF 8 models to provide insights to make management decisions on the expenditure of capital. These insights may be used in corporate planning by energy intensive companies and utilities. They may provide one of many inputs in making decisions. Some have been used by industry for special studies to investigate specific questions usually with data provided by the client.

Models are used to satisfy the tremendous curiosity about industrial energy use and its trends on the part of legislators, regulators, and educators. This is a perceived need which will be satisfied by one means or another. Everyone using or supplying energy is interested in the forecasts being as realistic as practical. The modelers share that interest. It is a widely held belief by industrial energy managers that the free market reacts to changes faster than any governmental action. In many cases by the time any government actions are mandated the situation has changed so that the proposed solutions are counter productive. To the extent that models predict demand and interfuel switching that is not realistic, and results are used to determine public policy, they can be damaging to the economy.

When a large component of manufacturing cost is incurred by energy consumption, this usage data is considered highly confidential. Attempts to collect such data, particularly efficiency and demand figures, are

resisted. Industry considers the cost of preparing mandatory government reports as significant and that such disclosures reduce the competitiveness of U.S. firms in domestic and international markets. The Energy Users Group cannot make any representation that more detailed data will be voluntarily made available for the modelers or for the DOE. This is a policy decision each company will make. The Energy Users Group has worked cooperatively with the modelers in an attempt to improve their models' ability to realistically forecast industrial energy demand, conservation, and interfuel substitution.

## CONCLUSIONS

This study examined the use of analysis in the study of U.S. industrial energy demand trends. Several issues became central in the investigations of the working group: (1) the effect of changes in the structure of the U.S. economy on industrial energy demand; (2) the effect of trends in the technologies used to produce industrial products on energy use; (3) fuel choice by industrial energy consumers; (4) the quality of the existing public data on industrial energy use and recommendations for additional data collection efforts; and (5) the appropriate use of models by corporations in the energy producing and consuming industries.

A major part of the work of the working group was the specification of inputs and interpretation of outputs for eleven scenarios that were examined with a number of alternative models of industrial energy use. This work was supplemented with a review of the literature on industrial energy demand analysis, with a particular focus on sectoral shift and data quality studies.

Several conclusions emerged from the deliberations of the working group. Other things equal, lower energy prices should result in more

energy use per unit of output. Nonetheless, several trends towards less energy consumption per unit of industrial output will continue even if the much lower energy prices of 1986 continue into the future. The output of the U.S. economy will most likely continue to move towards producing a greater proportion of less energy-intensive products. In addition, many of the newer technologies being introduced to produce energy intensive products employ less inputs of all types, including energy.

Despite the gradual reduction in the intensity of energy use by U.S. industry, the long-run trends towards increased market share of electricity in total energy consumption is likely to continue. Some of the models project increases in electricity use per unit of output while others project decreases; even in the latter, though, the electricity-output ratio is projected to decline less than the ratio of fossil fuel use to output. On balance, the new technologies being introduced to produce energy intensive products are more likely to be based on electricity than upon alternative fuels, and the new products being introduced are somewhat more heavily dependent on electricity in their manufacture.

The competition between electricity and fossil fuels is relatively long-run in nature, owing to the embedded nature of energy use in relatively expensive capital equipment. The installation of large numbers of dual-fired boilers and the continued volatility of oil and gas prices have focused great attention on shorter-term fuel switching between oil and natural gas. There was great variability in the model results on this issue. The working group also was of the opinion that lack of good data makes any projection of the short-term fuel switching response to changes in the relative prices of those two fuels quite difficult.

Table A-1

REFERENCE CASE ASSUMPTIONS  
 (% Annual Real Growth Rates: 1984-2010)

Primary Energy Prices

Oil	3.6%
Gas	4.8%
Coal	0.6%

Delivered Energy Prices

Fuel Oil	2.9%
Gas	3.2%
Coal	2.5%
Electricity	-0.4%

Economic Activity

GNP	2.6%
..Pulp & Paper	2.1%
Chemicals	2.5%
Oil Refining	0%
Primary Metals	1.2%
Durable Manufacturing	3.5%
Agric., Const. & Mining	2.0%
Misc. Manufacturing	2.1%

Other Prices

Wages	1.3%
Materials	0%
Corp. Bond Rate (1990)	7.1%
(2000)	5.6%
(2010)	4.3%