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An Assessment of Factors Affecting Industrial Electricity Demand

July 1983

Prepared for:
U.S. Department of Energy
Office of Policy, Planning, and Analysis
Electric Utilities Division

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CHAPTER 1

INTRODUCTION

The deteriorating financial condition of electric utilities, coupled with the overall economic and regulatory climate, has impaired the industry's ability to meet investment needs and may inhibit its adjustment to the demands of the next two decades. Thus, from a public policy perspective, the viability of the industry to efficiently and reliably meet electricity demand over the next two decades is an urgent issue.

Effective electric sector planning requires improved understanding of the demand for electricity. Reducing the uncertainty inherent in industrial electricity demand projections is an important objective. Improved understanding of demand will enable electric utilities to develop the most cost-effective mix of generation and other system technologies, and to avoid unnecessary expense by effectively scheduling construction programs. Such cost reduction measures, combined with appropriate rates of return on invested capital, provide the long-term basis for a productive and profitable industry serving its rate payers, its stockholders and the national interest. In view of industry's central role in economic growth and the sensitivity of certain industries to electric sector policies, mainly reflected in the price and availability of electricity, this study focuses only on electricity demand in the industrial sector. The intent of this study is to identify the principal factors affecting industrial electricity demand and to review analytical results of the principal electric sector models in the light of those factors and related sensitivities.

Purpose of the Study

Given the long lead time required to erect electric generating facilities, the utility industry must plan far in advance to accommodate future levels of demand. During the 1950s and the 1960s planning was a relatively simple task, because demand grew at a rapid, but steady rate. Today the utility industry faces great uncertainty in determining the future demand for electricity. This uncertainty presents serious problems in planning for capacity expansion.

A principal source of volatility in the capacity planning process has been the substantial changes in energy markets which occurred due to the rapid escalation of fuel prices and capital costs throughout the 1970s. Higher energy prices have altered electricity purchase and use patterns. Consumers and businesses have significantly curtailed their consumption of electricity in response to the higher prices. More recently, changes in the industrial sector of the economy have also contributed to the volatility of electric markets. Electricity is clearly the "high-tech energy form", increasingly used for such specialty purposes as electronics, microwave heating, and heat pumps, while such "bulk" markets as aluminum reduction and resistance heat decline. Long-term trends toward the service-oriented "post-industrial society" have been accelerated by rapidly increasing costs of all resources as well as by electric price increases and also have a significant effect on electric use patterns. While levels of

electricity use in residential and commercial sectors have been affected by rising electric prices, the electric use patterns for such services as lighting, appliances, and space-conditioning have remained relatively constant. On the other hand, the changes in industrial structure and product mix occurring as part of the overall changes in the structure of the United States economy and in its international trade patterns represent a potentially significant shift in patterns of electric use. These changing patterns of electricity consumption are not yet fully established or even characterized in a complete way. Whether demand growth rates will continue to decline or will stabilize is unclear. Therefore, planning for new electricity generating capacity, particularly in the industrial sector, is a very uncertain exercise.

Unfortunately, both under- and over-building electric generating capacity impose significant costs on society, although these costs are usually not equivalent. Only in extreme cases would under-building lead to such dramatic impacts as blackouts, brownouts or scheduled load-shedding. More likely but less visible results would be increased reliance on purchased power, reversion of economically obsolete units to baseload usage, or the hasty addition of oil- or gas-fired combustion turbines (which have high operating costs) for baseload usage. All of these options would raise electricity rates. Overbuilding tends to raise rates also, chiefly by driving up the capital component of the overall cost of generating electricity; at the same time, the fuel cost component would probably go down. Whether the net result would be an increase or decrease in rates is best addressed in the context of a specific utility.*

The importance of accurate long-run demand projections for electric utility planning and public policy, coupled with our concerns with the current financial health of many electric utilities, make it worthwhile to assess the principal determinants of industrial electricity demand, and evaluate their relative importance. Thus, this study's objectives are to:

- o identify the principal factors that affect industrial electric demand (independent of the nature and structure of forecasting models);
- o evaluate estimates of industrial electricity demand developed by ISTUM and ORIM (two major models of industrial energy use) using standard assumptions;
- o assess the magnitude and nature of forecast sensitivity to selected parameters;
- o discuss forecast sensitivity and identify major factors that can influence future demands; and
- o identify critical areas for future research on industrial electricity demand.

* The Department of Energy has recently sponsored a detailed review of the costs of over- and under-building electric generating capacity. See Analysis of the Electric Utility Industry in the U.S.: An Assessment of the Relative Costs of Overbuilding vs. Underbuilding Capacity and a Review of the "Death Spiral" Hypothesis (ICF, Inc.; Washington, DC, January 1983).

Industrial Electricity Demand: An Overview

The industrial demand for electricity is a derived demand. It is derived from the industrial sector's response to the demand for the products they produce. This is illustrated in Figure 1-1.

In this figure, the electric utilities supply electricity to all three sectors represented: the industrial sector, the commercial sector, and the residential sector.

Figure 1-1

Electric Utility Market Flows

The industrial sector, in turn supplies products to the residential and the commercial sector, products which require more or less electricity as a factor in their production. The industrial sector also supplies products to the commercial sector which, in turn, supplies goods and services to the residential sector. Again, these products, or goods and services, require electricity for their production. Finally, the products provided by industry to both the industrial, commercial, and residential sectors may require electricity for their operation. In each instance supply of electricity or of a commodity is matched by the demand for electricity or for that commodity (broken line).

The figure shows the preeminent role of the residential sector. The other sectors exist to provide goods and services to the residential sector. The sector demands electricity directly to operate its appliances and to provide heating, air conditioning, and lighting, but the sector also indirectly demands electricity when it purchases goods and services from the industrial sector or the commercial sector. Embodied in those goods and services is the energy, the electricity, used in their production. While the figure highlights information on the factors determining the residential sector's direct demand for electricity and its demand for goods and services with embodied electricity, it also

hides much of what is happening in the industrial sector; the sector's response to higher energy and electricity prices as well as to competition from lower priced, imported goods.

Factors Affecting the Industrial Demand for Energy and Electricity

In the short-run and the long-run the industrial demand for electricity is a function of several factors:

Short-Run

- Output or Value Added
- Employment
- Inventories
- Capacity Utilization
- Prices
- Plant Scheduling and Operation

Long-Run

- Economic Growth
- Output or Value Added
- Employment
- Trade Patterns
- Competition with overseas sources
- Final Product Mix
- Technological Change
 - Fuel-Use Mix
 - Process Change
 - KLEM Substitutions

Electric Growth Factor

Assessment of the relative importance of each of these factors and their likely value over the next two decades requires analyses at several different levels.

Generally speaking, higher economic growth leads to higher growth in the consumption and production of electricity and other fuel forms. The degree of this linkage, though not its direction, has been the subject of extensive analysis and debate. Selecting plausible levels of future economic growth in addition to population growth in the service area as a basis for planning is an important issue for electric utilities.

However, the composition of industrial output is important. The relative mix of energy intensive products (metals, for example), non-energy intensive products (e.g., electronic devices), and non-energy intensive services (educa-

tion, health care) is likely to change significantly over time due both to changes in domestic consumption patterns and relocation of manufacturing from the United States to overseas sources having some advantage in the cost of resources, energy, or labor. The plausible range of the future mix of these products is another dimension which must be explored.

Given a particular level of growth projected for the economy and a mix of final demand, the demand for electricity is further affected by the choice of production technology. For each particular economic function -- production of cars, of electronic chips, or whatever -- a range of production technologies can be employed, which use varying combinations of energy with other factors of production such as labor, capital, and materials. Most cost effective substitutions of capital for energy are called energy productive technologies. The choice of production technology is usually guided by the principle of producing the desired product at lowest total cost, sometimes stressing capital investment, sometimes life-cycle cost, when long-term markets and other factors are more secure. The degree to which the non-energy factors of production can be and are substituted for energy is an important factor determining electricity demand.

Even when the appropriate mix between energy and nonenergy factors of production is identified, there is further competition between energy forms. With appropriate conversion devices, electricity can substitute for non-electric forms where it is cost-effective to do so.

Finally, for each level of electricity demand, some mix of centralized and decentralized generation approaches will be required. The mix may be guided by the relative costs of various fuel forms and plant types so as to provide electricity by the least expensive means, or by some other decision criteria such as security of supply, capital cost, etc.

Analysis of these different factors affecting electricity demand has been pursued in many different ways. The level of economic growth and the mix of output (reflecting changes in consumer preferences, lifestyles, and the like) has been predominantly the province of macroeconomic models, the best known of these being the quarterly forecasting models of Data Resources, Inc. (DRI), Wharton Economic Forecasting Associates (WEFA), and Chase Econometrics. Extensive analysis of recent experience has also been conducted by Robert Marlay of MIT and the U.S. Department of Energy. However, relative consumer preferences for the various products and services (be they more or less energy-intensive) and production technologies can change rapidly in ways and for reasons not captured by the historical data normally used in estimating macroeconomic models. Consequently, those analyses are usually supplemented by survey data and the judgement of informed observers of social and technical trends.

Analysis of the choice of alternative means of production is also the province of another class of models which typically combine the product-mix projected from a macroeconomic model with fuel prices to calculate the mix of production technologies which will produce the given product slate at the lowest total cost, including the level and mix of fuels used. Examples of this class of models are the ISTUM models developed by Energy and Environmental Analysis, the family of industrial process models developed at Brookhaven National Laboratory, and the Oak Ridge Industrial Model (ORIM).

Finally, the identification of the mix of central station electric plants which will produce electricity at the lowest total cost has been assessed by still another class of models. At the national level, these include systems such as the Midrange Energy Forecasting System (MEFS), used by EIA, and the Time Stepped Energy System Optimization Model (TESOM) developed at the Brookhaven National Laboratory. At the utility service area level, most utilities use the PROMOD model developed by EMA, Inc. to represent their generation and transmission system and identify the lowest cost pattern of unit operation and system expansion.

In this study we focus on forecasting the industrial demand for electricity, identifying the factors determining that demand, and isolating shifts in industrial product mix which have not been adequately accounted for in past forecasts. But in estimating the effect of changes in product mix on industrial electricity demand we must control for changes in the efficiency with which these industries use electricity in the production process. Thus, in making our projections we used models which identified a variety of probable efficiency changes over the next 20 years. We were then able to isolate the effects of efficiency changes and shifts in product-mix on the growth in industrial electricity demand to the year 2000.

The version of ISTUM2 used for this study included an algorithm for "energy management" which, when exercised, significantly reduces projections of future industrial demand for electricity. However, we found this algorithm analytically unsatisfactory, and decided not to exercise it in developing our ISTUM2 base case.

The algorithm defines energy management as an improvement in "energy house-keeping" practices. (Thus energy management does not involve major capital investments in new equipment, new production processes, etc.; such investments are treated elsewhere in the ISTUM2 framework.) ISTUM2's treatment of energy management is a logistics curve approach which estimates the overall rate and level of implementation based on data for the initial implementation (less than 10% of the estimated potential). The percentage of energy savings from energy management practices is defined as a function of time (i.e., there is no fuel price sensitivity). This approach was adopted after a cost analysis revealed that virtually all known energy management practices were cost effective and could be implemented at low energy prices. This result is questionable since many energy management techniques are still not implemented in practice.

Energy management appears to be a "behavioral" issue, affected by production scheduling, labor agreements, and other operating factors in addition to straightforward energy or power savings. Many of the practices would serve to reduce peak power demands, not total electric energy consumption. In the ISTUM2 algorithm, however, the implementation of energy management practices is assumed to be a function of time (driven by rising energy management awareness among plant managers, information dissemination, etc.). Additional process level data are needed to better understand the rate and extent of implementation.

The three primary weaknesses of the present algorithm, at least with respect to predicting industrial electricity demand, are: (1) the approach does not differentiate between energy forms (i.e., the same percentage of savings is applied to each "fuel" in a given industry), (2) the historical data base for estimating the energy management potential and realized savings is crude, rela-

tive to the rest of ISTUM2's data, and (3) non energy intensive industries are assumed to have as much economic potential (on a percentage of fuel used basis) as energy intensive industries. These considerations led to our decision not to use the energy management algorithm in developing our ISTUM2 base case. We do not wish to imply that there are no potential electricity savings to be obtained through energy management. On the contrary, there may well be some attractive opportunities, but estimation of them requires a more sophisticated algorithm, combined with appropriate data inputs. In any event, we believe that the current algorithm, which would reduce industrial electricity demand in the year 2000 by about 0.5 quads (below the base case's 4.62 quads), substantially overestimates the future electricity savings attributable to energy management.

To improve the treatment of this issue, a study of energy management practices in industry should be made. The actual savings in power and energy should be determined, and broken out for electricity as well as fossil fuels. With help from energy management experts, some estimate of the total economic potential savings should be made. The sampled industrial plants should include both energy intensive and non-intensive, as well as both large and small firms (to capture differences due to size).

Overview of the Study

Shifts over time in the products produced by industry are caused by a variety of interacting factors, such as consumer tastes, the relative prices of the products and of competing services, rising incomes, technological change and the penetration of new products. Over time, each of these factors may change for a variety of reasons, causing the quantity and mix of the goods purchased (and therefore produced) to change. Electricity is used in the production of these goods. Production processes for different products are highly variable in terms of the quantity of electricity used to produce one unit of output. Thus, shifts in the industrial output mix may change the industrial demand for electricity as a factor of production depending on whether the shift is electricity-saving, electricity-using, or neutral, and whether, at the same time, there were changes in the efficiency with which electricity is used. Perhaps even more important, especially in the long run, are changes in the relative price of electricity as compared with the prices of available fuel substitutes. Comparisons of electricity with competing fuels strictly on the basis of price is, in any case, quite misleading because of the many special attributes of this high quality energy form such as controllability, effectiveness, and convenience. In forecasting the demand for electricity these elements must not be ignored.

In Chapter 2, we identify those factors affecting the industrial product mix -- taste, relative output prices, and relative input prices -- and isolate several determinants which we believe have not been adequately accounted for to date in industrial electricity demand forecasts. We discuss how the lower energy prices of foreign producers affect domestic producers and their product mix; how higher energy and electricity prices have induced domestic firms to relocate within the United States, often changing the quantity as well as the type of energy consumed in production; how those higher energy prices have caused heavy electricity users to place new plants overseas; and how the growth in the number of substitutes for intermediate products such as steel and alumi-

num with plastics and composites affects the composition of production and, hence, the demand for electricity. We also investigate how the changing age structure of the population brought on by the baby boom could change the mix of outputs produced by the industrial sector.

In Chapter 3, we review the history of the 1970s with regard to changes in output mix and the manufacturing demand for electricity, and with regard to changes in the use of electricity vis-a-vis the other inputs in the production process. In Chapter 4, we generate forecasts using two models which control for efficiency changes, but in different ways. In this chapter we present the sensitivity of these projections using three sets of assumptions about product mix.

In the last chapter, Chapter 5, we summarize our results and draw from those results implications regarding public policy and industrial electricity demand. Two appendices are included. In Appendix A we present ISTUM2 results from selected electricity intensive industries; and in Appendix B, we describe the ISTUM and ORIM models and their underlying assumptions in more detail.

Summary of Findings

In Chapter 2 we identify several electricity intensive industries where, for a variety of reasons, demand shifts appeared to be significant. For the aluminum industry, countries with low-cost hydropower and access to bauxite, such as Brazil, are enticing United States firms to locate their new reduction facilities abroad. Aluminum ingots produced in those countries will be shipped to the United States for fabrication and finishing. To some extent the same thing is happening in the steel industry where low-cost power, ore, and labor in foreign countries (e.g., Korea) have made U.S. steel less competitive. The chemicals industry is more sensitive to the cost of petroleum feedstocks than to electricity prices, but the industry is the largest industrial user of electricity and the movement of much of the primary and bulk chemical production to the Persian Gulf will have a significant effect on the domestic industrial demand for electricity. Many of the other industries analyzed such as primary metals, petroleum refining, rubber and miscellaneous plastics are also affected by the cost and availability of feedstock and environmental restrictions on plants rather than international competitiveness, but they represent a significant fraction of electricity demand and future international competitiveness should no longer be ignored in studying industrial electricity demand. Increasingly, U.S. industry is moving to the higher value-added downstream fabrication operations, which are generally less energy intensive than the primary production operations. While many of these situations will tend to reduce the growth rate of electricity demand, there is a continuing shift to electricity in new industrial processes that have the opposite effect. We find that the major forecasting models, including the macro models that they are aligned with do not take these important factors into account or, at best, are relatively insensitive to the continuing shifts.

Industries sensitive to domestic relocation (which will affect regional electricity demand) include aluminum, paper, and steel and associated industries such as lumber and primary and fabricated metals. These same industries are also subject to product substitution which will affect overall demand levels.

For example, steel and aluminum face uncertain market prospects in many instances due to competition with other products such as plastics and composites in durable manufacturing. Regional shifts of production will affect regional electric demands; however, no attempt was made here to develop regional analyses.

Besides the above determinants of product mix, we also investigated the effect of the population's age structure on taste and, hence, on industrial product mix. We found that the existing anecdotal and statistical evidence suggests that the effect of age on product mix is weak. Perhaps more should be done in this area, but for the purposes of this study factors such as international competition, plant location, and intermediate product substitution appear to have a significantly greater effect on industrial output mix and, therefore, on the industrial demand for electricity. We found that over the past several years aggregate industrial electricity growth has been lower than growth in industrial output. From 1970 to 1975 the electricity consumed to output ratio for industry increased from 5.31 to 5.63 or 1.0 percent per year compounded annually. However, from 1976 to 1979, the ratio fell from 5.53 to 5.33 or -1.22 percent per year.

The use of the industrial process models to project industrial electricity demand, such as ISTUM2 and ORIM, allow the analyst to control for, and assess, the effects of efficiency improvements. The ISTUM2 model projects electricity demand to be 4.62 quadrillion Btu in the year 2000, implying an annual growth rate of approximately 2.6 percent between 1980 and the year 2000. ORIM, in contrast, projects industrial electricity demand to be 5.58 quadrillion Btu in the year 2000 for an annual growth rate over the same period of 3.3 percent.

In this study, ISTUM2 was used as a basis for detailed analyses because of its greater number of industries and detailed end use efficiencies; ORIM was used primarily as a basis for comparison and analysis of possible range of aggregate demands. We analyzed the five largest electricity consuming industries (which use about 49% of total electricity consumed by the industrial sector) with regard to each of the following:

- o The growth in purchased electricity in comparison to the growth in industrial output and the growth in demand for other fuels;
- o Cogeneration and its effect on industrial electricity demand;
- o The effect of specific electricity technologies; and
- o The effect of process change (the use of entirely new methods for producing existing products).

From a detailed examination of the four most electricity using industries over the period 1980 to 2000 our conclusions concerning the sensitivity of electricity demand to major factors were that:

- n the installation of energy efficient technologies will not significantly reduce total industrial electricity demand

- o cogeneration will not appreciably reduce industrial electricity demand;
- o product mix shifts at the 4-digit level will be an important factor in the chemicals industry; and
- o process change will generally increase electrical use, but its effect will be very small compared to other factors.

To test the sensitivity of industrial electricity demand to future product mix changes we constructed two sensitivity scenarios. Note that these are not to be regarded as forecasts but as simulations designed to test the sensitivity of electric demand to specified shifts in product mix. While we have discussed the possible shifts that may occur due to changing consumption patterns and international competition, a detailed forecast of these shifts was beyond the scope of the study and was not attempted.

- o First, we assumed the 1980 product mix was produced in the year 2000; this enabled us to deduce the size and electricity effects of the product mix changes implicit in our macroeconomic input assumptions.
- o Second, we assumed that the two most electricity intensive industries -- chemicals and aluminum -- did not grow at all over the two decades and that growth rates in other, less electricity intensive industries increased to attain an equivalent GNP.

In the first scenario, we found that in the year 2000 a 1980 product mix would generate industrial electricity demand 11 percent higher than the base case. Second, holding chemicals and aluminum output constant, industrial electricity use falls 1.4 percent below the base case in the year 2000. The base case electricity annual rate of growth in electricity demand was 2.59 percent; in comparison, the constant product mix case generates an annual growth of 3.08 percent. Constant output for chemicals and aluminum has an insignificant affect on the annual growth rate of industrial electricity use, provided GNP growth is not reduced. (If there is no growth in the aluminum and chemicals industries, and this lack of growth is not offset by growth of other sectors, then the growth rate of electric demand is reduced to 2.24%.)

It is interesting to compare the specific baseline growth projections developed in this study with other current forecasts of total electric demand prepared by the National Electric Reliability Council (NERC), the Electric Power Research Institute (EPRI), and the Energy Information Administration (EIA), which indicate total electricity growth rates in the range of 1.04 to 1.32 times GNP up to 1990. (See Table 1-1.) The EIA forecasts of industrial electric demand fall in the range of 1.04 to 1.44 times GNP up to 1990, and the NERC, and EPRI forecasts of industrial demand, though unreported, are likely to fall in this range as well.

TABLE 1-1
Electricity to GNP Ratios

	Projected Annual GNP Growth Rates	Projected Annual Growth Rates in Industrial Pro- duction	Projected Annual Growth Rates in Industrial Elec- tricity Sales	Ratio of Growth Rates in Indus- trial Electricity Sales to Growth in Industrial Production	Ratio of Growth Rates in Indus- trial Electricity Sales to Growth in GNP
NERC (1)	2.5	2.61	3.0	1.15	1.20
EPRI (2)	2.5	2.89	3.3	1.14	1.32
EIA (3)	2.7	2.44	2.74-2.95	1.12-1.21	1.01-1.09

- (1) North American Electric Reliability Council, 1981 to 1991.
 (2) Electricity Producers Research Institute, 1981 to 2000.
 (3) Energy Information Administration, 1981 to 2000.

The analysis performed in this study produced two point estimates of industrial electric growth for the 1980-1990 period, corresponding to 0.7 and 1.0 times GNP growth. While the higher projection is within the range of other forecasts, the lower estimate is outside of that range. Although the primary purpose of this analysis was to perform sensitivity analyses around a given point estimate to evaluate the potential influence of such major variables and uncertainties as changes in product mix, process change, and efficiency improvements, we did subject the lower growth projection to further analysis and interpretation.

In our judgment this lower estimate is significant and indicates a strong possibility that during the recovery period of the 1980s, industrial electric demand could grow by as little as 0.7 times GNP. The key difference between the two point estimates is the rate and extent to which efficiency improvements are adopted. A major factor that will influence this outcome is the pattern of capacity utilization and expansion during economic recovery. If the early stages of the recovery are rapid, there will be significant pressure to use existing idle capacity for production. Some of this capacity is quite inefficient and, in some cases, obsolete. If the pattern of recovery forces the use of this capacity, then electric demand is likely to grow in the higher range relative to GNP. If, on the other hand, the recovery is quite slow and gradual, producers may opt to expand the more efficient existing lines and to open up new capacity that is more efficient. Under these circumstances the growth rate of industrial electric demand could be as low as 0.7 times GNP in the 1980s. In

the 1990s, the industrial electric growth rate is likely to return to more typical (historical) levels of 1.2 to 1.7 times GNP reflecting the continuing trend towards electrification of new manufacturing processes based on the high quality and controllability of electricity.

The possible range of electric growth rates that may occur in the 1980s has major implications for long term capacity expansion planning and public policy. To the extent possible, the key indicators that will determine the actual outcome have been identified and are discussed later in this section. These indicators should be watched closely and subjected to further interpretation and analysis as the economy recovers.

Interpretation

Our estimates of 0.7 and 1.0 as the possible ratios of industrial electricity demand growth to GNP growth for the 1980s are point estimates using the ISTUM2 and ORIM models, respectively. The ISTUM2 model is an industrial process model (See Chapter 4 and Appendix B) which assumes a rational implementation of energy and electricity efficient equipment in response to expected changes in the relative prices of energy in general and electricity in particular. ISTUM2 electricity use projections tend to be lower in the 1980s (0.7), but increase in the 1990s (1.5). ORIM projections (1.0 for the 1980s and 1.7 for the 1990s) tend to be higher than ISTUM2 projections for at least two closely related reasons.

The Nature of the Production Function. First, ORIM does not explicitly incorporate specific technologies in its production function. Instead, ORIM's technology has a more flexible structure. That is, energy and electricity efficient technologies are assumed to be smoothly phased-in both over time and in response to changing relative prices; ISTUM2 assumes very specific technologies that are incorporated into the production process as they become cost-effective.

ORIM's higher projections are related to its econometric structure. Econometric models, by their very nature, use past data or past information to arrive at parameter estimates, whether those parameters are fixed or up-dated periodically. The use of this historical data means that abrupt changes in the exogenous factors such as energy prices are, to a very large extent, smoothed out in the econometric models; that is, the response to the variables in the model is muted through extensive lag relationships. The historical nature of the information builds inertia into the model, which causes the model's response to be distributed over a longer period of time than in fact may be justified. Thus, ORIM's currently higher projections are related to the historically high growth in industrial electricity sales.

Uncertainty

While modeling of any real world phenomenon forces the analyst to make explicit assumptions, it does not mean that uncertainty has been eliminated or

even minimized. It only means that if we are prudent we will attempt to identify and account for major sources of uncertainty. Thus, our projections are based on some specific assumptions and the way they are incorporated in the structure of the ORIM and ISTUM2 models. The projections are based on the quality of the historical data (especially for ORIM), technological assessments (in ISTUM2), and on projections of exogenous variables such as gross national product, industrial production, and relative energy prices. Finally, the quality of the projections are affected not only by the variables incorporated in the models, but also by the magnitude and significance of the variables left out.

Given the above caveats, qualifications, and rationalizations, we think the projections of our two models encompass the range of projections of the majority of models forecasting industrial electricity demand, as well as the projections not explicitly based on econometric or industrial process models such as ISTUM2 or ORIM.

Thus, our estimates of the ratio of the rate of growth of industrial electricity sales to the rate of growth in GNP of 0.7 to 1.0 for the 1980s may be thought of as a range, but a range encompassing the projections of a variety of models or forecasting procedures with different underlying assumptions and structures and, therefore, uncertainties, but not as a statistical range from a single model or forecasting methodology.

To place our conclusions regarding the demand for electricity in context we must compare it with total electricity sales and with sales to the residential and commercial sectors. In Table 1-2 we present electricity sales by sector in billion of kilowatt hours. These numbers by themselves tell very little about the relative behavior of the sectors throughout the decade. Thus, in Table 1-3 we show the percent of electricity sales to each of the four sectors. We note that industrial electricity sales fall from 41 percent of the total in 1970 and 1974 to 39 percent for 1976 and 1979. At the same time, the sum of residential and commercial sales increase from 55 to 57 percent of total electricity sales over the decade. Thus, while product mix shifts within the industrial sector may be considerable, we should not lose sight of the shifts out of the industrial sector to the residential and commercial sectors -- that is, from goods to services. Modest shifts of 2 percent represent approximately 42 billion kWh of electricity in 1979, moving from the industrial sector to the residential and commercial sectors. While this is a shift and not a fall in total electricity sales it does have certain policy implications. Thus, while residential and commercial rates are higher per kWh so are the utility's costs in serving these sectors. Secondly, there may be cyclical implications for utility management since it is harder to manage residential and commercial use of electricity.

Early Warning Indicators

Given the uncertainties accompanying projections of industrial electric demand, and the possible magnitude and nature of their effect on the course of electricity supply, it could be useful to develop and monitor a set of indicators or early warning signals which could identify directional changes in industrial electricity demand. Such indicators could be selected from relevant measures of industrial activity, and used for policy and planning purposes. The

TABLE 1-2
Electricity Sales (Billions of kWh)

	1970	1974	1976	1979
Residential	448	555	613	694
Commercial	313	393	441	493
Industrial	573	689	725	816
Other	57	64	71	76
TOTAL	1391	1701	1850	2079

Source: U.S. Department of Commerce, Statistical Abstract of the United States, 1981, Washington, DC, 1982 p. 591.

TABLE 1-3
Percent of Electrical Sales by Major Sector

	1970	1974	1976	1979
Residential	32	33	33	33
Commercial	23	23	24	24
Industrial	41	41	39	39
Other	4	3	4	4

Source: Derived from Table 1-1

TABLE 1-4
Percent Growth in Electricity Sales by Sector
(Compounded Annually)

Sector	1970-74	1974-76	1976-79	1970-79
Residential	5.50	5.10	4.22	4.98
Commercial	5.86	5.93	3.79	5.18
Industrial	4.72	2.58	4.02	4.01
Other	2.94	5.33	2.29	3.24
TOTAL	5.16	4.29	3.97	4.57

Source: Calculated from Table 1-1, Electrical sales in billions of kWh

study has indicated the importance of the usual parameters (FRB Index, GNP, and product mix) used as indicators of industrial demand. In the course of the study, several additional indicators were also identified. Though a more thorough study of the design, construction, and implementation of a system of indicators should be undertaken, we present the following suggestions for additional near term indicators:

o Plant Openings and Closings

With low plant capacity utilization in a recession firms will tend to close down the high cost, inefficient plants and keep open the low cost, efficient plants. With a slow climb out of the recession, the firm may not reopen the inefficient plants, but instead, expand the more efficient plants or build new, efficient plants using less electricity per dollar of value added. A rapid increase in industrial demand, however, would encourage the firms to reopen the less efficient plants, using a larger proportion of electricity per dollar of value added. Therefore, an investigation of the relationship between an average lag in industrial electricity sales and both plant openings and closings may provide a useful indicator of industrial electricity sales.

o Capacity Utilization

Another variable closely related to the above is the percent of plant capacity utilized. The rate at which capacity utilization changes over the business cycle may serve as a useful leading indicator in predicting changes in industrial electricity sales. A study of the interrelatedness and cyclical behavior of the two series would be necessary as well as an investigation of the theoretical links between the two variables.

o Inventories

Industrial electricity is a factor of production whose demand is related to the rate of production. Thus, another useful candidate for leading indicator honors would be linkages between the rate of change of inventory stocks and industrial electricity demand.

o Electricity Using or Saving Machinery and Equipment

Tracking the sales of electricity using or saving equipment (controls, high efficiency motors, and machine tools) coupled with some of the above variables may also be useful in indicating future shifts in industrial electricity demand.

The relationships of each of these additional candidates to the magnitude and direction of industrial electricity sales will have to be thoroughly investigated and the linkages during different phases of the business cycle explored until the patterns are apparent, the average lead-periods (months or weeks) identified, and the variation about that average estimated. The latter estimation is important for if the variation is too wide then the variable is not useful as a leading indicator.

CHAPTER 2

DETERMINANTS OF INDUSTRIAL ELECTRICITY DEMAND

Introduction

Most long-range forecasts of industrial electricity demand require the development of a set of exogenous assumptions about future changes in industrial sector output, input prices, both energy and non-energy, and the efficiency with which the inputs will be used. Until recently, the industrial sector was treated as a homogeneous unit with the implicit assumption that the output mix did not change over the forecast period. In the short-run, this assumption is both necessary and realistic. However, in the long-run one must address the fact that industrial output mix changes and that those changes may be important when generating long range forecasts of industrial electricity demand.

Recently, industrial electricity forecasting methodologies have been developed which forecast electricity use at the two-digit SIC level with some further disaggregation to explicitly account for energy intensive industries such as aluminum and iron and steel. These output forecasts are combined with the fuel price forecasts in the various industrial process models to project the demand for electricity by industry and in total. Electricity demand forecasts using this procedure are generally more accurate and more economically justifiable than previous forecasting procedures. These procedures begin with macroeconomic forecasts which are then filtered through interindustry models. The macroeconomic forecasts account for exchange rate changes, but not for changes in international productivity; for changes in population, but not for changes in age structure. Further, these methods almost totally ignore trends in domestic and international plant relocation. It seems likely, therefore, that these more sophisticated models of the industrial demand for electricity and for other energy may be further refined and enhanced by more explicitly accounting for changes in international competition, population age structure, and international and domestic plant relocation.

Such refinements are important for they will allow not only for more accurate forecasting and, hence, planning by the electric utilities, but also for better understanding of the effect of energy policy on the components of industrial electricity demand. We know that energy regulatory policies and decisions affecting electricity prices have a significant influence on the rate and the extent of loss of market share to foreign producers, the domestic relocation of manufacturing plants, and the degree of intermediate product substitution. These issues are complex and, while they may be superficially accounted for in some industrial electricity demand forecasts, they are usually not addressed in detail. Therefore, one of the questions we address in this study is whether more explicit attention to these issues will significantly affect industrial electricity forecasts. We believe that attention should be given to the modeling of product-mix and process change and the factors that determine such changes. The rewards from incorporating these factors would be more precise and more reliable forecasts.

In this chapter we set the scene by identifying the manufacturing sectors in which these issues may arise, and by discussing in qualitative terms the influence that electric sector pricing policies may have on these issues. In particular, it is of interest to consider the role of industrial electricity prices in relation to such factors as:

- o the cost and availability of raw material,
- o the cost and availability of labor, and
- o the land-use and zoning issues determined by environmental concerns.

In the second part of this chapter, we discuss factors affecting consumer tastes and, ultimately, consumer spending patterns such as the population's age structure and migration patterns. In both sections of the chapter we survey and discuss what is empirically known but we undertake no statistical studies of our own.

In Chapter 3, we review the effect on industrial electricity use of shifts in product-mix during the 1970s and define and discuss the concept of output elasticity and its use for policy purposes. In Chapter 4, we use industrial process models which control for efficiency changes to investigate the sensitivity of industrial electricity demand to various product-mix scenarios and, in Chapter 5 we summarize our results.

Our goal in this study is to be suggestive, and to explore the sensitivity of industrial electricity demand to various types of change, particularly changes in these determinants affecting product mix. We do not explicitly model those determinants; instead we investigate their role in forming electricity demand and discuss the strength and direction of their influence. From this discussion we generate reasoned, and we hope reasonable, scenarios which are used in ISTUM2 and ORIM to forecast industrial electricity demand for the years 1985, 1990, 1995, and 2000.¹

International Competition, Plant Relocation, and Product Substitution

The issues of international competition, plant relocation, and product substitution are not dealt with effectively by most industrial energy demand models or by the macroeconomic models often used in conjunction with energy demand models. The macroeconomic models represent aggregate demand and incor-

1 As we noted, existing models which project industrial electricity demand use, as a basic input, projections of industrial production as well as factor price projections. To test the significance of product-mix changes on industrial electricity demand we did not expand ISTUM or ORIM by adding appropriate equations or parameters; instead we analyzed the likely affect of factors such as a product substitution, international competition, etc., on product-mix and adjusted industrial output projections accordingly. These adjusted output projections are first approximations used for sensitivity testing in Chapter 4.

porate own-price elasticities and cross-price elasticities to the extent they have been modeled and to the extent they are accounted for in the time series that make up the data base. In the majority of these models, the manufacturing sector's response to price changes or policy changes is generally smooth and continuous. In the real world, conditions are quite different. Discrete events such as the loss of specific markets or plant relocations exhibit a type of threshold behavior where little evidence of the prospective plant relocation or market loss may be apparent, and suddenly a significant change in behavior occurs. In view of these events, which affect our ability to forecast electricity demand, it seems clear that an increased emphasis on certain critical industry situations is warranted.

The framework for the discussion of these issues is based on the information provided in Table 2-1 where 22 manufacturing sectors are listed in order of electric intensity (kilowatt-hours of electricity per dollar of value added), along with the actual electric use and value added. Although the discussion to follow usually refers to industry average conditions, it must be remembered that actual plants within an industry represent a wide range of energy efficiencies. Thus, in each industry there will be specific plants and facilities that are more sensitive to electric sector policies as well as those that are less sensitive than indicated on the average. In Table 2-1, we indicate the sensitivity of industries within the manufacturing sector to international competition, plant relocation, or product substitution and identify the major energy policy variable that affects the industry. In some cases, the industry may not be sensitive to specific policy issues, but is a major consumer of electricity. In these cases, the major interest identified is "demand analysis"²; that is, it is important to understand the behavior of the industry group in responding to major shifts in the demand for its products in order to improve regional electricity demand forecasts. Most policy actions affect electric prices, a variable to which most industries are quite sensitive.

The discussion here addresses issues in individual sectors. Analysis of industrial energy demand must consider the interindustry effects of a situation that arises in one industry. These effects are usually analyzed through input-output or interindustry matrices that are incorporated in many of the major models.

Evidence of Increased International Competition

The increased integration of the United States into the world economy and our failure to maintain international competitiveness in many products has increased the net value of imports over exports that together now equal almost 40 percent of the total value of all goods produced in the United States. (For comparison, in 1969, they accounted for only 16 percent.)

2 Demand analysis explores the structure of demand, identifies the determinants of demand, and analyzes the responsiveness of demand to changes in the structure and to fluctuations in the determinants (e.g., prices and income). The goal is to understand how policy decisions will affect demand and, hence, industry and firm performance; and to project demand.

TABLE 2-1

Summary of Sensitivity of Sectors to Major Issues, and Policy Relevance

Order	Industry	Sensitive to:			Principal Electric Sector Policy Issue
		International Competition	Domestic Relocation	Product Substitution	
1	Aluminum	x	x	x	Price
2	Paper		x		Cogeneration (PURPA)
3	Steel	x	x	x	Price
4	Chemicals	x		x	Demand Analysis
5	Other Primary Metals	x	x	x	Demand Analysis
6	Petroleum Refining	x			Demand Analysis
7	Rubber, Misc. Plastics	x		x	Demand Analysis
8	Textiles	x		x	Demand Analysis
9	Lumber and Wood		x	x	Cogeneration (PURPA)
10	Stone, Clay, Glass				-----
11	Fabricated Metals		x	x	Demand Analysis
12	Elec. Machinery	x			Demand Analysis
13	Food				-----
14	Furniture				-----
15	Transportation Equipment	x			Demand Analysis
16	Machinery	x			Demand Analysis
17	Misc. Manufacturing				-----
18	Printing and Publishing			x	-----
19	Measuring Equipment				-----
20	Apparel			x	-----
21	Leather			x	-----
22	Tobacco				-----

The imposition of protectionist measures to defend U.S. markets from foreign competition have raised prices for American consumers. During the decade of the 1970s exports of U.S. manufactured goods declined by 23 percent. Over 20 percent of automobiles sold in the United States are produced abroad, compared to 8 percent in 1970; 14 percent of steel, compared to 9 percent in 1970; over 50 percent of consumer electronic products, compared to 10 percent in 1970 (See Table 2-2). The list grows longer year-by-year.

Table 2-2

GROWTH OF U.S. IMPORTS IN SELECTED PRODUCTS
(Imports as a Percent of Consumption)

Industry of Product	1960	1979
Automobiles	4.1	21.0
Steel	4.2	14.0
Consumer Electric Products	5.6	50.6
Calculators	5.0	43.1
Metal-Forming Machine Tools	3.2	25.6
Footwear	2.3	37.3
Textile Machinery	6.6	45.5
Apparel	1.8	10.0
Metal-Cutting Machine Tools	3.3	26.4
Industrial Inorganic Chemicals	2.0	19.0
Food Processing Machinery	3.0	18.7
Cutlery	8.2	90.0

SOURCE: U.S. Department of Commerce, Bureau of Industry Analysis, U.S. Industrial Outlook, Selected Issues. Also see Magaziner, I.C. and R.B. Reich, Minding America's Business, Harcourt, Brace, Jovanovich, New York, NY, 1982, p.33.

To more effectively forecast the industrial demand for electricity we are interested in how much longer this trend will continue and which of our industries are most vulnerable. Of particular importance to industrial electricity consumption are the shifts in the growth of various sectors, which would suggest that a reallocation of investment spending among industries is appropriate. Industries which are heavily capital and energy intensive such as steel, cement, fibers, automobiles, and commodity plastics, have been growing slowly. Industries providing much of the recent growth -- such as computers, industrial machinery, and electronic instruments -- tend to be far less capital and energy intensive.

3 See Magaziner, I.C. and Reich, R.B. Minding America's Business, Harcourt, Brace, Jovanovich, New York, N.Y., 1982, p.2.

Industry Examples

United States' industry faces severe competition from overseas producers in the following sectors:

1. **Aluminum:** Severe competition exists between the United States and countries with low cost hydropower and access to bauxite, e.g. Brazil. This situation has been exacerbated by regulatory policies, such as the escalation of industrial rates relative to residential rates and the pooling of low cost hydropower resources. Outlook is for no growth and possibly further degradation in aluminum smelting capacity; smelting is the most electric intensive part of the aluminum industry even with the advanced energy efficient Alcoa process. Competitiveness of this sector in international markets is highly sensitive to electric sector policies, but recent dislocations may be irreversible.
3. **Steel:** Severe competition exists for electric furnace operation between the United States and countries having access to low cost power. Other portions of the industry are sensitive to competition from newer plants overseas with access to low cost ore and with low cost labor, e.g. Korea. The United States could have an advantage in electric mini-mills for scrap recycling due to proximity to scrap sources if the cost of power is reasonable, and if scrap transport costs and export policies are adjusted. Competitiveness of this sector in international markets is moderately sensitive to industrial electricity pricing policies.
4. **Chemicals:** While a large consumer of electricity, the chemicals industry is more sensitive to the cost of petroleum feedstocks than to electricity. Much of the new capacity for primary and bulk chemicals (ethylene) has moved to the Persian Gulf and other low cost oil-producing countries. To illustrate the sensitivity to electricity prices, the contribution of electric costs to value added is only 10-15 percent in the first, and to date the only, large volume electro-organic process, the synthesis of adiponitrile brought on stream by Monsanto in 1965. Such technologies as the chloralkali process are, of course, even more electric intensive and thus more sensitive to industrial electricity prices. These factors indicate that the U.S. industry will ship more intermediate and specialty chemicals where proximity to markets is more important. The Toxic Substances Control Act (TSCA) will, of course, also have a strong influence on the domestic viability of these products. In summary, the international competitiveness of the chemicals industry is influenced to a great extent by factors other than industrial electricity prices; however, the outcome will have a significant effect on industrial electric demand since the industry is the largest user of electricity in absolute terms among those listed.

4 The numbers refer to the industries as listed in Table 2-1, p. 2-4.

5,6,7 **Other Primary Metal, Petroleum Refining, Rubber, Miscellaneous Plastics:** The cost and availability of feedstock and environmental restrictions on plants rather than industrial electricity prices influence the international competitiveness of these industries. Like the chemicals industry, they represent a significant fraction of industrial electricity demand, and therefore analyses of electric demand should consider the future competitiveness of the U.S. industry on world markets.

15,16 **Transportation Equipment and Machinery:** These sectors are feeling increased competition from foreign firms with lower labor costs and proximity to rapidly growing markets. For example, Japan is producing for the Asian market. While the sensitivity of these industries to electricity prices are low, they represent a significant fraction of industrial electricity demand and thus must be addressed in demand analysis.

Sensitivity to Domestic Relocation

In many instances, electricity prices can have a strong influence on plant location and relocation within the United States. While such relocation is less serious as a national problem than the loss to foreign producers, as discussed previously, the regional impacts of such dislocations can be important. While plant location is primarily determined by cost considerations, including fuel costs, it also has a major influence on the fuels used by industry. Table 2-3 indicates those industries that are particularly sensitive to relocation due to industrial electricity prices.

Sensitivity to Product Substitution

Several electric intensive industries (particularly aluminum and steel) face uncertain market prospects due to competition with other materials such as plastics and composites in durable manufacturing and especially in defense weapons systems, glass and paper for containers, and plastics in construction. Most industrial energy demand analyses do not deal with the implications of such substitutions in any depth. The substitution rate will clearly be influenced by electricity prices in the case of aluminum and steel.

TABLE 2-3

Industries Most Affected by Economic Pressures for Relocation

1. Aluminum (high electric prices and lack of access to cheaper hydropower)

2. Paper and 9. Lumber and Wood:

Regional competition between Northwest and Southeast; nationally, the influence of cogeneration policies such as PURPA, especially regarding the cost and availability of natural gas. That is, PURPA requires utilities sell electricity at nondiscriminatory rates to companies generating their own power from cogeneration, that utilities purchase excess electricity from cogenerators, that cogenerators not be classified as utilities and, therefore, not be regulated.

3. Steel and 11. Fabricated Metals:

Location of mini-mills where electricity prices are moderate.

TABLE 2-4

Industries Most Sensitive to Product Substitution

1. Aluminum and 3. Steel: Higher priced industrial electricity increases the price of raw aluminum and steel creating an incentive to substitute lower price plastics and fibers where possible.
2. Paper and 9. Lumber and Wood: PURPA and its promotion of cogeneration may lower the price of fibers and make them more competitive with intermediate materials such as aluminum and steel.
4. Chemicals, 5. Other Primary Metals, 7. Rubber and Miscellaneous Plastics, 8. Textiles, and 11. Fabricated Metals: Whether these industries are sensitive to product substitution will depend not only on the price of electricity, but also on technological possibilities of substitution and on the underlying structure of demand. Textiles are made from fibers and from plastics. The chemical industry as well as agriculture supply the raw materials for the textile industry. The extent of the substitution will depend on many factors, but primarily underlying movements in the structure of demand.

Factors Affecting Consumer Taste and Income

The previous discussion dealt with the affect of electricity or other energy and non-energy costs on the composition of industrial output and the lower world, as compared to domestic, prices which caused consumer demand to shift to imported products or producers to shift production to lower cost locations. In this section, we focus on consumer characteristics, such as demographic factors which may have an effect on consumer spending patterns as they affect the composition of industrial output. We do not discuss the shift from industrial products to services here, a shift frequently attributed to a population with a high proportion of elderly. We first identify the factors that affect tastes; second, we discuss the influence of age and income on spending; finally, we explore the effect of age on consumption patterns.

Demographic Factors

The demand function for industrial products is also a function of relative prices, income (household), and tastes. "Tastes" are determined by a multitude of individual characteristics since they vary with education, ethnic and cultural background, region of the country in which the consumer lives, sex of consumer, age of the consumer, number of family members, occupation, and so on. Many of these factors are highly correlated -- for example, age, education, sex, and occupation are highly correlated with income. The majority of the factors affecting tastes are demographic factors and, for our purposes, the consumer's age is the most important and significant. Age is the most important because it is the demographic factor which is currently changing and which we expect to change most significantly in the future. We must, however, be aware of the effect of the other factors on the products demanded, for if their influence is not controlled for, or allowed for, they can confound our simple statistics and lead to spurious interpretations.

While age as a factor causing shifts in product mix does not appear to be very significant, we will briefly discuss its role and present some statistical results because it is often assumed to be an important determinant of product mix change.

The Influence of the Population's Age Distribution on Income and Spending

The life cycle hypothesis asserts that age -- because it affects a family's income, assets, and needs -- has a decided impact on the household's spending patterns. The average propensity to consume out of income and the marginal propensity to consume out of income will, therefore, be influenced by the age distribution of the population. When growth in population slows down or speeds up, the number in specific age groups changes from decade to decade, and usually not in a consistent manner. At present, there is a bulge in the young adult group, aged 25 to 35. This results in large differences in age groups causing shifts in the consumption function due to differences in spending and saving over a family's life cycle.

When a family is young, its income is usually lower than the income it expects to earn at a later age. Young families also have a critical need to accumulate capital in the form of household goods, cars, and housing; and to build up human capital through education. Consequently, most families accumulate few, if any, financial assets until the children leave home. After the children are gone, incomes are usually at their highest; however, the need to save is greater for the family must accumulate assets as it looks toward retirement. After retirement, current income drops off sharply, and most families dissave at a rapid rate.

By going into debt, young families generally consume more than their income: mortgage borrowing is a prime example. After retirement families maintain their pattern of consumption by selling assets, or dissaving. Their consumption level may fall because income plus dissaving may be inadequate to maintain spending at previous rates.

Age is important not in itself but because it is closely related to other characteristics that directly affect the way consumers spend their money. Analysts of consumer behavior often group these characteristics -- particularly whether a person is married or not, and the number and ages of any children -- to describe distinct stages of the household life cycle.

"As people age, they leave their parent's homes and live on their own, they marry and have children, their children grow up and move away, and they return to a family of two, or through death or divorce, to living alone again. The household's spending patterns reflect these family groupings and responsibilities -- from the initial move to separate living quarters, to the need for more space when children are born, toys when they are young and college education when they are older, and then turn to the habits and tastes of a small household this time of older adults, when the children are gone."⁵

Table 2-5 shows how both income and consumption actually were related to age in the Bureau of Labor Statistics Consumer Expenditure Survey of 1972-73. Note that in that table the propensity to consume differs with both age and income. Both young and old have a high average propensity to consume. But notice also that low income people also have a high average propensity to consume and that both young and old tend to have low incomes compared to the middle-aged. The degree to which consumption changes with population depends on the shifting weights of each group and the differences in their consumption patterns, thus demography more readily explains what happens over longer periods than over a decade or less, since age groups do not vary much in the short run.

5 Russell, Louise B. The Baby Boom Generation and the Economy (The Brookings Institute: Washington, DC, 1982), p. 92.

TABLE 2-5

The Effect of Changes in Percentage in Age Classes
on the Average Propensity to Consume

<u>Age of Head</u>	<u>Reported Income Disposable Income (1972 Dollars)</u>	<u>Average Consumption (1972 Dollars)</u>	<u>Average Propensity to Consume 1972</u>
14-24	\$ 5,773	\$ 5,916	1.025
25-34	9,969	8,504	.853
35-44	12,114	10,168	.839
45-54	13,069	10,192	.780
55-64	10,277	7,785	.758
65 and Over	5,764	4,754	.835

Source: U.S. Bureau of Labor Statistics, Consumer Expenditure Survey, 1972-73.

Age and Consumption Patterns

As we have seen, average consumption spending declines with age, along with wealth holdings and their availability for consumption. Further, the physical demands accompanying the consumption of certain goods may limit their purchase (e.g., forms of recreation). On the other hand, expenditures on drugs, and health and medical expenditures per capita, are usually higher for persons aged 65 and over than for younger persons. In general, family size and age, next to income appear to exert the main influence on family consumption. This is, in part, due to the influence of age on durable goods purchases, to shifts in the response of consumption to the life cycle, to the development of consumer buying habits, to other age controlled phenomena, and to the lifetime of the durable goods under consideration. If the ratio of the expected life of aged consumers to the average life of their available durable goods is lower than that of youthful consumers, then the consumption of older persons is likely to be affected by their inventory of goods as well as by their consumption habits. Forecasts of average annual growth rates of population by age group are shown in Table 2-6.

Compared to other age groups the elderly are relatively free of debt, and they tend to favor certain categories of goods and services. Thus, an increase in the relative proportion of old to working age tends to increase the minimum purchase levels of some goods (food, clothing, and services) but has the reverse effect on housing durables. Obviously, health care, transport, communication, housing, and services can be better adapted to the needs of an aging society.

TABLE 2-6
Average Annual Rates of Growth of
Population by Age Group

	1981	1985	1990	1995	2000
Total Population	0.9	0.9	0.8	0.7	0.6
Under 5	3.7	2.2	0.0	-1.1	-0.7
5 - 16	-2.1	0.3	2.0	1.5	-0.3
16 and Over	1.3	1.0	0.6	0.7	0.9
16 - 24	-0.5	-1.9	-2.3	-0.5	2.4
25 - 44	3.0	2.6	1.3	0.1	-1.0
45 - 64	0.1	0.0	0.9	2.2	2.9

Source: Data Resources, Inc., U.S. Long-Term Review; Spring, 1981.

Our discussion of the age related behavior of consumers leads us to several qualitative conclusions: that young households spend relatively more on durable goods than older households. Young households save by purchasing material goods, older households by purchasing financial assets.

As part of a recent study on the economic consequences of the baby boom, Louis Russell of the Brookings Institution investigated the distribution of money income by age group and the average percentage of money income spent on furniture and automobiles. If this study shows a significant quantitative shift in consumption patterns among age groups, then our generalized qualitative conclusions would be somewhat substantiated.

Table 2-7 shows the shifts in the distribution of total money income among age groups that occurred between 1967 and 1975 and that are projected to occur between 1980 and 1995. These shifts suggest that the average percentage spent on durables should have risen during the 1970s, and should continue to rise during the 1980s before declining in the 1990s as the baby boom generation reaches middle age.

Table 2-8 presents two sets of estimates of the average percentages of income spent on furnishings and automobiles over the period 1970-1995. In each case the first set of estimates (Column I) extends the percentages spent by each age group in 1972-73 to the income distribution for future years (from Table 2-7) and calculates an overall average for the future years of interest. For the second set of estimates (Column II) the percentage spent by each age group in 1972-73 was adjusted up or down to reflect the level of real income for the group in each year. The adjustment procedure was based on linear regressions relating spending on furnishings and automobiles to before tax income.

TABLE 2-7

Percent Shares of Total Money Income by Age of
Household Head, Selected Years, 1970-75, and
Projections for 1980-1995

Year	U n d e r					
	25	25-34	35-44	45-54	55-64	65 and Over
1970	5.2	19.0	23.2	25.0	18.0	10.6
1975	5.3	21.6	20.8	33.3	17.2	11.9
1980	5.3	23.1	21.9	20.9	17.0	11.8
1985	4.8	23.6	24.6	19.0	16.1	11.9
1990	4.0	22.9	26.8	20.0	14.4	12.0
1995	3.6	20.3	27.7	23.0	13.4	12.0

Source: Russell, Louise B. The Baby Boom Generation and the Economy,
The Brookings Institution, Washington, D.C. 1982, p. 122.

TABLE 2-8

Average Percentage of Total Money Income Spent on
Household Furnishings and Automobiles, Selected Years,
1970-95

Year	<u>Household Furnishings</u>		<u>Automobiles</u>	
	I	II	I	II
1970	3.18	3.23	6.51	6.63
1975	3.21	3.25	6.52	6.68
1980	3.23	3.22	6.54	6.53
1985	3.25	3.21	6.52	6.40
1990	3.26	3.19	6.48	6.28
1995	3.22	3.12	6.44	6.15

Source: Russell, op. cit., p. 123

Both sets of estimates show that the effect of the population's age structure on the consumption of household furnishing and automobiles has been, and can be expected to be, very small at best. On the one hand, we can see from Table 2-8, when the percentages spent by each age group are held constant at the levels of 1972-73 (Column I), the overall percentage spent on furnishings rises only slightly, from 3.18 percent in 1970 to a high of 3.26 percent in 1990, before declining; and the average percentage spent on automobiles peaks somewhat earlier, rising from 6.51 in 1970 to 6.54 in 1980, and falling thereafter. On the other hand, when the percentage spent by each age group are not held constant (Column II), but are more realistically allowed to rise or fall in response to real income, the effect of the age structure disappears and the average percentages decline throughout the period, except for 1970-75.

The results of Russell's analysis are in agreement with other studies in that the effect of age structure on the composition of durable goods consumption is small. For example, it appears that age structure can be expected to raise the percentage spent on furniture and appliances by less than one-tenth of one percent between 1970 and 1990, and even this effect disappears when changes in income per household are taken into account. Much the same is true for expenditures on automobiles.

Summary

Much of the information on the effect of age structure on the pattern of consumer spending is anecdotal with few statistical surveys taken to back-up those studies. What statistical evidence there is supports the statement that the elderly spend proportionally less on automobiles and on furniture and that they spend proportionally more on pharmaceuticals. But the statistical evidence also shows that the effect of age on furniture and automobile consumption is weak, and thus the effect of age on the pattern of consumption and the derivative pattern of fuels used in production is likely to be insignificant.

There are, however, several considerations to be emphasized regarding the studies reported here. First, they are not sufficiently disaggregated. While the statistical data of spending on durables such as automobiles and household furniture is suggestive it does not provide enough information regarding the effect of age structure on expenditures for other goods. Second, the tendency for income and the changing structure of the family to be highly correlated with age and spending patterns tends to confound simplistic statements regarding a population's age structure and its pattern of consumption.

Thus, more work needs to be done in further disaggregating the available data and in controlling for other factors correlated with age and with spending on goods and services. A great deal of data exists in the U.S. Bureau of Labor Statistics, Consumer Expenditure Survey, 1972-73. Much of the data has been used by demographers to study specific spending and saving patterns and to explain household decisions to purchase oil, electricity, natural gas, or coal. But no general survey of consumer expenditures related to age and controlling for income (and, to the extent possible, for changing family structure) have been undertaken.

In short, while common-sense tells us that the age structure of the population should have an effect on product-mix what statistical evidence there is implies that the effect is weak. Thus, we do not use age related product-mix shifts in the remainder of this study. However, we do use shifts that are the result of international competition, plant location, and product substitution. Statistical evidence coupled with our commonsense theory of the firm suggests that these determinants of industrial output mix have been important in the past and will be important in the future.

CHAPTER 3

INDUSTRIAL ELECTRICITY CONSUMPTION 1970-1980

To improve our projections of the overall growth in industrial electricity consumption, we must have a better understanding of the determinants of electricity intensity among the various industries. A review of the shifts in electricity use among those industries (especially the electricity intensive ones) over the decade of the 1970s will identify both product and factor substitution patterns which affect the industrial use of electricity.

In this chapter, we elaborate on the theory of the industrial demand for electricity in order to identify and better understand the determinants of electricity demand in the 1970s. We then use two-digit manufacturing sector data to estimate the effect of changes in product mix on the growth of industrial electricity demand over that period. This analysis of manufacturing consumption patterns over the last decade will provide a background with which to judge potential electricity intensities for future scenarios.

Overview

In absolute terms, industrial electricity demand over the period 1970-1980 increased by 38 percent, or 3.32 percent compounded annually. However, this increase obscures many substantive underlying changes. For example, the rapid increase in energy prices in the mid-seventies and the recession that accompanied the increase significantly reduced the rate of growth for both industrial output and the demand for energy and electricity. However, electricity growth in terms of the amount of electricity used to produce a real dollar's worth of output increased through 1976. While electricity intensity (measured as kWh per constant dollar of value added) was increasing between 1974 and 1976, labor intensity was decreasing. As the economy turned upward in 1976, capital expenditures increased. In addition, labor employment per unit of output increased. The new expenditures on capital equipment produced a more efficient capital stock which provided the groundwork for a reduction in electricity intensity for the period 1976 to 1980. Whereas electricity intensity in manufacturing had increased by 33 percent over the period 1970 to 1976, it dropped by 18 percent over the period 1976 to 1980.*

* The industrial sector includes the manufacturing sector plus construction, mining, transportation, communications, and utilities. The aggregate statistics in this chapter refer to the industrial sector as a whole (i.e., Tables 3.1 and 3.2). The disaggregate statistics refer to 2-digit SIC manufacturing industries (Tables 3.3 to 3.7 and Figures 3.1 to 3.6). The need for this distinction is that disaggregated data on electricity consumption is available only for the manufacturing sector.

In addition, after 1974, with the rapid increase in energy prices and concomitant increases in the prices of energy intensive goods, manufacturing (and the economy) began to shift away from more expensive energy intensive products to less expensive, less energy intensive products. Prior to 1974, changes in the mix of manufacturing output slightly decreased electricity growth. Subsequent to 1974, shifts away from energy intensive products reduced energy growth by as much as 0.5 percent per year. This sensitivity of electricity demand to the change in product mix may not have been a once-and-for-all shift in electricity demand, but may instead represent a higher-than-anticipated consumer awareness and responsiveness to changes in relative prices, and that increase in consumer awareness could affect the future demand for electricity.

Thus, focusing on the disaggregate electricity and manufacturing data, we observe a reduction in electricity intensity in the manufacturing sector throughout the decade with a more rapid reduction in the later years, and a lower growth rate of electricity use in the manufacturing sector. This reflects the ability of the manufacturing sector to change over its capital stock in response to rapid changes in relative prices. The reduction in electricity intensity and the shift to less electricity intensive products tends to reduce the long-term growth rate for electricity in the industrial sector. At the same time, however, the extent to which this will persist depends on the rate at which electricity will substitute for other energy and the rate at which energy efficient capital can substitute for less energy efficient capital.

During the period 1970 to 1980, industrial electricity use, GNP, and industrial production increased at roughly the same overall rate. However, the ratio of industrial electricity use to industrial production increased from 1970 to 1975 and then decreased to 1980 (Table 3-1). High electricity prices induced a trend towards the more efficient use of electricity in production which carried to the end of the decade. From 1976 to 1980, both GNP and industrial production increased about one-third faster than industrial electricity use (Table 3-2).

The rate of growth in industrial electricity use increased at a slower rate than industrial production because: consumers shifted to lower cost, lower electricity intensive goods; manufacturers purchased more electricity-efficient capital equipment and used inputs in more efficient production combinations.

Electricity Consumption and the Theory of the Firm

Economic as well as common-sense tells us that an increase in the price of a factor of production will, other things equal, cause a decrease in the use of that factor. This holds in the short-run for variable factors of production, and in the long-run for all factors of production. The increase in the price of one factor of production, other prices constant, increases the cost of producing the same level of output. Facing a market demand with a specific price, a profit maximizing firm will reduce its level of output and, most likely, the use of all inputs will decrease in the short-run. That is, the hire of variable inputs such as labor will fall and fixed inputs will be used at less than full capacity.

TABLE 3-1: THE ECONOMY AND INDUSTRIAL ELECTRICITY 1970-1980

YEAR	GNP ¹	INDUSTRY ² ELECT.	TOTAL ³ ELECT	FRB ⁴ INDUST INDEX	IND ELECT FRB	IND ELECT GNP	TOTAL ELECT GNP
1970	1085.6	573	1,391	1.078	532	0.53	1.28
1974	1248.0	689	1,701	1.293	533	0.55	1.36
1975	1233.8	662	1,733	1.178	562	0.54	1.40
1976	1300.4	725	1,850	1.304	556	0.56	1.42
1977	1371.6	757	1,951	1.381	548	0.55	1.42
1978	1436.9	782	2,018	1.461	535	0.54	1.40
1979	1483.0	818	2,079	1.525	536	0.55	1.44
1980	1474.0	794	2,126	1.470	540	0.54	1.44

TABLE 3-2: ANNUAL ECONOMIC AND INDUSTRIAL ELECTRICITY GROWTH, 1970-1980
(PERCENT CHANGE)

YEAR	GNP	INDUSTRY ELECT.	TOTAL ELECT	FRB INDUST INDEX	IND ELECT FRB	IND ELECT GNP	TOTAL ELECT GNP
1970-74	3.55	4.72	5.16	4.65	0.05	0.93	1.53
1974-76	2.08	2.58	4.29	0.42	2.13	0.90	2.18
1976-80	3.18	2.30	3.54	3.04	-0.73	-0.91	0.35
1970-80	3.11	3.32	4.33	3.15	0.15	0.19	1.18

1 GNP figures are in 1972 dollars

2 Billions of kilowatt hours; excludes agriculture and mining; Source: ASM
1980 Annual Survey of Manufacturers, Fuels and Electric Energy Consumed.

3 Billions of kwhr; Source: U.S. Statistical Abstract

4 1967 = 1.0

This "comparative statics" analysis assumes either a fixed production technology and an instantaneous adjustment in factor prices, product prices, and production decisions, or that the time dimensions associated with these processes are not relevant. In practice, however, the dynamics of changing relative prices are important. Even though in the long run all factors of production are variable, in the short run some factors are less variable than others. For example, assuming that there were no gains in efficiency or that there was no technological change embodied in the factors of production, a decrease in the product demand would tend to lower its price, induce reductions in output and in the employment of other factors. However, because of the different degrees of "fixity" of the factors of production, factor employment will decrease at different rates. Similarly, as demand expands and output prices are forced upward, increased production would, in the short run, increase the use of certain inputs.

More specifically, in an economic downturn, industrial output will decline as will, consequently, manufacturing's use of electricity.* This quasi-fixed nature of electricity relative to, for example, labor suggests that manufacturing electricity use will decrease proportionally less than output. This relative inability to vary the use of electricity in the short-run, at least compared to a factor such as labor, means that in the production process, the dynamics of the short-run adjustment to the fall in demand substitutes electricity for labor. If, on the other hand, electricity prices increase faster than the wages of labor, then the long-term dynamics suggest that labor and electrically efficient capital will be substituted for that higher priced electricity.

In an economic upturn, industrial output will increase at a greater rate than industrial electricity consumption with the more rapid increase in the re-employment of labor in the production process. (However, in the early stages of an upturn, neither input would necessarily increase if, in the prior period, capital investment provided for more efficient equipment requiring less labor and electricity use per unit of production.) To elaborate, for most industries, electricity use does not vary in direct proportion to output: it provides support facilities as well as drives equipment in the production process. However, certain electricity-intensive industries such as aluminum, some fabricated metal products, and chemicals use electricity in the production process to such an extent that electricity consumption is directly proportional to the output of the industry. In this case, electricity consumption would be expected to vary with output and would be more directly affected by the changing price of electricity.

While the theory of the firm tells us that, in the long run, other inputs will be substituted for relatively higher priced electricity, it has always remained somewhat an anomaly that electricity use has increased, often dramatically, even though its price per Btu delivered was higher than for oil, natural gas, or coal. Clearly, firms are willing to pay more for electricity because its cleanliness allowed cost reductions elsewhere in the production process.

* But electricity is a quasi-fixed factor of production in that many of its productive uses cannot easily be cut. Lighting is an example of the relatively fixed use of electricity and motor drive a variable use.

But there is a more economically meaningful explanation of electricity's popularity. Electricity use was the culmination of a search by many industries for a form of energy, not necessarily the cheapest form, which possessed certain economically desirable characteristics. Thus, the industrial use of electricity can often be translated into tangible cost reductions in which the introduction of energy-intensive techniques in one place generated more than compensating savings elsewhere.* Electricity also offers superior opportunities for the control and manipulation of heat and mechanical energy not easily matched by other fuels. Further, for many uses of electricity there is no alternative energy form.

Electricity Use in Two-Digit SIC Manufacturing Industries

During the 1970s, three successive trends of industrial electricity use occurred. From 1970 to 1974, the economy was in a growth period that resulted in general increases in both product demand and the employment of all factors of production. From 1974 to 1976, the economy experienced a recession in which the real prices of energy and electricity rose substantially and real output declined. (See Figures 3-1 and 3-2.) From 1976 to 1980, the economy rebounded and, though the real prices of energy and electricity continued to rise during this period, the economy was much healthier.

From 1970 to 1980, electricity use in industry grew at an annual rate of 3.32 percent while industrial output grew at an annual rate of 3.16 percent. These statistics, however, totally obscure the dynamics of the decade. From 1970 to 1974, industrial electricity grew at an annual rate of 4.72 percent, outpacing growth in industrial production, which rose at a rate of 4.65 percent. From 1974 to 1976, the growth rate in industrial electricity use was about 6 times that of industrial production, that is, 2.58 percent per year versus 0.42 percent per year, respectively. However, from 1976 to 1980, industrial production grew at the rate of 3.04 percent per year whereas industrial electricity use grew only at the rate of 2.30 percent per year. During this latter period, wholesale prices increased at the rate of approximately 9 percent per year and industrial electricity prices at approximately 14.9 percent per year. Moreover, throughout the entire decade, industrial electricity prices increased more rapidly than wholesale prices.

* See Rosenberg, Nathan. Inside the Black Box: Technology and Economics (Cambridge University Press, New York, NY, 1982), p. 94; Jorgenson, Dale W. The Role of Electrification in Productivity Growth; Dale W. Jorgenson Associates, pp. 1-8; and Schurr, Sam, et al, Energy in America's Future (Baltimore, Johns Hopkins University Press; 1979), pp. 88-92.

Figure 3-1
FRB Indexes of Industrial Production
Selected Industries
(1967=100)

Source: U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers. Fuels and Electric Energy Consumed, Washington, DC, 1980

Figure 3-2
Average Price of Electricity
Sold to the Industrial Sector
(Dollars per 100 kilowatt-hour)

Source: U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers. Fuels and Electric Energy Consumed, Washington, DC, 1980.

Figure 3-3

Electricity Use
Selected Industries
(Billions of KWH)

Source: U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers Fuels and Electricity Consumed, Washington, DC, 1980.

In the manufacturing sector, the cost per kWh of electricity increased over the decade. Figure 3-4 shows that the annual percentage change in cost was positive and, in general, large for the period. The annual percentage change in the total cost of electricity was less for each 2-digit industry during the years 1976-1980 than for the years 1974-1976. Notable exceptions, however, are paper and allied products and chemicals and allied products. The rapid increase in the price of oil during 1973-1974 and the coal strike during 1974 tended to drive up the cost of generating electricity. The variation across industries reflects regional differentials in fuel generation costs as well as differences in industrial rate structure. In addition, for some industries the actual quantity of electricity used decreased over the period 1976-1979 (though not for the electricity intensive industries shown), whereas the amount of electricity used had generally increased from 1974-1976. This phenomenon reflects the short and long run responses to rapid increases in the prices of energy and electricity.

During the period of 1970 to 1974, electricity use increased in absolute terms as did the electricity to labor ratio. Firms were using electricity more intensively in the production process. During the period 1974 to 1976, output decreased. However, electricity use did not decrease, in general, and clearly did not decrease to the extent output did. During that period the use of electricity relative to labor was mixed depending on the industry as indicated in Figure 3-6. For most industries it appears that in the short-run it is easier to furlough labor and because of the relatively fixed nature of the electricity-using aspects of the production process, the use of electricity did not decrease as much as the use of labor. Capital expenditures showed a mixed reaction in the 1974-1976 period. In some industries capital expenditures increased relative to the other inputs and in other industries it decreased relative to these inputs (Figure 3-5).

In the subsequent period, 1976 to 1980, FRB output increased as the economy was strong. As output increased, the demand for electricity and labor increased. However, the demand for labor generally increased relative to that of electricity (Figure 3-6). Labor appears to be less fixed in the production process than electricity. That is, as electricity demand increased, electricity was still relatively fixed and labor could be expanded more rapidly in the production process. It also appears that those industries which experienced large investment expenditures during the 1974 to 1976 period also experienced a slower growth in electricity demand between 1976 and 1980. One would expect that as new capital equipment were put in place in response to higher energy and electricity prices from 1974 to 1976, this capital equipment would be more electricity efficient and hence would require less electricity per unit of output. Clearly the annual percentage growth in electricity use per employee is greater when the economy contracts (especially following rapid price increases) than when the economy subsequently expands - electricity use is relatively more fixed in the short run and, in the long run, capital investment in new equipment reduces the demand for electricity.

Figure 3-4

Cost of Electricity per KWH
Selected Industries
(1967 Dollars Per Thousand KWH)

Source: U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers, Fuel and Electricity Consumed, Washington, DC, 1980.

Figure 3-5
 Capital Expenditures Per Employee
 Selected Industries
 (Thousands of 1967 Dollars per Employee)

Source: U.S. Department of Commerce, Bureau of Census, Annual Survey of Manufacturers, Fuel and Electricity Consumed, Washington, DC, 1980.

Figure 3-6
KWH Per Employee
Selected Industries
(Thousands of KWH)

Source: U.S. Department of Commerce, Bureau of Census, Annual Survey of Manufacturers, Fuel and Electricity Consumed, Washington, DC, 1980.

Aggregation from Smaller to Larger Industries

In aggregating the data from the establishment of firm level to the two-digit level, many of the important aspects of business decisions become obscured. The observed changes in energy consumption at the two-digit level mask the variation that occurs at the level of the firm. For example, at this level, we observe very different changes in the overall behavior of energy use and labor employment. In fact, it is difficult to separate responses to differences in product demand, changes in relative input prices, the dynamic aspects of the production process and energy efficiency gains at the four-digit level, much less at the two-digit level. However, if we had firm-specific data, we could observe changes in the substitution patterns among the various factors of production. In addition, we could observe the changes in the firms output mix. In general, as energy prices increase, output from energy intensive industries should become relatively higher priced and demand for that output should decrease relative to the demand for other products. Thus, as the price of electricity increases relative to that of other inputs, the price of electricity-intensive goods should increase relative to products that are less electricity-intensive.

On the other hand, within the production process for each specific industry, one would expect substitution away from the relatively high priced inputs. As the price of electricity increases relative to capital or labor, the firms should shift their input mix away from electricity toward labor and capital. The effect of this switch would be to put downward pressure on the prices of the final products and buffer the trend toward more labor and capital intensive goods.

The general overall effect would be a change in electricity use within a particular industry for two reasons: reduction in the demand for the product and hence an equivalent reduction in the demand for electricity; and secondly a substitution effect away from electricity toward other inputs. The first is a "product mix" shift which could occur as overall aggregate demand for all products changes or as the demand for a particular "electricity intensive" product varies relative to the demand for non-electricity intensive products. The second effect is an efficiency effect which results from a more effective combination of inputs to the production process as relative prices change or as capital goods become more electricity efficient internally. This latter process could occur by substituting new, more efficient capital goods for the old, inefficient capital goods with respect to electricity use.

These concepts can be used to identify the different effects for each two-digit industry. Essentially, if we observe a constant output-to-electricity ratio as the composition of aggregate output changed and if relative prices remain constant, then electricity use would grow at the same rate as output. On the other hand, if we observe a change in the output to electricity ratio, initially assuming that a one percent change in the inputs used produces a one percent change in output, then the change in electricity use is a combination of both an output and a substitution effect*. In other words, the increase in output will force a change in electricity use. The output effect will be toward an increase in electricity use, but the substitution effect may go either way.

* That is, the production function is homogeneous of degree one.

That is, the substitution effect may add to or subtract from the output effect. The substitution effect and its influence on electricity use will depend solely on available technology.

Product Mix Shifts Between 1970 and 1980

Table 3-3 presents 2-digit manufacturing industry value added as a proportion of total manufacturing value added (in 1972 dollars) for the years 1970 and 1980 as well as the change between 1970 and 1980. In nine of the industries, value added fell between 1970 and 1980; in eight, value added increased; and in three there was no change. The largest users of electricity (chemicals petroleum refining, and primary metals) decreased their share of value added. Thus, the demand for the higher priced electricity intensive products fell and demand in the less expensive electricity saving products increased. The causes for these shifts were discussed more fully in Chapter 2.

Shifts in Electricity Intensity: 1970-1980

In Table 3-4, we show the electricity intensity by industry for 1970, 1974, 1976, and 1980, and in Table 3-5, the difference in electricity intensity between 1970 and 1979, 1970 and 1974, 1974 and 1976, and 1976 and 1980.

For the period 1970 to 1974 when product demand was increasing, electricity efficiency was increasing in only 6 of the industries and decreasing in the remaining thirteen.

The period 1974 to 1976 shows all industries increasing their use of electricity per dollar of value added. This increased use of electricity can be largely explained by the preferred demand for electricity relative to other fuels, its quasi-fixed nature in the production process, and the more rapid reduction in output for the two-year period. In short, according to the theory postulated earlier, the relative fall in industrial output should, since electricity is a quasi-fixed factor, have increased the measured electric intensity of these products.

During the 1976 to 1980 period, the real price of energy and electricity continued to increase, and the economy was, in general, healthier. While the real price of electricity almost doubled over the period, and while its price was higher per Btu than other fuels, electricity prices were still not rising as rapidly as the prices for alternative energy forms such as oil and natural gas. Further, industrial output was increasing and again given the quasi-fixed nature of electricity it was, to some extent, being spread over a greater volume of output and, consequently, electricity intensity fell.

The Effect of Product Mix Changes on Electricity Use: 1970-1980

Over the period 1970 to 1980, industrial output increased at an annual rate of 3.15 percent (Table 3-2). Concomitant with this increase was a 3.32 percent

TABLE 3-3

Share of Total Value Added in the Manufacturing Sector
1970-1980 (in constant 1972 dollars)

Industry	Industry Pro- portion of Total Value Added 1970	Industry Pro- portion of Total Value Added 1980	Change in Industry Pro- portion of Value Added 1970 to 1980
20 Food and Kindred Products	0.106	0.095	-0.011
21 Tobacco Manufacturers	0.008	0.008	-
22 Textile Mill Products	0.032	0.032	-
23 Apparel & Other Products	0.039	0.041	0.002
24 Lumber & Wood Products	0.019	0.019	-
25 Furniture & Fixtures	0.017	0.019	0.002
26 Paper & Allied Products	0.039	0.036	-0.003
27 Printing & Publishing	0.061	0.067	0.006
28 Chemicals & Allied Products	0.101	0.086	-0.015
29 Petroleum Refining	0.019	0.013	-0.006
30 Rubber & Plastic Products	0.029	0.032	0.003
31 Leather & Leather Products	0.009	0.006	-0.003
32 Stone, Clay, & Glass	0.032	0.026	-0.006
33 Primary Metal Industries	0.068	0.051	-0.017
34 Fabricated Metal Products	0.069	0.065	-0.004
35 Machinery Except Electrical	0.105	0.126	0.021
36 Electrical Machinery	0.096	0.110	0.014
37 Transportation Equipment	0.106	0.113	0.007
38 Measuring Equipment	0.028	0.042	0.014
39 Miscellaneous Manufacturing	0.018	0.014	-0.004

* Columns may not add to 1.000 due to rounding

Source: U.S. Department of Commerce, Bureau of Census, Annual Survey of Manufacturers, Washington, D.C. Various years.

TABLE 3-4
ELECTRICITY INTENSITY BY INDUSTRY

Industry	1970	1974	1976	1980
20 Food and Kindred Products	1.17	1.40	1.44	1.32
21 Tobacco Manufacturers	0.39	0.43	0.49	0.56
22 Textile Mill Products	2.72	2.84	3.47	2.48
23 Apparel & Other Products	0.53	0.55	0.68	0.45
24 Lumber & Wood Products	1.93	2.35	3.21	2.34
25 Furniture & Fixtures	0.80	0.74	0.95	0.64
26 Paper & Allied Products	3.09	3.27	4.35	4.17
27 Printing & Publishing	0.55	0.44	0.57	0.44
28 Chemicals & Allied Products	3.30	4.10	6.10	4.72
29 Petroleum Refining	4.26	5.70	7.08	7.45
30 Rubber & Plastic Products	1.79	1.75	2.37	2.09
31 Leather & Leather Products	0.70	0.70	0.80	0.70
32 Stone, Clay, & Glass	2.78	3.04	3.66	3.59
33 Primary Metal Industries	6.79	7.53	9.57	9.88
34 Fabricated Metal Products	1.11	1.15	1.43	1.18
35 Machinery Except Electrical	0.77	0.69	0.95	0.74
36 Electrical Machinery	0.91	0.84	1.01	0.75
37 Transportation Equipment	0.92	0.79	0.99	0.81
38 Measuring Equipment	0.46	0.39	0.51	0.44
39 Miscellaneous Manufacturing	0.67	0.73	0.83	0.78
Aggregate Intensity	1.83	1.96	2.43	2.00

* kWh per 100 (1972) dollars of value added.

Source: U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers, Fuel and Electricity Consumed, Washington, DC, 1980.

TABLE 3-5
DIFFERENCES IN ELECTRICAL INTENSITY BY INDUSTRY*

Industry	1970-74	1974-76	1976-80	1970-80
20 Food and Kindred Products	0.23	0.04	-0.12	0.15
21 Tobacco Manufacturers	0.04	0.06	0.07	0.17
22 Textile Mill Products	0.12	0.63	0.99	-0.24
23 Apparel & Other Products	0.02	0.13	-0.23	-0.08
24 Lumber & Wood Products	0.42	0.86	-0.87	0.41
25 Furniture & Fixtures	0.06	0.21	-0.31	-0.16
26 Paper & Allied Products	0.18	1.08	-0.18	1.08
27 Printing & Publishing	0.11	0.13	-0.13	-0.11
28 Chemicals & Allied Products	0.80	2.00	-1.38	1.42
29 Petroleum Refining	1.44	1.38	-0.37	3.19
30 Rubber & Plastic Products	0.04	0.62	-0.28	0.30
31 Leather & Leather Products	-	0.10	-0.10	-
32 Stone, Clay, & Glass	0.26	0.62	-0.07	0.81
33 Primary Metal Industries	0.74	2.04	0.31	3.09
34 Fabricated Metal Products	0.04	0.28	-0.25	0.07
35 Machinery Except Electrical	0.08	0.26	-0.21	-0.03
36 Electrical Machinery	-0.07	0.17	-0.26	-0.16
37 Transportation Equipment	-0.13	0.20	-0.18	-0.11
38 Measuring Equipment	-0.07	0.12	-0.07	-0.02
39 Miscellaneous Manufacturing	0.06	0.10	-0.05	0.11
Aggregate Intensity	0.13	0.47	-0.43	0.17

* kWh per 100 (1972) dollars of value added.

Source: U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers, Fuel and Electricity Consumed, Washington, DC, 1980.

annual increase in electricity use in the industrial sector. Although industrial output and electricity use changed in the aggregate, the changes among the two-digit industries were often even more substantial. Some energy analysts have observed a "net conservation effect" in electricity use over the period; i.e., electricity use per unit of output has remained relatively flat. However, gains due to product mix shifts have not been wholly determined. The actual changes over the period 1970 to 1980 differ substantially depending upon the partition of the decade that we are analyzing. As one would expect, the effects from 1970 to 1974 differ substantially from those of 1974 to 1980.

In this section we isolate the "first-cut" effects of product-mix shifts at the two-digit level for different time periods during the decade 1970 to 1980.

To isolate the effect of product mix changes we first observe the two-digit electricity intensities for 1970 and 1980, where electricity intensity is defined as kWh of electricity used per unit of output. The variation in the growth rate of electricity use among those industries and for that period is quite marked. For example, kWh per dollar of value added fell in eight of the industries and increased in eleven of the industries. In chemicals and allied products, the 3.30 kWh per dollar of value added increased to 4.72 kWh per dollar over the 10 year period, while in primary metals production electricity use went from 6.79 kWh per dollar of value added to 9.88 per dollar of value added. In the electric-intensive industries discussed in Chapter 2, and to be discussed in Chapter 4 (namely the paper, chemicals, primary metals, petroleum refining, and stone, clay and glass industries), electricity intensity increased over the decade.

Product mix effects can be isolated by assuming the 1970 product mix in 1980, but with the 1980 electricity intensities. That is, by estimating electricity use as if the product mix had not changed, the effect of the product mix shift on the growth of electricity demand during that period can be identified. From this information the effect of the product mix shift on the reduction of electricity growth can be isolated. The equations for calculating these effects are given in Appendix C.

From Table 3-6, we see that actual electricity consumption in the manufacturing sector grew by 2.86 percent per year compounded annually. However, if we correct for product mix changes, that is, if we assume the same product mix in 1980 as in 1970, then the annual compound growth rate in electricity consumption rises from 2.86 percent to 4.30 percent.

This saving in manufacturing electricity demand of 1.44 percent per year adds up to several trillion Btu of electricity. But, as one would expect, among the various two-digit industries that make up the manufacturing sector there were many with much greater reductions and several with increases in electricity use and electricity growth as a result of the change in the mix of products produced over the decade. Eleven industries had their growth rates in electricity use reduced because of shifts in the mix of production and in nine the rate of electricity use increased. All of the electric intensive industries such as chemicals, primary metals, petroleum refining, and paper and allied products had slower rates of growth in electricity consumed as a result of the product mix shifts.

TABLE 3-6

COMPOUND ANNUAL GROWTH RATES OF MANUFACTURING ELECTRICITY CONSUMPTION

Industry	Annual Growth Rates Incorporating Changes in Product-Mix 1970-1980	Annual Growth Rates Without Changes in Product-Mix 1970-1980	Differences in Annual Growth Rates Due to Product-Mix Changes
20 Food and Kindred Products	2.00	3.14	-1.14
21 Tobacco Manufacturers	5.05	5.63	-0.58
22 Textile Mill Products	0.81	0.94	-0.13
23 Apparel & Other Products	0.88	0.39	0.49
24 Lumber & Wood Products	3.94	3.89	0.05
25 Furniture & Fixtures	0.86	0.15	1.01
26 Paper & Allied Products	4.15	4.91	-0.76
27 Printing & Publishing	0.59	0.32	0.91
28 Chemicals & Allied Products	3.96	5.66	-1.70
29 Petroleum Refining	3.90	7.78	-3.88
30 Rubber & Plastic Products	4.40	3.52	0.88
31 Leather & Leather Products	-2.74	1.43	-4.17
32 Stone, Clay, & Glass	2.38	4.58	-2.20
33 Primary Metal Industries	2.77	5.85	-3.08
34 Fabricated Metal Products	2.03	2.59	-0.56
35 Machinery Except Electrical	3.38	1.53	1.85
36 Electrical Machinery	1.37	-0.04	1.41
37 Transportation Equipment	1.33	0.71	0.62
38 Measuring Equipment	5.54	1.48	4.06
39 Miscellaneous Manufacturing	0.93	3.40	-2.47
Aggregate Intensity	2.86	4.30	-1.44

Source: U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers, Fuel and Electricity Consumed, Washington, DC, 1980. and Annual Survey of Manufacturers, Various Editions.

In Table 3-7, we see that changes in product mix over the decade 1970 to 1980 have actually contributed to a reduction in electricity use in the manufacturing sector. If we look at the segment 1970 to 1974, product mix adjustments actually contributed to a small decrease in the growth rate, while for the periods 1974 to 1976 and 1976 to 1980, the adjustments in product mix were toward significantly less electricity-intensive products.

TABLE 3-7

Growth Rates in Electricity Use
for Total Manufacturing
(Compounded annually)

	Actual	Assuming No Change in Product Mix	Product Mix Contri- bution to Industrial Electricity Use
1970 to 1974	5.59	6.24	-0.65
1974 to 1976	2.00	4.00	-2.00
1976 to 1980	0.69	2.31	-1.62
1970 to 1980	2.86	4.30	-1.44

Source: Calculated from earlier Tables

CHAPTER 4

INDUSTRIAL ELECTRICITY DEMAND TO YEAR 2000

Introduction

Decisions by utilities to build new power plants are based on several factors, but the anticipated demand for electricity in the future is obviously one of the most significant. The long lead times for approval of site preparation, construction, and operation require 10 to 15 year forecasts of future electric demands. Analytical models of energy use are often used to develop these forecasts of electric demands.

The variety of intellectual constructs used in modeling energy demand can lead to wide variations in their forecasts and simulations. In addition to the differences among models, results using a single model will vary depending upon the economic and technical assumptions used. Models are sensitive to future levels of economic activity, absolute and relative prices for fuels, mix of energy services and products that will be demanded, and so on. These factors are illustrated hierarchically in Figure 4-1. The first tier illustrated the need to account for the effect of changes in the level of economic activity on the demand for industrial products. Thus, for a 10 percent increase in industrial output (assuming a homogeneous production function of degree one), the demand for purchased electricity will increase by roughly 10 percent. While this assumption is not strictly accurate, it serves the purpose of this illustration. However, the impact of the other factors - the change in mix of products, in production technologies, and the mix of centralized/decentralized power generation - is harder to assess. These three factors significantly affect industrial electricity demand, and will be examined in more detail.

FIGURE 4-1

The second level of the hierarchy illustrates the need to account for differential growth between energy intensive and non-intensive industries as influenced by shifts in consumption patterns. Other things being equal, a shift from an electric intensive to a non-intensive industry will reduce electricity demand. For instance, holding total GNP constant but shifting output from the aluminum industry to microelectronics reduces purchased electricity demand since more kWh of electricity are required in the production of aluminum per dollar of value added than in the production of microelectronic devices.

The next two levels illustrate the need to account for changes in the production technologies used in the industrial sector. For a given level and mix of product demand there are many different input mixes that could be used. Energy, capital, labor, and raw materials are, to limited extent, substitutes for one another. For instance, many alternative production technologies offer lower energy consumption, but at higher capital costs relative to more conventional processes. Furthermore, within the energy category there are tradeoffs between electricity and other energy forms. Finally, once total electricity requirements are determined, there is still the question of how much will be purchased from the utility industry, and how much will be generated by the manufacturer on site.

Overview of Methodology

Two of the most important factors in any projection of industrial electricity demand are the mix of products demanded and the mix of labor, capital, and energy used in the production process. The mix of products is important because different products require different amounts of energy (and electricity) in their production process. The mix of energy, labor, and capital is an important factor because in almost any manufacturing process, capital or labor can be substituted for energy, at least over the long term. A substitution of this kind leads to an improvement in the efficiency of energy use.

Examining the effect of these factors on electricity demand in a systematic way requires either the use of an existing formal model which captures the effect of various factors on energy demand, or the development of an analytic framework that is functionally equivalent to such a model.

There are two predominant approaches to projecting industrial fuel use. On the one hand, econometric models project fuel use based on historic relationships between fuel use and key input variables such as fuel price and industrial growth. On the other hand, engineering process models, are based on technical data concerning the cost and performance of specific technologies. They calculate fuel demand based upon the actual performance of technologies which capture market share as based on specific decision rules within a scenario defined by projection of industrial growth and fuel prices.

The most highly developed econometric model is generally thought to be the Oak Ridge Industrial Model (ORIM), while the most highly developed process model is Version 2 of the Industrial Sector Technology Use Model (ISTUM2). Both of these models are described in detail in Appendix B.

As an illustration of the current range of analytic views on electricity demand growth, we developed a base case projection by calibrating both the models to the same projections of industrial growth, fuel prices, and capital cost projections. Comparison of these results highlights differences between econometric and engineering-economic based projections. Further, to determine the relative importance of those factors causing the widest fluctuations in the demand for electricity we conducted sensitivity analyses by perturbing appropriate base case parameters.

Description of the Base Case

The economic forecast used for the analysis was Data Resources Inc.'s Trendlong 2007A, published in Spring 1982. The major results of that forecast are summarized in Table 4-1. Gross National Product is projected to grow at an average rate of 2.5 percent in real terms during the 1980-2000 period which is the focus of this study. This is comparatively low by historical standards but representative of most current long term macroeconomic forecasts. Consistent with past trends, industrial production as measured by Federal Reserve Board (FRB) Production indices grows somewhat more rapidly than GNP.¹ The disaggregated FRB production indices used in the analysis are shown in Table 4-2.

1 For consistency with the engineering-economic model, a physical production index such as the FRB index is required. These are rendered into equivalent dollar-denominated sales projections (which grow at approximately the same rate as GNP) for use in ORIM. The difference in growth rates arises from the differences in definition of the outputs but does not affect electricity demand projections since both models are calibrated to the appropriate output measures.

TABLE 4-1
Base Case Economic Projections

	HISTORY				TRENDLONG2007A				
	1960- 1965	1965- 1970	1970- 1975	1975- 1980	1980- 1985	1985- 1990	1990- 1995	1995- 2000	2000- 2007
Composition of Real GNP - Average Annual Rates of Change									
Gross National Product	4.7	3.2	2.8	3.7	2.5	3.1	2.4	2.3	2.4
Final Sales	4.6	3.3	2.8	3.6	2.3	3.1	2.4	2.3	2.4
Total Consumption	4.3	3.8	3.0	3.7	2.7	2.9	2.4	2.2	2.2
Nonres. Fixed Investment	7.8	3.2	0.9	5.8	3.3	4.6	3.0	3.2	3.2
Equipment	8.7	4.3	3.0	6.3	3.9	4.9	3.4	3.7	3.6
Nonres. Construction	6.6	1.6	-2.7	4.8	2.0	3.9	2.1	1.9	2.0
Res. Fixed Investment	4.5	-1.1	0.4	2.6	6.2	1.9	-0.2	1.3	2.1
Exports	6.1	6.4	8.0	9.2	2.5	4.5	4.5	4.2	4.2
Imports	6.3	9.8	1.4	8.9	5.2	4.9	4.2	4.2	4.1
Federal Government	2.1	2.0	-2.5	2.1	2.4	2.5	1.8	1.8	1.8
State and Local	5.8	5.1	3.8	1.4	-0.5	3.0	2.3	2.0	1.8
Shares of Nominal GNP (Percent)									
Consumption	62.9	61.7	62.1	63.0	63.5	62.2	62.0	61.9	61.3
Business Investment	9.5	10.6	10.4	11.0	11.3	12.4	12.7	12.9	13.0
Residential Construction	4.7	3.7	4.4	4.5	4.1	5.0	4.7	4.6	4.8
Government Purchases	20.5	22.1	21.3	20.3	19.8	19.4	19.7	20.0	20.1
Prices and Wages - Average Annual Rates of Change									
Implicit Price Deflator	1.6	4.2	6.5	7.2	7.5	6.7	5.9	5.7	5.7
CPI - All Urban Consumers	1.3	4.3	6.7	8.9	7.5	7.1	6.4	6.3	6.3
Wholesale Price Index	11.4	2.7	9.6	9.0	7.6	7.5	6.0	5.5	5.6
Compensation per Hour	3.7	6.5	7.9	8.8	8.6	8.5	7.9	7.5	7.5
Production and Other Key Measures									
Industrial Production (Avg. %Ch)	6.3	3.7	1.8	4.5	3.3	3.6	3.0	2.9	3.2
Housing Starts (Mil. Units)	1.5	1.4	1.8	1.7	1.4	1.9	1.7	1.6	1.7
Retail Car Sales (Mil. Units)	7.6	9.0	10.0	10.4	9.7	11.6	12.4	12.7	12.9
Unemployment Rate (%)	5.5	3.9	6.1	6.8	8.1	6.7	6.5	6.4	6.4
Federal Budget Surplus (NIA)	-2.1	-5.0	-25.0	-41.0	-111.1	-93.5	-70.7	-58.3	-47.9
Money and Interest Rates									
Money Supply (M-1) (Avg. %Ch)	3.1	5.0	6.1	6.5	-0.2	1.0	2.4	3.5	3.8
New AA Corp. Utility Rate (%)	4.5	6.9	8.4	9.9	14.0	11.9	10.6	9.9	9.8
New High-Grade Corp. Bond Rate (%)	4.4	6.8	8.0	9.5	13.2	11.4	10.2	9.5	9.4
Federal Funds Rate (%)	3.1	6.1	6.8	8.6	12.9	10.0	8.2	8.0	7.9
Prime Rate (%)	4.5	6.7	7.5	10.1	15.1	11.7	9.9	9.3	9.2

TABLE 4-2

BASE CASE PRODUCTION INDICES BY SIC PROJECTED TO 2000
(Dimensionless)

Industry	1980	1985	1990	1995	2000
Crops	1.083	0.962	1.092	1.204	1.327
Livestock	1.076	0.962	1.092	1.204	1.327
Nonenergy Mining	1.167	1.236	1.518	1.736	1.955
Energy Mining	1.070	1.155	1.111	1.071	1.050
Construction	1.256	1.239	1.296	1.315	1.345
Food and Products	1.128	1.256	1.398	1.539	1.696
Tobacco Products	1.026	1.065	1.119	1.168	1.263
Textile Mill Products	1.030	1.060	1.230	1.335	1.449
Apparel and Products	1.008	1.014	1.140	1.205	1.286
Lumber & Wood Products	0.967	1.163	1.292	1.327	1.437
Furniture & Fixtures	1.095	1.309	1.613	1.850	2.109
Paper and Products	1.135	1.298	1.472	1.659	1.870
Printing and Publishing	1.138	1.240	1.437	1.632	1.837
Chemicals and Products	1.211	1.467	1.825	2.196	2.598
Petroleum Products	1.993	0.908	0.934	0.966	1.017
Rubber and Plastic Products	1.280	1.816	2.311	2.827	3.399
Leather and Products	0.909	0.868	0.935	0.916	0.826
Stone, Clay, and Glass	1.088	1.278	1.526	1.717	1.952
Steel	0.928	1.092	1.217	1.292	1.388
Aluminum	0.928	1.080	1.253	1.403	1.554
Other Primary Metals	0.927	1.059	1.200	1.302	1.415
Fabricated Metal Products	1.081	1.277	1.527	1.773	2.051
Nonelectric Machinery	1.207	1.516	1.941	2.393	2.925
Electrical Machinery	1.281	1.620	2.067	2.573	3.168
Transportation Equipment	1.006	1.332	1.617	1.890	2.204
Instruments	1.163	1.365	1.712	2.054	2.463
Miscellaneous Manufacturing	1.021	1.079	1.288	1.464	1.599
Total Production	1.098	1.321	1.573	1.819	2.100

Note: Using 1976 as a base set at 1.0 for all industries. Derived from DRI Trendlong 2007A, Spring, 1982.

For fuel prices used in the base case we selected the Low World Oil Price Projection from the Energy Information Administration's 1981 Annual Report to Congress. In this projection the real price of oil drops to \$26/barrel in 1985 and then rises to \$49 by 1995. The world oil price trajectory is shown in Table 4-3.

TABLE 4-3
World Oil Prices in EIA Low Scenario

Year	1980\$/bbl
1981	34
1985	26
1990	35
1995	49
2000	56

Source: 1981 EIA Annual Report to Congress

These prices reflect current consensus that the world oil market will be relatively soft in the 1980's, but that in real terms prices will rise during 1990's. Prices for fuels other than oil reflect EIA's detailed analyses of resource availability and infrastructure costs, as well as continuation of current federal laws affecting energy prices. The specific price projections used are summarized in Table 4-4. Since the Mid-Term Energy Forecasting System is used only for projections through 1995, these trends are extrapolated through 2000 for purposes of this analysis.

The capital charge rates used in both models was 15 percent in real terms. In ISTUM2 the lifetime of a technology is equipment specific, while in ORIM an average life is used.

TABLE 4-4

Industrial Electricity Prices

1980 \$/10⁶ Btus

	1985										
	Region										
	1	2	3	4	5	6	7	8	9	10	U.S.
INDUSTRIAL ***	7.40	6.30	4.60	6.14	9.16	9.67	9.70	4.25	8.10	4.07	9.90
(ELECT.)	15.01	13.06	11.36	11.05	11.60	14.34	13.73	7.42	15.60	4.42	11.69
(DIST.)	6.20	6.30	6.10	6.29	5.71	9.65	9.62	5.90	5.91	5.91	5.89
(RESID.)	5.01	5.24	5.45	4.93	4.98	5.01	5.03	4.70	4.81	4.91	5.07
(LGI)	4.91	5.00	5.20	5.46	4.99	5.01	4.84	5.09	4.17	4.17	4.98
(COAL)	7.24	2.31	1.95	2.67	2.02	2.45	1.73	1.27	2.65	2.03	2.09
(NET COAL**)	3.22	2.79	2.44	2.92	2.81	3.26	2.96	3.41	4.34	4.62	2.76
(FEEDSTOCKS)	5.81	5.79	5.70	5.76	5.68	5.70	5.65	5.65	5.57	5.57	5.71
(NON-FUEL NG)	5.04	4.85	4.16	3.68	4.04	3.70	3.27	3.17	4.57	3.99	3.74
(FUEL NG)	5.04	4.59	5.10	4.59	4.63	3.79	4.49	3.19	4.62	4.09	4.10
(SUBSTITUTE FUEL CAP)	4.46	4.69	4.99	4.39	4.42	4.45	4.47	4.23	4.75	4.35	4.44
(INDUSTRIAL SURCHARGE)		.13	.05	.71	.59		1.41	.01	.05	.11	.37

	1990										
INDUSTRIAL***	9.17	7.44	5.26	7.36	6.71	7.44	6.26	4.62	9.34	6.14	6.71
(ELECT.)	17.12	12.55	11.74	11.71	11.64	15.61	11.74	6.43	16.34	5.54	12.70
(DIST.)	8.26	8.30	8.15	8.30	7.72	7.66	7.63	8.39	7.82	7.43	7.80
(RESID.)	6.45	6.71	6.52	6.41	6.45	6.45	6.51	6.35	6.18	6.28	6.53
(LG)	6.56	6.65	6.92	7.00	6.61	6.63	6.46	6.70	5.83	5.83	6.61
(COAL)	2.39	2.46	2.08	3.05	2.19	2.73	1.87	1.34	2.95	2.16	2.29
(NET COAL**)	3.45	2.58	2.62	2.13	2.99	3.47	3.62	3.64	4.61	4.98	2.95
(FEEDSTOCKS)	7.55	7.82	7.82	7.81	7.72	7.76	7.70	7.78	7.52	7.52	7.75
(NON-FUEL NG)	6.05	6.45	5.85	5.45	5.77	4.55	5.11	4.80	6.32	5.55	5.41
(FUEL NG)	6.05	6.49	6.35	5.89	5.94	4.99	5.59	5.84	6.32	5.77	5.59
(SUBSTITUTE FUEL CAP)	5.99	6.21	6.42	5.91	5.95	5.98	6.01	5.85	5.68	5.70	5.96
(INDUSTRIAL SURCHARGE)		.05	.50	.42	.11		.69	1.04		.22	.19

TABLE 4-4 (Continued)

	1995										
	REGION										
	1	2	3	4	5	6	7	8	9	10	U.S.
INDUSTRIAL...	11.41	9.22	6.11	8.99	7.00	9.12	7.28	9.89	14.32	7.60	9.19
ELECT.	19.31	14.32	12.71	13.14	12.37	15.45	12.71	5.72	17.84	6.90	12.84
CEMENT	29.74	10.76	10.67	10.78	10.29	10.13	10.11	12.59	10.19	10.19	10.34
STEEL	6.66	5.05	5.31	6.75	6.64	6.67	6.65	6.76	6.44	6.54	6.50
IRON	8.94	9.02	9.32	9.41	9.02	9.54	8.27	9.42	8.24	8.20	9.12
COAL	2.59	2.42	2.24	1.43	2.31	3.24	1.96	1.43	3.24	2.37	2.52
WET COAL...	3.42	3.15	1.76	3.42	3.22	3.41	3.29	3.40	3.16	3.52	3.17
WET COAL...	10.61	10.55	10.55	10.57	10.48	10.51	10.46	10.56	10.12	10.15	10.50
IRON-STEEL...	8.59	8.42	7.51	7.15	7.41	6.11	6.75	6.57	8.19	7.27	7.59
STEEL...	6.66	6.76	6.00	6.49	6.53	6.60	6.59	6.57	8.26	6.29	7.58
SUBSTITUTE FUEL...	6.33	6.55	6.77	6.76	6.30	6.32	6.24	6.22	7.90	8.00	8.36
INDUSTRIAL SURCHARGE	0.17	0.24	0.42	1.39	1.12		1.64	0.00	0.06	1.03	0.55

Source: Energy Information Administration, 1981 Annual Report to Congress, Vol 3.

Model Results for the Base Case

Using the base case assumptions ISTUM2 projected electricity demand to be 4.62 quads by the year 2000 implying a growth rate of 2.59 percent annually between 1980 and 2000. With these same assumptions, ORIM projects a consumption of 5.58 quads of electricity by the industrial sector in the year 2000, or a growth rate of 3.26 percent annually in electricity sales. These projections are shown in Table 4-5 and Figure 4-2.

The reason for the differences between the two models is not hard to find. ORIM is an econometric model and relies among other things, on the historical relationship of energy to GNP as the basis of its forecasting. Given the historical relationship between GNP and electricity growth, it is not surprising that ORIM projects a relatively high growth rate for electricity sales. ISTUM2 is structured so as to be independent of the historical relationship between GNP growth and electricity. It is a technology based model and chooses the most appropriate technology (from a point of view of front-end cost, life-cycle efficiency, and reliability), that will perform the needed technological function. For example, in an industry where electricity use has been growing faster than production, ISTUM2 would ignore that trend if a cheaper substitute technology became available. ISTUM2 is also sensitive to product mix changes which as discussed in the next section can significantly influence demand.

The historical relationship of GNP growth to industrial electricity growth as well as ISTUM2 and ORIM's projections to the year 2000 are presented in Figure 4-3 and Table 4-6. While real GNP is growing at an annual rate of 2.5 percent between 1980 and 2000, ORIM and ISTUM2 project electricity growth at 3.3 percent and 2.6 percent respectively. Thus ORIM projects that the ratio between electricity growth and the economic growth in the eighties corresponds closely to the 1973-1980 experience, before returning to the higher ratio of the pre-1973 period. However, ISTUM2 projects a further decline in this ratio in the 1980s, followed by increases in the 1990s to a ratio close to the pre-1973 level.

FIGURE 4-2
Base Case Industrial Electricity Demand to 2000

TABLE 4-5

Industrial Electricity Demand - 1976 to 2000 (Quads)

	1976	1980	1985	1990	1995	2000
ISTUM-2	2.59	2.77	2.97	3.36	3.76	4.62
ORIM	2.59	2.94	3.28	3.88	4.59	5.58
Difference (Percent)	-	6	10	15	22	21

Note: The definition of the industrial sector is all manufacturing, mining, agriculture, and construction.

Interestingly, ORIM projected electricity demand in 1980 to be higher than the actual sales (as reported by EIA) and ISTUM2 projected demand almost on target.

ISTUM2 has a higher level of disaggregation than ORIM and for comparison we aggregated ISTUM2 sectors to fit the ORIM categories. The results for the year 2000 are shown in Table 4-7.

FIGURE 4-3.

Electricity Growth vs. Real GNP Growth
(Using 1960 as Base = 100)

TABLE 4-6

Actual and Projected Levels of Real GNP and Electricity Demand

	Real GNP (Trillions of 1978\$)	Purchased Electricity (Trillions of Btus)		
		Actual	ISTUM2	ORIM
1960	1.12	1.11	-	-
1965	1.41	1.46	-	-
1970	1.63	1.95	-	-
1975	1.81	2.35	-	-
1980	2.17	2.78	2.77	2.94
1985	2.53	-	2.97	3.28
1990	2.86	-	3.36	3.88
1995	3.19	-	3.76	4.59
2000	3.55	-	4.62	5.58

**Aggregate Relationships of Industrial Electricity
Growth to GNP Growth
(Annual Percentage Growth)**

	1951- 1973	1973- 1980	1980- 1990	1990- 2000
Economic Growth (Annual Percentage Growth)	3.6	2.4	2.8	2.2
Electricity Growth				
Actual	6.7	2.5		
ISTUM2			1.9	3.2
ORIM			2.8	3.7
Ratio				
Actual	1.9	1.0		
ISTUM2			0.7	1.5
ORIM			1.0	1.7

Source: Energy Information Administration, Monthly Energy Review, various issues and Model Results

TABLE 4-7

Comparison of ISTUM2 and ORIM Projections by Industry (2000)

Industry	ISTUM2 (Trillion Btus)	ORIM	Difference	
			Amount	Percent
Food	276	333	57	21
Paper	325	348	23	7
Stone, Clay & Glass	144	248	104	72
Iron & Steel	343	530	187	55
Other Metals	749	740	-9	-1
Chemicals and Misc.	1418	2016	598	42
Durable Manufacturing	964	1060	96	10
Total Manufacturing	4220	5275	1055	25
Agriculture, Mining & Constr.	400	400	-	-
Total Industrial	4620	5680	1060	23

Source: ISTUM-2 and ORIM Results

The major portion of the differences in the model projections occur in the highly electricity intensive industries: Chemicals and Misc., Iron and Steel, and Stone, Clay and Glass industries. These differences are partially explained by the developments taking place within each of these industries - developments that will directly change the amount of electricity consumed and will cause a change in the ratio of electricity use to output. In the chemicals industry, for example, the reduction in electricity use is principally a result of a shift in product mix within the industry and process change. ORIM does not explicitly capture product changes or technological innovations, and, to the extent such changes and innovations are important, ORIM will project a higher demand for electricity than ISTUM2. ORIM's generalized production function models technological change as a function of time whereas ISTUM2 incorporates specific technologies. ORIM tends to adjust more slowly than ISTUM2 in adjusting to changing circumstances. Critical factors that influence the overall level of electricity demand are discussed in greater detail below.

ISTUM2 Results by Industry

In this section we summarize ISTUM2's results for the five largest electricity-consuming industries and discuss the impact of the various factors affecting electricity demand within each industry. (ORIM was not suitable for this purpose because it uses an econometric approach and does not formally differentiate between the factors being studied here.) For each of the five industries, our analysis consists of:

- o a comparison of the growth in purchased electricity to growth in industrial output and growth in demand to other fuels
- o an examination of cogeneration and its contribution to reduced electricity demand
- o the impact of specific efficiency technologies such as high-efficiency motors and motor controls
- o the impact of process change (the use of entirely new methods for producing existing products)

As discussed earlier, industrial electricity growth in the aggregate is projected to be lower than real GNP growth. From a detailed examination of the five most electricity intensive industries, the broad conclusions are:

- o efficiency technologies - the reduction of electricity required per unit of service demand through technological change - has little effect on total demand.
- o cogeneration contributes little to overall reduction in electricity demand
- o product shift at the 4-digit SIC level is an important factor in the chemicals industry
- o process change is the only factor that increases electricity use but its effect is small compared to the others
- o electricity growth in these industries relative to production is higher in the 1985-2000 period than it is in the 1980-1985 period

The trends in the other industries are similar to those in the most electricity-intensive industries. Electricity intensity does not change dramatically in any of these industries.

The Effect of Changes in Specific Factors Affecting Electricity Demand

The base case projections of industrial electricity demand for both ORIM and ISTUM2 incorporate a particular scenario of overall economic growth, a specific mix of products demanded and a certain level of energy prices. The level as well as the relative price of fuels affects the degree and type of efficiency improvements incorporated, and the level of cogeneration employed. Process change and process controls are more complex factors since they are driven by both prices and the products demanded.

Because all these factors affect the amount of electricity that will be required, we constructed several sensitivity cases using the ISTUM2 base case.¹ The purpose of these sensitivity tests was to determine the effect on electricity demand of significant changes in these factors. We discuss the effect of product mix, efficient technology, process change, process controls, and cogeneration on industrial electricity demand. For the reasons discussed in Chapter 1, we did not include energy management techniques in our base line projections (see p. 1-9).

Product Mix

In the base case the DRI Trendlong 2007A scenario implicitly incorporates a product mix distribution among the industries, and if the mix of products demanded in the year 2000 is different from the base case, the amount of electricity required would be correspondingly lower or higher. It would be lower or higher depending on whether the actual products demanded were less electric-intensive than the average in their manufacturing process, and higher if they were more electric-intensive.

In order to bound the uncertainty inherent in the product mix question and test the extent to which the DRI projected mix influences electricity demand, two sensitivities were tested. In the first, the product mix was set to be identical to that which actually prevailed in 1980. The purpose of this case was to ascertain what the level of electricity demand would be if industrial output composition in the year 2000 was identical to that in 1980 (though larger in size).

In the second sensitivity case, we assumed no growth in the output of the two most electric-intensive industries, chemicals and aluminum. That is, we assumed that the 1980 output level for these two industries would remain constant to the year 2000. We also held the overall GNP growth at the same level as in the base case: i.e., the rest of the economy grew at a much faster rate than in the base case to compensate for the zero-growth in the chemicals and aluminum industries. The results of these scenarios are shown in Tables 4-8 and 4-9 and illustrated in aggregate in Figure 4-4.

1 ORIM does not lend itself to this kind of analysis because it does not formally differentiate between these three factors in its aggregate projection of energy demand.

TABLE 4-8

Electricity Consumption in 2000 for 1980 Product Mix Case
(ISTUM2 Projection)

Industry (2-digit SIC)	Base Case	Sensitivity Case	Change	Percent Change
	-----Trillions Btus-----			
Paper	325	362	37	11
Chemicals	743	974	231	31
Iron and Steel	343	461	118	34
Crops	105	105	--	--
Non-En. Mining	135	145	10	7
Food	276	325	49	18
Textiles	142	177	35	25
Lumber and Wood	89	108	19	21
Rubber and Plastic	204	153	-51	-25
Stone, Clay and Glass	144	146	2	1
Aluminum	547	669	122	22
Other Primary Metals	202	253	51	25
Fabricated Metals	173	170	-3	-2
Nonelectrical Machinery	319	255	-64	-20
Electrical Machinery	294	227	-67	-23
Transportation Equipment	178	153	-25	-14
All Others	400	400	--	--
Total	4620	5083	463	10

Notes: 1) Growth of total production (and GNP) is the same in both of the above cases.

2) The Base Case is derived from DRI Trendlong 2007A, Spring 1982.

TABLE 4-9

Electricity Consumption in 2000 for No Growth in Chemicals and Aluminum (Trillion Btu)
Derived from (ISTUM2 Projection)

Industry (2-digit SIC)	Base Case	No Growth Chems/ Aluminum	Change	Percent Change
Paper	325	346	21	6.5
Chemicals	743	667	-76	-10.2
Iron and Steel	343	367	24	7.0
Crops	105	113	8	7.6
Non-Energy Mining	135	145	10	7.4
Food	276	294	18	6.5
Textiles	142	152	10	7.0
Lumber & Wood	89	96	7	7.0
Rubber and Plastics	204	219	15	7.4
Stone, Clay, and Glass	144	155	11	7.6
Aluminum	547	321	-226	-41.3
Other Primary Metals	202	217	12	5.9
Fabricated Metals	173	186	13	7.5
Non-Electrical Machinery	319	342	23	7.2
Electrical Machinery	294	315	21	7.1
Transportation Equipment	178	191	13	7.3
All Others	400	431	31	7.8
TOTAL	4620	4557	-63	-1.4

Notes: 1) The growth of total production (and GNP) is the same in both of the above cases. Production in chemicals and Aluminum is kept at 1980 levels.

2) Base Case derived from DRI Trendlong 2007A, Spring 1972

FIGURE 4-4

Sensitivity of Electricity Demand to Product Mix
In ISTUM2 Projection

Case 1: Product Mix Identical to 1980

Case 2: No Growth in Chemicals and Aluminum Industry from 1980 level of production

Significantly, if the 1980 mix of products were produced in the year 2000, the resultant electricity demanded would be 10 percent higher than the base case. We thus see that the broad trends in the economy - apart from detailed changes within an industry as discussed earlier in connection with chemicals - are tending to produce a less electricity intensive industrial base.

In the second product mix sensitivity case, total industrial electricity demand is projected to be 4,557 trillion Btu or about 1.4 percent lower than the base case. This underscores the fact that if chemicals and the aluminum industry grew more slowly than forecast in the base case, as long as other industries grew faster (so as to keep GNP the same as the base case), the total amount of electricity demanded would not be appreciably affected. However, if the other industries did not grow faster, and GNP was lower than the base case, the growth of industrial electricity would drop to an annual rate of 2.24 percent.

Summarizing product mix's effect on the rate of electricity growth, we find that in the first sensitivity case electricity growth would have been at an annual rate of 3.08 percent as compared to 2.59 percent in the base case over the period 1980-2000. Thus, the effect of projected shifts in product mix reduced electricity growth by about one half of one percent annually.

While ISTUM2 was used for these sensitivity cases, we believe that ORIM would lead to comparable results and conclusions.

Energy Efficiency

The terms efficiency, conservation, and productivity have often been used in energy analysis and almost always stir debate if they are not explicitly defined. Efficiency, as used here, refers to the relationship between amount of energy used and a given amount of service or work (such as shaft power or maintaining a voltage between electrodes). Improvements in efficiency come from performing work by employing equipment that requires less energy. Included in efficiency are such improvements as: high-efficiency motors, and variable speed and power factor controls. In this analysis we have not included such measures as manual shut-off of pumps, motors, lights and other electrical equipment in this category, which are not hardware related technical improvements. The use of thermostats and other measuring equipment are also not included in our general category of efficiency improvements. We also do not include such things as new processes that produce the same products but use less energy than a conventional process (covered under Process Change) or cogeneration.

The overall impact of improvements in efficiency is summarized in Table 4-10. In the table, the impact of efficiency improvements on electricity demand is measured relative to the 1976 level. If no efficiency improvements beyond the 1976 level of technology were implemented by 2000, the demand for electricity would have been higher by 82 trillion Btu. The penetration into the market by efficiency technologies and methods has therefore served to reduce the industrial demand for electricity by 2 percent.

TABLE 4-10

The Impact of Efficiency Improvements on Electricity Demand
(ISTUM2 Projection)

	1976 (trillion Btu)	2000
Base Case (with efficiency improvements)	2590	4620
Base Case (efficiency held at 1976 level)	-	4702
Savings due to Efficiency	-	82
Percent Change in Demand	-	2

Process Change

Process change refers to the use of entirely new methods for producing existing products. With technological innovation continually taking place, new processes gradually replace existing methods of production. Process changes often evolve as a result of the need to change the raw materials used in a process. For example, in the steel industry the electric arc furnace is preferred when making steel from scrap. At other times the need for process change arises because the market for by-products or intermediate products changes dramatically, a not infrequent phenomenon in the chemicals industry.

In this analysis we studied process changes in the chemicals, iron and steel, aluminum, and paper industries. The overall impact of process change in these industries in terms of its effect on the future demand for electricity is summarized in Table 4-11.

TABLE 4-11

The Impact of Process Changes on Purchased Electricity Demand
(ISTUM2 Projection)

	1976 (trillions Btu)	2000
Base Case Demand	2590	4620
Base Case Without Process Change	-	4603
Increase as a Result of Process Change	-	17

Process change, as the table shows has the net effect of increasing the demand for electricity in 2000. In the forecast, the demand for electricity is higher by 17 trillion Btu because of the penetration of electricity-using technologies.

Process Controls

One specialized technology which is gaining increased attention as a factor affecting electricity demand is computer based process controls. In process industries, raw materials such as ore or chemical feedstocks are transformed in a series of manufacturing steps which result in a finished product such as steel, paper, or ammonia. This is illustrated in the Figure 4-5. Possible the most important single productivity improvement in these industries is the implementation of computer-based process control systems.

The role of the sensor in the process control system, illustrated in Figure 4-5, is to sense a physical property of the product stream such as temperature, flow rate, acidity, or moisture content. The sensor's measurement is converted into an electronic or pneumatic signal which is sent to a computerized controller subject to operator supervision and override. That controller compares current conditions in the process stream to desired conditions and then adjusts the process operations through means such as modifying flow rates or chemical composition of process inputs. In addition to the simple feedback relationship shown here, elaborate feedforward and multiple input functional relationships are possible.

FIGURE 4-5
Schematic For Industrial Process Control System

With these decision making systems (which can number in the thousands in a complex plant) monitoring results and adjusting plant operations, a plant process control system can maintain product quality and reduce the use of expensive energy and raw materials. The savings from such systems are often enormous relative to their costs.

In a modern plant, the cost of controls ranges from 6 percent to 15 percent of capital cost, depending upon the complexity of the plant. To date, the industries which have made the most use of advanced process controls are the chemical and petroleum refining industries. These industries purchased \$1.2 billion and \$850 million worth of controls respectively in 1981. These sales have grown at annual rate of 5 to 8 percent, but are expected to slow somewhat in the near future. Greater demand for new control equipment will come from the rubber, plastics and textile industries whose purchases are expected to grow in the 10 to 12 percent range annually through 1985. Process control purchases by industry are summarized in Appendix B.

Within these industry markets, the component mix of process control sales is going to evolve even more dramatically over the next few years. The bulk of the current market is for measurement, display, and control instruments. Valves and related actuating devices are the second largest category of products, while the programmable controllers represent the third segment. However, the dramatic growth segment of this industry is the programmable controllers, which are increasingly replacing the human operators who heretofore monitored and adjusted routine plant processes with the use of instruments and control devices. Although programmable controllers represented about 6 percent of the industry's 1981 sales, they have five times the growth rate of other product lines. These markets are particularly attractive in the current economic climate because the systems can be installed in existing plants at comparatively low capital cost to produce prompt savings.

Assessing the impact on electricity demand of process control instruments is difficult because these installations are not generally motivated by energy considerations. As yet we have found no empirically based calculation or case studies of the impact of these systems on electricity demand. Our conclusions were reached through an informal but systematic telephone survey of several classes of experts in process controls, in which empirical evidence or case studies were requested. The results are shown in Table 4-12.

TABLE 4-12

Impact of Process Controls on Purchased Electricity Demand (Survey Results)

	1976 (trillion Btu)	2000
Base Case Projection	2590	4620
Electricity Savings due to Process Controls	-	42
Percent Change in Electricity Demand		1

The categories of people surveyed were:

- o Academic Researchers
- o Sales/Engineering Executives of Process Control Manufacturers
- o Technical Society Officials
- o Process Industry Trade Association
- o Government Project Officers

The survey revealed no case studies which could provide a significant empirical basis for a quantitative estimate of the effects of improved controls on electricity demand. Very general engineering estimates of the effects of process controls on major processes showed that of the results obtained from process controls, energy savings were perhaps the least important. Increased process stability was the most important impact, followed by increased production. Energy savings were third, followed by increased yield. The range and average percentage improvements for each factor are shown in Appendix B.

These overall estimates must be interpreted with care as they include all computer control applications. These applications typically occur at three levels: in controlling energy conversion technologies (e.g., power factor controllers for electric motors or combustion controllers for boilers); in controlling flow and composition in major process steps; and in co-ordination between process steps in the plant.

Cogeneration

The use of the term cogeneration here applies to the various means by which electricity is generated on-site by a manufacturing firm. Cogeneration is not a new concept or technology and has been practiced by industrial firms in this country since the turn of the century. In fact, in 1950 almost 15 percent of the nation's electricity was generated by industrial plants. Recently, cogeneration has received a lot of attention as a way of cutting overall energy use in a plant where both electricity and steam are required.

As discussed in Appendix A on industry specific results, the impact of cogeneration is very small under the scenarios run in this analysis. The overall impact in the industrial sector from summing up the industries studied is shown in Table 4-13.

In the table, electricity demand is shown for the base case and for an identical case with just cogeneration technologies backed out to their 1976 levels. The effect of cogeneration technologies in the 1980-2000 period is to reduce electricity demand by 88 trillion Btu, or a reduction of about 2 percent.

TABLE 4-13
The Impact of Cogeneration on Purchased Electricity Demand
(ISTUM2 Projection)

	1976	2000
	(trillion Btu)	
Base Case with Cogeneration	2590	4620
Base Case with Cogeneration at 1976 levels	-	4708
Savings Due to Cogeneration	-	88
Percent Change in Demand	-	2

Sensitivity to Electricity Prices

As with any commodity, the price of electricity will influence the level of future demand. The issue of importance is whether industrial decision makers expect a higher future electricity price relative to other fuels. If they do, they are likely to either substitute electricity-using technologies with fossil fuel based technologies where that is feasible and cheaper in the long run, or implement more advanced efficiency technologies, both of which will reduce the overall demand for electricity. On the other hand, if decision makers are expecting much lower relative prices for electricity, electricity use is likely to go up.

In order to test the sensitivity of electricity demand to the expected price trajectory of electricity prices, two cases were run using the Oak Ridge Industrial Model (ORIM)¹. In the first case, the price trajectory of electricity was increased by 20 percent over the base case trajectory of prices. In the second case expected future prices were reduced by 20 percent. The base case price scenario for electricity and for the two sensitivity cases are shown in Table 4-14. In both the cases, the prices of other fuels were kept at their base case levels.

¹ ORIM was selected rather than ISTUM2 for this sensitivity analysis because econometric formulations of industrial energy use are designed with price sensitivity as a major focus, and because of the ease of conducting this test from a programming point of view. We would expect ISTUM2 sensitivity relative to its base case to be comparable.

TABLE 4-14
Range of Electricity Prices Used in ORIM Sensitivities

	1985	1990	1995	2000
Base Case	11.69	12.08	12.88	13.52
High Price	14.03	14.50	15.46	16.22
Low Price	9.35	9.66	10.30	10.82

Note: All prices are shown in 1980\$/Million Btu

The results obtained by running ORIM are shown in Figure 4-6. The demand for electricity in 2000 in the base case was 5.58 quadrillion Btu implying a growth rate in electricity sales of 3.3 percent annually in the period 1980-2000. In the high electricity price scenario, the demand for electricity is projected to drop to 5.35 quadrillion Btu, which translates into a growth rate for electricity of 3.0 percent annually between 1980 and 2000. In the low price scenario, electricity demand is projected to increase to 5.74 quadrillion Btu with the corresponding growth rate being 3.4 percent.

The impact of even a 20 percent change from the price projection used affects electricity demand less than changes in the industrial product-mix.

Summary and Conclusions

The impact of these factors on the aggregate demand for purchased electricity in the industrial sector is summarized in Table 4-15, and in Figure 4-7.

The figure illustrates that product mix changes are the most important factors affecting electricity demand. The shift from the current mix of products to a less energy intensive mix is projected to cut consumption by 464 trillion Btu.

TABLE 4-15
Summary of Factors Affecting Electricity Demand In ISTUM Projections
(ISTUM2 Projection)

	1976 (trillion Btu)	2000
ISTUM Base Case Projection	2590	4620
<u>Savings in Base Case Due to Factor</u>		
Energy Efficiency	-	82
Product Change	-	464
Cogeneration	-	88
Process Controls	-	42
Process Change*	-	-17

* The negative sign is due to the fact that process change increases electricity use.

Of the other factors, cogeneration is projected to cut the demand for purchased electricity by 88 trillion Btu, and process controls could reduce demand by up to 42 trillion Btu. While not insignificant, these quantities have only a small impact on overall electricity demand in comparison to the effect exerted by product changes.

Several important conclusions can be drawn from this analysis. The most significant of these, in our opinion, is that the rate of growth in industrial electricity consumption, both in absolute terms and relative to the growth of GNP, is likely to be lower than we have seen historically. In the 1960s, industrial electricity sales grew at an annual rate of 5.8 percent compared to real annual GNP growth of 3.9 percent. Electricity was growing almost 50 percent faster than GNP. After the oil embargo in 1973, however, energy markets changed dramatically and industrial electricity growth between 1973 and 1980 slowed to a growth of 2.5 percent annually compared to a 2.4 percent growth in real GNP. Even more striking is a trend that has emerged since 1976. Between 1976 and 1980, industrial electricity growth fell below real GNP growth and grew at a rate of only 60 percent of the growth rate of real GNP. These trends are illustrated in Figure 4.7.

The primary reason for the trend that has been exhibited since 1976 is the slowdown in growth in the electric-intensive industries in this period.

In our analysis, of the two models used, the Oak Ridge Industrial Model (ORIM) projects industrial electricity growing at 3.3 percent annually compared to annual real GNP growth of 2.5 percent between 1980 and the year 2000. However, the rate of growth in those two decades is not uniform. Between 1980 and 1990, ORIM projects growth to be 2.8 percent annually which is exactly the

projected rate of real GNP growth in that period. In the subsequent period, 1990-2000, the annual rate of growth projected by ORIM accelerates to 3.7 percent or 1.7 times the rate of growth of real GNP (which is projected to grow at 2.2 percent annually in this period).

The ISTUM2 results contrast somewhat with the ORIM results. The ISTUM2 projection for overall industrial electricity growth between 1980 and the year 2000 is 2.6 percent, which is slightly higher than the projected rate of growth of real GNP. Again, the trend projected for the 1980s is different from that for the 1990s. In the period 1980-1990, the ISTUM electricity growth rate projected is only 0.7 times as much as real GNP growth. Between 1990 and the year 2000 however, the rate accelerates considerably and the model projects growth of 3.3 percent annually, or 1.5 times the rate of growth of real GNP.

The purpose of this analysis was to analyze the future significance of factors affecting future industrial electricity demand. We identified the principal factors to be product mix and process change. Process controls, efficiency technologies, and the implementation of cogeneration were found to be of lesser importance. Our findings are summarized below:

- o Product mix significantly affects the demand for industrial electricity. The base case projects the economy moving towards a less energy intensive mix of products than is currently produced. If this shift did not take place, and the mix of products that is currently produced were actually demanded in the year 2000, the demand for purchased electricity could be higher by about 464 trillion Btu.
- o Technological innovation is widespread in industry and several new processes for manufacturing conventional products are likely to be used in the next twenty years. Many of these processes are more electricity intensive. Also these process changes in many industries are closely linked to product changes in the industry. However, our analysis indicates that process change will only increase the demand for electricity by about 17 trillion Btu. The major uncertainty in this estimate is the level of implementation of electric induction heating and plasma processes in both the iron and steel industry and all other primary metals. If these two technologies did gain significant market share (about 20 percent by the year 2000) electricity demand could be up by an additional 140 trillion Btu.
- o Cogeneration is only a minor factor affecting overall electricity demand. In the base case scenario, cogeneration technologies reduced the demand for grid electricity by only 88 trillion Btu.
- o New Process control technologies too are of little importance in their impact on electricity demand. These types of control systems are principally deployed in the chemicals, utility, primary metals and paper industry. However, they are used primarily to improve process stability, increase production and increase yield. Their potential for reducing electricity consumption is estimated to be about 42 trillion Btu.

FIGURE 4-6

ELECTRICITY PRICE SENSITIVITIES USING ORIM

FIGURE 4-7
GROWTH RATES OF REAL GNP AND ELECTRICITY, 1960-2000

Aggregate Relationships of Industrial Electricity
Growth to GNP Growth

	1951- 1973	1973- 1980	1980- 1990	1990- 2000
Economic Growth (Annual Percentage Growth)	3.6	2.4	2.8	2.2
Electricity Growth (Annual Percentage Growth)	6.7	2.5	1.9 (ISTUM2) 2.8 (ORIM)	3.2 (ISTUM2) 3.7 (ORIM)
Ratio	1.9	1.0	0.7 (ISTUM2) 1.0 (ORIM)	1.5 (ISTUM2) 1.7 (ORIM)

Source: Energy Information Administration, Monthly Energy Review, and Model Results.

In contrasting the projection of the two models used in this analysis, it must be noted that the intent is not to cast these as "high" and "low" projections of electricity growth rates. The two projections are entirely independent estimates using very different modeling techniques. Each of the models incorporates levels of risks and uncertainties. Every effort was made to run both the models on the same economic assumptions, but it is difficult to adjust the results for data uncertainties within each model. Therefore any attempt to average the results of the two models to arrive at a "best guess" is inappropriate.

However, it should be reiterated that the ORIM projection was 6 percent higher than actual electricity sales in 1980, and the ISTUM2 projection was almost on target. If one reduces the ORIM projection by 6 percent the projected electricity demand in the year 2000 would be 5.25 quadrillion Btu. The electricity growth rate for the 1980 to 2000 time period for ORIM would then be 3.2 percent per year.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The principal factors that affect industrial electric demand have been identified and discussed. In a review of forecasting methods and models, including ISTUM and ORIM and the models they are used with we find that most models do not deal directly with some important factors. Thus, there is considerable uncertainty in the forecasts produced with these models. Despite these shortcomings, it was possible to evaluate the sensitivity of the model results to several of the principal factors and to reach some overall conclusions about future growth of industrial electric demand.

The use of electric power per unit of output varies considerably across industry sectors, due primarily to the nature of products produced and the processes employed. Even within a given sector the electrical intensity of firms, and, therefore, of the industries to which they belong, varies, and often quite significantly. It is also the case that the industrial demand for electricity is probably the most difficult of the major sectors to analyze and forecast; the primary difficulties are the huge variety of products produced and the accompanying production technologies which vary not only across industries, but also over time with the progress of technological innovation. In addition, the proprietary nature of information at a detailed plant or product level poses problems not encountered in other sectors such as residential and transportation. One particularly difficult aspect of the problem of forecasting aggregate industrial electricity demand was dealt with by disaggregating to the 2-digit and, occasionally, to the 4-digit industry level to identify those factors causing industrial production to shift from one industry to another, from one product to another.

While several additional factors come to mind, four were explored in some detail:

- o international competition;
- o plant relocation -- domestic and international;
- o age structure of the population; and
- o intermediate product substitution.

Other factors, such as the effect of industrial capacity utilization on electricity demand, were explored, but in much less detail. Where possible, the discussion was quantitative. In some cases the discussion was, by necessity, more qualitative, exploring the nature, the structure, the mechanisms and the models that translate the above determinants into industrial electricity demand. We used two end-use, or industrial process, models to take into account macro-economic and interindustry projections of growth in industrial production at the two-digit level which combined with fuel price forecasts projected the growth rate in electricity demand for that industry. In addition, the qualitative part of the study suggested scenarios and interpretations for the quantitative re-

sults and the quantitative section forced some refinement and reformulations in the qualitative work.

In the remainder of this summary, we will discuss:

- o major findings;
- o major uncertainties;
- o the credibility of the projections;
- o short-comings of the analytic methods; and
- o future research.

Major Findings

In the United States, the growth in industrial demand for electricity has declined somewhat in recent years due to reduced economic growth, changes in the structure of GNP, and higher electric prices. Related to the lower economic growth and changes in the structure of GNP is the loss of markets to overseas producers including: the shift in the production of basic aluminum to bauxite rich countries with low-cost hydropower; the shift in the production of steel to countries with low-cost power, iron ore, and labor; and the shift in the production of basic chemical feedstocks to the oil-rich countries of the Persian Gulf. The demand for electricity to be used in the production of basic chemicals, steel, and aluminum will continue to fall as U.S. industry moves to the higher value added downstream fabrication operations, which are generally less energy intensive than primary production operations.

Other industries such as primary metals (other than iron and steel), petroleum refining, rubber and miscellaneous plastics represent a significant fraction of electricity demand; however, for these industries the cost and availability of raw materials and environmental restrictions determine the rate of growth in their output and, therefore, the industrial demand for electricity. The uncertain market prospects faced by steel and aluminum are due not only to international competition, but also to competition with other products such as plastics and composites in durable manufacturing.

Higher priced electricity in particular and energy in general are, to a large extent, responsible for the international relocation of the aluminum industry and for the iron and steel industry.

The use of industrial process models such as ISTUM2 and ORIM, in projecting industrial electricity demand allowed us to control for and assess the effects of various methods of improving electricity efficiency. For example, the ISTUM2 model, which incorporates most major efficiency improvements, forecasts industrial electricity demand to be 4.62 quadrillion Btu by the year 2000 implying an annual growth rate of approximately 2.59 percent between 1980 and the year 2000. ORIM, in contrast, projects industrial electricity demand to be 5.58 quadrillion Btu in the year 2000 for an annual growth rate over the same period of 3.4 percent, implying that other effects offset the impact of efficiency improvements.

Further, from a detailed examination of the four most electricity using industries we concluded:

- o The installation of electricity efficiency technologies were insignificant in reducing electricity requirements per unit of output;
- o Cogeneration contributed little to the overall reduction in electricity demand;
- o Product-mix shifts at the four-digit level were an important factor in chemicals and primary metals; and
- o Process change generally increased electricity use, but its effect was very small compared to other factors.

As an illustration of the sensitivity of industrial electricity demand to product mix changes in the future we constructed two scenarios and made projections using the ISTUM2 model. First, we assumed that the 1980 product mix was held constant and produced in the year 2000. Second, we assumed that the two most electricity intensive industries -- chemicals and aluminum -- did not grow at all over the period, but that growth rates in other, less energy intensive industries, increased to attain an equivalent GNP. Using the first of two scenarios we found that in the year 2000 a 1980 product mix will generate industrial electricity demand 10 percent higher than the ISTUM2 base case; and using the second of the two scenarios, holding chemicals and aluminum output constant, industrial electricity use falls 1.4 percent below the ISTUM2 base case in the year 2000. For the base case, the annual rate of growth in industrial electricity demand was 2.59 percent, with the assumption of constant chemicals and aluminum output having an insignificant affect on the annual growth rate of industrial electricity use.

Finally, another important result of the analysis is that industrial electricity growth is likely to increase by as little as 0.7 to 1.0 times the GNP growth rate during the 1980s. In the 1990s, industrial electric growth is likely to return to a more typical (historically) level of about 1.5 to 1.7 times the GNP growth rates. These findings have serious implications for long-term capacity expansion planning and public policy.

It is interesting to compare the specific baseline growth projections developed in this study with other current forecasts of total electric demand prepared by the National Electric Reliability Council (NERC), the Electric Power Research Institute (EPRI), and the Energy Information Administration (EIA), which indicate total electricity growth rates in the range of 1.04 to 1.32 times GNP up to 1990. (See Table 1-1.) The EIA forecasts of industrial electric demand fall in the range of 1.04 to 1.44 times GNP up to 1990, and the NERC, and EPRI forecasts of industrial demand, though unreported, are likely to fall in this range as well.

The analysis performed in this study produced two point estimates of industrial electric growth, corresponding to 0.7 and 1.0 times GNP growth. While the higher projection is within the range of other forecasts, the lower estimate is

outside of that range. Although the primary purpose of this analysis was to perform sensitivity analyses around a given point estimate to evaluate the potential influence of such major variables and uncertainties as changes in product mix, process change, and cogeneration, we did subject the lower growth projection to further analysis and interpretation.

In our judgment this lower estimate is significant and indicates a strong possibility that during the recovery period of the 1980s, industrial electric demand could grow by as little as 0.7 times GNP. The key difference between the two point estimates is the rate and extent to which efficiency improvements are adopted. A major factor that will influence this outcome is the pattern of capacity utilization and expansion during economic recovery. If the early stages of the recovery are rapid, there will be significant pressure to use existing idle capacity for production. Some of this capacity is quite inefficient and, in some cases, obsolete. If the pattern of recovery forces the use of this capacity, then electric demand is likely to grow in the higher range relative to GNP. If, on the other hand, the recovery is quite slow and gradual, producers may opt to expand the more efficient existing lines and to open up new capacity that is more efficient. Under these circumstances the growth rate of industrial electric demand could be as low as 0.7 times GNP in the 1980s. In the 1990s, the industrial electric growth rate is likely to return to more typical (historical) levels of 1.2 to 1.7 times GNP reflecting the continuing trend towards electrification of new manufacturing processes based on the high quality and controllability of electricity.

The possible range of electric growth rates that may occur in the 1980s has major implications for long term capacity expansion planning and public policy. To the extent possible, the key indicators that will determine the actual outcome have been identified and are discussed later in this section. These indicators should be watched closely and subjected to further interpretation and analysis as the economy recovers.

Major Uncertainties

As the analysis developed, we identified several major uncertainties, which we grouped as short-term and long-term uncertainties. In the short run the major problem is how changes in industrial capacity utilization and employment will affect industrial electricity demand. We do not have a good picture of how the industrial demand for electricity will change as various industries move from their current level of approximately 60 percent capacity utilization to about 90 percent during recovery. Normally, during a recovery industrial electric demand would grow at a less rapid rate than industrial output. Currently, however, undercapacity is rather heavily concentrated in the electricity intensive industries such as automobiles, steel, and aluminum. The behavior of industrial electricity demand in a recovery will depend on how these industries perform during the recovery and whether production is increased by opening plants now shut down or by opening new, more efficient, facilities.

In the long-term the domestic viability of the key electricity intensive industries dependent on low cost electricity or domestic feedstocks -- e.g., aluminum and petrochemicals -- is a critical national issue and one that will affect prospects for electric demand growth. Unless the current trend of moving

all new alumina and aluminum reduction plants to bauxite-rich countries with cheaper hydro power is reversed the aluminum ingot production in the United States will decline steadily as current plants become outmoded and are retired. While this move is certainly related to the foreign availability of low cost hydro power and the cutting of raw material transportation costs, it is also a function of domestic pricing policies, developing-country politics, and the bauxite source countries' desire for industrial plants and their accompanying employment. Whether the trend will continue in the long term is problematical; for the short term we believe it is certain to continue in the absence of government or regulatory action. In the production of petrochemical feedstocks there is currently no way that domestic firms can compete with extremely low cost Middle East feedstocks, and hence the industry is moving toward specialty chemicals and pharmaceuticals and away from commodity chemicals.

Another uncertainty is the growth in the demand for manufacturing goods as opposed to services and the U.S. share of that domestic manufacturing demand. Much of the international competitiveness could, in the near-term, turn around slowly, though its implications for industrial electricity demand suggest there will be a change primarily because of technological improvements in the use and control of electricity. This trend towards productive, high-efficiency uses of electricity leads to significant changes in electricity markets from a situation where electricity has been dealt with primarily as a bulk commodity -- i.e., aluminum and resistance heating -- to a situation with more specialty uses -- such as electronics, microwaves, and heat pumps. Further use of new technology will accelerate this trend through computer control for hourly and daily load management. Due to its uniformity and precise controllability, electricity is clearly the "high-tech" energy form.

All things taken into account, industrial demand for electricity is likely to grow in the 2 to 4 percent range at an annual average over the next 20 years. Table 5-1 lists the combination of circumstances leading to higher than average growth in industrial electricity demand, and the circumstances that lead to lower than average growth rates. Finally Table 5-2 shows those 2-digit industries that appear sensitive to federal government and regulatory authority actions affecting price, as well as those industries which, while not sensitive to price or other regulatory actions, do contribute to the uncertainty about future electric demands.

Credibility of the Projections

Credibility is a function of both the models and the data used to make the electricity projections. Both types of models used, and the data that underlies them, have strengths and weaknesses.

Data

The data, for example, are categorized or classified around the Standard Industrial Classification (SIC) code developed by OMB. The economists' definition of an industry sector is not necessarily the same thing as the SIC definition. Further, firms in an SIC coded industry may produce other products besides the one for which they were classified by the federal government. For

TABLE 5-1

Assumptions Underlying Growth Rate
Projections in Industrial Electricity Demand

	Annual Growth %	
	1980-1990	1990-2000
Real GNP Growth	2.8	2.2
Growth in Total Industrial Output	3.6	2.9
World Oil Price Growth	0.9	4.8
Domestic Natural Gas Price	3.5	3.1

Aggregate Relationships of Industrial Electricity
Growth to GNP Growth

	1951- 1973	1973- 1980	1980- 1990	1990- 2000
Economic Growth (Annual Percentage Growth)	3.6	2.4	2.8	2.2
Electricity Growth (Annual Percentage Growth)	6.7	2.5	1.9 (ISTUM2) 2.8 (ORIM)	3.2 (ISTUM2) 3.7 (ORIM)
Ratio	1.9	1.0	0.7 (ISTUM2) 1.0 (ORIM)	1.5 (ISTUM2) 1.7 (ORIM)

Source: Energy Information Administration, Monthly Energy Review, and Model Results

TABLE 5-2
Industrial Sensitivity

A. Industries Most Sensitive to Actions Affecting Electricity Prices:

Aluminum
Steel

B. Industries Most Sensitive to Actions Affecting Natural Gas Prices:

Paper
Lumber and Wood

C. Industries Most Critical to Accuracy of Electric Demand Projections:

Chemicals
Other Primary Metals
Petroleum Refining
Rubber and Miscellaneous Plastics
Textiles
Fabricated Metals
Electrical Machinery
Transportation Equipment
NonElectric Machinery

D. Industries that are sensitive to Demand Projections in their Own Planning:

Electrical Machinery
Petroleum Refining
Aluminum
Steel

example, the SIC system classifies Westinghouse by its main product line: electrical goods and equipment. Westinghouse also produces gas-fired incinerators and plywood. The SIC system, however, allocates all of Westinghouse's assets to electrical goods and equipment. This classification procedure poses significant problems in attempting to relate electricity use to specific products in the market basket of goods and services.

The point that must be made is the difficulty in obtaining pertinent data on electricity demand in the various sectors and for specific products. Energy use in the industrial sector is much more complex than in the residential-commercial sectors, due to the multiplicity of intermediate and substitute products, the variety of industries, fuels, and services, and the proprietary nature of much of the data. In the residential and commercial sector there is considerable information on the stock of housing and appliances, and on electricity usage patterns by income group and region. In addition, the major energy uses (heating, cooling, etc.) are easily characterized, and market penetration rates for new technology are quite stable allowing the analyst to project electricity demand with much more accuracy than in the industrial sector. Transportation sector energy use is somewhat the same: the stock of vehicles combined with forecasts of growth rates in the major components of that stock, of expected miles traveled, and of gallons used per mile again allow the analyst to develop fairly reliable forecasts.

Models

Many of the factors critical to industrial electricity demand have been studied and incorporated in models developed to forecast the demand for energy and electricity. As we indicated, macroeconomic models combined with interindustry models develop, at a fairly aggregate level, economic growth and product-mix projections as represented in consumption patterns for energy intensive goods and services. While these models include considerable detail on industry structure, they do not deal explicitly with technological change, plant location, trade balances, and similar issues that affect the energy intensive domestic industries. Industry models, such as ISTUM and ORIM, have been developed with more technological detail and with emphasis on fuel substitution through parameters affecting the choice between fuels and electric power to perform specific energy services or functions. These models require an enumeration of the characteristics of energy utilization technologies and processes that pose difficulties, particularly in long term analyses. In addition, they require that specific criteria (usually cost) be established for fuel choices. There appear to be attributes of electricity compared with alternative fuels that are not easily captured in the criteria used to guide fuel selection in these models. Clearly, the higher growth rates for electricity compared with total energy that have persisted over long periods cannot be explained by price differentials or other simple fuel selection criteria. These preferences for electric power have been attributed to a variety of causes including the high quality form of electric power that is readily converted at high efficiency to useful work, the high degree of controllability of electric power and the ability to direct the energy to precise locations and functions, as in computers, control systems, and microwave heating.

Despite the shortcomings of formal models in reflecting all of the factors behind the demand for energy, they may be used to explore the sensitivity of electric demand to factors that are included with reasonable completeness in the modeling framework. It is in this spirit that much of the analytical work reported here was done. In addition, several of the important factors that may affect electric demand to an equal or greater extent, but that are not incorporated effectively in the models, are discussed at a more qualitative level. For example, the loss of chemicals and aluminum production to overseas sources having lower electric or feedstock costs will have a major impact on industrial electric demand, but is not dealt with directly in any of the forecasting models.

Shortcomings of Analytic Methods

Our analysis shows that the two basic types of forecasting models used, the econometric and end-use process models, have advantages and limitations, but the analyst cannot readily reject either method nor proclaim either method as the only way to proceed. Econometric models, by their very nature, carry forward the past performance of the market or sector being modeled in the model's estimated parameters. The influence of the past on forecasts tends to make the econometric model somewhat conservative in forecasting major turning points. Econometric models generally lag in generating any change whether it be up or down and often attenuate the magnitude of that change. However, they effectively capture many implicit factors that are important. They are especially useful in the manner in which they capture the interrelatedness of market behavior and in the completeness allowed by the aggregate level at which they are employed. However, because of the generalized way in which econometric models incorporate technological change by the firm and the formation of tastes by the household, they are not thought to be detailed enough to identify specific policy options or reactions to proposed policies or specific events.

The main strength of process models is the industry detail by fuel use and service category that accounts for specific technological and fuel choice parameters. The weakness of process modeling is related to its strength in detail. That is, these very details, these technologies and fuel use categories must be enumerated, and only what is known or anticipated can be incorporated into the model. Process models such as ISTUM are most useful in the shortrun -- say 4 to 8 years -- where technological change can be projected and the details enumerated. They are less accurate over the 8 to 20 year forecasting horizon. Over longer periods, econometric models with their more generalized production functions estimated on past data tend to assume that technological change will continue much the same as it always has. In this sense econometric models or models with more generalized econometric-like production functions, such as ORIM, are more flexible, at least regarding technological change. The truth is probably somewhere in between, and for this as well as other reasons we need to continue to work with the process models to understand the detailed relationships and policy implications, and econometric models to strengthen and model new relationships and new developments.

Combining both modeling approaches with judgemental analyses seems the most credible way of projecting industrial electricity demand. Process models can be useful in providing detailed information on relationships between industrial

activity and electricity demand, and on the effects of specific policies. Econometric techniques are useful in capturing a more complete and flexible picture of economic market behavior, though at an aggregate level.

Future Research

The following six research issues should be further investigated for the industrial sector:

- o development and assessment of industrial demand indicators for load forecasting (See Section on Early Warning Indicators in Chapter 1);
- o continued research on the magnitude and policy implications of those intangible factors such as controllability and convenience that have made electricity the preferred form of energy for many purposes;
- o the development and testing of a simple pooled time-series - cross section regression model using data at the 4-digit level which would use relative factor prices, real product demand, and factor shifts to explain changes in industrial electricity use over time;
- o additional detailed study of market penetration of specific technologies which substitute for grid electricity such as improved motors, controls, and cogeneration; and
- o investigation of the sensitivity of regional industrial demand projections to the incorporation of prospective shifts in industrial output at the 2, 3, and 4 digit SIC level.

Appendix A

ISTUM2 Results by Major Electricity Using Industry

Chemicals SIC 28

The chemicals industry is extremely diverse comprising over 10,000 establishments manufacturing over a thousand different major products. Of these, however, a few of the basic chemicals are the most important because they account for most of the tonnage and a major portion of the energy consumed in the industry. The production and energy intensity in 1976 of some of the most energy intensive chemicals are shown in Table A-1.

Table A-1
The Most Energy Intensive Chemicals (1976)

	Production (Billions lbs)	Energy Use Feedstock (Trillion Btu)	Process (Trillion Btu)	Total (Trillion Btu)	Energy Intensity Btu/lb
Ethylene	25.6	116.2	15.5	131.7	5144
Phosphoric Acid	18.8	48.9	18.7	67.6	3595
Polyethylene	12.8	29.6	1.3	30.9	2414
Chlorine/Caustic					
Soda	21.6	16.9	33.0	49.9	2310
Ammonia	33.4	36.6	24.3	60.9	1823

The most energy-intensive chemicals are not, however, the ones that consume the most electricity per pound of product. The most electricity intensive chemicals are chlorine and phosphoric acid, since chlorine is produced through an electrochemical process and conventional phosphoric acid production requires the use of an electric furnace. These segments of the industry account for about a fifth of the electricity consumed in the chemicals industry.

The function that consumes the most electricity in the industry is machine drive (see Appendix B), i.e. the use of pumps and motors. Pumps and motors are used in several operations, principally transport, mixing, compression, refrigeration and physical separation.

In the base case scenario, the chemicals industry is projected to grow faster than the rest of the economy. Using Federal Reserve Board (FRB) indices, chemicals production grows at an annual rate of 3.9 percent (between 1980 and 2000) in comparison to overall industrial production projected to be growing at

3.3 percent. However, the mix of chemicals that is likely to be demanded in 2000 is much less energy-intensive than at present.¹ In particular the trends embodied in this forecast are a reduction in the amount of ethylene/polyethylene and ammonia that will be produced in the U.S. and an increase in the production of final products (such as drugs, pharmaceuticals, toiletries, etc.).

Figure A-1 compares the growth rates of production against growth in electricity and total fuel. In the figure, the three quantities are normalized using 1976 levels as a base set equal to 100.

As the figure illustrates, there is a dramatic reduction in the amount of energy and electricity used per unit of output. Production grows to 250 percent of its 1976 level, but only 52 percent more electricity is required sustain that level of production. This is a significant departure from the trends observed in this industry in the 1970s.

The factors accounting for these changes and the lower growth rate of electricity, relative to production are:

- o product shifts at the 4-digit SIC level
- o cogeneration
- o process change
- o efficiency technologies

Each of these factors is examined below in greater detail.

Product Change: The actual mix of chemicals produced at the 4-digit SIC level is the critical factor in determining the future demand for electricity. The base case projections embody a mix of chemicals that is much less energy intensive than the current mix. The result of this product shift is to reduce the demand for electricity by 360 trillion Btu by the year 2000. That is, if the chemical industry grew at 3.9 percent and produced a mix of chemical products identical to 1980 (instead of the less intensive mix in the base case), the demand for electricity would be higher by an increase of 57 percent over the amount projected for the year 2000.

Cogeneration in the industry gains market share up to 1990 but starts to decline thereafter accounting for only 69 trillion Btu of savings by 2000². The decline after 1990 is principally a result of the trajectory of natural gas prices after 1990 relative to electricity. Natural gas prices in 1995 are 35 percent higher than they were in 1990, whereas electricity prices between 1990 and 1995 rise only about 7 percent. Though this trend moderates between 1995 and 2000, in the period between 1985 and 2000 natural gas prices are increasing at a much higher rate than electricity prices, principally because of the effects of deregulation of all natural gas after 1985.

1 Based on the DRI Trendlong projection and earlier work for DOE documented in Mellon Institute's, "Final Report on Industrial Energy Productivity Project", September 1982.

2 About the same level as in 1980.

FIGURE A-1

CHEMICALS - SIC 28
(ISTUM2 Projection)
Growth Indices
(1976 = 100)

Cogeneration in the chemicals industry is particularly attractive in the manufacture of chlorine, where large amounts of electricity are needed in the electrolytic cell and large amounts of steam are required for removing excess water from the caustic soda co-product.

Process Change: Process change is important in the chemical industry and significantly affects costs of producing chemicals, the demand for feedstocks, by-products obtained and so on. In order to determine what the impact of process change might be, trends in several 4-digit industries were studied. The types of changes that are occurring in the industry may be broadly categorized as:

- o minimization of feedstock carbon,
- o minimization of process "chain length", and
- o minimization of "free energy" inputs.

The first of these is of interest primarily to the petrochemical industry. While the primary feedstocks of the industry are petroleum refinery products and natural gas, coal is beginning to gain market share.

Minimizing chain length is simply the reduction in the number of intermediate steps required to produce a given product. Given a choice between a longer and shorter chain, the latter is almost always preferred because of savings in both capital and labor. Some of the trends in chain shortening are discussed in Appendix B.

The minimization of free energy inputs refers to the choice of a particular method of production because its process energy (as opposed to feedstock energy) needs are significantly lower than a competing process.

In our analysis the process changes that will be significant in the next twenty years are:

- o production of acetylene using the crude oil submerged flame process,
- o production of ammonia from the partial oxidation of coal,
- o the coal based production of methanol from synthesis gas,
- o increased penetration of diaphragm cells for chlorine production, and
- o the Kel-chlor process for the recovery of chlorine from waste hydrochloric acid.

These process modifications were part of the ISTUM2 base case run. In order to compute the magnitude of the effect that these processes had on electricity demand, service demands were adjusted so that no change would occur in these industries. The resultant change was that electricity demand was reduced by about 40 trillion Btu by 2000.

Efficiency Technologies: Except for the electrolytic use of electricity in the Diaphragm cell in the chlorine industry, electricity is predominantly used by pumps and motors in the chemicals industry. High efficiency motors and variable

speed controls are therefore the most important energy efficiency technologies. Table A-2 shows the market shares of the high-efficiency motors. Also to be noted is that in the size 6 range covering motors of over 3000 HP, motors gain market share from fossil-fuel fired steam turbines. This is because they become more attractive as oil and gas prices escalate at much higher rates than electricity prices.

In sum, the most important factor influencing electricity demand in the chemicals industry is product mix shifts within the industry. Cogeneration, process change, and efficiency improvements influence demand, but their combined effect is less than the impact of the change in the mix of products produced. The impacts of the various factors is shown in Table A-3. The factors are represented in terms of the amount of electricity that they "save" in the base case forecast. For example, in the year 2000, if there were no cogeneration, the base case electricity projection would be higher by 69 trillion Btu.

A recent Argonne report³ suggests that there are two additional factors that might influence the demand for electricity in the chemicals industry.

These are: (1) the use of electric heat pumps in low temperature process heat applications and (2) the use of plasma environments in the production of acetylene. Industrial heat pumps that are currently available are limited to temperatures of 95°C, though DOE has been supporting the development of a heat pump to supply superheated steam. Since this pump is not likely to be available commercially for some time it does not show up as a dominant factor in the ISTUM2 demand projection. Assuming its availability in 1990 and a 50 percent market share in low-temperature process heat applications by 2000, industrial heat pumps would add roughly 100 trillion Btu to electricity demand. The use of plasma in the production of acetylene was not considered since the technology is unlikely to be available till the 1990s. Even if were available, acetylene accounts for only a small portion of the chemicals product slate, so the impact of this technology on the electricity demand projection for 2000 would be negligible.

Paper and Allied Products SIC 26

Electricity in the paper industry is used primarily for machine drive, moving pulp and paper through the various processes and for drying the wet paper in the paper making step. Figure A-2 illustrates the relationships between growth in production, electricity, and total fuel in the paper and allied products industries. The demand for purchased electricity tracks production closely. Total fuel consumption is much lower because electricity consuming technologies gain market share.

3 Argonne National Laboratory, Analysis of the Demand for Electricity (Unpublished draft, Sept. 1982).

TABLE A-1

CHEMICAL INDUSTRY
MACHINE DRIVE MARKET SHARES
(ISTUM2 Projection)

		<u>1976</u>	<u>1990</u>	<u>2000</u>
<u>Size 1</u>				
Under 5HP	Standard Motor	100%	100%	100%
<u>Size 2</u>				
5-50HP	Standard Motor	100%	58%	48%
	Hi Efficiency Motor		42%	52%
<u>Size 3</u>				
50-125HP	Standard Motor	100%	70%	63%
	Hi Efficiency Motor		30%	37%
<u>Size 4</u>				
125-500HP	Standard Motor	100%	67%	60%
	Hi Efficiency Motor		33%	40%
<u>Size 5</u>				
500-3000HP	Standard Motor	29%	48%	51%
	Standard Turbine	71%	40%	32%
	Hi Efficiency Turbine		12%	17%
<u>Size 6</u>				
Over 3000HP	Standard Motor	100%	100%	100%

CONSERVATION IMPACT
(Trillions of BTUs)

	<u>1976</u>	<u>1980</u>	<u>1985</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>
Variable Speed Drive	--	--	.29	.69	1.05	1.29
Automatic Hand Valve*	--	.38	.46	.52	.53	.53
Total	--	.38	.75	1.21	1.58	1.82

* This is a device that conserves steam by matching steam rates to the load requirements. It can be used in both new and retrofit applications on steam turbines.

FIGURE A-2

Paper - SIC 26
(ISTUM2 Projection)

Growth Indices
(1976 = 100)

TABLE A-3
Impact of Different Factors on Electricity Demand - Chemicals Industry
(ISTUM2 Projection)

	1976	1980	1985	1990	1995	2000
Base Case Projection	490	628	666	727	735	743
<u>Saving due to Factors</u>						
Product Shifts	-	-	195	250	303	360
Cogeneration	42	69	76	78	75	69
Process Change	-	-	22	28	34	40
Efficiency	-	5	8	12	13	15

Note: All units are trillions of Btu of purchased electricity

In the period 1980-1990 two distinct trends emerge. For 1980-1985, in the base case, production grows at 2.9 percent per year, while ISTUM2 projects electricity growth at an annual rate of 3.6 percent. A large part of the demand for electricity is caused by the falling share of cogenerated electricity and by electric motors' rising share of the motor drive service category, but the major portion of the new demand is due to developments in paper drying processes. In the 1985-90 period, the overall trends reverse and production grows at 2.5 percent per year while electricity consumption grows at 4.3 percent per year. This is due to the gradual and continuous movement towards energy intensive processes.

The major factors affecting future electricity consumption in the pulp and paper industry, as projected by ISTUM2, are shown in Table A-4. Cogeneration's contribution begins to decline in absolute terms, after 1985. As a percentage of total electricity supplied to the industry, its share drops substantially by 1990, accounting for about 14 trillion Btu of additional demand to the grid than would be the case if its market share was held at the 1980 levels. This partially explains why purchased electricity grows faster than production in the post 1995 period.

TABLE A-4
The Impact of Different Factors on Electricity Demand - Paper Industry
(ISTUM-2 Projection)
(trillion Btu)

	1976	1980	1985	1990	1995	2000
Baseline	123	147	175	216	269	325
Savings due to Factors						
Efficiency Technologies	-	-	1	1	2	7
Process/Product Change	-	-13	-15	-19	-28	-36
Cogeneration	8	14	14	14	13	12

The improvement in the efficiency of the machine drive service category is important in holding back the growth rate of electricity demand, improving by a total of 3 percent between 1980 and the year 2000 for a saving in the year 2000 of roughly 7 trillion Btu of electricity.

Process/product change is the second most important factor. In the paper industry the process used is most often dependent on the product required and the two cannot be examined in isolation. Therefore, in this analysis, their effects are accounted for as a combination.

The electricity "savings" due to process/product mix are illustrated in Table A-4. As the table shows, the net impact of process/product change causes electricity consumption to grow faster than it would if the factors were held to the 1976 levels. Two basic trends emerge in the product mix changes. Chemical pulping becomes a smaller percentage of output, raising the mechanical pulp process share substantially, and, consequently, raising the demand for machine-drive. The second important shift in the product mix is growth in paper products used in printing and writing. Their collective share of total paper production grows from 24 percent in 1980, to 31 percent in the year 2000. These product shifts, as illustrated in Table A-5 have an impact of electricity consumption in paper drying, as will be illustrated below.

TABLE A-5
Product Mix Changes in the Paper Industry - Pulp (ISTUM-2 Projection)

	Pulp Mix (%)	
	1976	2000
Chemical	81%	78%
Chemi-Mechanical	10	8
Mechanical	9	14
TOTAL	100%	100%

Table A-6 shows the impact of process change in several service categories. The most prominent of these is the growth in electricity use in paper making. This is due primarily to the increased use of electricity in the paper drying process (which for accounting purposes is in the paper making service category). As was stated above, printing and writing paper become a bigger share of total paper production in the later periods of the analysis. For quality control reasons, these coated papers are typically dried with electric dryers, which provide more uniform heat and better temperature control.

TABLE A-6
Product Mix Changes - Paper Mix (ISTUM2 Projection)

	Pulp Mix (%)	
	1980	2000
Newsprint	7%	7%
Printing and Writing	24	31
Packaging	9	7
Tissue	7	7
Paper Board	49	45
Construction	4	3
TOTAL	100%	100%

TABLE A-7
Process/Product Change Electricity Savings in SIC 26 (ISTUM2 Projection)

	1980	1985	1990	1995	2000
Pulping	1.26	0.18	-1.2	-3.67	-4.93
Bleaching	0.76	1.82	3.64	5.92	8.39
Paper Making	0.6	-2.58	-9.22	-20.03	-34.73
Machine Drive	-14.93	-14.30	-12.58	-11.68	-8.03
Chemical Recovery	-0.96	-0.20	-0.82	1.91	3.29

Another interesting trend exhibited in the process/product change analysis is the impact of the move to mechanical pulp. In part, this is responsible for the higher electricity demand in pulping and machine drive, but it is also partly responsible for the lower electricity demand in bleaching. That is because the drop in chemical pulp production lowers the service demand for bleaching (chemical pulp requires more bleaching per ton than mechanical pulp).

Table A-8 shows how the configuration of pulping technologies changes between 1976 and the year 2000. In general, the movement is toward pulping technologies with higher electricity consumption per ton of product.

TABLE A-8
Pulping Technology Share of Production (ISTUM2 Projection)

	1976	2000
Batch Digester (Chemical)	53%	23%
Continuous Digester (Chemical)	28	55
NSSC Batch Digester	4	6
NSSC Continuous Digester	6	2
Ground Wood Pulper (Size 1)	4	3
Thermo-Mechanical Pulper (Size 1)	-	3
Ground Wood Pulper (Size 2)	5	4
Thermo-Mechanical Pulper (Size 2)	-	4
TOTAL	100%	100%

In summary, the trends in electricity use in the paper industry do not markedly differ from those observed in the 1970s. It is useful to compare this analysis to the Argonne study. The Argonne report suggests that electricity demand for paper drying will grow due to the use of microwave drying. This technology was not modeled in ISTUM2, because, after evaluating its cost characteristics, it was determined that it was not sufficiently cost competitive to include in the market competition analysis. No objection to this conclusion was raised in the ISTUM2 review process by the paper industry representatives on the Steering Group. But electricity consumption in paper drying does increase faster than production because of two very competitive technologies, the electric paper dryer (as discussed above) and electrically powered vapor recompression. In fact, electric vapor recompression's market share expands in several drying sectors including concentration, pulping, and paper making. It works similarly to a heat pump, using electricity to displace steam in the various drying services.

Iron and Steel SIC 33

In the iron and steel industry the service categories which account for most of the electricity consumption are machine drive for rolling mill operations, and steel making with the electric arc furnace. Figure A-3 illustrates the growth in production, electricity and total fuel for the iron and steel industry. The most striking feature of this figure is the decline in total energy requirements. This is due to the reduction in coking operations and the consequent lower consumption of metallurgical coal. However, purchased electricity demand closely follows production. This net result masks two opposing trends in electricity consumption in this industry. The efficiency of some

FIGURE A-3

Iron and Steel - SIC 331
(ISTUM2 Projection)

Growth Indices
(1976 = 100)

electric service categories increases, but there are also increased market shares for electricity-consuming technologies in the industry.

Table A-9 summarizes the important factors affecting future electricity consumption in the iron and steel industry as projected using ISTUM2. As the table shows, energy efficient technology is a relatively unimportant factor with savings in the year 2000 only slightly over 1 trillion Btu. Cogeneration is also an unimportant factor in estimating future purchased electricity demand.

TABLE A-9
Impact of Different Factors on Electricity Demand - Iron and Steel Industry
(ISTUM2 Projection) (trillion Btu)

	1976	1980	1985	1990	1995	2000
Base Case Projection	225	214	251	270	34	343
<u>Savings due to Factors</u>						
Process Change	-	-1	-7	-6	-15	-21
Cogeneration	.89	.82	.9	.83	.73	.65
Efficiency Technology	-	-	.1	.4	.9	1.2

The most important factor in the industry is process change. As Table A-9 illustrates, purchased electricity consumption is 21 trillion Btu higher in 2000, because of process change technologies. But this number masks some conflicting trends. Table A-10 shows the impact of process change for steel making and machine drive. The movement toward electric arc furnaces required an additional 58 trillion Btu of electricity by the year 2000. This movement toward electric arc furnaces is driven by the increased use of scrap metal in steel making operations. But this effect is greatly offset by the drop in electric demand for machine drive (caused by other process changes) by 32 trillion Btu in 2000. Process change technologies are prominent in other service categories, but none of the others have a substantial impact on electricity demand.

TABLE A-10
Selected Process Change Savings for SIC 331
(ISTUM2 Projection) (trillion Btu)

	1980	1985	1990	1995	2000
Steel Making	-20.1	-31.6	-38.8	-47.1	-57.8
Machine Drive	17.6	22.0	27.3	29.6	32.2

Argonne National Laboratory, in a recent report to the Department of Energy, projected that plasma melt iron making would gain substantial market share

against conventional iron making processes, resulting in a large increase in demand for electricity from this service category. Plasma melt iron making was not included in the ISTUM2 model because the technology data that was available when the iron and steel industry was modeled in ISTUM2 was too uncertain to be included in the model. Cost and performance data (energy and material requirements) were not sufficiently precise for representation. Therefore, electricity demand growth as a result of plasma melt iron making cannot be ascertained from the ISTUM2 printouts.

However, exploring the issue within the ISTUM2 construct, the most relevant question is how much additional iron making capacity will the industry build in the balance of this century. Many experts believe that not much will be built because a great deal of excess blast furnace capacity currently exists. The percent of hot metal iron produced per ton of steel has dropped and is expected to continue to do so. This, admittedly, has been driven by the high cost of producing coke for the blast furnace (a problem the plasma melt process solves), but the fact remains that there are many idle blast furnaces around the country.

Therefore, in order for the plasma melt process to penetrate the market, it must compete against the cost of production from existing blast furnaces, i.e. variable costs. Naturally, the cost per ton of iron produced through plasma melt is far less attractive when compared to an existing blast furnace than when compared to the cost from a newly built blast furnace (i.e. with capital costs included).

ISTUM2 shows total iron production to be roughly flat throughout the period of analysis. But by the year 2000, direct reduction of iron, another alternative process, wins about 18 percent of the market. Blast furnaces modified with hydrocarbon injection still dominate the market with 74 percent of the production, since they are retrofit items with low capital cost.

Since the plasma melt process involves significant capital costs it is unlikely that it would gain market share from an existing blast furnace with hydrocarbon injection. However, it will compete against the direct reduction of iron. We therefore hypothesized that its maximum market share would be 20 percent by the year 2000. Table A-11 shows the impact of plasma melt processes on electricity demand in the industry. The first row shows the electricity required if all iron production were through the plasma melt process. The second row is the assumed percentage of production from this technology for each year of the analysis. The impact on additional electricity consumption is the third row. As the table shows, by the year 2000, this technology could add roughly 63 trillion Btu of demand for electricity. If the reader wishes to assume a different rate of penetration, he need simply substitute his assumed production share for each year, and multiply that percentage by the numbers in the first row.

It should be pointed out that the above method is optimistic for plasma melt market penetration. It assumes that the rate of iron production would match that of steel (if so, the demand for electric arc furnaces would probably drop, given the availability of hot metal iron). Also, it assumes that plasma

TABLE A-11
Possible Impact of Plasma Melt Iron Making on Electricity Demand
(trillion Btu)

	1980	1985	1990	1995	2000
At 100% of Iron Production*	260	273	257	296	317
Assumed Share of Production	0	5%	10%	15%	20%
Increase in Electricity	-	14	26	39	63

* From ISTUM2 Projection

melt, a relatively unknown but high capital cost technology, makes substantial inroads to an industry that is under financial and competitive pressure and has little capital to spend.

Another technology in the metals industries for which Argonne projects substantial growth is the electric induction furnace. The difference in assessment between Argonne and the ISTUM2 results is due to what Argonne sees as a far larger applicable market. ISTUM2 shows electric induction completely dominating forging operations, providing 66 percent of forging operations by the year 2000. The conventional gas fired furnace, which has an extremely low efficiency, loses market share to induction in all new and replacement applications.

The Argonne report suggests that induction can compete in the much larger market of reheat operations. The ISTUM2 project team and industry advisory committee did not believe that induction was sufficiently economical to compete in reheat operations, and did not include it in the model. But using the Argonne estimate of electricity consumption per ton of iron reheated through electric induction, the macro economic assumptions used in the baseline projections, and an assumed rate of production share, we have estimated the potential impact of electric induction reheat operations, consistent with the baseline scenario. As with the plasma melt discussion, Table A-12 has been designed so that the reader can substitute any given production share.

TABLE A-12
Possible Impact of Induction Heating in Reheat Operations
(trillion Btu)

	1980	1985	1990	1995	2000
At 100% of Reheat Operations* (Btu * 10 ¹²)	304	337	353	389	407
Assumed Share of Production (Percent)	0	5%	10%	15%	20%
Impact (Btu * 10 ¹²)	-	17	35	58	81

* From ISTUM2 Projection

This rough estimate of the potential for these two technologies (electric induction reheating and plasma melt iron making) shows that the base line projection is quite sensitive to the market penetration of these technologies. Adding together their respective impacts in the year 2000, we would see an additional 144 trillion Btu of electricity demand required at the grid (all other things held constant). This would double the annual growth rate of electricity in the primary metals industries between 1980 and the year 2000. This issue warrants closer attention in the future.

Aluminum Industry - 3334

The aluminum industry is the second largest industrial user of electricity. In 1976, the industry purchased 258 trillion Btu of electricity, of which 234 trillion was required for the electrolytic reduction process, and 8 trillion was used in melting.

In the base case scenario, electricity consumption in the aluminum industry is projected to grow at a rate of 4.1 percent annually between 1980 and 2000. This rate of growth is twice the rate of growth of production over the same period. Figure A-4 illustrates the relative growth of production against energy and electricity use (normalized using 1976=100).

Significantly, total electricity use grows faster than production after 1980. This occurs in spite of improvements in the electrolytic cell, and is due to the increased penetration of electric resistance melters. Market share for these furnaces increases from 12 percent in 1980 to 64 percent in 2000. Electric induction heating furnaces also gain market share increasing from 9 percent of the market in 1980 to 11 percent in 2000.

Process changes in the electrolytic reduction of alumina are the most significant technological factors affecting electricity demand. At present, the process used takes purified alumina, dissolves it in an electrolyte and then separates out the aluminum using an electrolytic cell. The cell has been in use since the late nineteenth century and is called the Hall cell. The average efficiency of cells in the U.S. stands at around 32 percent.

Several modifications to the basic Hall cell have been suggested and are being implemented in the aluminum industry. ISTUM2 projects that the average efficiency of the stock of cells in 2000 will be about 44 percent.

A more fundamental change in the electrolytic process is the chloride method, also referred to as the Alcoa process. In this cell, the alumina is converted to aluminum chloride before electrolysis. As a consequence, the electricity used in the cell is reduced to about 5 kWh per pound of aluminum. ISTUM2 projects the Alcoa process to gain 60 percent of the market share by

FIGURE A-4

Aluminum - SIC 3334
(ISTUM2 Projection)

Growth Indices
(1976 = 100)

2000. It should be noted here that the Argonne report, in contrast to this projection, predicts that the Alcoa process will probably not capture significant market share by 2000 unless electricity prices rise even faster than natural gas.

If the Alcoa process does not penetrate the market, average electricity use for the industry would be higher by roughly 5,000 kWh/ton. In the year 2000, electricity use would jump by 18 billion kWh or 61 trillion Btu over the base case projection. The technology market shares projected by ISTUM2 for electrolytic reduction and for aluminum melting are shown in Tables A-13 and A-14.

The influence of the various factors affecting overall electricity use in the industry is shown in Table A-15. The impact of cogeneration is very small. These trends represent a market change in the electricity intensity of the industry.

Food SIC 20

The food industry includes all establishments engaged in the manufacture of foods and beverages as well as those engaged in producing animal feeds. The industry ranks fourth in its consumption of electricity.

The large electricity consuming services in the food industry are refrigeration, concentration, and machine drive. The model's results for the food industry are summarized in Figure A-5. Production grows at 1 percent per year, between 1980 and 1985, while purchased electricity demand grows modestly at 1.6 percent over the same period. But after 1985 electricity begins to grow more rapidly, at a rate of 2.8 percent annually compared to production growing at 2.2 percent.

The faster growth rate for electricity in the post 1985 time frame appears to be due to an acceleration in fuel switching in several service categories. For instance electricity demand in the clean direct heat service category grows at 8 percent per year in the post-1985 period. Also, electricity demand in the concentration service category grows faster than total electricity at 4 percent per year, due to the market penetration of electrically powered vapor recompression. In this case, increased use of electricity leads to reduced use of steam and a net fuel savings. In the efficiency area, trends in motors and controls are similar to those shown in the chemicals industry. We also believe that a significant opportunity exists for increased efficiency in refrigeration which is not captured in the current version of the model.

Consistent with the other industries discussed in this section, the amount of electricity produced through cogeneration declines. The cogeneration and energy efficiency impacts are shown in Table A-16. Overall, there is little change in this industry in the historical pattern of electricity use.

TABLE A-13
Aluminum Electrolysis Market Shares (ISTUM2 Projection)

	1976	1990	2000
Hall Cells	100%	49%	27%
Alcoa Process	-	51%	73%

TABLE A-14
Aluminum Melting Market Shares (ISTUM2 Projection)

	1976	1990	2000
Size 1: Gas	25%	12%	7%
Distillate	5%	1%	1%
Electric Resistance	21%	71%	76%
Electric Induction	49%	15%	17%
Size 2: Gas	83%	86%	88%
Distillate	17%	14%	12%

TABLE A-15
Energy Efficiency and Cogeneration Savings in Aluminum (ISTUM2 Projection)
(trillion Btu)

	1976	1980	1985	1990	1995	2000
Purchased Electricity	259	246	287	382	446	547
Principal Efficiency Technologies	-	2	25	79	119	172
Cogeneration Savings	-	.42	1.49	2.36	2.46	2.21

FIGURE A-5

FOOD - SIC 20
(ISTUM2 Projection)
Growth Indices
(1976 = 100)

TABLE A-16
Energy Efficiency and Cogeneration Savings in Food (ISTUM2 Projection)
 (trillions of Btu)

	1976	1980	1985	1990	1995	2000
Purchased Electricity	152	168	182	206	233	276
Principal Efficiency Technologies	-	.17	.33	.61	.92	1.29
Cogeneration Savings	.56	6.46	5.87	5.73	5.25	4.41

APPENDIX B

MODELS OF INDUSTRIAL ELECTRICITY USE

For planning purposes utility management requires a long-range forecast of the demand for electricity -- specifically in kilowatts and kilowatt-hours. These forecasts are used in planning the quality and type of capacity expansion, as well as in planning for investment financing, pricing, load management, and so on. Long-range demand forecasts are also required as the starting point in the utility's corporate strategic plan. In an attempt to forecast more accurately, electricity consumers are disaggregated into more homogeneous groups such as: residential demand for electricity, commercial demand for electricity, and industrial demand for electricity. In this Appendix we survey the past and current methods used in projecting the demand for kilowatt-hours in the industrial sector. The purpose of this survey is to give the reader an understanding of the evolution of forecasting models and, specifically, of the structure of end-use or process models.

Evolution of Forecasting Methodologies

The electric utility industry has used three basic forecasting methodologies: the time series model, the econometric model, and the end-use or industrial process model. However, each approach has significant weaknesses:

- o In the time series approach, the analyst projects electricity demand solely as a function of time. The degree of complexity varies from simple trending to the use of auto regression and moving-average terms, as in the Box-Jenkins approach.
- o In the econometric approach, the analyst uses historical data extending back some 15 to 20 years to fit equations relating electricity sales to such underlying economic and demographic determinants of usage as electricity price, natural gas price,

per capita income, industrial value added, and number of customers. To develop his projections, the analyst assumes future values of the determinants, inserts those values into the fitted equations, and generates projections of the industrial demand for kilowatt-hours.

- o In the end-use or industrial process modeling approach, the analyst forecasts electricity demand separately for each major application or process utilizing electric energy. For example, industrial electricity demand will be disaggregated by space heating and air conditioning, water heating, machine drive, etc.^{1/}

While the three types of methodologies overlap they are not mutually exclusive. During periods of stable growth, such as the 1950s and 1960s, analysts preferred the time series method which, until 1973, was the approach generally used by the electric utility industry. The method was simple and accurate, and whatever basic economic changes were occurring were themselves correlated with the passage of time and tended to counterbalance each other to maintain the 7.2 percent annual growth rate during that period.

After 1973, however, time series methodologies presented forecasters with projections which were much higher than actual demand turned-out to be -- a trend which seemed likely to persist.

Econometric modeling, an approach already in use by a few of the major electric power companies, incorporated the slowdown in economic activity - in income and population growth - and increases in electric prices. Econometric models produced forecasts of electricity sales significantly lower than those produced by time series methods, yet some serious problems emerged. Analysts were:

- o unable to design an econometric framework allowing the forecaster to account for policies, such as load management programs;
- o unable to effectively relate electricity sales forecasts with the peak demand forecasts required for system planning; and

1 DeSouza, Glenn, Energy Policy and Forecasting (D.C. Heath and Co., Lexington, MA: 1981), B-2 Ch-3.

- o uncertain of the manner in which econometric estimates derived from historical data are able to forecast future trends, and especially turning points.

Because of these problems some of the larger electric utility systems and regulatory commissions developed end-use models. The considerable detail contained in end-use models enabled them to delineate the economic and technological factors that may cause future electricity sales to depart from the historical norm. Their demand projections were generally lower than demand projections using econometric models. However, end-use models, though conceptually appealing, are difficult to implement. For example, in the industrial sector, data on the diversity of electricity uses are not readily available and the development of end-use models is, therefore, difficult.

Because we used the ISTUM2 and ORIM model in Chapter 4's sensitivity analysis of the industrial demand for electricity, we review both ISTUM2 and ORIM and compare them with two simpler end-use models, BNL and IESM.

Structural Models of Industrial Energy Use

In this section we review and evaluate four industrial process models:

- o The updated version of The Industry Sector Technology Use Model (ISTUM 2).
- o The Oak Ridge Industrial Model (ORIM).
- o The Brookhaven National Laboratory Process Models (BNL), and
- o The Industrial Energy Services Module (IESM).

Table B-1 summarizes the characteristics of these models. All are technology choice models which seek to meet energy demand with the least cost mix of technologies. No other modeling approach (e.g., econometric) provides as much detail regarding the economic and technical factors driving industrial energy markets.

ISTUM 2

The builders of ISTUM2 undertook a massive data collection effort incorporating the best available data on industrial sector capital stock. The model includes an explicit representation of the major process technologies in the four most energy intensive industries, as well as considerable detail on various "generic" technologies. For example, machine drive services as represented in ISTUM 2 incorporate a substantial portion of the detail contained in Arthur D. Little's study of electric motors, which provides the best available information regarding the size distribution and capacity utilization distribution of electric motors, by two digit SIC code. This type of information is extremely valuable because machine drive accounts for nearly 80 percent of industrial electricity use. The technology data base in ISTUM-2 includes the energy and material use characteristics of the major process technologies, fully illustrates the mass energy flows available for each technology, and carefully documents its assumptions and calculations. In addition, a cost estimate is presented and documented for each alternative technology.

In the decision framework competition takes place at several levels. For the energy intensive industries, the model is based on process technology choice which minimizes the total cost of production, rather than energy costs.

TABLE B-1

SUMMARY OF CHARACTERISTICS OF INDUSTRIAL ENERGY USE MODELS

MODEL	SCOPE	# OF INDUSTRIES	# OF SERVICES	PROCESS DETAIL	TECHNOLOGY DETAIL	DECISION RULE	RETROFIT
ISTUM 1 (EEA)	ALL MFG, AGRICULTURE	26	23	NO	ABOUT 200 CONVERSION TECHNOLOGIES	COST MINIMIZATION, BEHAVIORAL ADJUSTMENT OPTIONAL	NO
ORIM (ORNL)	ALL MFG	9	4	GENERALIZED	GENERALIZED	COST MINIMIZATION	NO
PROCESS MODELS (BNL)	3 INDUSTRIES, OTHERS UNDER DEVELOPMENT	3	26	YES	HIGHLY DETAILED	COST MINIMIZATION	YES
IESM (STANFORD)	ALL MFG	4	5	GENERALIZED	30 CONVERSION TECHNOLOGIES	COST MINIMIZATION	NO
ISTUM 2 (EEA-MELLON)	MFG, AGRICULTURE, CONSTRUCTION, MINING	27	52	KEY INDUSTRIES ONLY	SEVERAL HUNDRED, INCLUDING PROCESS DETAIL	COST MINIMIZATION, BEHAVIORAL ADJUSTMENT OPTIONAL	YES

ISTUM 2 Characteristics

ISTUM 2 includes 27 industries (primarily at the 2 digit SIC level), 52 energy service categories, at least two size categories, (e.g., 5 HP, 15 HP, 125 HP) and two capacity utilization levels. Each submarket is considered for each of the 10 DOE regions, providing a great deal of submarket detail. Table B-2 lists all of the industries contained in ISTUM2, and Table B-3 lists its energy service categories.

Figure B-1 illustrates the technology competition framework. That is the model considers the trade off between fuel and capital (the recuperator) by comparing their costs on a consistent basis: the cost of saving the fuel (the annualized capital and operating costs of the recuperator) against the fuel price.

The results of this "competition" represent an input to the analysis of the energy carrier options. Here, the energy carrier technologies are competed. For example, the cost of coal furnaces is determined, in part, by the economic level of heat recovery on coal furnaces determined in the previous step. So that, at the carrier level, the alternative furnaces are competed with each other to determine what percentage of the energy service markets are won by each technology. For instance, if the carrier technologies were boilers, the model determines what percentage of the steam market each of the alternative technologies (fuel types) would win. Knowing the market shares of each technology, and its costs, the model then calculates the cost of providing the energy service (e.g. steam).

Again, we use the results of the previous step (the energy carrier competition) as an input to this step. The cost of each process technology is determined, in part, by the cost of energy carriers. For instance, if the process technologies consist of two options, one of which uses high quantities of steam

TABLE B-2

STANDARD INDUSTRIAL CLASSIFICATION CODES
COVERED IN ISTUM-2

<u>SIC</u>	<u>NAME</u>
1	Crops
2	Livestock
10, 14	Non-energy mining
11-13	Energy Mining
15-17	Construction
20	Food
21	Tobacco
22	Textiles
23	Apparel
24	Lumber
25	Furniture
26	Paper
27	Printing
28	Chemicals
29	Petroleum
30	Rubber
31	Leather
32	Stone, Clay & Glass
331	Iron & Steel
3334	Aluminum
334	Other Primary Metals
34	Fabricated Metals
35	Non-electric Machinery
36	Electric Equipment
37	Transportation Equipment
38	Instruments
39	Miscellaneous

TABLE B-3
ISTUM2 ENERGY SERVICE CATEGORIES

Boiler generated steam	Cement making
Cogenerated steam	Glass melting
Machine drive	Pulping
Space, H, V, and AC	Bleaching
Electricity generation	Papermaking
Refrigeration	Chemical recovery
Transportation	Pulp drying
Lighting	Paper lime calcining
Direct steam	Distillation
Heating, dirty	Cracking
Heating, direct, clean	Alkylation
Drying, dirty	Hydrogen production
Drying, direct, clean	Hydrotreating
Lime calcining	Reforming
Concentration	Agglomeration
Paint drying	Ironmaking
Textile drying	Coking
Food drying	Steelmaking
Metal melting	Primary finishing
Forging	Secondary finishing
Heat treating, generic	Heat treating
Feedstocks	Organic chemicals
Aluminum melting	Inorganic chemicals
Aluminum heating	Plastics and resins
Aluminum electrolysis	Chemical fertilizers
Brick firing	Chemical feedstocks

FIGURE B-1

TECHNOLOGY COMPETITION FRAMEWORK IN ISTUM2

(per unit of product), the other which uses low quantities of steam, then the outcome of the boiler competition in the previous step is important. That is because the cost of steam is an important component in determining the total cost of the several systems.

The ISTUM 2 logic flow is presented in Figure B-2. Without explaining each module in detail, this discussion will serve to show the relationships between the several components. The industry flow models determine how much of each of the intermediate products are required to meet the exogenously determined final product demand, for each industry. For instance, given a total demand for various types of paper, this module determines how many tons of the various types of pulp will be required. We use this information to determine the actual size of the market for pulping technologies (regardless of these technologies respective market shares). We will describe the process in more detail, later in this section.

The Technology Competition Module performs the optimization described earlier, i.e., it determines the market shares of the various technologies as a percentage of the market. The Penetration Lag Module alters these "economically optimal" market shares to reflect other decision criteria not contained in the optimization (e.g. financial constraints, vendor supply constraints). This produces the "actual" market shares, as a percentage, for each technology.

The Data Base Module monitors the vintages of capital stock, keeping track of the additions in the last period, and the retirement in each period, for all of the technologies. It provides the data required by the Capital Turnover Module, to determine how much existing capacity there is for each process.

The Capital Turnover Module then determines, how much new capacity is required to meet the intermediate and final product demand, as calculated in the industry flow model. With the shortfall in capacity determined, the model

FIGURE B-2

allocates the additions to capacity to the respective technologies, based upon the outcome of the technology competition analysis; the technology market shares described earlier. Given fuel type and efficiency assignments for each technology, fuel demand by type is calculated.

ORIM's Characteristics

As illustrated in Table B-4 ORIM contains nine industries, and four service sectors. ORIM examines each of these markets at the regional level, using the 10 DOE regions. While ORIM's representation of industrial energy consumption is complete, it lacks detail. For example, the aluminum industry is not explicitly considered, and electrolytic services are not explicitly compared. This means that electrolytic technologies in both the aluminum and chemical industries (both significant contributors to industrial electricity demand) are generated in a broader competition analysis which does not take explicit account of the technical alternatives for changes in electricity demand from these industries.

The fundamental decision framework used in ORIM is outlined in equations B-1 through B-3. The fuel share module is less important to this analysis, since fuel mix options are not numerous for most industrial energy services using electricity. The equations for the fuel share module demonstrate how the technology selection process is modeled. Equation B-1 calculates the cost of each technology, considering all the factors of production. Using a logit function to represent the variability of costs, the cost of each technology is raised to an exponent. The percentage market share of each technology is simply its costs divided by the sum of the costs for all of the technologies competing in this market, as shown in Equation B-2.

TABLE B-4

ORIM'S DIMENSIONS

<u>INDUSTRIES</u>	<u>SERVICE SECTORS</u>	<u>FUELS</u>
Food	Process Steam	Distillate
Paper	Process Heat	Residual
Industrial Chemicals	Mechanical Drive	LPG
Petroleum Refining	Electric Sources	Natural Gas
Stone, Clay, Glass		Coal
Steel		Electricity
Non-ferrous Metals		
Durable Manufacturing		
Miscellaneous Manufacturing		

NOTE: Orim projects fuel use at the ten DOE region level.

EQUATIONS B-1 through B-3

Equation B-1

$$PI = \sum AI \quad PE + \sum AF \quad PF + CN$$

where;

PI = The cost of energy services for a given technical option

AI = I-O coefficients for energy

AF = I-O coefficients for other factors

PE = Prices of energy

PF = Prices of other factors

CN = Adjustment factor for nonmarket forces

Equation B-2

$$AM = \frac{PI^{rn}}{\sum PI^{rn}}$$

where;

AM = Market share for an option

RN = The exponent of the fuel share logit function which represents the variability in costs)

Equation B-3

$$A_I = \frac{\partial G}{\partial P_I}$$

where;

A_I = The conservation factor (of service type i)

G = The cost function

P_I = The price of energy service of type i

The Conservation Module, represented in Equation B-4 is more important to this analysis, since electricity usage is generally subject to reduction through the use of additional capital (e.g., improved windings in electric motors). This module calculates only shortrun conservation costs. It is based on the economic concept of Shephards Lemma, which relates the optimum input-output coefficients to the partial derivatives of the cost function. This concept is employed to determine the optimal mix of energy services, capital and labor in the conservation module, that is, the trade off between energy service demand and the other factors of production. This factor is then used to adjust the demand for the energy services.

Figure B-3 illustrates the logic flow of ORIM. The inputs are listed on the left. They consist of industrial output by region and industry, fuel prices, factor prices and an assumed technological change factor.

The Investment Module uses the industrial output projections and expected factor prices to determine the characteristics of future vintages of capital stock. The model documentation describes this part of the analysis as representing the long run conservation effects, which we assume is the major adjustments to capital stock which occurs in process change. The second output of the Investment Module is the allocation of industrial output to the active vintages of equipment tracked in the model.

The Fuel Share Module requires factor prices, and the capital stock adjustments from the Investment Module, to determine the fuel share factors (fuel/service) and the price of services for each of the four energy service sectors. It consists of 32 markets for process heat, 20 for mechanical drive and 4 for electrical services. The conservation module takes factor prices and the price of energy services to determine the intensity factor (service/output).

FIGURE B-3

EQUATION B-4

$$\text{MINIMIZE } \sum_t^8 \left\{ \sum_j \left[K_t(j) + E_t(t) + F_t(j) \right] W_t^j + \sum_k c_y(e) \right\}$$

where

- j = Set of conversion technologies
- e = Set of energy services
- K_t = Capital cost at installation of conversion technologies
- E_t = O&M cost of all future operation of conversion technology
- F_t = Fuel cost of all future operation of conversion technology
- W_t^j = Amount of conversion technology j installed in period t
- C_t = Cost of conservation (process change) technology for service e installed in period t.

Finally, the Demand Module calculates fuel demand (for each fuel type) using the following equation:

$$\text{Fuel Demand} = \frac{\text{Fuel/Service} * \text{Service/Output} * \text{Output}}{\text{Technological Change}}$$

IESM and the BNL Process Models

The final two models to be discussed are IESM and the BNL Process Models. Both models are treated briefly because of their high degree of aggregation they are not used in the study, though they are of interest as precursors to the ISTUM and ORIM models.

IESM Characteristics

Although it is a well designed model of industrial energy use, we eliminated IESM from consideration. We felt it would not add additional insights beyond those of the ISTUM and ORIM models. IESM, a simplified version of ISTUM 1, costs less than ISTUM to run, allowing more sensitivity analysis at lower cost, but obviously with much less detail.

Table B-5 presents IESM's dimensions. Industry groups are generalized to 4 basic categories, and energy services to 5. To evaluate changes in the mix of industrial output from industry to industry, this framework is not sufficiently disaggregated. Also, the service sector disaggregation is insufficiently detailed to consider the various heterogeneous requirements for electricity dominated services.

The decision framework for IESM technology selection is illustrated in equation B-5. It minimizes the cost of energy services, in eight time periods, by selecting the least cost set of technologies using a linear programming format. The technology costs, as represented in the model, are on an annualized

TABLE B-5

IESM DIMENSIONS

INDUSTRIES

Energy-Intensive Manufacturing

Energy-Nonintensive Manufacturing

Machinery

Mining

SERVICE SECTORS

Steam

Direct Heat

Indirect Heat

Electric Services

Space Heat

FUELS

Oil

Gas

Coal

Electricity

Solar

EQUATION B-5

$$\begin{array}{ll} \text{MINIMIZE} & \sum_t \frac{(I - T) (E_t(X) + K_t(X) - D_t(X))}{(I + r)^t} \\ X & \end{array} \quad \begin{array}{l} \text{Subject to} \\ Ax \leq b \end{array}$$

where

X = Set of technologies

E_t = Current expenses in period t

K_t = Capital expenses in period t

D_t = Depreciation allowance in period t

T = Profits tax rate

$Ax \leq b$ = Constraints on resources

basis, and include the cost of capital equipment, fuel, and operation and maintenance.

BNL Process Model Characteristics

The representation of industries in the BNL process model is not comprehensive and they are expensive to run. Each industry modeled, in the BNL industry structure, is represented as a single, stand alone analytical structure, separate from all of the other structures. As Table B-6 illustrates, there are three industry models available; iron and steel, pulp and paper, and aluminum. Other industry process models (available from other sources) include petrochemicals, plastics and polyesters and petroleum refining. Additional models are under development. The difficulty in using this family of models is that each has to be learned, with respect to understanding its fundamental structure, and develop the capability to get the logic to execute on the DOE computer.

Figure B-4 illustrates the level of depth available in the BNL process models, with an example from the pulp and paper industry. Each box represents a physical product with the lines representing the alternative process paths from one intermediate product, to the next level of production. At the top of the figure are three basic material inputs. Those are fed in the various processes to produce the next level of intermediate product, the pulp types, represented in the second level of boxes. Various pulp types are bleached, semibleached, or left unbleached, before being fed to the paper forming processes. Finally, the choice of pulp and paper forming technology is made to fulfill the final product mix, the categories of which are represented in the bottom row of boxes. The fundamental strength of these process models is their ability to optimize the technology selection based upon the total cost of production rather than just

TABLE B-6
BNL PROCESS MODEL DIMENSIONS

<u>INDUSTRIES</u>	<u>FUELS</u>
<u>AVAILABLE</u>	OIL
IRON AND STEEL	NATURAL GAS
PULP AND PAPER	COAL
ALUMINUM	ELECTRICITY
	SOLAR
	BIOMASS
<u>EXISTING MODEL IDENTIFIED</u>	INDUSTRIAL WASTE
PETROCHEMICALS	
PLASTICS AND POLYESTERS	<u>SERVICE SECTORS</u>
PETROLEUM REFINING	DEFINED INDIVIDUALLY
	IN EACH MODEL
<u>DEVELOPMENTAL</u>	
CEMENT	
COPPER	
TEXTILES	
DAIRY	
MEAT	
GLASS	

ILLUSTRATIVE PROCESS FLOW: A PAPER INDUSTRY EXAMPLE

FIGURE B-4

energy services. This was not available any where else but from the BNL and related process models, until the advent of ISTUM2.

Finally, equation B-5 illustrates the basic decision framework for the process models. These are all formulated in a linear programming format. Each model minimizes the total cost of production, subject to a series of constraints, such as the level of output required for each product.

Summary

Of the four models reviewed, ISTUM 2 has the most detailed and documented data base. It incorporates a sophisticated decision framework to evaluate the technology choices, and, therefore, seems to be the most complete and desirable model for our purposes. It is the newest of such models; its designers having the advantage of reviewing and evaluating the other models prior to commissioning ISTUM2. ISTUM2 is a state-of-the-art in industrial energy model

The ORIM model has an elegant economic decision making theoretical basis, but lacks ISTUM 2's empirical data base. The IESM and the BNL process models are too narrow and constrained to compete with the richness and robustness of ISTUM and ORIM.

ISTUM2 Modeling of Energy Management

Energy management is defined in ISTUM2 as those activities which reduce fuel consumption through labor intensive rather than capital intensive operations. Examples include, operator training, frequent monitoring of equipment, prompt replacement of malfunctioning equipment, and shutting down auxiliary units when not needed.

In ISTUM2 energy management is based on historical trends and on the judgment of experts in industrial energy management to determine the potential savings from energy management and that rate at which that potential may be realized.

Using data collected in DOE's Energy Efficiency Improvement and Recovered Material Utilization Reports, an estimate for total energy conservation achieved over what period was taken for each of the intensively studied industries; paper and allied products, chemicals and allied products, petroleum and coal products, and primary metals. Industry experts were then consulted to determine what percentage of those historical savings were attributable to energy management. These estimates are shown in Table B-7. Savings attributable to energy management for each quarter are listed in the last column.

Next, an estimate was needed for the ultimate potential energy savings due to energy management. This was obtained from experts at Energy Management Services, a division of E. I. DuPont de Nemours & Co., Inc. They advised that 10% of the energy consumed in 1980 could be saved through energy management. This estimate of potential savings was placed on a 1976 basis, that is, savings over the 1976 level of consumption, for each industry. This was added to the historical savings to determine total potential energy savings due to energy management, relative to 1976 consumption, shown in Table B-8.

The next step in the process was to determine the econometric model which best described the historical data, given the hypothetical potential. After trying several functional forms, a translated exponential (logistic) curve was determined to best describe the rate improvement of savings due to energy management. Figures B-5 to B-8 illustrate the results for each of four industries. As the figures show, the historical estimates fit the models quite well. Also, it is important to point out that the historical estimates account for roughly 1/3 of the total potential savings due to energy management.

FIGURE B-5
Pulp and Paper

FIGURE B-6
Chemical Products

FIGURE B-7

Petroleum Refining

FIGURE B-8

Iron and Steel

Table B-7

ENERGY MANAGEMENT FUEL SAVINGS ESTIMATES

<u>Industry</u>	<u>Year-Quarter</u>	<u>Total Savings</u>	<u>Post '76 Savings (%)</u>	<u>Rounded</u>	<u>Est. EM Portion (%)</u>	<u>Cum. EM Savings (%)</u>
Pulp and paper	1976 - 3	9	-	-	-	-
	1977 - 2	10	1.1	1	0.50	0.50
	1977 - 4	11	2.2	2	0.50	1.00
	1978 - 2	12	3.3	3	0.50	1.50
	1978 - 4	14	5.5	6	0.50	3.00
	1979 - 3	17	8.8	9	0.50	4.50
	1980 - 1	21	13.2	13	0.50	6.50
Industrial Chemical	1976 - 3	10	-	-	-	-
	1977 - 2	12	2.2	2	0.75	1.50
	1977 - 4	13	3.3	3	0.75	2.30
	1978 - 2	15	5.5	6	0.75	4.50
	1978 - 4	17	7.7	8	0.75	6.00
	1979 - 3	22	14.4	14	0.50	7.00
	1980 - 1	22	14.4	14	0.50	7.00
Petroleum refining	1976 - 3	10	-	-	-	-
	1977 - 2	13	3.3	3	.25	.75
	1977 - 4	16	6.6	7	.25	1.75
	1978 - 2	13	3.3	3	.50	1.5
	1978 - 4	16	6.6	7	.50	3.5
	1979 - 3	15	5.5	6	.75	4.5
	1980 - 1	19	9.9	10	.75	7.5
Iron and steel	1976 - 3	4	-	-	-	0
	1977 - 2	2	-2.1	-2	-	0
	1977 - 4	3	-1.05	-1	-	0
	1978 - 2	7	3.15	3	.75	2.3
	1978 - 4	9	5.25	5	.75	2.5
	1979 - 3	9	5.25	5	.50	2.5
	1980 - 1	11	6.30	6	.50	3.0

SOURCE: The Industrial Energy Efficiency Improvement Program (EEIP), Department of Energy, Office of Industrial Programs, December 1980, DOE/CE-0015.

Table B-8

POTENTIAL FUEL SAVINGS DUE TO ENERGY MANAGEMENT

<u>Industry</u>	<u>Total '80 Realized Savings (%)</u>	<u>'80 EM Realized Savings (%)</u>	<u>EM Potential Savings (%)</u>
Paper	21	6.5	15
Chemicals	22	7.0	16
Petroleum	19	7.5	17
Iron and Steel	11	3.0	12

Source: The Industrial Energy Efficiency Improvement Program (EEIP)s
Department of Energy, Office of Industrial Programs, December 1980,
DOE/CE-0015

Chemicals - SIC 28

Electricity use in 1976 by function is shown in the table below:

Table B-9
Electricity Use in 1976 by Function

	Purchased Electricity (Trillions Btu)	Percent
Space Conditioning	4.1	0.7
Lighting	19.5	3.5
Electrolytic/Furnaces	133.4	24.0
Fertilizer Production	30.2	5.4
Machine Drive	366.4	66.4
	<u>553.6</u>	<u>100.0</u>
Boiler Generated Steam	-21.7	-
Cogenerated Steam	-42.2	-
Total Purchased Electricity	489.7	

Source: ISTUM2 Data Base and DOE Energy Consumption Data Base

Chain Length Minimization

Figure B-3 is an illustration of how a number of different process chains can be used to produce two final products, ethylene glycol (antifreeze) and vinyl acetate (plastic, adhesive). The solid circles represent products sold by the industry, whereas dashed circles are intermediates and by-products often consumed within the plant.

Aluminum - SIC 3334

The tables show the trends projected by ISTUM2 for aluminum electrolysis and aluminum melting.

Aluminum Electrolysis Trends

Year	Electricity/lb in Kwh
1960	8.0
1970	7.7
1980	7.7
1990	6.9
2000	6.4

The trends in Aluminum melting to show a movement towards a lower energy-intensity and higher electricity-intensity.

Aluminum Melting Trends

		Percent		
	Million Btu/ton	Gas	Oil	Electricity
1980	3.69	69.8	14.6	15.6
1990	2.85	57.3	7.0	35.7
2000	2.41	43.6	4.1	52.3

Process Controls

The table below shows the major markets for process control equipment by industry groups. The figure illustrates the improvement in performance in production as a result of computer applications.

Table B-10

Major Markets for Process Control Equipment

Chemical industry buys 25 % of all process control equipment

Industry	Sales ^a (\$ millions)		% growth rate ^b
	1981	1980	
Chemicals	1214	1080	12.3
Petroleum	857	1500	15.0
Electric & gas utility	786	1360	14.7
Primary metals	732	1220	13.6
Paper & pulp	352	510	9.7
Food & beverage	341	550	12.7
Stone, clay & glass	182	280	11.4
Water & sewage	104	180	11.4
Textiles	59	110	16.7
Rubber & plastics	49	100	19.3
Mining & other ^c	235	370	12.0
TOTAL SALES	\$4911	\$6146	13.3 %
Net exports ^d	\$ 541	\$ 978	15.7 %
TOTAL SHIPMENTS	\$5452	\$6119	13.5 %

^a Amounts do not add up to totals because of rounding. ^b Includes a 7% per year estimate for inflation. ^c Includes foundry and pharmaceutical industries. ^d Excess of exports over imports.

Source: Chemical & Engineering News, Dec. 7, 1981

FIGURE B-9
CHAINS

Table B-10

Major Markets for Process Control Equipment

**Chemical industry buys 25 % of
all process control equipment**

Industry	Sales ^a (\$ millions)		% growth rate ^b
	1981	1980	
Chemicals	1214	1880	12.3
Petroleum	857	1500	15.0
Electric & gas utility	786	1360	14.7
Primary metals	732	1220	13.6
Paper & pulp	352	510	9.7
Food & beverage	341	550	12.7
Stone, clay & glass	182	280	11.4
Water & sewage	104	160	11.4
Textiles	59	110	16.7
Rubber & plastics	49	100	19.3
Mining & other ^c	235	370	12.0
TOTAL SALES	\$4811	\$6140	13.3 %
Net exports^d	\$ 541	\$ 978	15.7 %
TOTAL	\$5452	\$6118	13.5 %
SHIPMENTS			

^a Amounts do not add up to totals because of rounding. ^b Includes a 7 % per year estimate for inflation. ^c Includes foundry and pharmaceutical industries. ^d Excess of exports over imports.

Source: Chemical & Engineering News, Dec. 7, 1981

Figure B-10

Ranges of Production Improvements
Achieved Through Computer Applications

Industrial improvements through computer applications. Numbered bars show, 1, increased process stability; 2, reduced fuel consumption; 3, increased yield, and, 4, increased production. Values in parentheses are percent average improvement.

Source: Computer Technology: Its Potential for Industrial Energy Conservation. U.S. Department of Energy DOE/CS/2123-T2.

APPENDIX C

These equations represent the effect of product mix shifts on electricity growth

Let: a_{70}^i be the electricity intensity for industry i in the year 1970,

v_{70}^i be shipments for industry i in the year 1970,

k_{70}^i be industry i 's share of total industry shipment in 1970,

E_{70}^i be observed electricity use in industry i in 1970;

then

$$k_{70}^i = \frac{v_{70}^i}{\sum_i v_{70}^i}$$

Since

a_{80}^i represents 1980 electricity intensity for industry i ;

then

$$a_{80}^i k_{70}^i \sum_i v_{80}^i = \hat{E}_{80}^i$$

where

$\hat{E}_{80}^i$ represents the electricity that would have been used in industry i in 1980 if there had not been any product shifts

Clearly, $(\hat{E}_{80}^i - E_{80}^i)$ may be positive, negative, or zero depending on i ,

and

$\hat{E}^T = \sum_i (\hat{E}_{80}^i - E_{80}^i)$ represents the change in total electricity use in the industrial sector due to product mix shifts.