# 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.

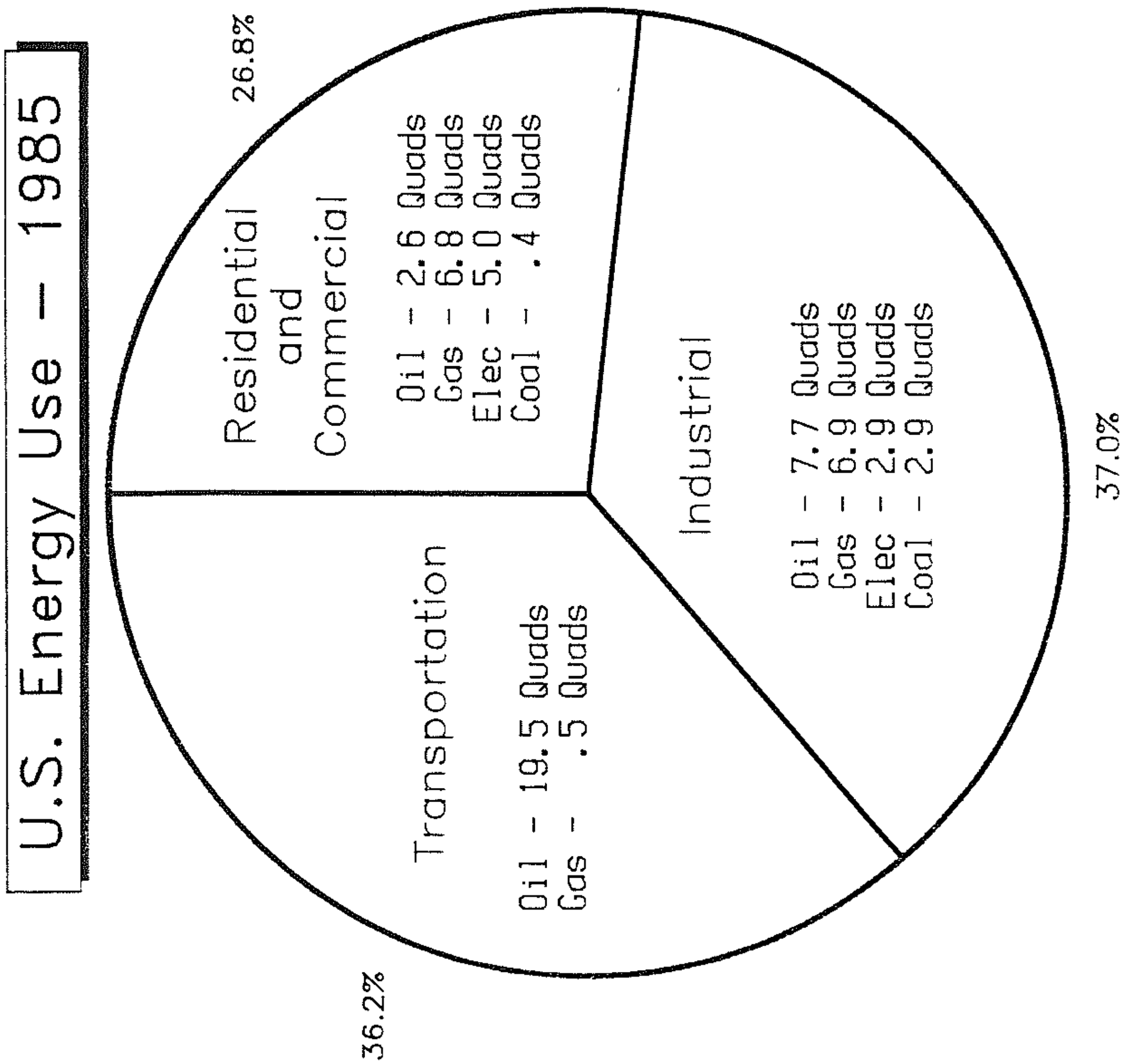
## INTRODUCTION

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

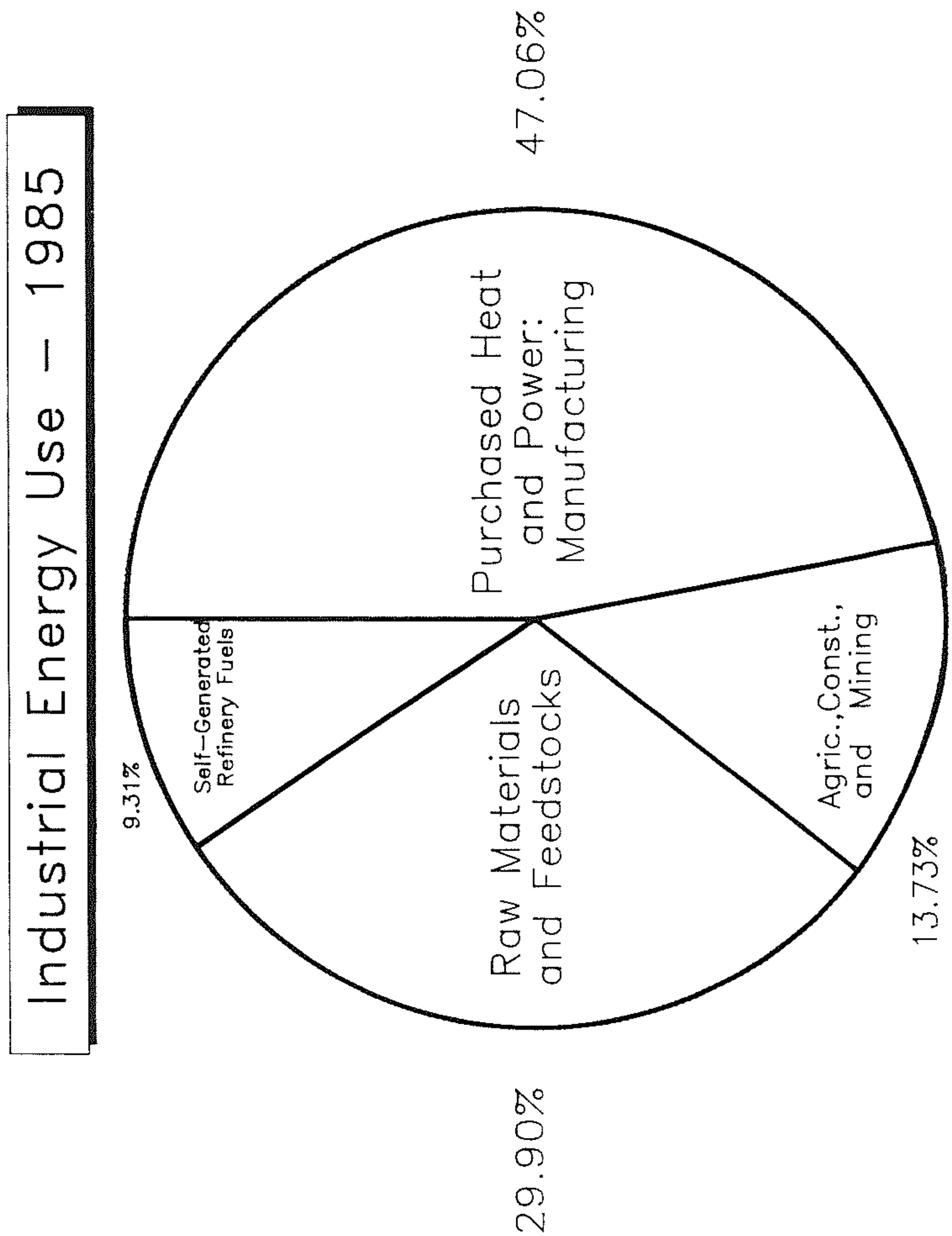


Table 1
Industrial Fuel Demands - 1985*
(Quadrillion Btus)

| | Petroleum Products | Natural Gas | Coal | Purchased Electricity | Self-Generated Fuels | Total |
|---|---|---|---|---|---|---|
| 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 | 6.6 | 6.1 | 2.9 | 2.9 | 1.9 | 20.4 |

* 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

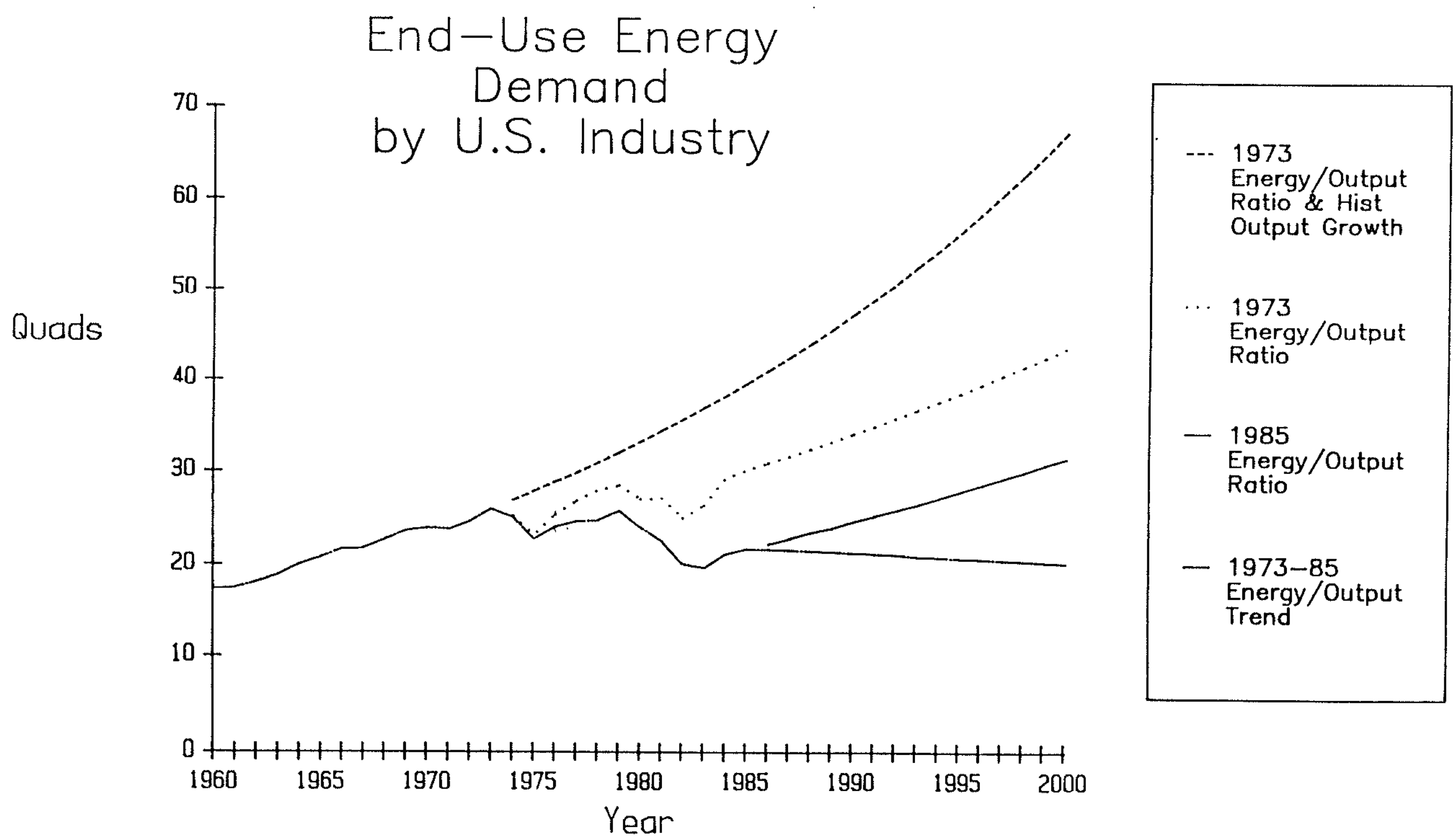
Past trends in energy use by U.S. industry provide a useful benchmark for any attempt to project future trends. Figure 3 shows actual end-use energy demand by U.S. industry from 1960 to 1985 as well as four trend extrapolations through the year 2000.

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

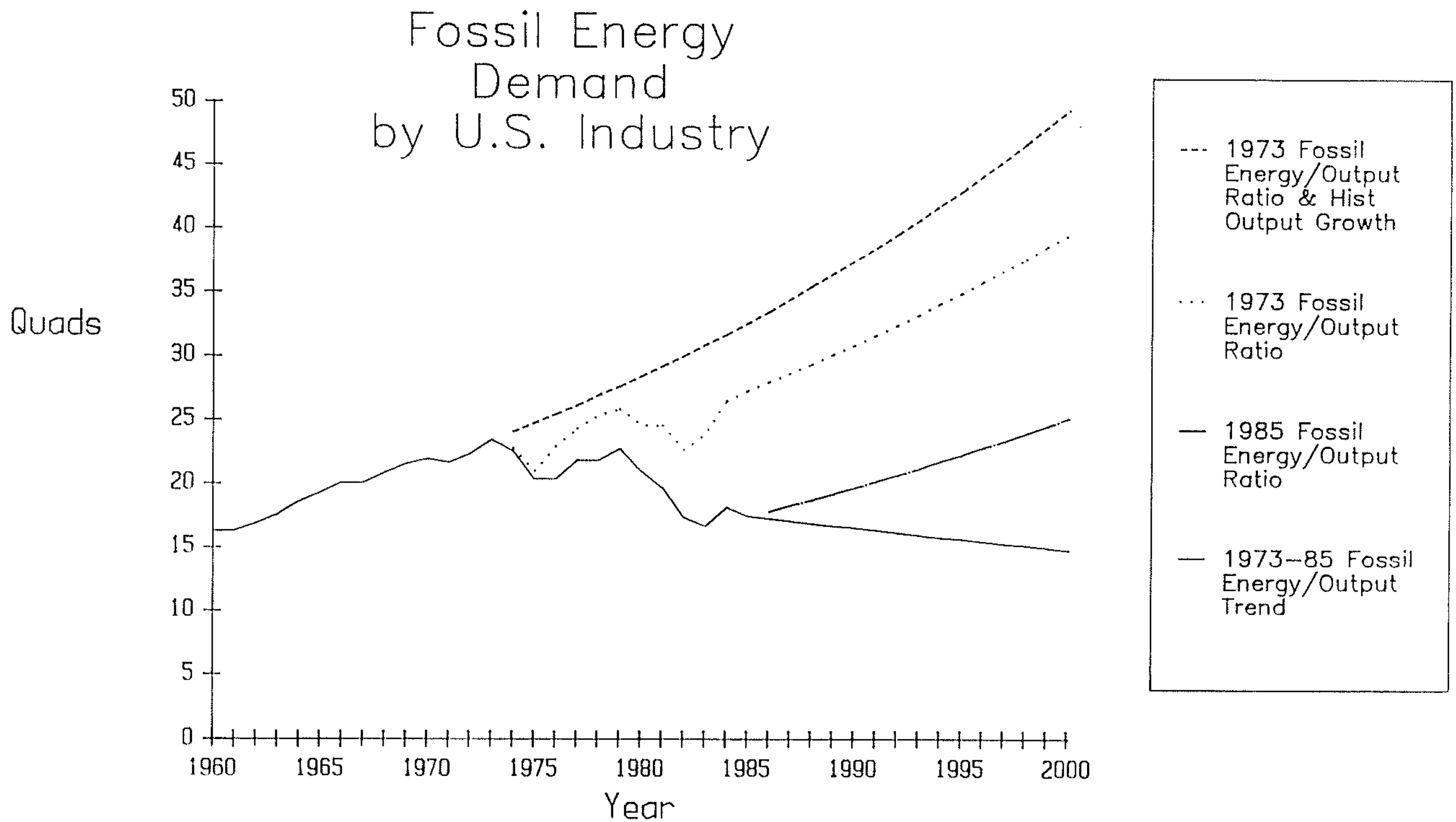
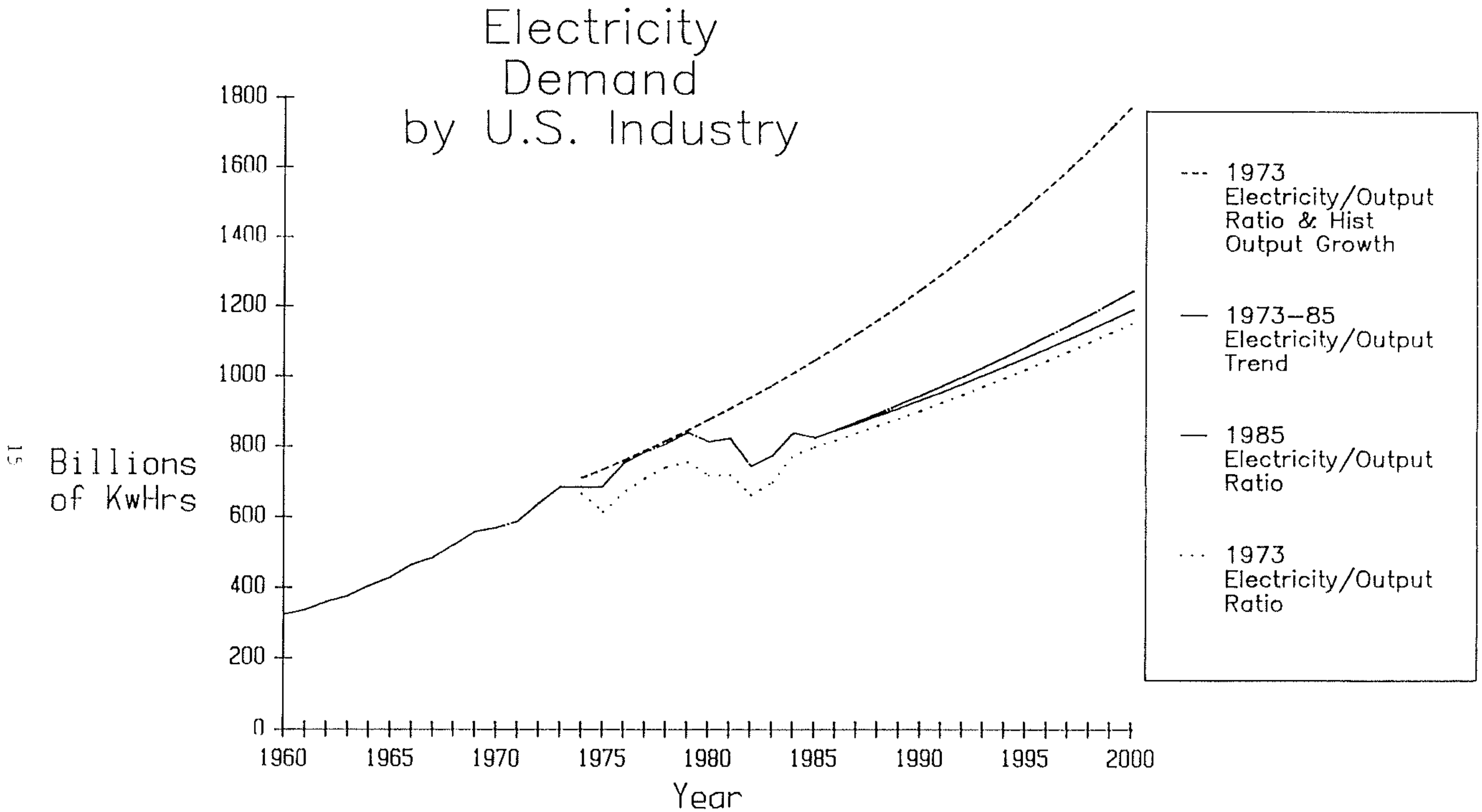


Figure 5: Industrial Electricity Use Trends



## 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 of 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 macroeconometric 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.

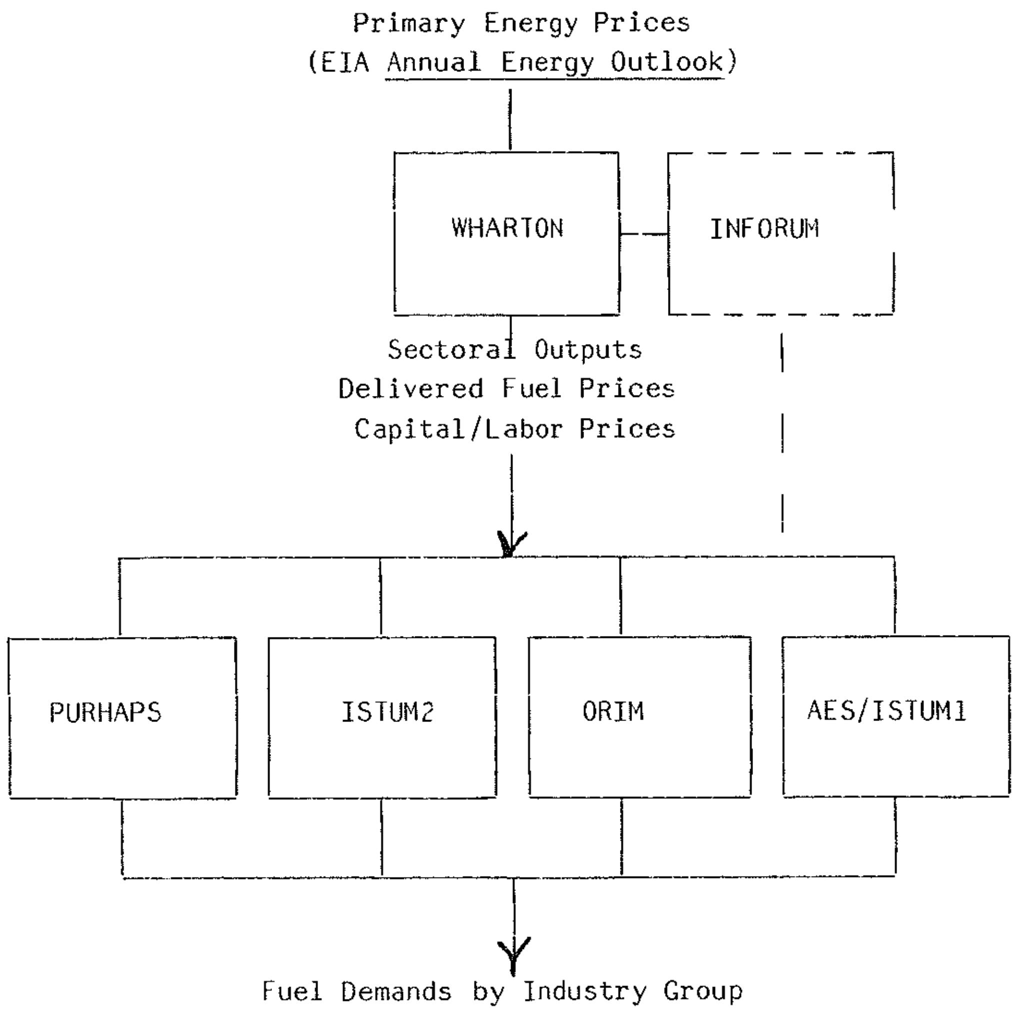
The Reference case represents a reasonable reference path for comparing the scenario results, rather than a consensus on the most likely forecast of industrial energy demand.

## 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.

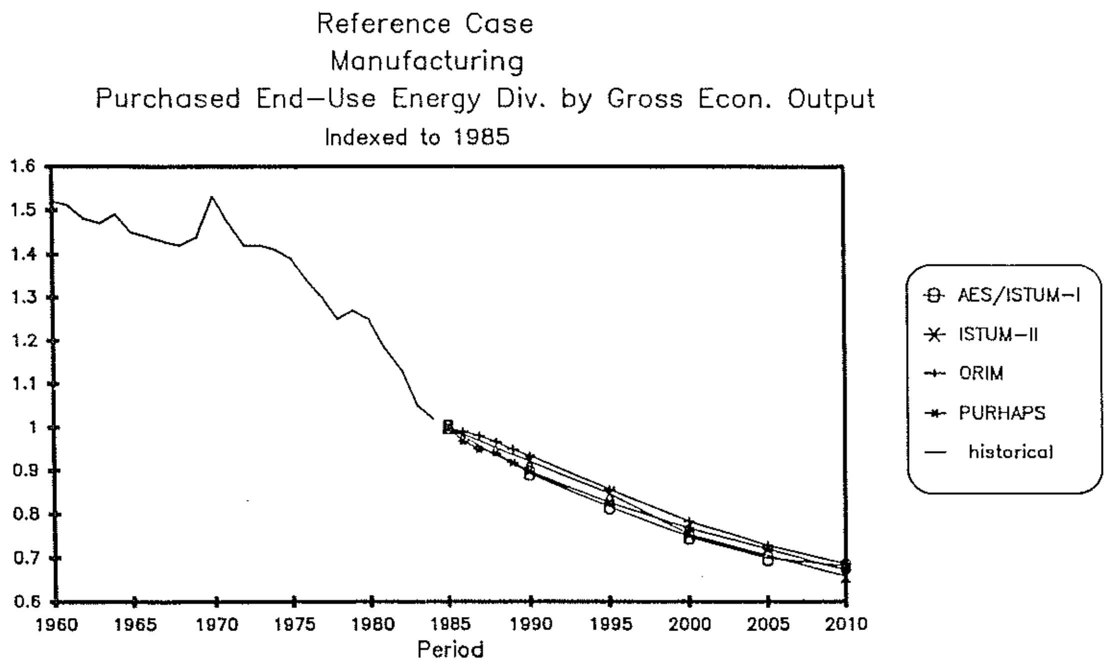



Figure 7A: Energy Use per Unit of Output in Manufacturing

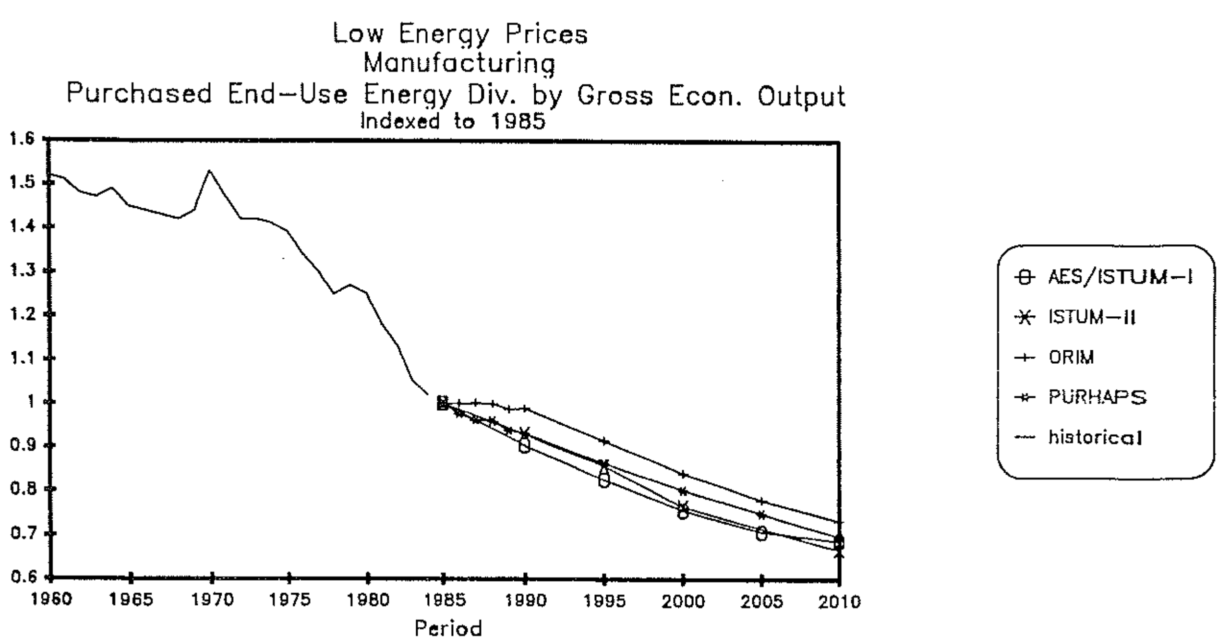


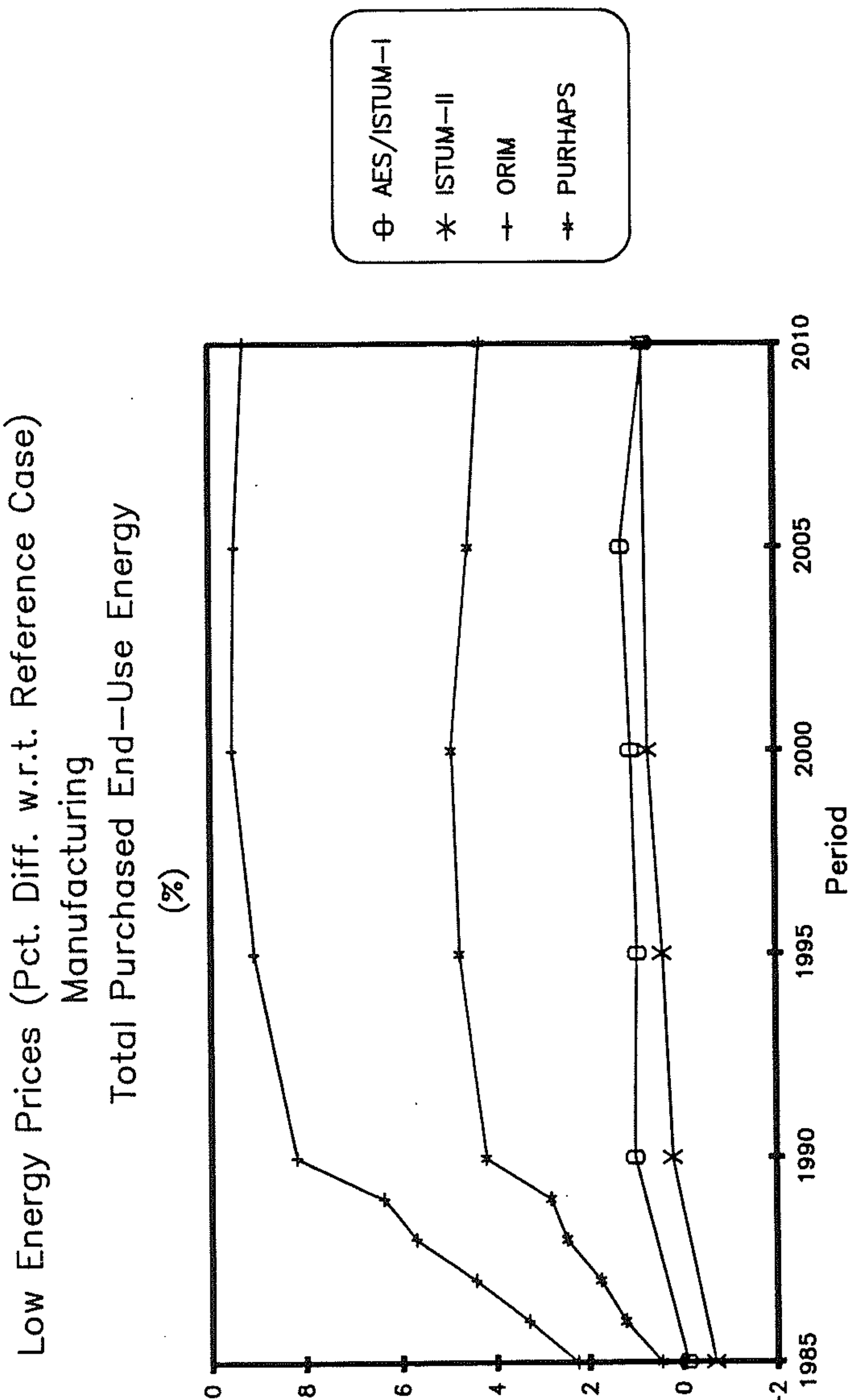

Figure 7B: Energy Use per Unit of Output in Manufacturing

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

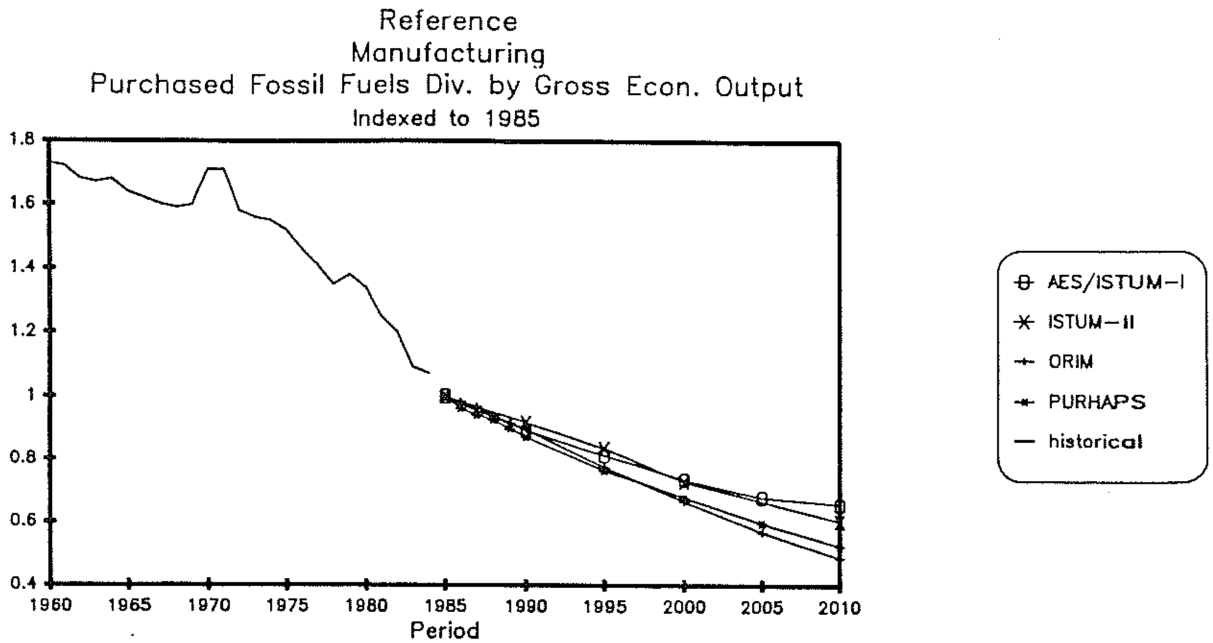



Figure 9A: Fossil Fuel Use per Unit of Output in Manufacturing

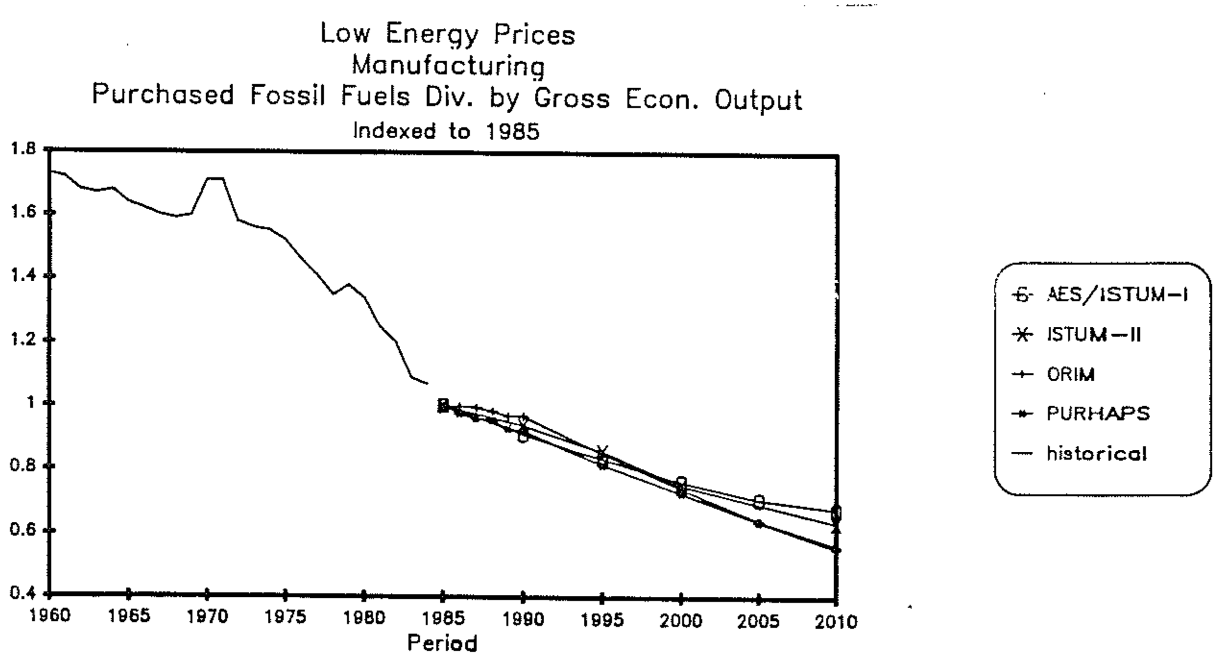



Figure 9B: Fossil Fuel Use per Unit of Output in Manufacturing