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U.S. electrical energy dilemma and an energy model for the electrical utilities of Iowa

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Iowa State University, Ph.D., 1975
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U. S. electrical energy dilemma and an energy model for the electrical utilities of Iowa

by

Turan Gonen

A Dissertation Submitted to the
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The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

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I. INTRODUCTION

As a society becomes more wealthy, it can and does provide more goods and services that require larger amounts of energy. The climate and economic specialization of a region, as well as the cost of energy, can affect the relationship between energy consumption and standard of living. Nevertheless, it is reasonable to expect that as a nation increases its per capita income, its consumption of energy will also rise.

The United States has entered an era of profound alteration in traditional patterns and trends in the field of energy. Price relationships, rates of use, sources of supply, and national security all have become areas affected with uncertainty and conflict.

While the need for concern regarding the rapid depletion of the U. S. energy resources has long been evident to those in the energy field, awareness of the seriousness of the situation has only recently become apparent to the general public. The use of the phrases, "The Energy Crisis" or "The Energy Dilemma" has contributed to this awareness and to the need to work toward a satisfactory solution.

The Arab oil embargo of recent years has greatly aggravated this crisis. However, the underlying causes lie farther back in the past and hopes of long term remedies lie well into the future. Full-blown energy problems did not hit the country until 1973, although there were much earlier hints of impending trouble. Among them were the refusal of numerous natural gas utilities to connect new residential customers, and and voltage reductions and load shedding instituted by a number of eastern electric utilities during summer peak load periods.

As electric systems become progressively more complex and interconnections proliferate, system planning becomes an increasing challenge in the electric utility industry. Generally, the system planning activities center on definitive short term analysis of power system performance with peak load projections up to ten years in the future. System planning is more than a one-man or one-department problem. Development of reliable and economical systems requires the skills of systems operators and the judgement of management as well as the talents of planning engineers.

All factors considered, computer programs are useful tools for the development of reliable and economical systems. Generally, all system planning activities may be divided into three tasks: 1) synthesis - creation and development of preliminary plans, 2) analysis - technical evaluation of reserve requirements and simulated operation for load flow and stability analysis, 3) optimization - economic evaluation to identify minimum cost alternatives from plans to meet reliability criteria. To perform these tasks, numerous quantitative modeling techniques, which are mostly computerized, are available and are used extensively. Load flow, system stability, short circuit, system expansion, reliability, and numerous other modeling programs are used for accurate analysis. Repetitive analysis of this kind, tempered with sound judgment, is the basic approach to system synthesis.

Such short term planning is a must for all growing utilities. But, long term conceptual planning is also needed to evaluate conditions that will affect the whole industry as well as individual utilities, thirty years or more into the future. Such planning activities are frequently deferred in lieu of seemingly more critical problems, but their importance should not be underestimated.

It is essential that research and development (R & D) investment priorities reflect the future needs of the country as well as those of individual companies. These future needs should be defined, since much research concerning new techniques is already underway and R & D investment decisions are continually being made by both industry and government. Some information about future needs and problems may, of course, be derived from short term analyses and forecasts, but short term planning provides no information concerning the extensiveness, seriousness or persistence of these problems in the more distant future. Presently, there are problems which are unsolvable by conventional means that eventually were revealed by short term planning, and that might not now exist, had they been anticipated through long range analysis and planning at an earlier time.

The present deplorable natural gas situation is an excellent example of the consequence of insufficient long range planning. Even though natural gas is less plentiful than any other fossil fuel, low prices were fostered in the 1950's and 1960's. Consequently, the consumption of natural gas increased very rapidly, so that it now accounts for about one-third of all energy consumed in this country. The low prices not only increased consumption, but also provided no incentive for further exploration. The natural gas shortage was already a reality when the problem finally was recognized.

Because of the rapid changes in technology, fuel resources, and environmental constraints, the need for long term system planning becomes more urgent than in the past. Long term planning is not intended to specify step-by-step detailed system developments, but rather to outline the most likely system expansion pattern based on today's view of the future. Long term planning provides a guide for initiating short term decisions and actions, outlining R & D requirements and priorities, and recommending utility policies and their associated timing. A long term system evaluation enables planners to explore various options in supplying electric energy and their associated effects on fuel resources, land, water, and financial requirements.

Anyone undertaking long term planning must keep abreast of knowledge in several interrelated disciplines, since developments in any of them could affect the whole energy field. For instance, transmission requirements are affected by power plant technology and siting, which in turn are affected by fuel developments.

Long term planning must be quantitative as well as qualitative. This is a direct consequence of the fact that the essential characteristics of and the relationships between the various energy related fields are quantitative in nature. But, it is not essential or possible for long term analyses to be as precise as short term analyses must be, which can pose a problem for engineers who are accustomed to working with accuracy. It is impossible to attain true precision when forecasting and planning for the distant future, but this does not preclude the necessity of quantitative analyses, nor does it render long term planning invalid -

it just makes it more challenging. To be worthwhile, the forecast must simply allow better operation than could be achieved without it. Quinn (1) states that the alternative is to continue to act on simple hunches about the future and to do this, says Quinn, is to be irresponsible.

The first part of this study, which is discussed in Chapters II, III, and IV, deals with the entire energy field, particularly stressing electric power. Energy sources are examined; energy supply and demand are projected to the year 2000 on the basis of statistical data; various U. S. energy forecasts are compared; and some energy-related topics are discussed in relation to these forecasts. The subject studied is extremely broad, and of necessity, some areas are treated more lightly than others.

In the second part of this study, which is discussed in Chapters V and VI, and computerized electric energy cost model was developed for the electric power industry to minimize the cost of energy used for electric generation by optimum allocation of various fuel-mixes over a period of n years, where the energy is subject to a large number of physical and environmental constraints. A mechanism was built into the model, which facilitated rapid evaluation of the consequences of different proposed energy policies.

In order to keep the size of the model within reasonable bounds (because of a limited computer budget, difficulties involved in obtaining the necessary coefficients, and a time limitation), the model is applied to the State of Iowa rather than to the whole country. Results of the applications of the model are presented in Chapter VI.

Some studies and computer output and programs, if included in the body of the text, would distract from the main theme. These are included in the Appendices, and attention is directed to them wherever appropriate. Also, in order to define some of the terms encountered most commonly in discussing energy, both in this study and in general usage, a glossary is included.

II. REVIEW OF THE LITERATURE

A. Energy Dilemma

An extensive literature search was done concerning the energy dilemma of the United States (1-171). Many papers were found on the general concepts of energy rather than on the future of the problem. Most of the concepts in these papers are reviewed in the following chapters in order to compare the results of this study with the results of the others.

What is the dilemma in energy? To many scientists, the dilemma is a temporary phenomenon, which will be resolved soon by the availability of cheap and abundant nuclear power. Many nonscientists think of it only in terms of power brownouts or gas shortages. It has also become fashionable to blame the environmentalists for the problem.

Dalal (2) pointed out that the energy problem was far more complex than power plant location or the trans-Alaska oil pipeline. He argued that the energy problem exists not only on the supply side, but also on the demand side. He suggests that some of the technological solutions that are popular today might not be desirable in the long run, and that new technological initiatives are necessary, along with certain changes in demand, to achieve energy stability. In the long run, however, he concludes that the problem cannot be solved by sophisticated technology alone, but will require the combined efforts of economists, technologists and sociologists to devise a stable, affluent society that can exists in harmony with nature.

Since many energy-associated problems are global in nature and must be solved in concert with other nations, some authors have tried to bring a new perspective to the United States' energy dilemma by studying the world's energy resources and consumption.

In 1964, an extensive study was done by Guyol (3) which surveyed the electric power industry in 162 countries in the world. He concluded that the data that appear in national reports on the electric power industries of different countries do not fit into a single pattern. Consequently, it is difficult to compare the industry of one country with that of another. It is even more difficult to combine data on several countries and thus arrive at a composite picture of the electric power industry in the world, or in any major region of the world except Western Europe and the noncommunist portion of the Far East. The study attempted to correct this situation by collecting data on the electric power industry in every country of the world, putting these data in comparable forms, and combining them to produce certain regional and world aggregates.

Because the electric power industry is important not only in its own right but also because of its role in human affairs, Guyol has carried his study into an exploration of certain factors affecting or affected by the industry. He observes some relationships between the quantities of electricity consumed and amount of work performed in the economy as a whole and in particular sections of the economy.

In 1971, Darmstadter (4) studied quantitative aspects of long run trends in energy consumption, production, foreign trade, and transformation of the world's fuel base away from coal and toward oil and natural gas during this century. He pointed out that these latter changes, which occurred at different times and rates in the major geographic regions, were particularly important for two reasons: they reflected significant changes which were taking place in the world's industrial life and in economic activity in general. Furthermore, they caused wholly new patterns of regional economic interdependence. This interdependence was seen most sharply in the industrial countries such as Japan, those in Western Europe and now the U.S. upon largely underdeveloped regions such as the Middle East and North Africa for their petroleum requirements.

In 1972, Felix (5) concluded that the industrialized nations need extra energy resources, because only increasing prosperity could provide a successful challenge to the environmental problems. These extra resources were also required to contribute more than they had in the past to needs in the underdeveloped areas within their own borders, as well as to reduce the growing gap between the industrialized nations as a whole and the developing world.

Freeman (6) wrote that there were several trends which combine to influence the future availability of energy. According to him these contributing factors include: 1) forecast of continued exponential growth in energy use, 2) forecast of continued growth in the portion of energy used as electricity, 3) continuing expectancy of the affluent to achieve an improved quality of life, 4) depletion of domestic oil and gas reserves, 5) concern for environmental protection.

Cook (7) studied the energy use pattern in the U.S. for 1970 and pointed out that two of the primary sectors of the budget, transportation and electric power generation, are responsible for the relative inefficiency of energy usage. He also noted that electricity accounted for only fifteen percent of useful work performed, yet it is the component of energy people worry about most. This is because electric power generation has been increasing at a rate of seven percent annually (doubling every 10 years), whereas the energy budget has been increasing about 3.2 percent annually. The American Petroleum Institute claimed that the energy budget would increase at 4.1 percent annually in the coming decade. This indicates that per capita consumption is constantly increasing, which suggests that even strict birth control is not going to eliminate the need for more power (8).

Altman, et al. (9) also agree that continued exponential growth cannot continue forever. The reasons for this are simple: 1) the rate of utilization of fossil fuel, and in the near future nuclear fuels, is becoming a large fraction of the total supply. 2) The waste products of energy utilization such as waste heat and air and water pollutants are also becoming extensive enough to have adverse affects on the environment.

Multiple authors have assembled data on energy consumption in the past and some have forecasted future trends. Hottel and Howard (10) and Starr (11) have traced energy usage back to 1850, when wood was the dominant fuel, and documented the rise of coal, petroleum, natural gas, and hydroelectric power to 1970. Gaucher (12) extrapolated the data from 1800 to 1970 into the 21st and 22nd centuries. Cook (7) summarized the data and projections to the end of the 20th century in terms of the percentage of the total energy consumption attributable to each fuel. In addition, Hottel and Howard and Cook correlated energy consumption with Gross National Product (GNP) and population. Considerable detail on the structure of energy use was presented in Morrison and Readling's report (13) on their energy model of the United States. Ritchings (14) and Cook (15) presented data on the portions of energy used in the residential, commercial, industrial, transportation and power production sectors.

In their study Meadows, et al. (8) concluded: 1) If the present growth trends in the world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth in the world will be reached sometime within the next one hundred years, 2) It is possible to alter these growth trends to establish a condition of ecological and economic stability that is sustainable far into the future, 3) If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success. For example, by examining the various aspects of the energy dilemma, the required technology can be developed to meet the societal objectives.

Man's attempt to improve his living and working conditions requires the expenditure of power. Only three forms of energy are potentially available which could eliminate or significantly reduce the adverse effect on the environment. These are: 1) solar energy, 2) geothermal energy, 3) fusion power. Of these, solar energy utilization is in its infancy; geothermal energy availability is limited; and fusion power is in its research stage.

Altman, et al. (9) argued that the development of solar and possibly fusion energies were a must. Statistics indicate that the United States, with less than seven percent of the world's population, uses roughly 45 percent of the world's resources. A slightly larger ratio applies to the use of nuclear and fossil fuels. If the rest of the world wanted to achieve the United States' rate of energy consumption, this would, according to Altman et al, require an eight-fold increase of the present rate of energy resource production in the world. This would not only be difficult to achieve, but would lead to rapid exhaustion of many of the new commonly-used energy resources. They divided the total energy problem into four main categories: 1) energy needs for propulsion, 2) energy needs for environmental control, 3) energy needs for process heat, 4) energy needs in the form of electric power. They discussed these categories from the points of view of the distant future and the near future.

Landsberg and Schurr (16) reviewed all available energy sources, and reached the conclusion that solar energy was the most desirable form of energy in the long run. Because: 1) its use does not disturb the earth's radioactive equilibrium, 2) its use results in essentially no pollution of any kind, 3) it is an energy source for which one does not have to compete.

Fusion energy appeared next on their list as far as desirability was concerned. They pointed out that it would have the following drawbacks as compared to solar energy: 1) it would produce large amounts of power which would then have to be distributed over a long distance, 2) it could disturb the earth's radioactive balance.

They argued that nuclear fission energy was rather undesirable. It may be needed as a transition system, but in the long run it would suffer from the following disadvantages: 1) safety problems concerning the plants, the shipping and processing of radioactive materials and final disposal, 2) very limited efficiency leading to thermal pollution, 3) psychological resistance based on past failures of fail-safe systems, 4) extreme vulnerability in times of war.

Therefore, Landsberg and Schurr concluded that fossil fueled power plants may yet turn out to be sensible choices particularly if the following developments take place: 1) coal gasification, 2) development of high efficiency turbines, 3) development of waste heat utilization.

B. Energy Forecasts

The prediction of the details for future energy consumption is a difficult process because of the multitude of factors influencing this consumption. Indeed, the measurement uncertainties, the random nature, and the increasing interactions of these factors make energy forecasting an inexact science.

During the past few years numerous forecasts have been undertaken by various organization. Each of these forecasts has its individual characteristics and its own rationale. Some of these forecasts are reviewed in the following pages.

In 1972, a study was done by the Department of the Interior (17) which represented a far-sighted approach based on primarily historical growth patterns. Its purpose was to assess the present energy demand and to forecast the future demand as accurately as possible. It relied heavily on the use of oil and gas to meet the nation's future energy needs. It predicted that 37 percent of the nation's energy will come from petroleum in the year 2000. Of this, only 29.7 percent will come from domestic supplies. The remainder will be required to come from supplemental supplies such as imports or increased production from new reserve discoveries. In addition, it also predicted that 18 percent of the nation's energy for the year 2000 will come from gas. Of this, 28 percent was expected to come from imports.

In the same year, the National Petroleum Council (18) attempted to present a comprehensive look at the U. S. energy outlook for the next 10-15 years. The conclusions in this study were based on supply and demand balances derived from four supply cases and an intermediate demand projection. It assessed the financial requirements implicit in its domestic supply projections and also assessed the balance of trade implications of import projections. The study showed that a very broad range of outcomes in the energy future was possible.

In 1974, the Ford Foundation's study (19) presented three alternative futures based on different assumptions about energy growth patterns. The first future was the "historical growth" scenario which assumed that the use of energy will continue to grow much as it has in the past. The second was a "technical fix" scenario, which maintained the same growth in energy services, but stressed national effort to reduce growth in energy use through improved efficiency. The third was the "zero energy growth" scenario which would require changes in both lifestyles and the economy to reach a steady no-growth state in energy consumption by the late 1980's. Each of these scenarios was further generalized by considering alternative mixes of resources to achieve these futures.

Also in 1974, a study called Megastar (20) was produced. The purpose of this study was to provide a methodology for assessing alternate energy futures and to apply that methodology to the critical evaluation of three previously proposed energy scenarios. These were Westinghouse's Nuclear Electric Economy scenario and the Ford Foundation's technical fix scenario, and a Megastar generated alternative scenario to the Ford technical fix scenario. These three scenarios represented different paths of energy consumption from the present to the year 2000. The objective of this study was to analyze the requirements necessary to realize each of these scenarios and the impacts of those requirements on the society. The study suggested that the decision-makers and the society should have the greatest possible awareness of the implications of alternative policies before decisions were made.

The Project Independence Report (21) was prepared by the Federal Energy Administration (FEA) in 1974. It was initiated to evaluate the United States' energy problems and to provide a framework for developing a national energy policy. However, the study did not recommend specific policy actions. While the Ford Foundation report based its analysis upon three different energy demand scenarios, the FEA report based its analysis primarily on varying assumptions for the price of crude oil. It analyzed various strategies for energy policy based on a world crude oil price of four dollars per barrel, seven dollars per barrel, and the present price of eleven dollars per barrel. The report examined a base case labeled "business as usual" and three alternatives: 1) accelerated development,

2) an effort focusing on conservation and "demand management", and 3) an emergency program whose main elements would be a national stockpiling effort, standby conservation measures, and cooperation among consuming nations. This analysis weighted the nation's domestic energy policy alternatives, not only in terms of their vulnerability to support disruptions, but many other important factors, such as economic and social impacts, environmental effects, and regional differences.

In this thesis, the entire energy field is covered, with special emphasis on electric power. The sources of energy, projected energy supply and demand to the year 2000 on the basis of statistical data are reviewed and a survey of U. S. energy forecasts are made in order to make a comparison between the projections. Some energy-related issues are discussed in light of the projections.

Furthermore, a new approach to optimize energy costs for the utilities and consequently for the consumer is introduced. In order to achieve this, a computerized electric energy cost model has been built for the electric generation by optimum allocation of various fuel-mixes over a period of n years, where the energy is subject to a large number of physical and environmental constraints.

III. ENERGY DEMAND PROBLEM

A. The Role of Energy

The pattern of energy consumption in industrialized societies differs substantially from that in nonindustrialized societies. Nonindustrialized societies still are heavily dependent on the traditional energy sources of antiquity-local solar energy that is made available through the agencies of food, work animal feed, fuel wood, fuel dung, agricultural wastes, windpower, and direct waterpower. Field work is largely accomplished by the power of human and animal muscles, and its energy sources are food and animal feed. Per capita consumption of energy is very small - only a few times the food energy required to sustain life. In contrast, industrialized societies consume large quantities of fossil fuel and electricity, the fuel consisting of coal, oil, and natural gas, and the electricity generated partly from fuel and partly from falling water. Fossil fuels, and to a lesser extent electricity, are shipped long distances from their points of origin to their points of consumption. Per capita consumption of energy is as much as a hundred times that contained in food.

The industrial revolution was man's first significant step toward an energy intensive society. Since then, man has become increasingly dependent on machines to produce goods and services, thereby obtaining a greater yield than would be possible by muscle power alone. But this machinery requires energy, and the level of production of goods and services is more or less proportional to the energy input. In 1970, in the U. S., the social and industrial machinery, which produced 974 billion dollars worth of goods and services, was fueled by some 68.8 quadrillion[1] Btu of energy, nearly all of which was produced from fossil fuel (7).

The efficiency of energy use in producing goods and services depends on the kinds of goods and services produced and the technical efficiency of the industrial machinery. It is unquestionably desirable to increase the technical efficiency of our energy conversion devices, since the same useful products could therby be made available with less fuel. This can only be done through further technological advances. It is interesting to note that the average heat rate of electric power plants in the U. S. in 1920 was 37,200 Btu/kWh (22), but in 1970 it was about 10,900 Btu/kWh (23). The technical efficiency of the total U. S. energy system, from potential energy at points of initial conversion to work at points of application, is about 50 percent. The economic efficiency of the system is considerably less. This is true because work is expended in extracting, refining and transporting fuels, in construction and operation of conversion facilities, power equipment and electricity-distributed networks, and in handling waste products and protecting the environment (7-27). The technical efficiency of energy utilization will continue to change with technological innovation, and the kinds of goods and services that people want will change with time. In forecasting, one attempts to anticipate these changes in a quantitative way. Any technological change must be preceded by research, development, and field application of new concepts. In the energy field, each stage requires a huge investment in technical manpower and capital. Energy research must compete for funding with other

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[1] One quadrillion = 10^{15} in this study, as is common in U. S. usage.

projects of high national priority - and the needs are usually greater than the resources. Technical manpower also is limited, since knowledge and expertise in any new field are limited. These human and monetary restrictions generally delay major technological changes in the energy field. Furthermore, even after the R & D stage and the production of a successful prototype, more time passes before a new process can be integrated with the existing social structure. Consequently, it takes much time, perhaps decades, for a society to implement major technological changes in the energy field (7). Development of nuclear technology can be mentioned as an example.

A measure of a nation's production of goods and services is its gross national product (GNP). Figure 3.1 shows the relationship between GNP per capita and energy consumption per capita for a number of countries in 1968 (28). As one might expect, there is a strong general correlation between energy consumption and GNP, but it is far from being a one-to-one correlation. Some countries have a high level of energy consumption with respect to GNP; other countries have high output with relatively less energy consumption. Such differences reflect contrasting combinations of energy-intensive heavy industry and light consumer-oriented and service industries (characteristic of different stages of economic development), as well as differences in the efficiency of energy use.

B. Energy Consumption Growth

The annual consumption of all forms of energy in the U. S. has increased seventeenfold in the past century, with a corresponding population

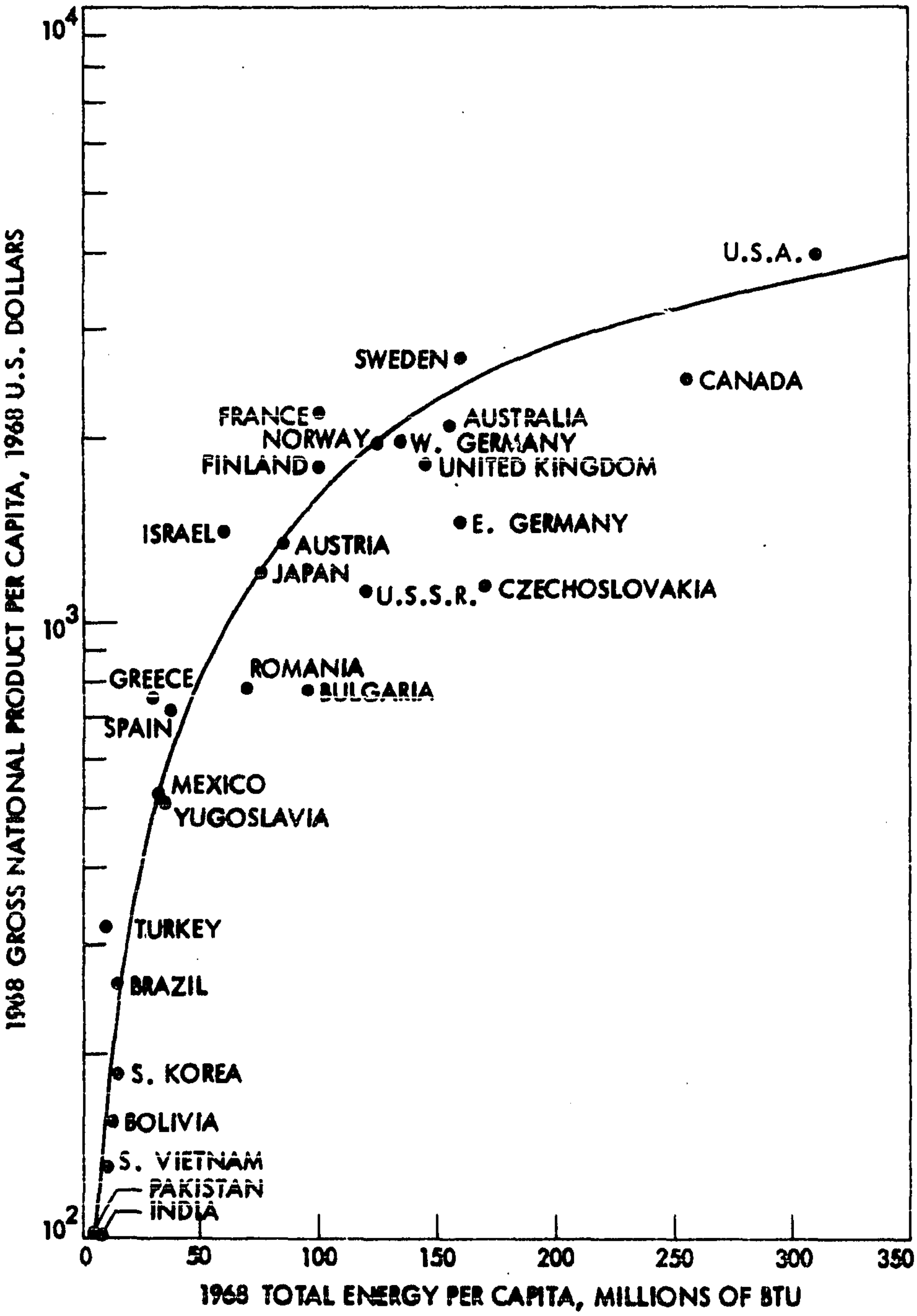

Figure 3.1. Total energy consumption per capita versus GNP for various countries in the world in 1968 (28)

increase of little more than fivefold. Figure 3.2 shows this trend, using statistics from the U. S. Bureau of Mines (11). The growth rate of total energy consumption since 1850 has been 2.8 percent. The great depression of the 1930's had a retarding effect on the growth. The growth rate from 1960 to 1970 was about 4.8 percent per year. The total energy consumption during the period from 1850 to 1970 was approximately 2.34 Q, where one Q is equal to 10^{18} Btu. Fuel wood was the dominant energy source in 1850. By 1910 coal accounted for about 75 percent of the total energy consumption and fuel wood accounted for only some 10 percent. In the 50 years between 1910 and 1960, coal lost its leading position to natural gas and oil. Today, nuclear power is emerging as a national energy source.

Until roughly the beginning of the twentieth century, all energy production involved combustion of fuel at the point of energy use. However, a new industry was born when the first electric power station, Pearl Street Electric Station in New York City, went into operation in 1882. The electric utility industry grew rapidly, at first primarily to meet illumination requirements, but later to provide for many other uses. The history of electric energy sales in the U. S. is shown in Figure 3.3, which shows a growth rate of about 7.53 percent per year. By 1920, the production of electricity accounted for about 11.5 percent of the annual energy demand. The portion of total energy consumption used in electric power production continued to rise, as shown in Figure 3.4, and today's power plant use is about 25 percent of the national energy consumption.

Part of the tremendous increase in energy consumption since 1850 is

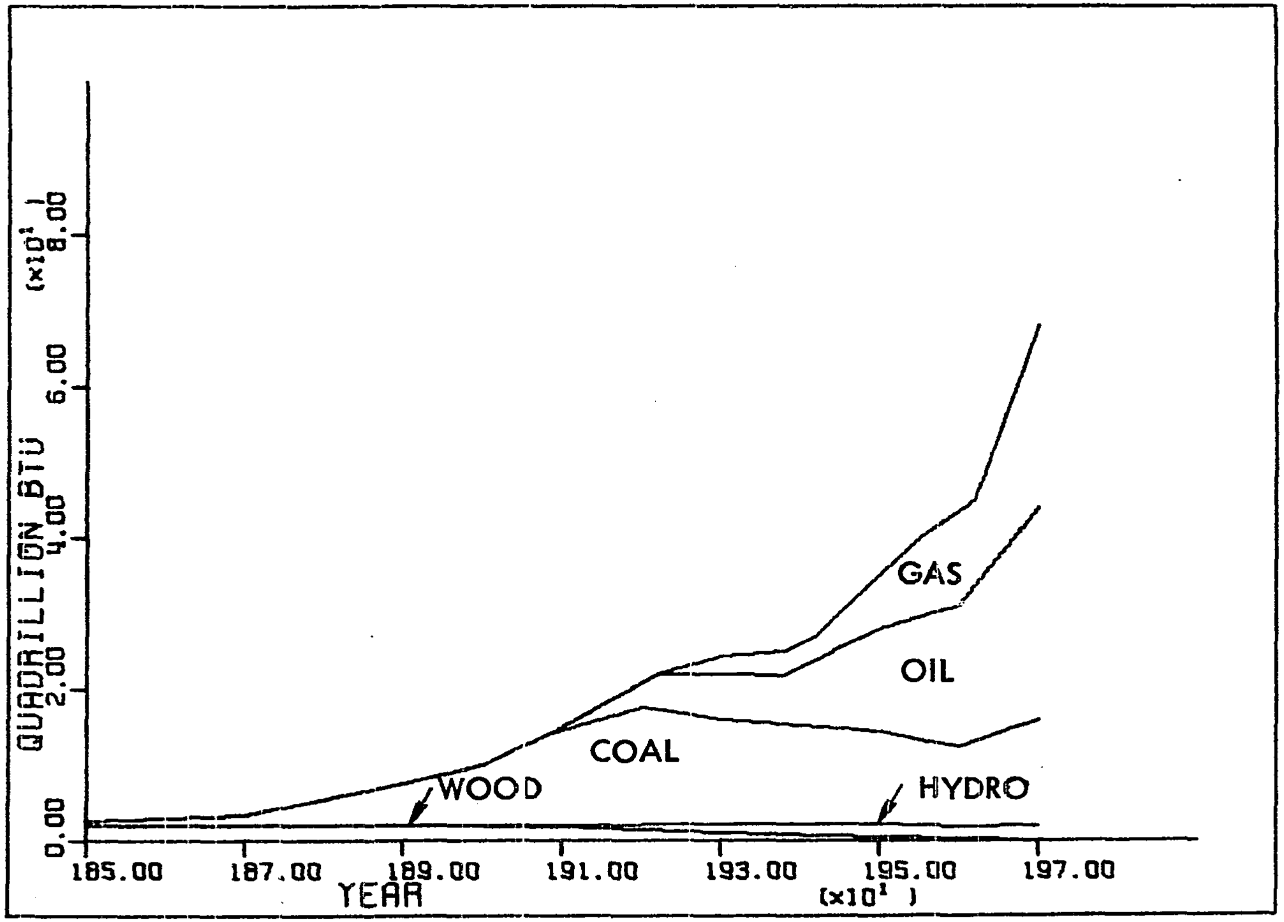

Figure 3.2. Historical total energy consumption in the U. S. (11)

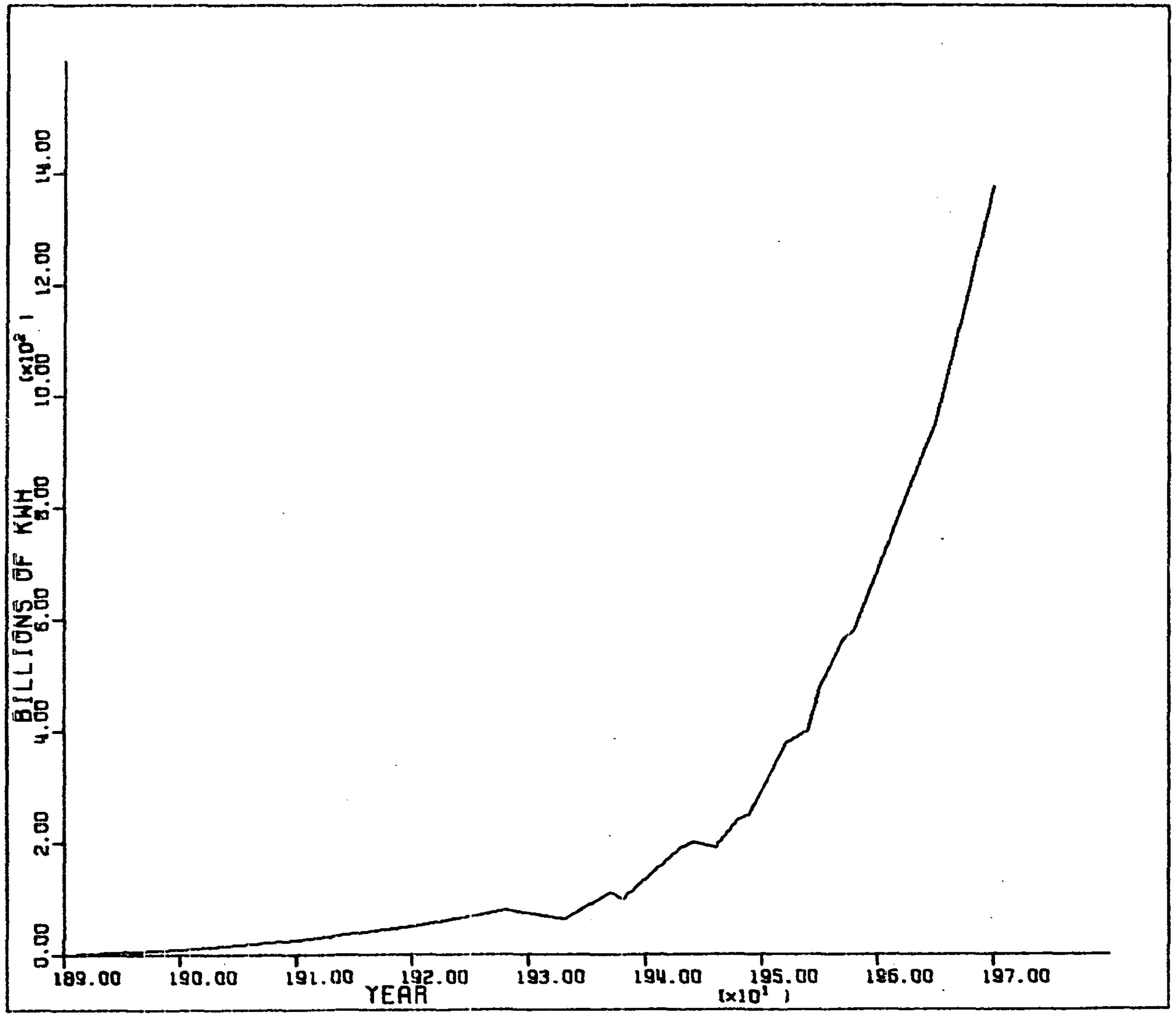

Figure 3.3. Historical electric energy consumption in the U. S. (35)

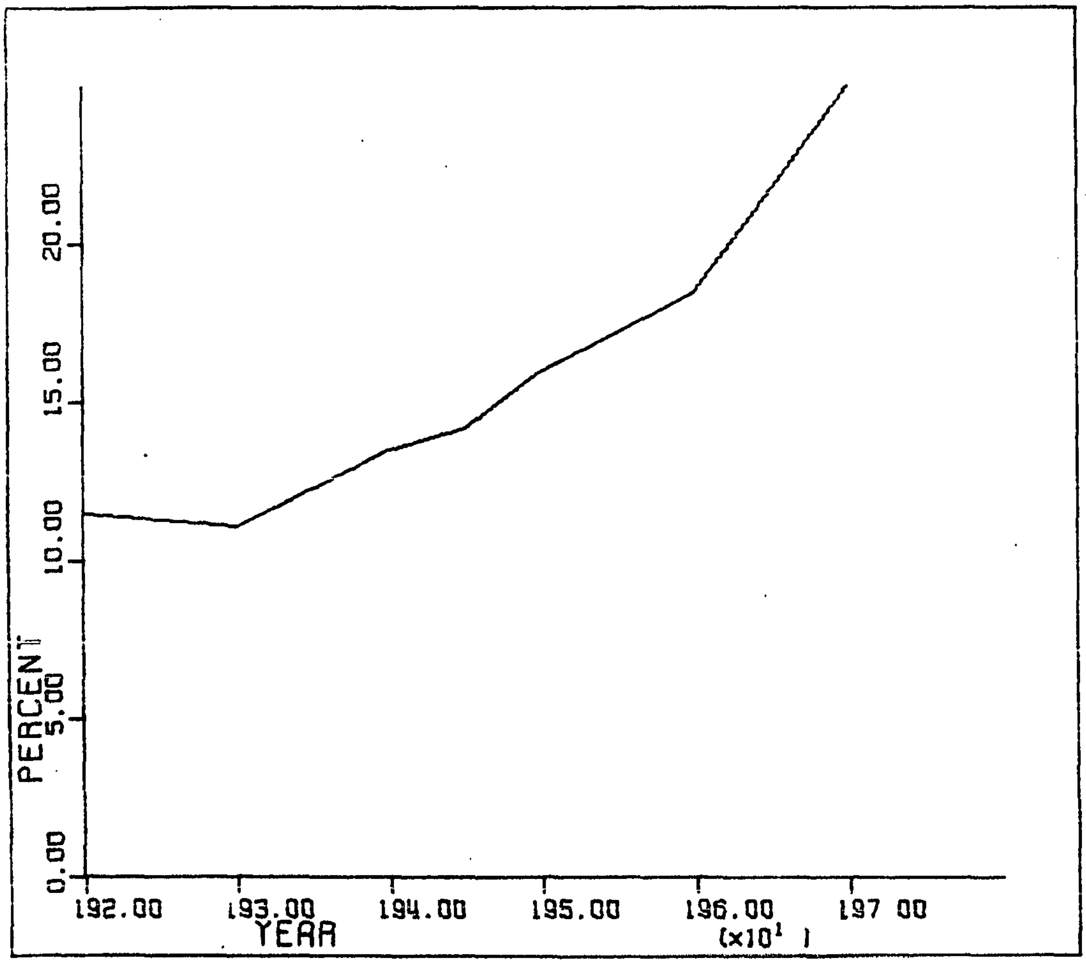

Figure 3.4. Historical total energy converted to electricity in the U. S. in percent

at least partially attributable to population growth. The U. S. population increased exponentially from about 23 million in 1850 to about 208 million in 1970, which is equivalent to approximately 1.74 percent per year. The growth in total energy consumption was even faster. Consequently, the per capita consumption of energy also increased substantially during this period. Figure 3.5 shows the growth in per capita energy consumption from the period of 1850 to 1970, which was necessary to sustain a similar increase in the average living standard. Growth in per capita energy consumption was equivalent to about 1.03 percent per year during this period. However, there was virtually no growth at all in the per capita use of energy during the three decades from 1850 to 1880. The effective growth rate from 1880 to 1970 was about 1.21 percent per year, and the growth rate during the last two decades, 1950 to 1970, has been about 2.29 percent per year.

C. Energy Consumption

An examination of the amount of energy utilized by various sectors of the U. S. economy reveals that much of the recent increase is due to increased utilization by the household, commercial and transportation sectors, rather than by the industrial ones. In 1970, almost 10 percent of the country's useful work was done by electricity. Figure 3.6 indicates the role of the electric utility industry in supplying the nation's energy needs. The numerical values shown in this figure are based on information from several sources (22, 23, 29, 30, 31).

All energy conversion produces unrecoverable waste heat. This heat

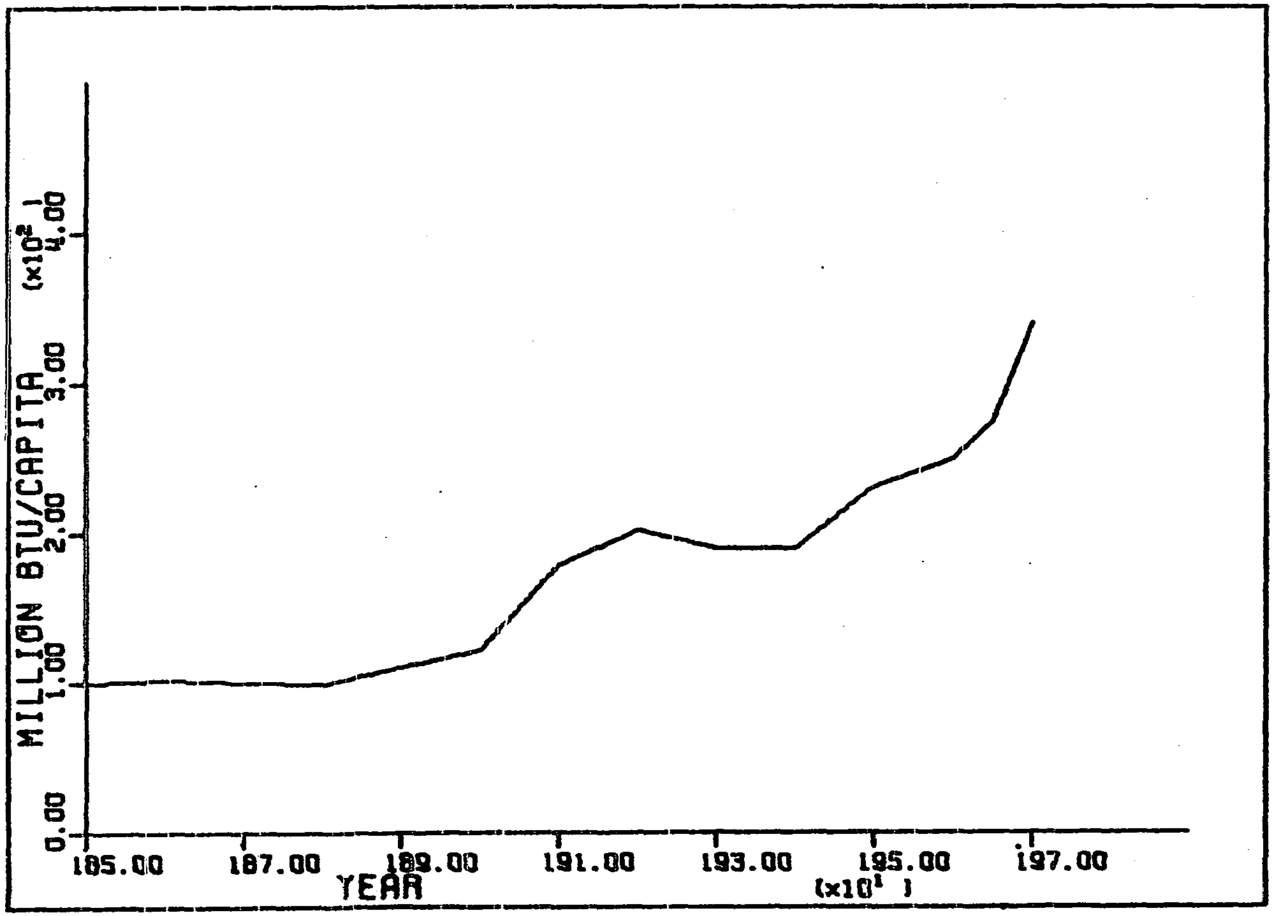

Figure 3.5. Historical energy consumption per capita in the U. S. (30)

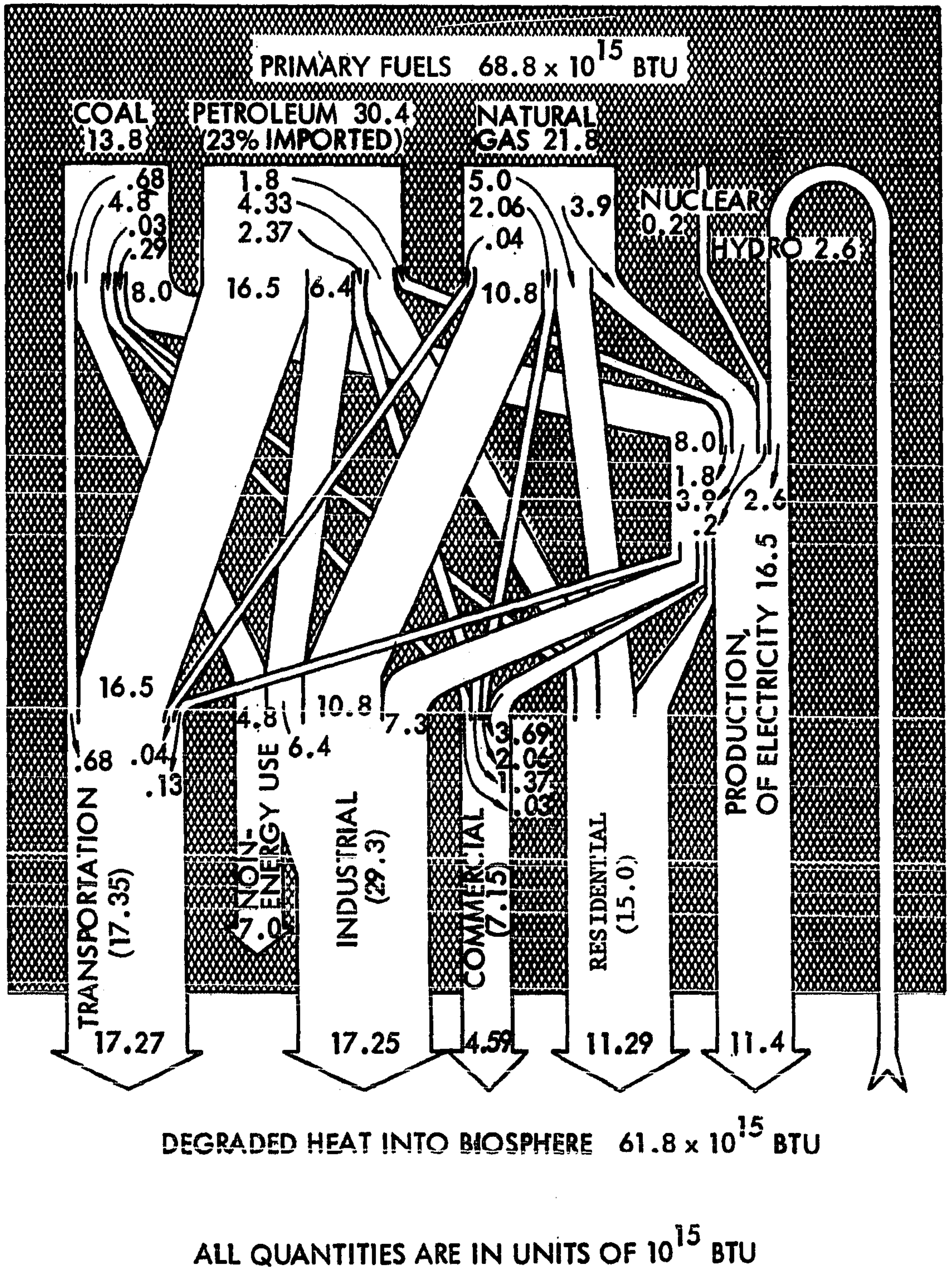

Figure 3.6. Energy consumption in the U. S., 1970

ultimately radiates to space. The worldwide man-made thermal load, however, is so small compared with the solar heat load as to be insignificant on a global scale. In the year 2000 the worldwide use of energy will still be much less than a thousandth of the sun's heat input to the earth. Nevertheless, one can expect that the concentrated generation and consumption of energy in densely populated areas will be capable of affecting both the local climate and ecological systems. According to Starr, the only practical solution may be to limit the population density of our major cities (11).

The top of Figure 3.6 shows the primary energy sources, and the bottom of the figure shows user categories. The electric power industry used about 24 percent of the primary energy, 31 percent of that in producing electrical energy, and in the process losing 69 percent of it as waste heat. The waste heat was rejected at the power plant, and not shipped to the user location, as in the case of the other three quarters of the primary fuel (23).

Horizontal dimensions in Figure 3.6 are approximately proportional to the quantity of energy in 10^{15} Btu. Petroleum and natural gas are the dominant fuels, supplying over 75 percent of the primary energy required for the nation. Coal represents a smaller proportion of the supply, about 20 percent, and the rest is primarily hydro and nuclear energy. Small and insignificant sources are ignored for simplicity. About 23 percent of the oil requirement was provided by imports (29, 31).

The four ultimate user sectors are dimensioned to reflect the quantity of energy they consume, including their share of the waste heat produced at the electric power plants. This total consumption is divided into primary fuel consumed and electricity used. The industrial sector generally accounts for the greatest share of energy use, about 43 percent; the transportation sector uses somewhat less, 25 percent; and the residential sector is still less, 22 percent. The commercial sector uses the least, accounting for about 10 percent of all energy consumption (29).

All energy conversions are more or less inefficient, of course, as the figure clearly indicates. In the case of electricity, there are losses at the power plant, in transmission and at the point of application of the power; in the case of fuels consumed in end uses, the loss comes at the point of use. The waste heat produced at electric power plants, 11.4×10^{15} Btu, does, of course, enter the biosphere. Nearly all of the electric energy that is carried to various points of use, degrades to heat. Other fuels consumed in the user sectors degrade to heat, except for a portion of fossil fuel used for nonenergy purposes, which amounts to nearly one-third of the primary energy used in the industrial sector. Thus, the energy associated with these industrial raw materials, equivalent to about 7.0×10^{15} Btu in 1970, does not become degraded heat in the environment. In this category are such items as lubricating oil, asphalt for road surfaces, chemical feedstock, etc. (22, 28).

Of all the energy fuels used in 1970, only hydropower contributes no net heat to the biosphere. The reason for this is that hydropower begins as solar energy and is converted to hydraulic energy in the water cycle. It would degrade to heat whether or not part of it became electricity in the process.

Fossil fuels, of course, also represent stored energy from the sun, but the storage process has occurred slowly over millions of years. The rate of release of this stored energy is so rapid when it is burned that it amounts to a large net input of heat into the biosphere. For this reason, approximately 59.2 x 10^{15} Btu of heat were added to the biosphere through human energy processing in the United States in 1970. Figure 3.6 is a useful reference, and offers a quantitative description of the entire energy system in the United States today. It also puts various fuels and consuming sectors in their proper perspective.

D. U. S. and World Population Growth

The birthrate in the U. S. is declining. The historical low, recorded during the 1930's, was 18.4 births per 1000, while at the peak of the baby boom in 1957 the rate was 25.3 births per 1000. In 1974, it stood at only about 14.8, the lowest in U. S. history (32, 33). The birthrate was 17.7 per thousand people in 1969, while the death rate was 9.5 per thousand. Thus, although the birthrate has declined steadily since the mid 1950's, as shown in Figure 3.7, it is still considerably greater than the death rate (34).

Another indicator, the total fertility rate, has also reached a historical low. This is the sum of the rates at which women, taken in groups of 1000 at each of the reproductive ages, bear children in any particular year. In 1974, the rate was decreasing and was down to nearly 1,800. This figure implies that if all women born in a given year were to bear children at that rate over their entire reproductive lives, they would eventually bear an average of 1.8 children each.

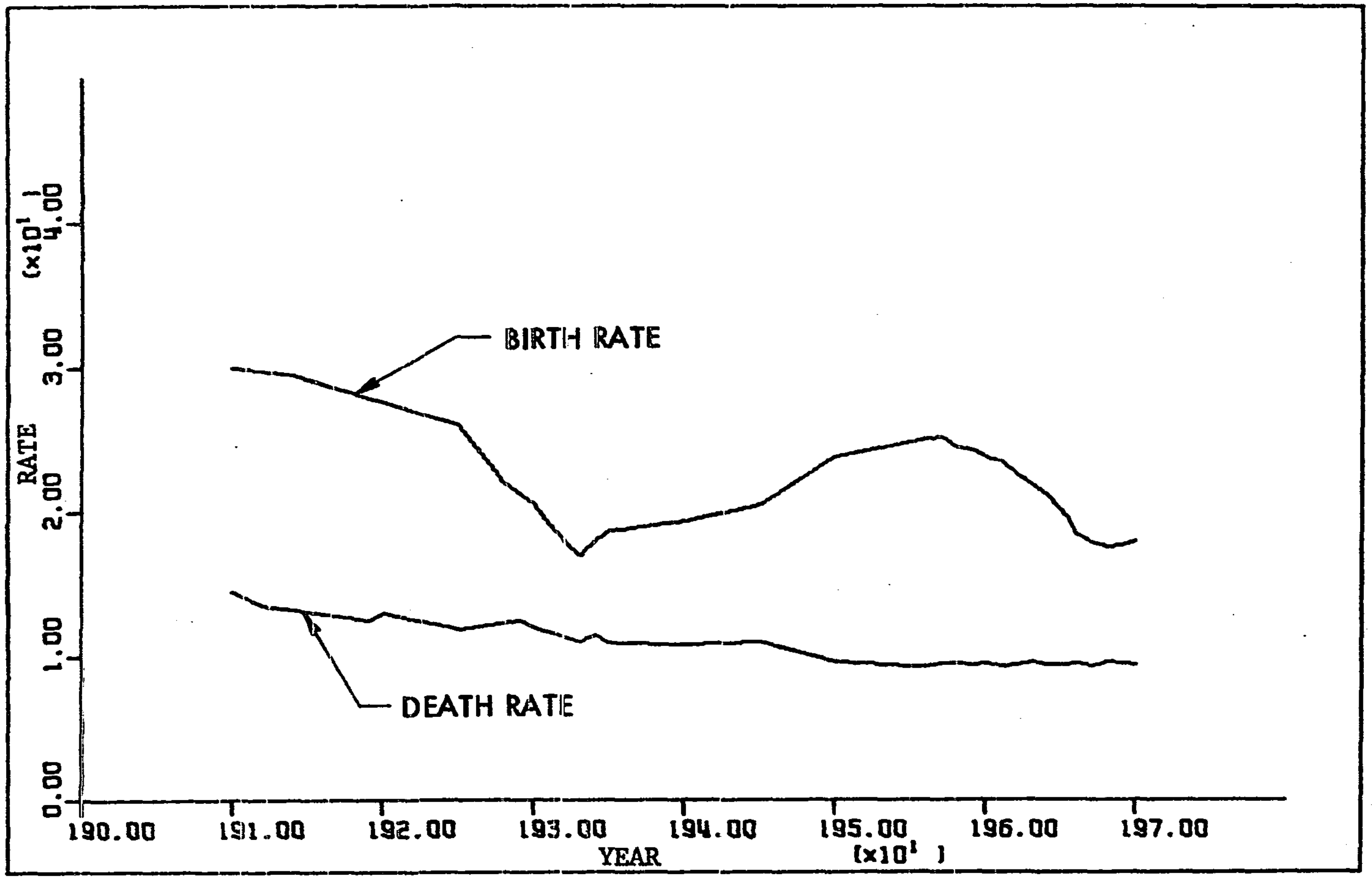

Figure 3.7. Historical birth rates and death rates in the U. S. (34)

The present low total fertility rate is of special interest because it is in the range that, if continued over the long run, would stop U. S. population growth or cause it to decline. A group rate of 2.1 children per woman is equal to the U. S. replacement rate. That rate would produce a stationary population - that is, zero population growth (ZPG) in about sixty years or so, if the same level of fertility were to continue in the future (32, 33, 34).

The demographers use "demographic transition" theory to explain what happens to population growth as tradition-bound societies become modernized. In the first stage, according to this theory, improved public-health practices and better nutrition enable people to live longer, causing death rates to decline sharply. But, birthrates remain high, and hence, the population grows rapidly. In the next stage, the society becomes more urban and better educated. This tends to keep children out of the work force longer, thus they become more of a cost to the parents than a source of income. Moreover, as modernization continues, people are able to save more money to provide for the needs of their old age, and governments may even start public pension systems. These developments reduce the need for parents to rely on children for financial support in later life. Because of these factors, families have fewer children. Unfortunately, the theory is vague about what happens when a demographic transition is completed. Demographers do agree, however, that a low birthrate is characteristic of the final stage of the transition. In that sense, the U. S. and at least nineteen other developed countries with low fertility rates may be nearing the end of their transitions (34).

There is a striking difference between U. S. and world population growth, which are shown in Tables 3.1, 3.2, and Figure 3.8 and 3.9. The rate of population growth in the U. S. has been decreasing during the last century, whereas the world population growth rate has been increasing. In general, the industrialized countries of the world have had lower population growth rates than the less-developed countries in recent years, as is shown in Table 3.2 (35). It is apparent that the present rate of world population growth cannot be sustained indefinitely. According to Starr, environmental or other restrictions will sooner or later cause the death rate to increase substantially, and the least developed countries will be the first to suffer (11).

Table 3.1. World population estimates (35)

Year	Population (Millions)
10,000 B.C.	1 ± x 10
1 A.D.	275 ± 80
225	290 Max.
700	270 Min
1000	295
1200	310
1400	350
1650	493
1750	694
1800	887
1850	1,170
1890	1,500
1900	1,550

Table 3.1. Continued.

Year	Population (Millions)
1925	1,907
1950	2,497
1960	2,996
1965	3,297
1970	3,655
1975	4,080
1980	4,562
1985	5,096
1990	5,687
1995	6,278
2000	6,919

Table 3.2 shows some population and economic data for 31 countries of the world. The countries are listed in ascending order of GNP per capita. The table reveals that the GNP of the entire world is 2.88 times that of the U. S. In other words, the U. S. generates 35 percent of all the goods, wealth, and services generated in the world per year.

By an Act of Congress in March, 1970, the U. S. Commission on Population Growth and the American Future was established. It was charged with the responsibility of sponsoring studies of the broad range of problems associated with population growth and their implications for America's future. In the commission's report (33), it was concluded that 1) No substantial benefit will accrue from the continued growth of the U. S. population, 2) A reduction in the growth rate will create

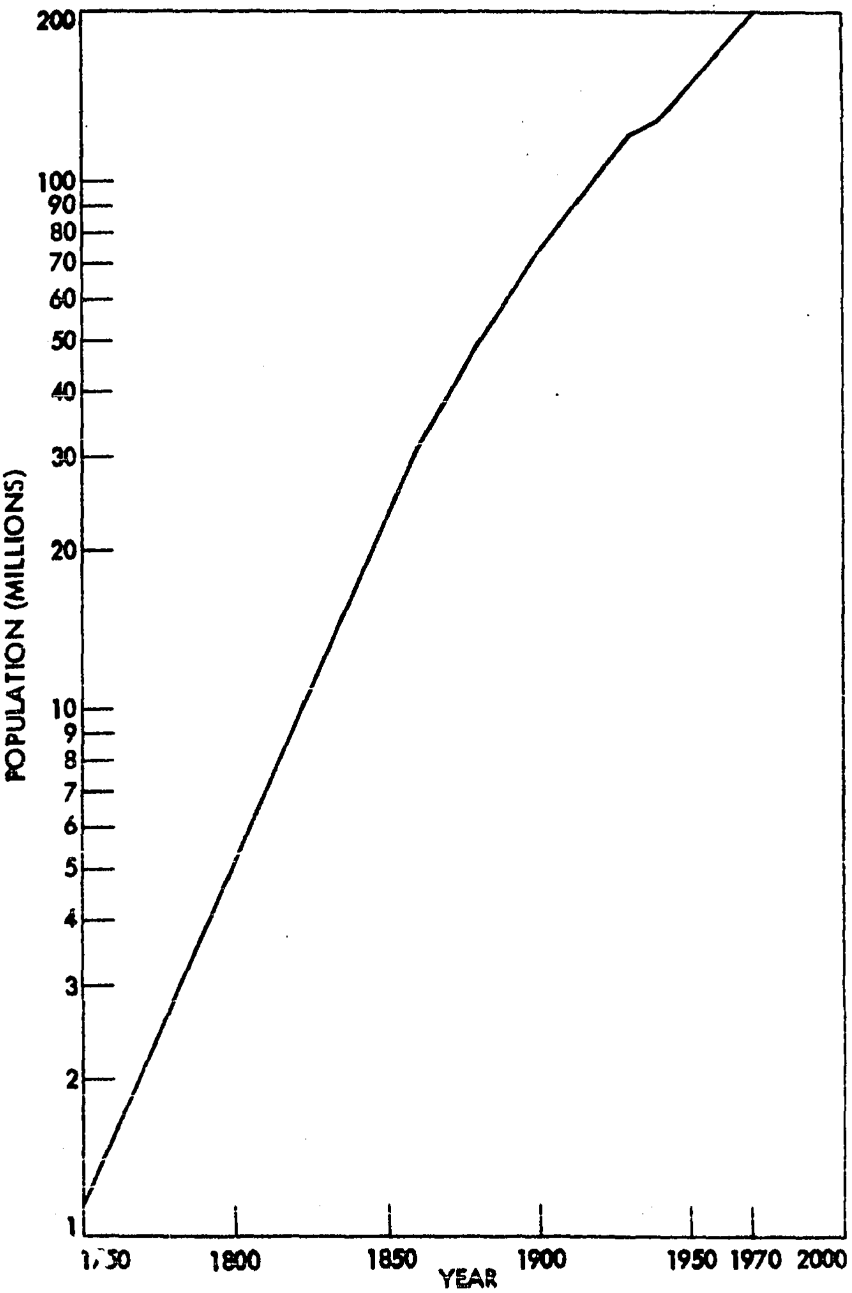

Figure 3.8. Historical population growth in the U. S. (35)

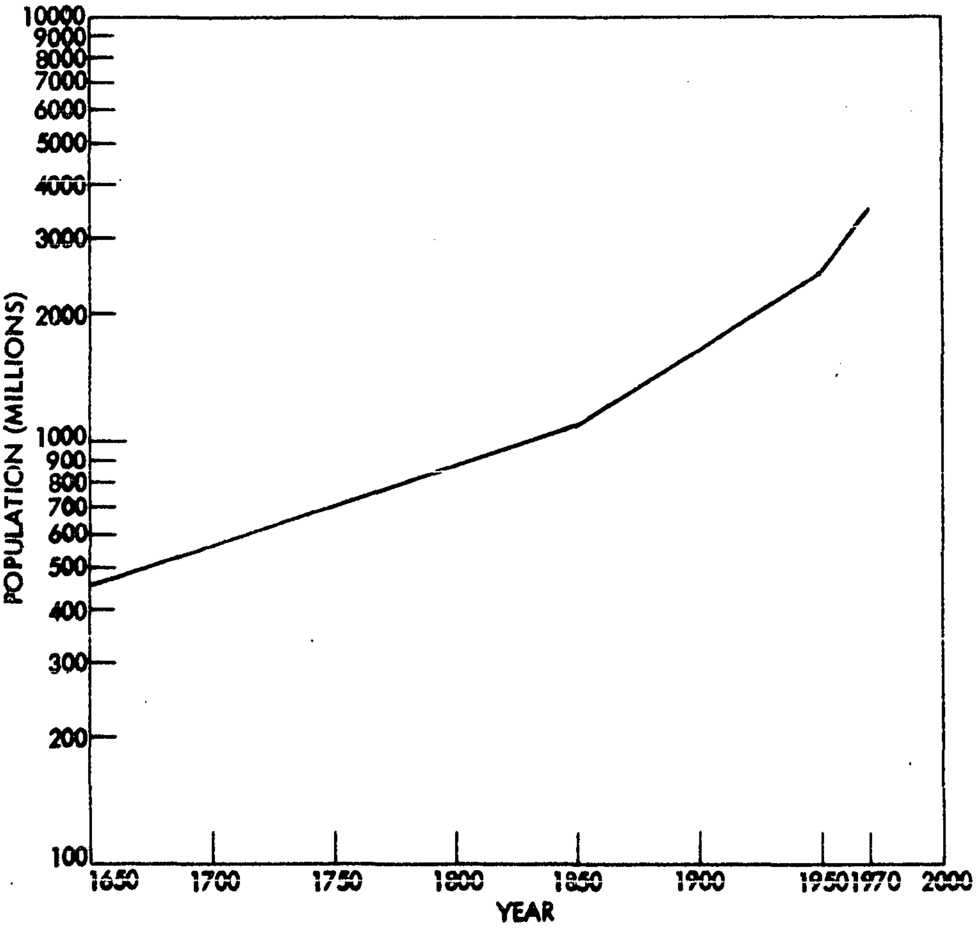

Figure 3.9. Historical world population (See Table 3.1)

Table 3.2. World population data, 1971 (In descending order of GNP per capita) (30)

Countries	GNP per Capita (US$)	Population (10^6)	Birth Rate per 1000 People	Death Rate per 1000 People	Population Growth Rate	Number of Years to Double Population
Southwest Africa	-	0.6	44	25	2.0	35
Ethiopia	70	25.6	46	25	2.1	-
China	90	772.9	33	15	1.8	39
North Vietnam	90	21.6	-	-	2.1	33
India	100	569.5	42	17	2.6	27
Pakistan	100	141.6	50	18	3.3	21
South Vietnam	130	18.3	-	-	2.1	33
Syria	210	6.4	47	15	3.3	21
Brazil	210	95.7	38	10	2.8	25
Iran	310	29.2	48	18	3.0	24
Turkey	310	36.5	43	16	2.7	26
Colombia	310	22.1	44	11	3.4	21
Cuba	310	8.6	27	8	1.9	37
Portugal	460	9.6	19.8	10.6	0.7	100
Greece	740	9	17.4	8.2	0.8	88
Poland	880	33.3	16.3	8.1	0.9	70
Libya	1020	1.9	46	16	3.1	23
USSR	1110	245	17.0	8.1	1.0	70
Japan	1190	104.7	18.0	7.0	1.1	63
Italy	1230	54.1	17.6	10.1	0.8	88

Table 3.2. Continued.

Countries	GNP per Capita (US$)	Population (10^6)	Birth Rate per 1000 People	Death Rate per 1000 People	Population Growth Rate	Number of Years to Double Population
Israel	1360	3.0	26	7	2.4	29
East Germany	1430	16.2	14.0	14.3	0.1	233
Netherlands	1620	13.1	19.2	8.4	1.1	63
Finland	1720	4.7	14.5	9.8	0.4	175
United Kingdom	1790	56.3	16.6	11.9	0.5	140
West Germany	1970	58.9	15.0	12.0	0.4	117
Norway	2000	3.9	17.6	9.9	0.9	78
Canada	2460	21.8	17.6	7.3	1.7	41
Sweden	3540	0.8	43.0	7.0	8.2	9
Kuwait	3540	0.8	43.0	7.0	8.2	99
United States	3980	207.1	18.2	9.3	1.1	58

Cumulative World GNP (1968) = $\$2.304 \times 10^{12}$ = 2.88 x (U. S. GNP).

Number Average National GNP = $1206.

Number Average GNP per capita = $660.

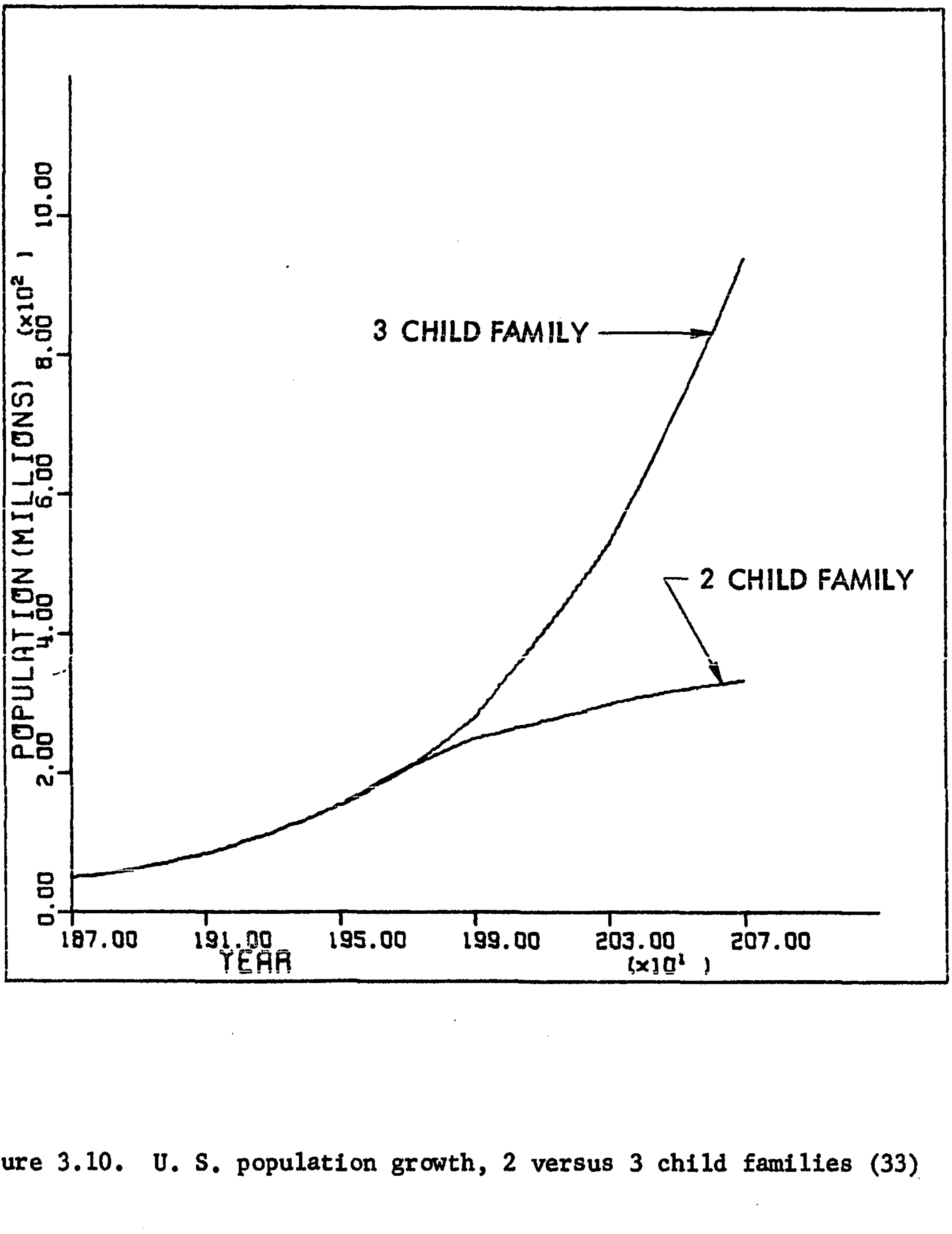

Figure 3.10. U. S. population growth, 2 versus 3 child families (33)

important economic benefits, especially if the nation develops policies to take advantage of the opportunities for social and economical improvement that slower population growth would provide, 3) Population growth is one of the major factors increasing the demand for resources and the resulting detrimental impact on the environment, 4) An average of two children per family will result in zero population growth in the long run.

The Commission's report includes a graph (Figure 3.10) showing the projected future U. S. population assuming the average family has two children rather than three, beginning in 1970. The U. S. population would stabilize in 60 to 70 years if the birthrate were held at about 2.11 children per woman.

It is, of course, very unlikely that the birthrate will stay extremely close to the replacement level for 60 years; it is more likely to fluctuate. But, the goal of zero population growth has been established, and the birthrate has declined to the replacement rate in recent years. The most reasonable and meaningful forecast of U. S. population growth through the next century should be based on a gradually declining growth rate which generates a Gompertz curve (See Appendix B). The growth rates shown in Table 3.3 generate such a curve. Table 3.4 indicates U. S. population as

Table 3.3. Projected U. S. population growth rates

Period	Approximate Population Growth Rate (% per year)	
1950-1960	1.57	Historical
1960-1970	1.31	"
1970-1980	1.22	Projected

Table 3.3. Continued.

Period	Approximate Population Growth Rate (% per year)	
1980-1990	1.01	Projected
1990-2000	0.73	"
2000-2015	0.68	"
2015-2030	0.54	"
2030-2050	0.23	"
2050-2070	0.15	"
2070-2100	0.00	"

projected using the growth rates in Table 3.3. As can be seen from Table 3.4, U. S. population will reach 279 million by the year 2000, 309 million by the year 2015, 335 million by the year 2030, and 361 million by the year 2070. This projection of the U. S. population, based on what the Commission sees as a desirable and achievable goal, is used in the following pages as part of the basis for an energy forecast.

Table 3.4. Projected U. S. population using growth rates in Table 3.3

Year	Population (10^6)	Year	Population (10^6)
1950	152.271[a]	2030	335.110
1955	165.931[a]	2035	338.982
1960	180.684[a]	2040	342.898
1965	194.592[a]	2045	346.859
1970	208.020[a]	2050	350.867
1975	221.001	2055	353.506
1980	234.815	2060	356.165

[a] Historical values.

Table 3.4. Continued.

Year	Population (10^6)	Year	Population (10^6)
1985	246.915	2065	358.850
1990	259.638	2070	361.544
1995	269.254	2075	361.544
2000	279.226	2080	361.544
2005	288.850	2085	361.544
2010	298.805	2090	361.544
2015	309.104	2095	361.544
2020	317.540	2100	361.544
2025	326.207		

E. Energy Forecasts

A forecast is not the same as a prediction. A prediction implies supposed knowledge of what will happen at some time in the future. A forecast is much more cautious. It implies that if a variety of conditions that hold today continue to hold in the future (including, for example, structure of demand and rates of growth), or if these conditions change in ways that are specified as part of the forecast, then a certain future situation will be the result. In essence, forecasters report the probable consequences of present assumptions and present trends. In a sense, forecasts are extensions of the past which are based on certain assumptions. But, if the assumptions are incorrect, so will the resulting forecasts be. Therefore, it is necessary to choose assumptions carefully, bearing in mind that they are the basis for the forecasts. Since judgement plays a part in long range forecasting, it is fruitful to examine forecasts in the same discipline that have been made by others. In the energy field, many forecasts have been prepared in recent years. An extensive tabulation of these appears in the following pages.

GNP and energy consumption in the U. S. have increased at about the same rate for many years. For this reason, many energy forecasts have been based on the assumption that this relationship will persist. From 1920 to 1970, the U. S. real GNP, in 1958 dollars, increased from 140 billion to 720 billion dollars, equivalent to about 3.35 percent growth annually. During the same period, energy use grew from 20 x 10^{15} Btu to 68.8 x 10^{15} Btu, equivalent to 2.53 percent annual growth. Thus, the ratio of energy use to real GNP declined over this 50 year period, as shown in Figure 3.11 (29, 36). However, since 1966, the energy/GNP ratio has been climbing. Whether this reflects a changing ratio of services to material goods in the GNP, or a reduction in the efficiency of energy use in the production of goods, is not yet clear. At any rate, the historical decline in the energy/GNP ratio will not necessarily continue. In fact, environmental cleanup is likely to consume tremendous amounts of energy in the future, yet it will contribute little to the GNP, at least as the GNP has historically been measured (37). Thus, many of the earlier energy forecasts, which are based on continued growth of GNP and a declining energy/GNP ratio, probably predict energy levels in the year 2000 which are too low.

Any attempt to forecast the future growth of energy use requires a

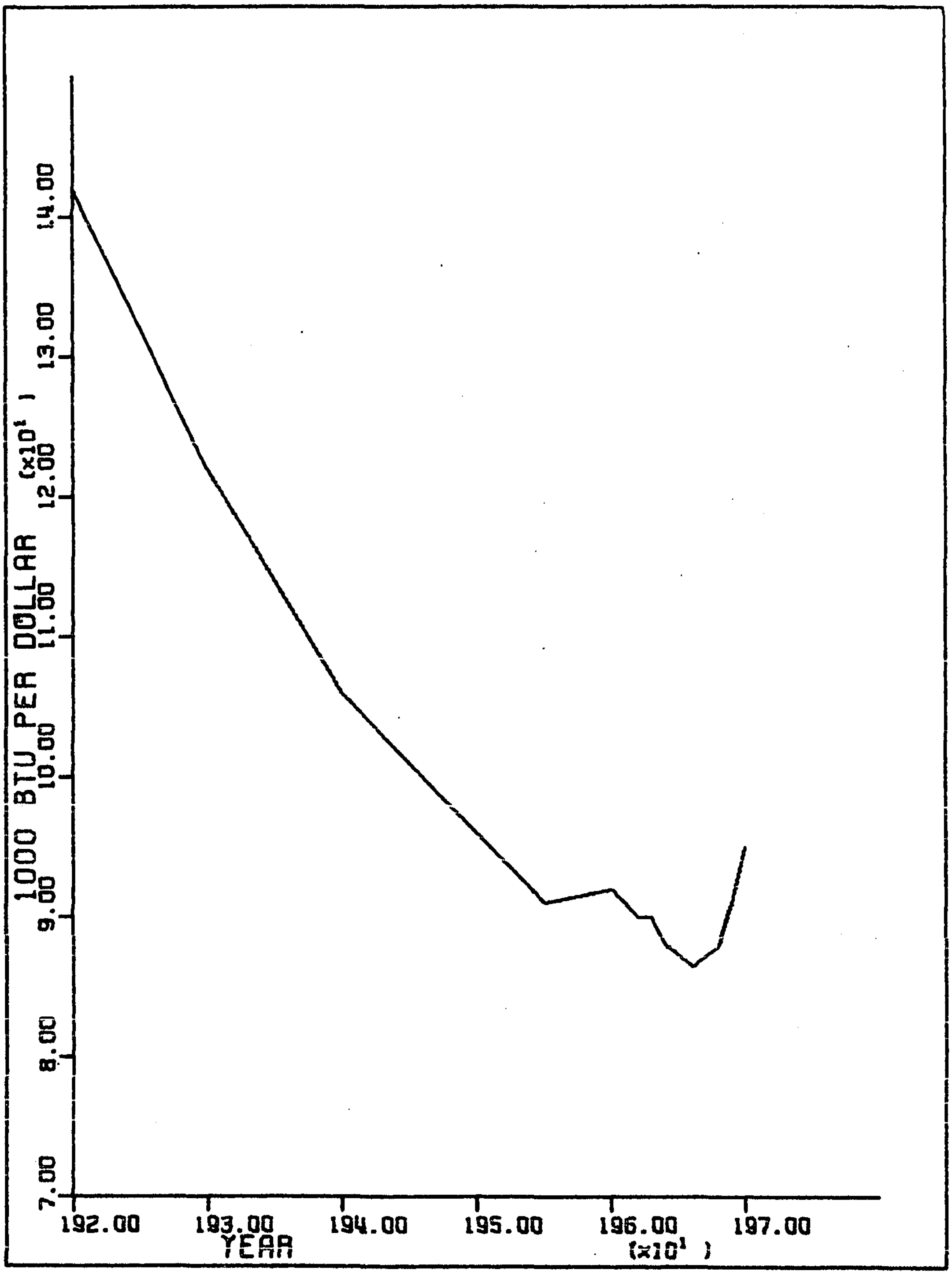

Figure 3.11. Historical energy/GNP ratio in the U. S. (28)

thorough analysis of the forces which might possibly sustain the historical trend or cause it to increase, and of those forces which might retard or limit it. However, in attempting to forecast energy growth for three decades into the future, it is important to consider the past three decades as providing the most relevant portion of historical data. If conditions during the next three decades were the same as during the last three decades, the energy growth rate would be the same. Since this obviously will not be the case, the probable differences must be examined. However, the extrapolation of a historical trend can be a valid forecast in itself, although perhaps a crude one (38). This initial forecast can be improved through qualitative examination of possible accelerating and retarding forces. One of the factors which tends to cause the energy use growth trend to continue is the expectation of continued population growth through the year 2000. As can be seen in Figure 3.10, the population growth rate will not fall off significantly until about the year 2000, even if the birthrate remains at the replacement level. But, population growth has only been about 1.2 percent per year, while energy growth rate was about 3.4 percent during the period from 1940 through 1970, and has been even higher in the last few years. Thus, population growth, in itself, is insufficient to maintain this historical trend in energy use growth.

Many forecasts predict growth in real GNP at an annual rate of 3.5 to 4 percent through the year 2000 (39, 40). While it is difficult to defend this projection scientifically, it is likely that people, government officials, and industrialists will strive hard to achieve it. Thus, it is reasonable to expect the GNP to increase during the next three decades more or less as it did in the past three, 4.2 percent annually from 1938 through 1970. However, the historical reduction in the energy/GNP ratio will probably not continue. At present, the most reasonable expectation may be that this ratio will level out over the next 30 years (41), whereupon, energy growth would proceed at about the same rate as the GNP.

Energy will gradually become more expensive in the future, which is a reversal of the historical trend. This will occur primarily for two reasons: the cost of fuel production and the cost of environmental protection (43). The price of fuel is increasing because the most accessible reserves have been depleted, as they were extracted first. Environmental protection, a relatively new aspect of the energy field, is increasing the cost of energy because it requires the use of cleaner, more expensive fuels. If the energy industry uses the more abundant but dirty fuels, it will incur major capital expenses and operating penalties. There is no major technical difficulty in meeting environmental standards in the next three decades, although short-term schedules for air and water pollution control may be unrealistic (44). However, environmental protection will significantly raise the cost of energy (37). Within the bounds of the elasticity of energy demand, higher prices may discourage some of the growth in energy use. Higher cost should also provide an impetus to increase the efficiency of energy conversion and energy use (45).

In summary, the factors affecting future energy growth are population growth, GNP growth, technological developments and environmental energy requirements on one hand, and expected higher energy prices on the other. Considering these qualitative factors and the historical trends in energy consumption and economic growth, it appears that an annual energy growth rate of 3.5 - 4 percent is most likely and quite reasonable for the period from 1970 to 2000 (46). This conclusion differs little from the energy forecasts of others, as shown in Tables 3.5 and 3.6. Table 3.5 shows, in 10^6 Btu, various forecasts of total energy consumption per capita for the U. S., while Table 3.6 shows, in 10^{15} Btu, total energy consumption forecasts for the U. S. Forecasts, in MBtu of upper and lower limits and means for total energy consumption per capita for the U. S. are calculated and shown in Table 3.7. Several forecasts indicate significantly slower future growth, but they were prepared before the upturn in the energy/GNP ratio became apparent in the mid-1960's. Other forecasts are rather similar, while some predict an even higher future energy growth rate. The forecasts for the year 2000 range from 105 x 10^{15} to 337 x 10^{15} Btu. Based on consumption of 68.8 x 10^{15} Btu in 1970, this represents a range of 3.0 to 4.0 percent in the effective annual growth rate. Figure 3.12 shows the historical growth of energy use in the U. S. and the preferred "average" forecast to the year 2000, in addition to the ranges of most other forecasts. This forecast has a 3.5 percent compound growth rate.

As shown in Figures 3.3 and 3.4, electricity consumption has grown significantly faster than total energy consumption, accounting for 25 percent of total energy use in 1970. Table 3.8 shows, in percent, forecasts of total energy converted to electricity in the U. S., from

Table 3.5. Forecasts of total energy consumption per capita for the U. S. in MBtu

Year	EAE Ref. (22)	USEP Ref. (145)	USE Ref. (147)	EUR Ref. (150)	ETTY Ref. (150)
1850	102	-	-	-	-
1855	103	-	-	-	-
1860	101	-	-	-	-
1865	96	-	-	-	-
1870	99	-	-	-	-
1875	97	-	-	-	-
1880	100	-	-	-	-
1885	99	-	-	-	-
1890	111	-	-	-	-
1895	111	-	-	-	-
1900	126	100	-	-	-
1905	158	136	-	-	-
1910	179	160	-	-	-
1915	177	160	-	-	-
1920	201	186	-	186	-
1925	193	180	-	-	-
1930	192	181	-	181	-
1935	161	150	-	-	-
1940	190	180	-	180	-
1945	233	225	-	-	-
1950	231	224	225	224	223
1955	246	240	-	242	239
1960	-	248	250	250	246
1965	-	277	-	279	274
1970	-	-	337	335	329
1975	-	-	412	-	371
1980	-	-	-	-	419
1985	-	-	563	-	479
1990	-	-	-	-	-
1995	-	-	-	-	-
2000	-	-	720	-	686

CGAE Ref. (61)	EUS Ref. (61)	FFF Ref. (61)	PCCP Ref. (61)	PEC Ref. (61)	TCUS Ref. (61)
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
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-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	268
220	230	-	-	278	-
251	260	291	288	-	-
284	295	-	-	-	-
320	337	332	336	358	366
357	386	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	439	474	499	524

Table 3.6. Total energy consumption forecasts for the U. S. in 10^{15} Btu

Source	Ref. No.	1970	1975	1980	1985	1990	2000	2020	2050
Schurr	150	-	75	-	-	-	-	-	-
Weeks	150	-	-	92	-	-	187	-	1110
McKinney	150	63	72	-	-	-	-	-	-
Landsberg	61	60	-	79	-	102	135	-	-
Sporn	150	-	72	-	-	-	105	-	-
Sporn	60	69	-	-	116	-	155	-	-
Sporn	150	-	-	78	-	-	-	-	-
Putnam	150	-	63	88	-	-	148	-	-
Teitelbaum	150	-	67	80	-	-	-	-	-
Searly	150	62	73	86	-	121	170	-	-
Jones	162	70	86	105	130	-	-	-	-
Lasky	150	-	-	82	-	-	-	-	-
Lamb	150	60	68	78	-	-	-	-	-
Vogely	61	-	-	86	-	-	-	-	-
NAE	41	69	-	102	-	151	223	-	-
CGAEM	61	64	80	98	120	-	-	-	-
EUS	61	61	75	93	118	-	-	-	-
NFES	61	-	-	82	-	-	-	-	-
RAF	61	60	-	79	-	-	135	-	-
PEC	61	-	-	86	-	-	-	-	-
ER	61	-	-	61	-	-	-	-	-
OEUS	-	-	-	97	-	-	-	-	-
USP	61	-	-	88	-	-	-	-	-
EMUS	61	64	76	88	-	-	169	-	-
PCCP	61	-	-	91	-	-	155	-	-
FFF	61	-	-	86	-	-	170	-	-
TCUSEC	61	-	-	90	-	-	174	-	-
BOM	41	-	-	-	-	-	168	-	-
Starr	11	-	-	-	-	-	168	-	-
NPC	18	68	-	103	125	-	-	-	-

Table 3.6. Continued.

Source	Ref. No.	1970	1975	1980	1985	1990	2000	2020	2050
White	61	-	-	-	-	-	170	-	-
EBASCO	23	67	-	104	-	-	-	-	-
BATTELLE	61	-	-	-	-	-	170	-	-
AEC	150	-	-	82	-	-	135	207	347
AEC	150	-	-	80	-	-	130	210	-
Vogely	150	-	88	-	-	-	-	-	-
Vogely	163	-	-	84	-	-	159	-	-
E. World	150	-	81	-	-	-	125	-	-
Dole	155	70	-	98	-	130	-	-	-
Ritchings	158	-	80	-	110	-	-	-	-
Nassikas	36	-	95	-	-	140	-	-	-
Laird	36	-	-	-	-	-	-	-	-
Morton	36	69	-	-	133	-	192	-	-
GCG	62	67	-	115	-	195	337	-	-
H. & H.	10	69	-	95-105	-	-	177-210	-	-
USET	17	-	80	96	117	-	192	-	-
USE	147	69	89	-	133	-	192	-	-
Landsberg	150	-	-	84	-	-	138	-	-
Searle	150	-	-	86	-	-	178	-	-
RFF	150	-	75	-	-	-	-	-	-
EBASCO	150	-	72	-	-	-	-	-	-
RFF	150	-	-	79	-	-	-	-	-
PAP	151	-	-	87	-	-	-	-	-
SRI	151	-	-	92	-	-	-	-	-
FNCB	151	-	-	87	-	-	-	-	-
PIR	151	-	-	92	-	-	-	-	-
HO	151	-	-	97	-	-	-	-	-
Mills	162	66	77	89	-	-	163	-	-
DOI	61	-	-	84	-	-	159	-	-
Shaw	152	-	-	80	-	-	131	-	-

Table 3.6. Continued.

Source	Ref. No.	1970	1975	1980	1985	1990	2000	2020	2050
Perry	152	65	-	95	-	125	165	-	-
Nassikas	162	66	-	95	-	140	-	-	-
DOI	150	-	-	73	-	-	123	-	440
DOI	150	-	-	82	-	-	160	-	750
Evans	161	-	-	90	-	120	150	-	-
Weeks	150	-	-	90	-	-	180	-	-
TE	150	-	-	83	-	-	-	-	-
McKinney	150	-	-	81	-	-	-	-	-
Schurr	150	-	-	88	-	-	-	-	-
TE	150	-	-	81	-	-	-	-	-
RANGE:		60-70	63-95	61-115	110-133	102-195	105-337	207-210	347-1110
AVERAGE:		65.6	77.2	88.2	122.4	136.0	160.4	208.5	661.8

Table 3.7. Upper and lower limits and mean for total energy consumption per capita forecasts for the U. S. in MBtu

Year	High	Mean	Low	Comment
1850	102	102.0	102	Historical
1855	103	103.0	103	"
1860	101	101.0	101	"
1865	96	96.0	96	"
1870	99	99.0	99	"
1875	97	97.0	97	"
1880	100	100.0	100	"
1885	99	99.0	99	"
1890	111	111.0	111	"
1895	111	111.0	111	"
1900	126	113.0	100	"
1905	158	147.0	136	"
1910	179	170.0	160	"
1915	177	168.5	160	"
1920	201	191.0	186	"
1925	193	186.5	180	"
1930	192	184.6	181	"
1935	161	155.5	150	"
1940	190	183.3	180	"
1945	233	229.0	225	"
1950	231	225.4	223	"
1955	246	241.8	239	"
1960	268	252.4	246	"
1965	279	259.7	220	"
1970	337	298.7	251	"
1975	412	340.5	295	Forecasted
1980	419	352.6	320	"

Table 3.7. Continued.

Year	High	Mean	Low	Comment
1985	563	446.3	357	Forecasted
1990	-	-	-	"
1995	-	-	-	"
2000	720	557.0	439	"

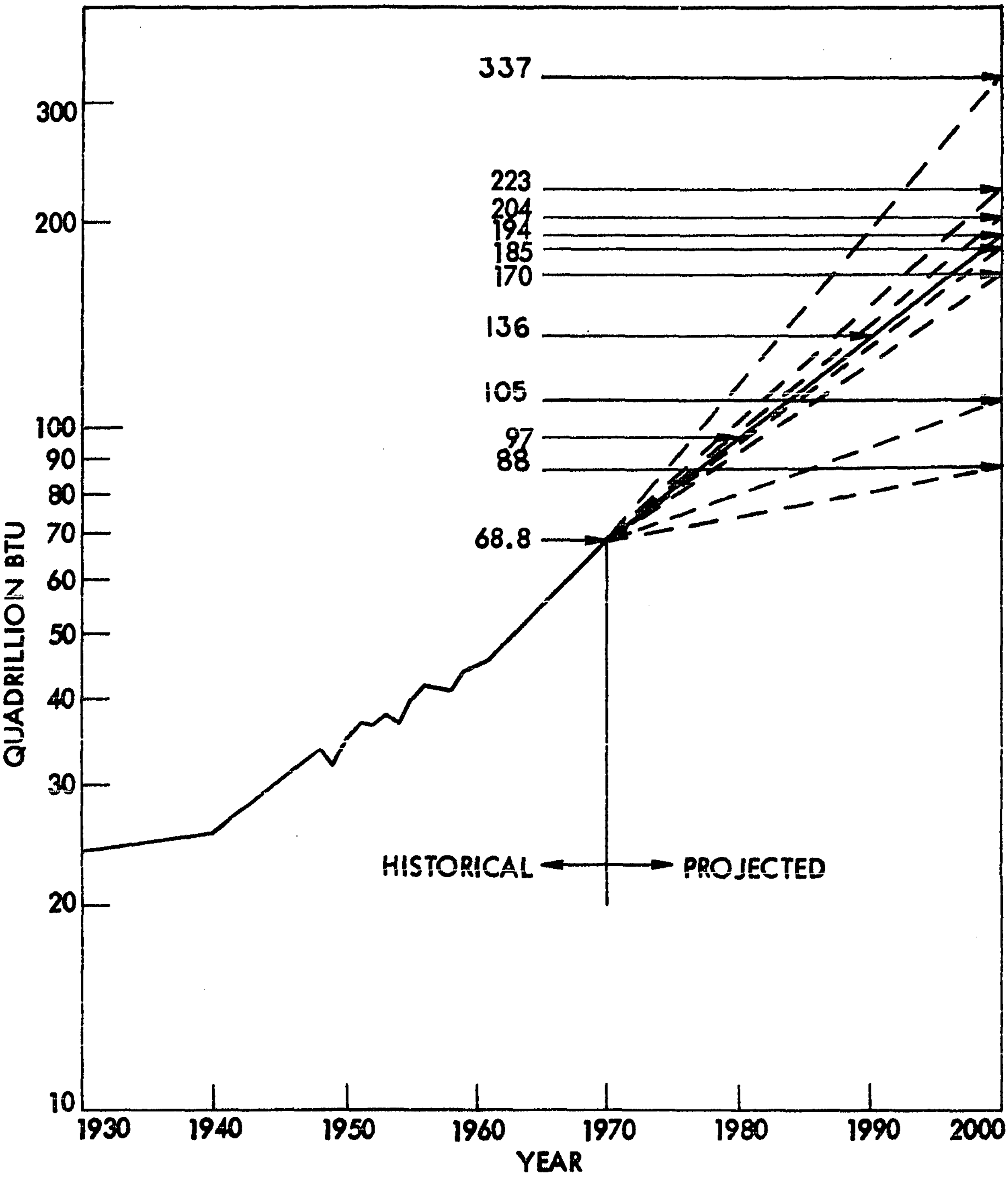

Figure 3.12. Historical and projected energy consumption in the U. S. (See Table 3.6)

Table 3.8. Forecasts of total energy converted to electricity in the U. S. in percent

Source	Ref. No.	1970	1975	1980	1985	1990	2000
EUS	61				38		
FPC	65	26				41	
WH	31	25		35		50	
USET	17		28	31	35		42
Sporn	60				35		53
GCG	62	24			29		37
EBASCO	23	25		29			
NAE	41	25		33		42	46
Starr	11	25					38
CMB	18	25		33	37		
NPC	23	25		32	36		
RANGE:							
		24-26	28	29-35	29-38	41-42	38-53
MEAN:							
		25.0	28.0	32.2	35.0	44.3	43.2

1970 to the year 2000. The ranges of the forecasts and the "average" forecast are also shown in this table. In order to find the curve best fitted to this "average" forecast, a number of regression models were tested. The polynomial regression model of

$$TFC = b_0 + b_1y + b_2y^2 + e \qquad (3.1)$$

proved to be the best with a correlation coefficient of 0.980 and regression coefficients $b_0 = 123677.686$, $b_1 = -125.807$, and $b_2 = 0.0319$. Use of analysis of variance to test the null hypothesis of

$$\begin{aligned} H_0&: \ b_j = b_{j0} \\ H_1&: \ b_j \neq b_{j0} \end{aligned} \qquad (3.2)$$

at the 0.05 level of significance, resulted in sound rejection of the hypothesis. Table 3.9 illustrates the analysis of variance. According to this regression analysis, electricity production will account for 39 percent of the total energy use by the year 2000. The results are shown in Tables 3.17 and 3.21.

Table 3.9. Analysis of variance table for the null hypothesis

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed f(2,n-3)	Critical $f_{0.05}(2,n-3)$
Regression	216.895	2	108.447	49.473	9.55
Error	4.384	2	2.192		
Total	221.280	4			

In the past, electric energy and the electric energy industry have grown very rapidly because electric energy was convenient, efficient, clean, flexible, and inexpensive at the point of use. Fuel costs were not a dominant factor affecting this growth. But, in the future this situation will be totally different. In 1972, fuel costs were already 80 percent of the annual production costs, as can be seen from Table 3.10 and Figure 3.13.

Table 3.10. Weighted average annual production costs for fossil-fueled electric plants, in mills per kWh (43)

Year	Operation and Maintenance	Fuel	Total
1958	0.91	2.94	3.85
1959	0.85	2.82	3.67
1960	0.85	2.81	3.66
1961	0.81	2.78	3.59
1962	0.79	2.75	3.54
1963	0.75	2.66	3.41
1964	0.74	2.64	3.38
1965	0.75	2.60	3.35
1966	0.73	2.61	3.34
1967	0.77	2.65	3.42
1968	0.75	2.68	3.43
1969	0.76	2.77	3.53
1970	0.83	3.15	3.98
1971	0.94	3.77	4.71
1972	0.99	4.06	5.05

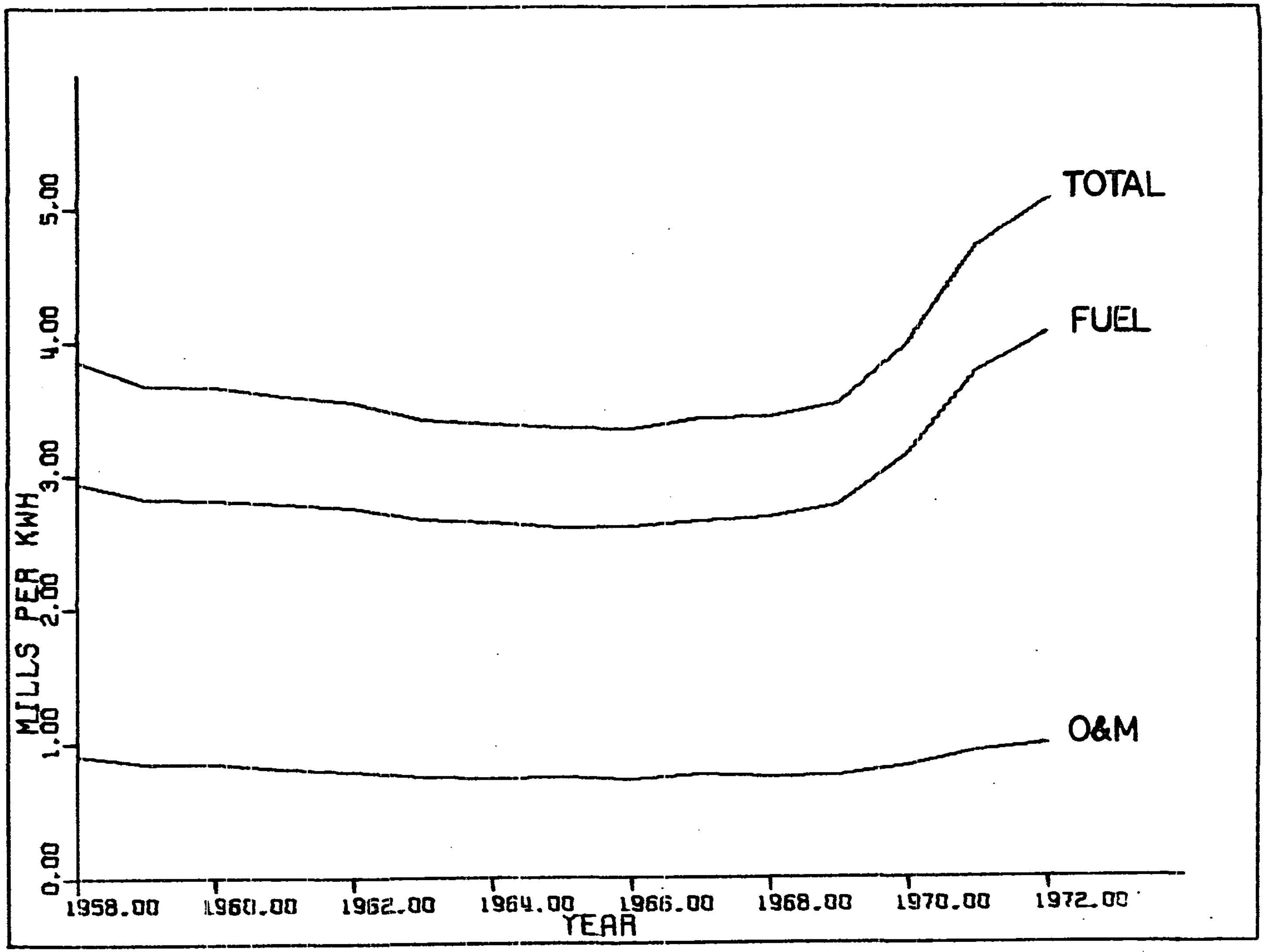

Figure 3.13. Weighted average annual production costs for fossil fueled electric plants (See Table 3.10)

Table 3.11 and Figure 3.14 show the weighted average fossil fuel costs, "as burned", for electric utility steam-electric generation from 1962 through 1972.

Table 3.11. The weighted average fuel costs, for electric utilities, in cents per MBtu (43)

Year	Coal	Gas	Oil	Weighted Average
1962	25.6	26.4	34.5	26.5
1963	25.0	25.5	33.5	25.8
1964	24.5	25.4	32.7	25.3
1965	24.4	25.0	33.1	25.2
1966	24.7	25.0	32.4	25.4
1967	25.2	24.7	32.2	24.7
1968	25.5	25.1	32.8	26.1
1969	26.6	25.4	31.9	26.9
1970	31.1	27.0	36.6	30.7
1971	36.0	28.0	51.5	36.4
1972	38.0	30.3	58.8	39.9

Having remained stable since the end of World War II, the average price for fuel in the U. S. suddenly started to increase in 1969, long before the Arab oil embargo, in concert with inflation. According to the Edison Electric Institute, the fuel cost per kWh in the U. S. in 1975 will be more than double its 1969 level. Therefore, rising fuel costs, though clearly a significant strain on the financial structures of the public utilities, will eventually, and sometimes immediately, be

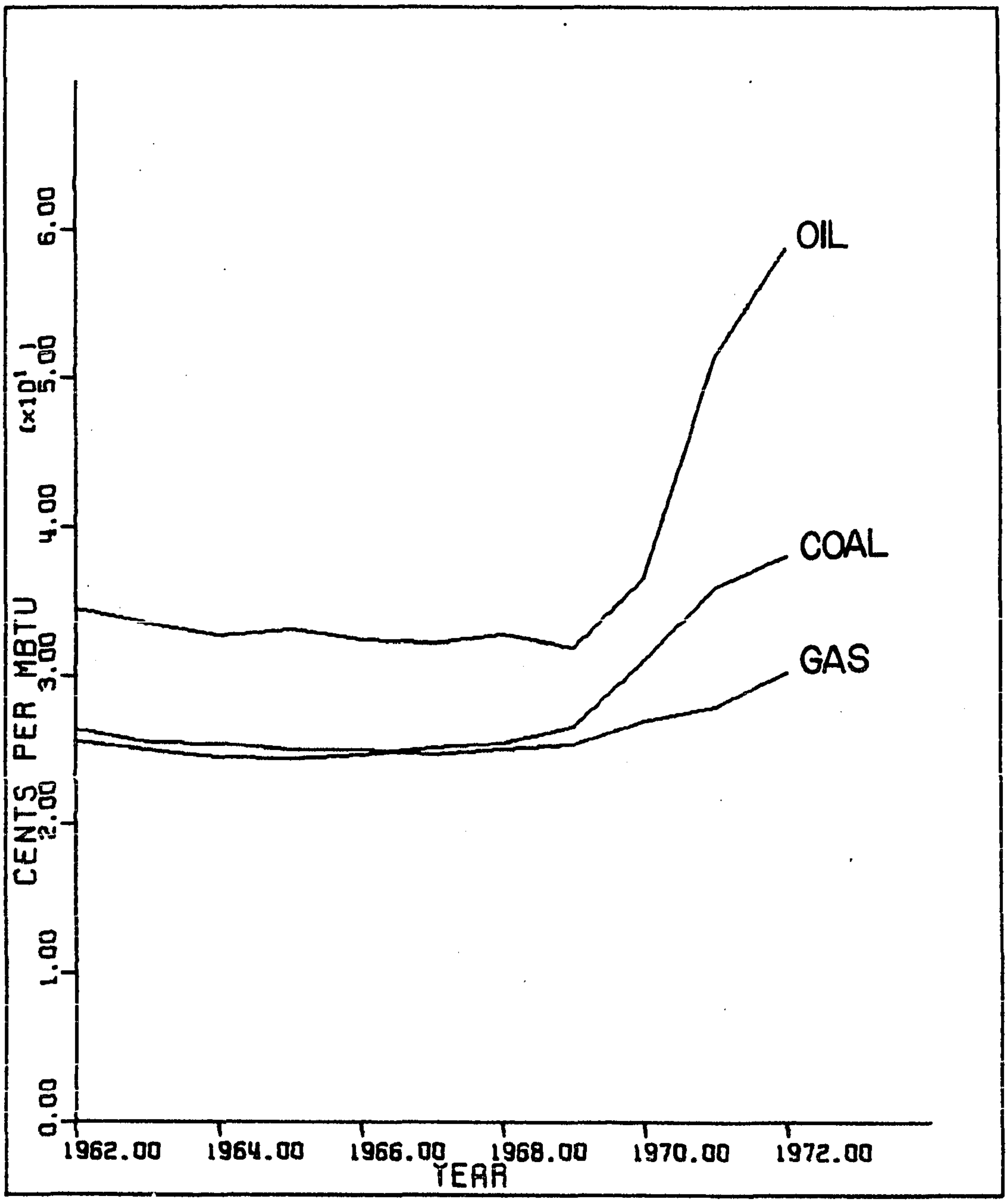

Figure 3.14. Weighted average fossil fuel costs for electric utilities (See Table 3.11)

passed on to the consumer in the future, which may, in turn, affect the growth of electrical energy consumption. Far more dangerous in the long run are four other factors: 1) the effect of the high cost of money in the U. S. on capacity-expansion funding, whether it is for nuclear or conventional technology, 2) inflation-whipped equipment and labor costs, 3) the effect of U. S. energy conservation practices on utility revenues, and 4) increasing environmental expenses.

Nevertheless, increasing affluence and higher living standards will lead to increased ownership of home appliances, such as air conditioners, dishwashers, compactors, self-defrosting refrigerators, and color televisions. Thus, the electricity consumption of the consumer sector is likely to continue to increase in the future.

In 1970 the U. S. consumed 1,550 billion kWhs of electrical energy. Forecasters generally agree that the demand for electrical energy will continue to increase at nearly constant compound growth rates for the rest of the century. Table 3.12 shows a survey of electrical energy forecasts for the U. S. In order to find the curve best fitted to the "average" forecast shown in Table 3.12, a number of regression models were tested. The polynomial regression model of

$$\mathrm{TFC} = 269357.336 - 496.998y + 0.183y^2 + e \qquad (3.3)$$

proved to be the best, with a correlation coefficient of 0.992. The results of the regression analysis are shown in Tables 3.17 and 3.21.

In 1973, the electrical power peak load for the U. S. was 343,900 MW (43). Table 3.13 shows a number of electrical power peak load forecasts

Table 3.12. Survey of electrical energy forecasts for the U. S. in 10^9 kWh

Source	Ref. No.	Electric Energy Consumption (10^9 kWh)							
		1970	1975	1980	1985	1990	2000	2020	2050
DOI	61	1522	2063	2729	-	-	-	-	-
AEC	150	-	-	2700	-	-	8000	-	-
Senate	150	-	-	2700	-	-	-	-	-
FPC	150	1484	2024	2693	-	-	-	-	-
TE	61	1448	1995	2581	3363	-	-	-	-
BOM	150	-	-	2739	-	-	-	-	-
Sartorius	61	1323	1885	2740	3905	-	-	-	-
Nathan	61	-	-	2641	-	-	5874	-	-
E. World	150	1500	2026	2757	3704	-	-	-	-
TE	150	-	-	2760	-	-	-	-	-
FPC	150	-	-	2990	-	-	-	-	-
RFF	150	-	-	2300	-	-	-	-	-
Sporn	150	-	-	2800	-	-	-	-	-
Schurr	150	-	1966	2300	-	-	-	-	-
Sporn	150	-	2000	3000	-	-	6000	-	-
Sporn	150	-	2160	2820	-	-	7000	-	-
Sporn	60	1529	-	-	4000	-	8640	-	-
FPC	41	1535	-	3075	-	5828	10,000	-	-
NAE	41	1638	-	3202	-	5978	10,150	-	-
PCCP	61	-	-	2641	-	-	5870	-	-
DCC	63	1400	-	-	-	-	10,000	-	-

Table 3.12. Continued.

Source	Ref. No.	Electric Energy Consumption (10^9 kWh)							
		1970	1975	1980	1985	1990	2000	2020	2050
GCG	62	1400	-	-	-	-	12,000	-	-
WH	31	-	-	3085	-	5700	-	-	-
EW	64	1391	-	2804	3820	5380	-	-	-
USE	147	-	-	-	-	-	10,677	-	-
USET	17	-	2130	3000	4140	-	9010	-	-
WH	150	1489	-	2626	-	-	-	-	-
EEI	150	1481	-	2795	-	-	8000	-	-
Lamb	150	1450	-	2800	-	-	-	-	-
AEC	150	-	-	2857	-	-	9000	-	-
E. World	150	-	-	3315	-	-	-	-	-
Landsberg	150	1780	-	3088	-	4882	7767	-	-
WE	164	1302	-	2818	-	4813	8125	-	-
FPC	156	1522	2180	3075	4246	5828	-	-	-
EPS	149	1550	2272	-	-	-	-	-	-
EWF	154	1540	2227	3200	4474	-	-	-	-
EWF	153	1497	2103	2927	4041	-	-	-	-
AEC	160	-	-	2700	-	4800	8000	12,500	18,500
FPC	160	-	-	2700	-	-	7100	-	-
Ritchings	158	1500	2020	2750	3700	-	-	-	-
EEIB	148	1527	-	-	-	-	-	-	-
Vogely	158	-	-	2731	-	-	9070	-	-

Table 3.12. Continued.

Source	Ref. No.	Electric Energy Consumption (10^9 kWh)							
		1970	1975	1980	1985	1990	2000	2020	2050
Star	159	-	-	-	-	-	9000	-	-
Felix	159	-	-	3300	-	5700	8850	-	18,950
Mills	157	-	-	-	-	-	9112	-	-
RANGE:									
		1323-1638	1885-2272	2300-3300	3363-4474	4813-5978	5874-12,000	12,500-12,500	18,500-18,950
MEAN:									
		1491.3	2075.0	2830.8	3939.3	5434.3	8511.1	12,500.0	18,725.0

Table 3.13. Electrical power peak load forecasts for the U. S. in 10^3 MW

		Peak Load (10^3 MW)				
Source	Ref. No.	1970	1975	1980	1985	1990
EW	150	262	360	490	650	
FPC	150	271	370	494		
EEI	150	265		501		
EEIB	148	276				
PS	149	275	423			
FPC	150	277	396	554	766	1051
EWF	154	275	390	549	769	
EWF	153	265	370	510	700	
WH	164	275	390	560	790	1045
RANGE:						
		262-277	360-423	490-560	650-790	1051-1045
MEAN:		271.2	385.6	522.6	735.0	1048.0

for the U. S. In order to find the curve best fitted to the average forecast shown in Table 3.13, several regression models were tested. The logarithmic regression model of

$$TFC = e^{-126.331 + 0.066y} \tag{3.4}$$

proved to be the best, with a correlation coefficient of 0.999. The results of the regression analysis are shown in Tables 3.17 and 3.21.

Table 3.14 shows, in percent, several forecasts of what the primary energy sources for electric power generation in the U. S. will be in the future. Forecasters agree that the primary energy sources for electric power generation in the U. S. by the year 2000 will be nuclear energy and coal. Oil, gas, and hydro will comprise only a small proportion of the sources which will be used for electrical energy generation.

At present, the transportation sector is a relatively minor user of electric energy. However, within two decades mass transportation systems for short and medium distance travel in and near urban areas will probably become major electricity users (45, 47). During the years from 1985 to 2000, there may also be an increasing number of electric cars, which could become significant electricity users. The influence of electric vehicles on the power system load factor is discussed in Appendix C.

The most dramatic and direct challenge to increasing energy consumption has emerged from confrontation between the electric utility industry and environmentalists. Environmental concerns are likely to be considered far more important than they have been in the past in future decision-making that affects the energy supply. Environmentalists

Table 3.14. Forecast of primary sources for electric power generation in the U. S. in percent

Source	Ref. No.	Year	Coal	Oil	Gas	Hydro	Nuclear
CMB	18	1965	55.0	6.0	21.0	18.0	0.0
		1970	49.0	11.0	24.0	15.0	1.0
		1980	35.0	2.0	14.0	13.0	36.0
		1985	29.0	17.0	11.0	8.0	35.0
GCG	62	1970	49.2	13.7	21.4	14.4	1.3
		1980	21.2	16.7	10.6	9.1	42.4
		2000	3.2	3.2	1.6	4.0	88.0
Sporn	60	1960	53.4	6.0	21.2	19.4	-
		1970	46.5	11.8	24.2	16.1	1.4
		1985	40.0	10.1	9.2	6.9	33.8
		2000	19.4	24.7	4.2	3.7	48.0
EBASCO	23	1980	34.7	26.7	2.7	7.7	28.2
WH	31	1990	35.0	9.0	2.0	-	54.0
Nassikas	36	1970	55.0	14.6	27.6	-	2.8
		1980	41.9	12.1	14.4	-	31.6
		1990	28.7	6.8	9.4	-	55.1
MEAN:							
		1960	53.4	6.0	21.2	19.4	-
		1965	55.0	6.0	21.0	18.0	0.0
		1970	48.9	12.0	22.3	15.2	1.6
		1980	33.2	14.4	10.4	9.9	32.1
		1985	34.5	13.6	10.1	7.4	34.4
		1990	31.8	7.9	5.7	-	54.6
		2000	19.2	6.0	2.9	3.9	68.0

strongly criticized electric power companies, no doubt partly because the companies are conspicuous. But, actually the increased environmental emphasis will probably accelerate growth of the electrical share of the market. There are several reasons why this is likely: fuel combustion sites are often far from population centers; few large installations can more economically control combustion by products than can many smaller ones; the nuclear energy industry is growing very rapidly. Nuclear energy may meet 25 percent of the U. S. energy needs by the year 2000, partly because nuclear energy is more readily converted to electrical energy than are other energy sources.

Because of these factors, the next three decades will probably see electric power's share of the energy market grow faster than it has in past years. If past trends were extrapolated without modification, a share of 38 to 53 percent in the year 2000 would be forecasted. Hence, a target figure of 45 percent seems reasonable and justified.

A dramatic increase in fuel conversion efficiency has been achieved in this century by the electric power industry. In 1900, less than 5 percent of the energy in the fuel was converted to electricity (the early-day turbine-generators, with their steam supplied by coal-fired boilers, required approximately 6 pounds of coal to produce 1 kWh). Today the average efficiency is about 32 percent. This figure may reach about 36 percent by the year 2000. Table 3.15 shows historical and projected heat rates for steam-electric generating units in the U. S., in Btu per kWh. Figure 3.15 shows that heat rates for the most efficient fossil-fueled steam-electric generating units decreased until 1950, and

Table 3.15. Historical and projected heat rates for steam-electric generating units in the U. S., in Btu/kWh (28, 40)

Year	Heat Rate	Comment	Year	Heat Rate	Comment
1925	25,000	Historical	1961	10,552	Historical
1930	19,800	"	1962	10,493	"
1935	17,850	"	1963	10,438	"
1936	17,800	"	1964	10,407	"
1937	17,850	"	1965	10,384	"
1938	17,450	"	1966	10,399	"
1939	16,700	"	1967	10,396	"
1940	16,400	"	1968	10,371	"
1941	16,550	"	1969	10,457	"
1942	16,100	"	1970	10,508	"
1943	16,000	"	1971	10,536	"
1944	15,850	"	1972	10,479	"
1945	15,800	"	1973	10,429	"
1946	15,700	"	1975	8,900	Projected
1947	15,600	"	1980	8,600	"
1948	15,738	"	1985	8,300	"
1949	15,033	"	1990	8,050	"
1950	14,030	"	1995	7,850	"
1951	13,641	"	2000	7,750	"
1952	13,361	"			
1953	12,889	"			
1954	12,180	"			
1955	11,699	"			
1956	11,645	"			
1957	11,365	"			
1958	11,090	"			
1959	10,879	"			
1960	10,701	"			

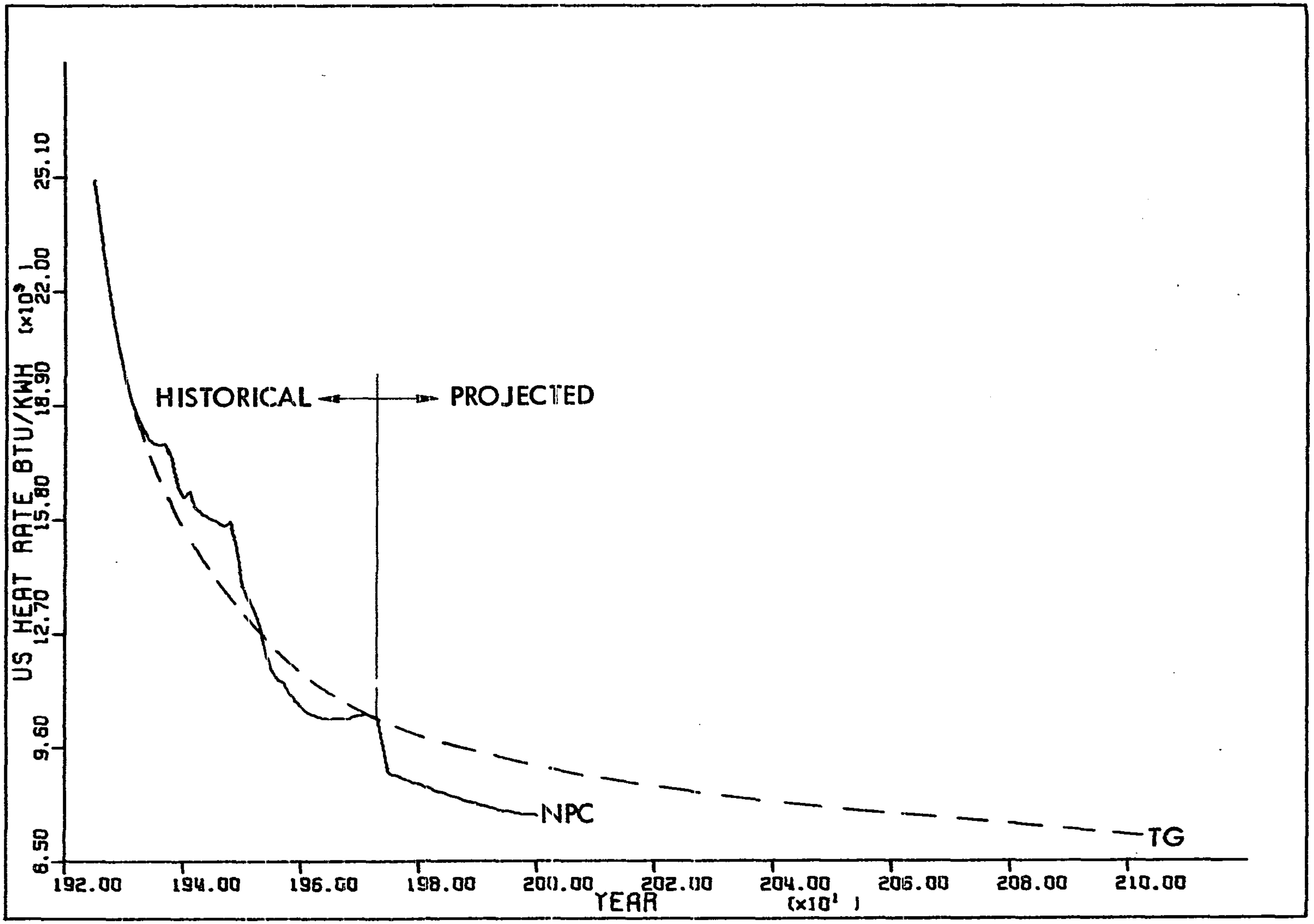

Figure 3.15. Historical and projected heat rates for steam-electric generating units in the U. S.

then leveled off. Heat rates, as projected by the Federal Power Commission, through the year 2000 are also shown (designated by NPC) in this figure. In order to find the curve best fitted to the historically declining heat rates, a number of regression models were tested. The polynomial regression model of

$$TFC = 25.56.692 - 470.324y + 4.675y^2 - 0.014y^3 + e \qquad (3.5)$$

proved to be the best, with a correlation coefficient of 0.947. Use of analysis of variance to test the null hypothesis of

$$\begin{aligned} H_0 &: b_j = b_{j0} \\ H_1 &: b_j \neq b_{j0} \end{aligned} \qquad (3.6)$$

at the 0.05 level of significance, resulted in sound rejection of the hypothesis. Table 3.16 illustrates the analysis of variance. The forecasted heat rates, as calculated using this regression analysis, are plotted and designated by TG in Figure 3.15, and are also shown in Tables 3.17 and 3.21.

Table 3.16. Analysis of variance table for the null hypothesis

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed $f(3,n-3)$	Critical $f_{0.05}(3,n-3)$
Regression	577102821.571	3	192367607.190	253.685	2.83
Error	31848199.646	42			
Total	608951021.217	45			

Table 3.17. Electrical energy forecast for the U. S. for the years from 1970 to 2000

Year	Total Energy Consumption (10^{15} Btu)	Electrical Energy			
		Percentage of Total Energy Consumption	Heat Rate (Btu/kWh)	Produced Energy (10^9 kWh)	Peak Load (10^3 MW)
1970	68.8	25.0	10508.0	1550.0	276.9
1975	73.9	28.0	10452.0	1979.7	364.5
1980	87.9	32.1	10402.0	2712.5	491.5
1985	103.6	35.0	10123.0	3581.9	649.0
1990	121.9	44.2	9951.0	5414.5	965.8
1995	141.6	44.7	9712.0	6517.2	1144.5
2000	164.5	45.0	9557.0	7745.6	1360.3

The curve derived as a result of the regression analysis appears to be more reasonable than the Federal Power Commission's heat rate projection curve. The reason for this is that the rate of decline in average heat rates will not be as rapid as in the past until improved alloys are developed to permit higher steam pressures and temperatures. Apart from steam conditions, recent improvements in both turbines and boilers have contributed to somewhat lower heat rates. Increases in unit size have also provided some advances, but better metals and higher throttle temperatures offer the best potential for enabling further major improvements. As larger and more efficient units are placed in service and some of the older and very inefficient capacity is retired or placed in cold standby, the average heat rate can be expected to improve. However, such improvement would tend to be offset by environmental control factors, including the increasing use of residual oil to meet sulfur oxide emission regulations, the addition of precipitators and scrubber facilities, and greater use of cooling towers rather than once-through cooling. Other offsetting factors would be the continuing decrease in the quality of coal and the operation of some inefficient units at high plant factors because of delayed installation of more efficient new capacity.

Forecasts of total U. S. energy requirements and electric power requirements to the year 2000 are summarized in Table 3.17. Data from 1970 are included for reference (28, 36, 49). Only a small improvement in the annual load factor[1] was assumed in making the load forecast.

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[1] Annual Load Factor = (kWh Produced/8760 x (kW Peak Load))

F. Future Society

Although the birthrate has decreased to the replacement level, the U. S. population probably will not stabilize for 60 to 70 years. A rapidly growing energy supply will be needed to provide for increasing transportation needs, waste recycling, environmental improvement, domestic comforts, and the growing demand for goods and services (8).

Even when population growth does slow down, growth in the GNP will probably not be significantly slowed, since industrial systems are becoming more automated (33). Hence, growth in GNP per capita would be speeded by a decrease in population growth. The same is true of per capita income, which has historically grown proportionately more than the population. If population growth ceases, even faster growth of per capita income is likely. This could happen sometime after the year 2000, provided the population growth projection is fairly accurate and zero population growth is ultimately achieved.

In "Future Shock," Toffler predicts that in the "super industrial" American society of tomorrow, service industries will ultimately become "experimental industries" (52). (Service industries include dry cleaners, hospitals, restaurants, etc.) Man's societies have successively been based on hunting, then agriculture, and now industry. The present day industrial society is now changing to a post-industrial society. Man at first was satisfied with basic food and shelter; then he wanted material goods; now he wants innumerable goods and services. Contrary to traditional economic thought, Toffler envisions that man's desire for material goods will become saturated, whereupon he will desire to "consume" experiences, rather than material goods.

In the physical world, no quantity can grow exponentially indefinitely without being limited by some force or another (See Appendix B). Toffler's thinking is consistent with this fact. Although the production of material goods has increased exponentially for an extended period of time, its historical curve will eventually resemble the Gompertz curve (Figure B.1, Appendix B). This will occur primarily because human goals will change. Man will be fairly content with his abundant food supply, his shelter, and his material goods, and so will embark on new pursuits. The change in the rate of growth of material goods production will come gradually, though, not suddenly because resources are exhausted, as in the model of the jar and the fruit flies (See Appendix B).

This scenario is not feasible for the 20th century. Americans are not nearly satisfied with the goods and services they possess, in spite of the fact that they have more than anyone else in the world. And, there will continue to be poverty in this country, at least for awhile (54). Because different people are satisfied with different degrees of material comfort, there is no way of knowing what degree of comfort will eventually satisfy most people. But, certainly poverty must be eliminated and a much higher average standard of living must be attained before people will be satisfied with the material goods that they have. This may be more possible when the population begins to stabilize, since per capita income or the average living standard could then increase more rapidly. When this country no longer has the worries of providing basic necessities to a growing population, it can then make great strides in eliminating poverty and establishing a stable affluent society which will begin to strive for nonmaterial goals.

In an industrial society, goods and services cannot be produced and physical comforts cannot be provided on a large scale without energy consumption. Thus, stabilization of demand for material comfort and goods would cause growth of energy consumption per capita to decrease and stabilize. Such reasoning is as valid for any industrial nation as it is for the U. S. But, there are many poor countries in the world where people are starving and it is these same countries where population growth rates are the highest (See Table 3.2). This situation inhibits any kind of progress in these countries and also increases the threat of war because of the huge gap between them and the industrialized nations. The industrialized societies can promote world stability by helping the developing nations to solve their problems, which are made worse by rapid population growth (54).

G. Energy Demand Forecast for the 21st Century

The scenario presented in the previous section is highly subjective and cannot really be quantitatively analyzed. There is no way to predict when or at what level people's demand for energy will be satisfied. But, as has been discussed, this will probably not happen until the population begins to stabilize which will be after the turn of the century. In theory, it will happen after population growth slows, because it will take time for the per capita level of material wealth to increase, which will be a result of slower population growth. Considering anticipated growth of human knowledge and probable future progress, the demand for energy should be satisfied in the 21st century.

Since a crude model is better than no model at all, it was postulated that per capita growth of energy use will follow a Gompertz curve defined by the growth rates in Table 3.18. The probable total energy consumption in the U. S. through the next century was forecasted, as shown in Table 3.19, using this curve and the projected population growth rates in Table 3.3. Energy was assumed to be available, but at a price reflecting the cost of environmental protection and byproduct capture and recycling. The U. S. population, energy use per capita, and the resulting annual rate of energy use are plotted to the year 2000 in Figure 3.16.

Table 3.18. Annual growth rate of total energy consumption

Period	Growth Rate of Btu/Capita (% per year)
1950-1970	2.45
1970-2030	2.29
2030-2040	2.0
2040-2050	1.6
2050-2060	1.4
2060-2070	1.0
2070-2080	0.7
2080-2090	0.5
2090-2100	0.2

In this projection, which is based on the scenario of the future

Table 3.19. Forecasted total energy consumption for the U. S.

Year	Consumption/Capita (10^6 Btu)	Population (10^6)	Total Energy Consumption (10^{12} Btu)
1950	225.4*	152.3*	34,328.4*
1955	241.8*	165.9*	40,114.6*
1960	252.4*	180.7*	45,608.7*
1965	259.7*	194.6*	50,537.6*
1970	298.7*	208.0*	65,600.0*
1975	334.5	221.0	73,924.5
1980	374.6	234.8	87,956.1
1985	419.5	246.9	103,574.6
1990	469.8	259.6	121,960.1
1995	526.1	269.3	141,678.7
2000	589.1	279.2	164,476.7
2005	659.8	288.9	190,616.2
2010	738.8	298.8	220,753.4
2015	827.4	309.1	255,749.3
2020	926.6	317.5	294,195.5
2025	1037.7	326.2	338,497.7
2030	1162.0	335.1	389,386.2
2035	1283.0	339.0	434,937.0
2040	1416.5	342.9	485,717.9
2045	1533.5	346.9	531,971.2
2050	1660.2	350.9	582,564.2
2055	1779.7	353.5	629,124.0
2060	1907.9	356.2	679,594.0
2065	2005.2	358.9	719,666.3
2070	2107.5	361.5	761,861.3
2075	2182.3	361.5	788,901.5
2080	2259.8	361.5	816,917.7
2085	2316.8	361.5	837,523.2
2090	2375.3	361.5	858,671.0

Table 3.19. Continued.

Year	Consumption/Capita (10^6 Btu)	Population (10^6)	Total Energy Consumption (10^{12} Btu)
2095	2423.3	361.5	876,023.0
2100	2423.3	361.5	876,023.0

*Historical values

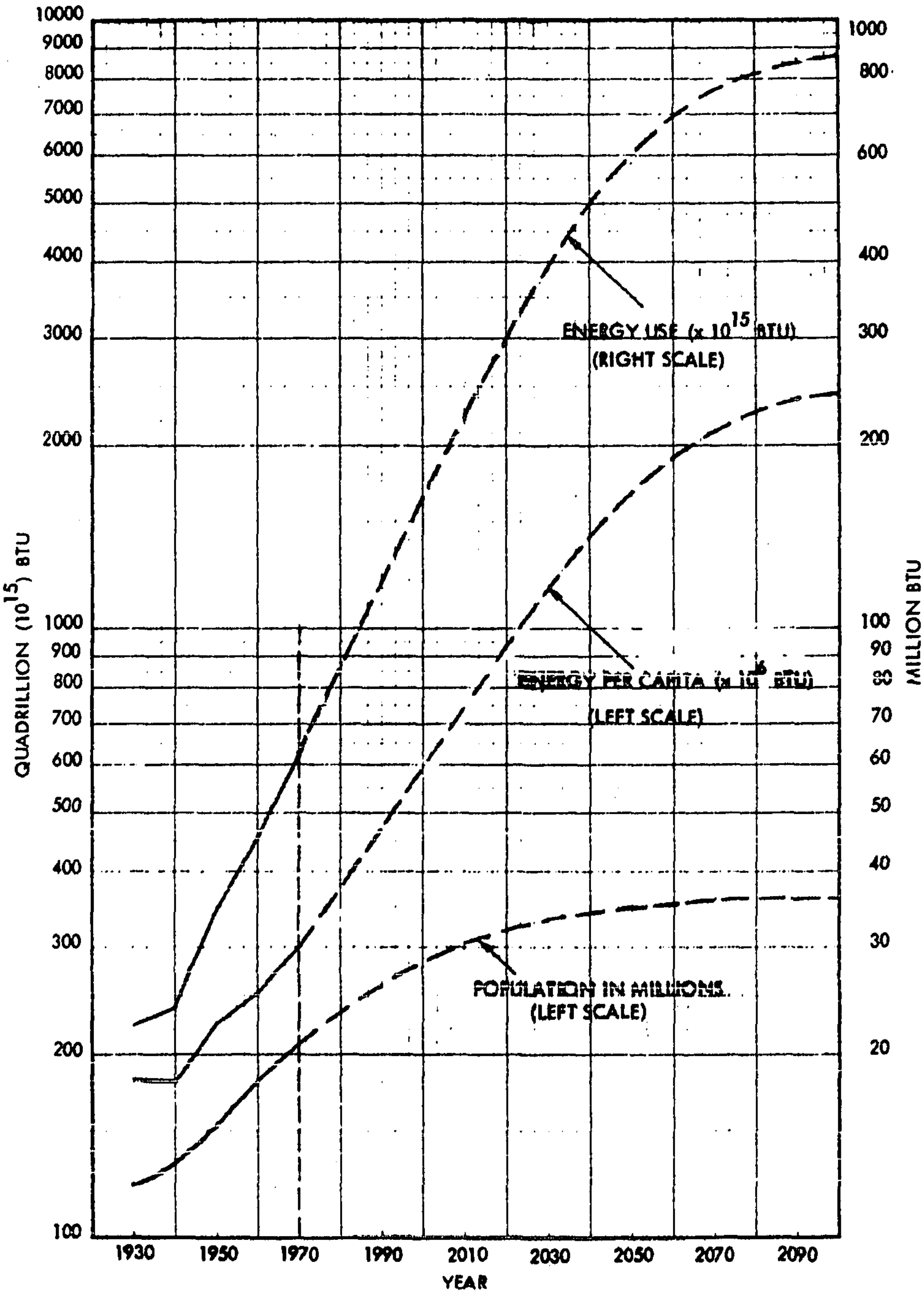

Figure 3.16. Projection of U. S. population, energy use per capita and total energy use to the year 2100 (See Table 3.19)

presented in the previous section, annual U. S. energy consumption by the end of the 21st century is approaching 10^{18} Btu and has stopped increasing. This quantitative projection is, however, no better than the theory on which it is based, which may be incorrect. Hence, this projection of energy consumption in the 21st century as well as any succeeding analysis, must be viewed in context of the scenario from which it derives.

For a point of reference in evaluating these energy projections, it is helpful to remember that the total energy consumption in the U. S. from 1850-1970 was about 2.34 Q (See Section B). The integral of the total energy curve in Figure 3.16, which was calculated using the computer program given in Appendix D, from 1970 to any given year, is shown in Figure 3.17. Table 3.20 represents the cumulative energy consumption from 1970 to the given date. From this table one can quickly determine the energy requirement for any given interval, based on this energy forecast. For example, in the period from the year 2000 to 2015, (6.896624 - 3.230753) or 3.665871 x 10^{18} Btu will be required. In other words, more energy is projected to be consumed in this 15 year period than in the 120 year period from 1850 to 1970. These figures are used as part of the basis for a fuel forecast in Chapter IV.

Based on broad assumptions about expected socioeconomic conditions and trends, U. S. energy needs have been projected to the year 2000. The type of energy, which this will be after the year 2000, has not been considered, although 45 percent of it is expected to be electric energy. This figure was derived through extrapolation of the historical trend as well as judgment, and agrees reasonably well with other forecasts,

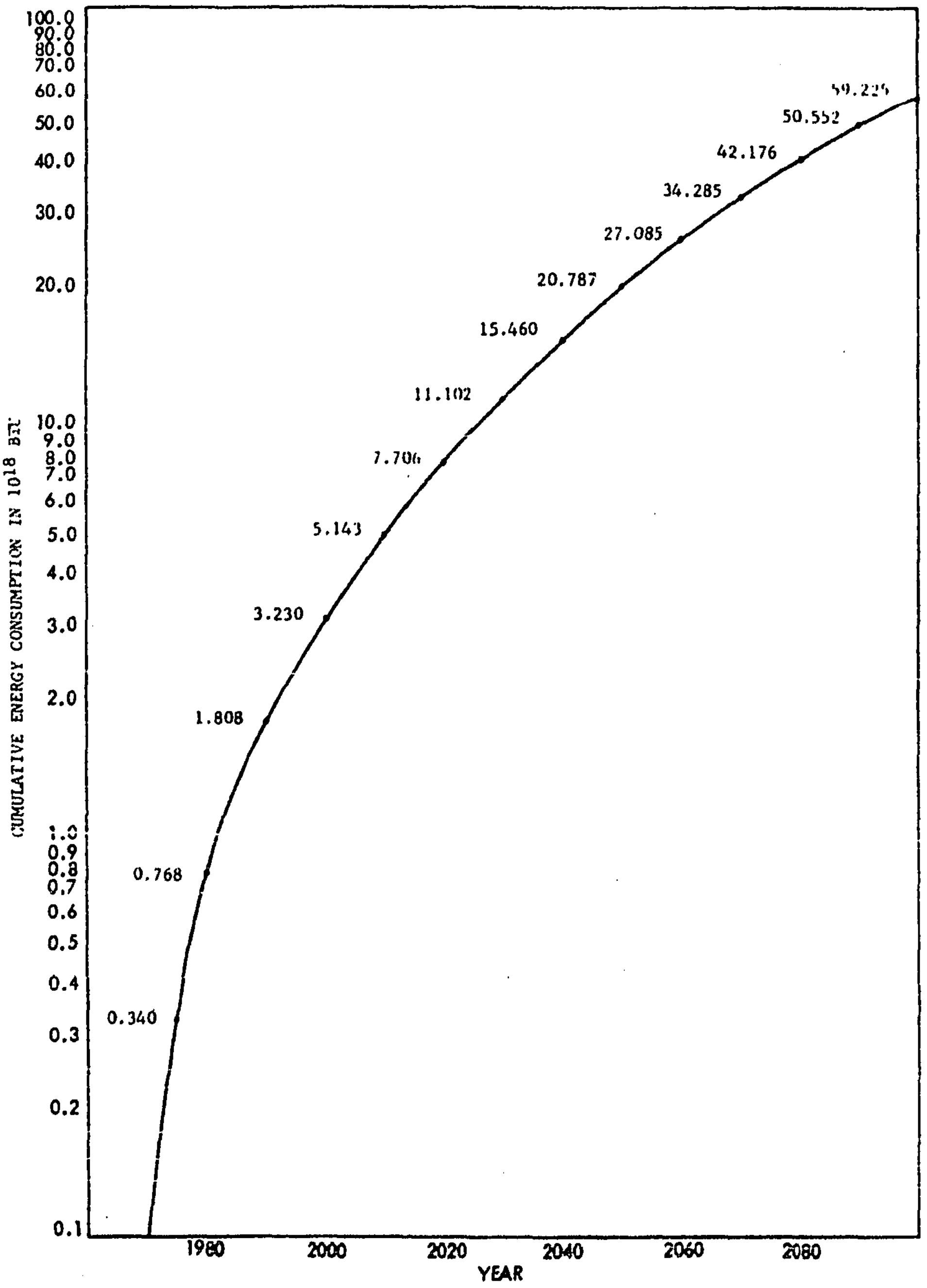

Figure 3.17. Cumulative total energy consumption in the U. S. from the year 1970 to the year 2000 (See Table 3.20)

Table 3.20. Forecasted cumulative total energy consumption in the U. S.

Interval (From 1970 to the year)	Cumulative Energy Consumption (10^{18} Btu)
1975	0.340537
1980	0.768476
1985	0.882206
1990	1.808833
1995	3.030655
2000	3.230753
2005	4.680992
2010	5.143578
2015	6.896624
2020	7.706822
2025	9.848339
2030	11.102776
2035	13.733304
2040	15.460862
2045	18.582938
2050	20.787807
2055	24.401858
2060	27.085564
2065	31.180468
2070	34.285765
2075	38.773823
2080	42.176407
2085	46.930649
2090	50.552543
2095	55.496512
2100	59.225771

as shown in Table 3.8.

Considering the energy needs and available fuels that are forecasted for the next century, energy is expected to be increasingly converted to electricity after the year 2000. By the early part of the 21st century, the U. S. will be using most of its energy as electricity, although about 15 percent of the energy consumption is expected to remain nonelectric. Nonelectric energy would include, for example, liquid fuel for aircraft, rockets, and land vehicles, gaseus fuel for specialized applications, and fuel used for nonenergy purposes. In Figure 3.18, an attempt has been made to quantify the portions of energy that will be used in various forms in the future, considering the forecasts of energy needs to the year 2000 and the huge energy needs expected in the early part of the 21st century. The means by which this was done is discussed in Chapter IV. In Table 3.21 some forecasts of electric energy production in the 21st century are presented, which are based on the data in Figure 3.16 and 3.18. In calculating the heat rates it was assumed that power plant efficiencies would gradually improve. In the 21st century, nuclear fission plants will operate at efficiencies of up to 35 to 40 percent, and coal-fueled plants will operate at efficiencies approaching 40 to 45 percent. Nuclear fusion plants might be 45 to 50 percent efficient (10).

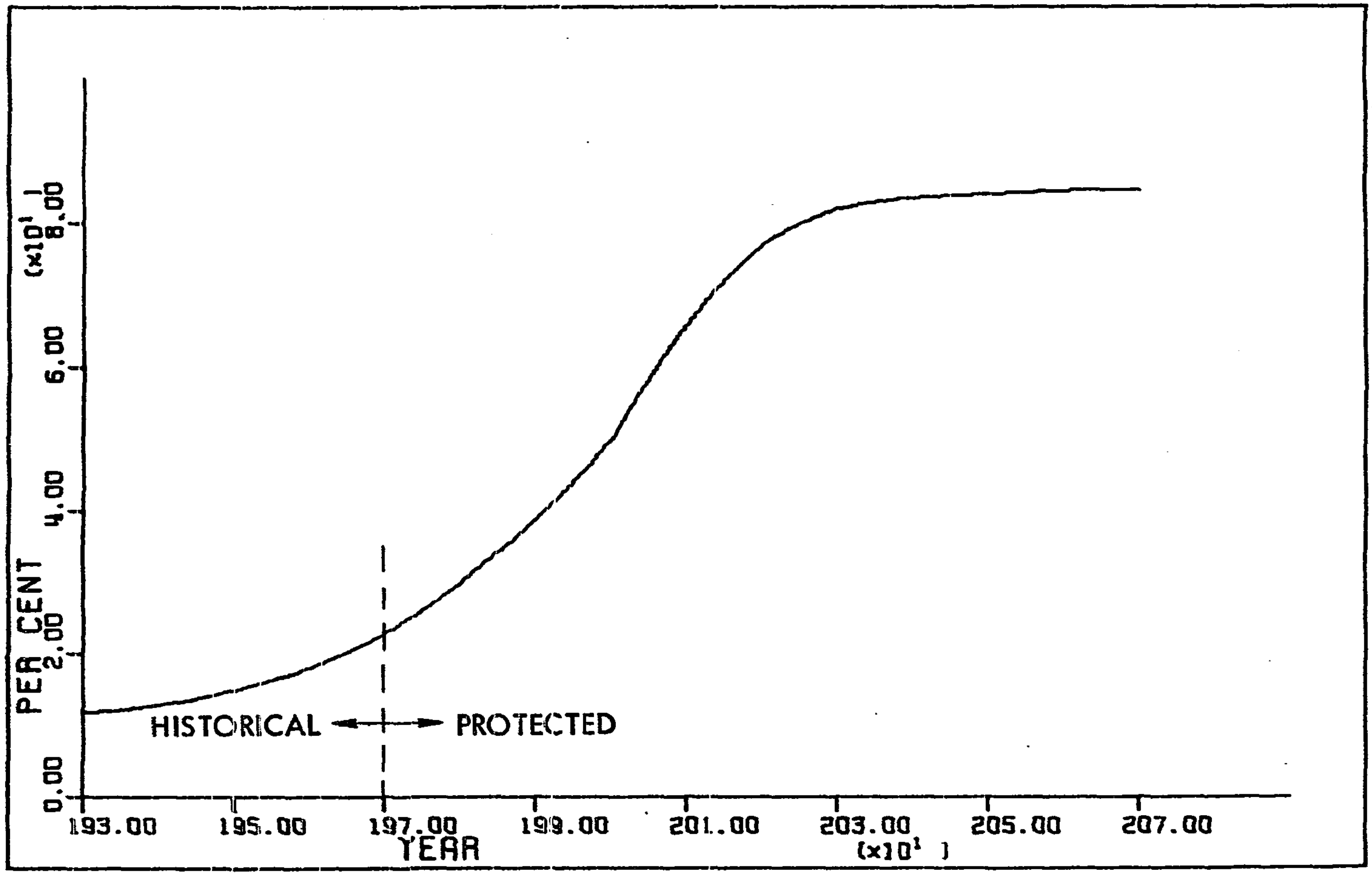

Figure 3.18. Historical and projected total energy converted to electricity in the U. S., in percent

Table 3.21. Electrical energy forecast for the U. S. for the 21st century

Year	Total Energy Consumption (10^{15} Btu)	Electrical Energy				
		Percentage of Total Energy Consumption	Heat Rate (Btu/kWh)	Plant Efficiency (%)	Produced Energy (10^{12} kWh)	Peak Load (10^6 MW)
2000	164.5	45.0	9557.0	35.7	7.745	1.360
2015	255.7	72.0	9001.0	37.9	20.453	3.537
2030	389.4	81.0	8550.0	39.9	36.890	6.285
2050	582.6	82.0	8124.0	42.0	58.805	9.872
2070	761.8	83.0	7582.0	45.0	83.394	13.770
2100	876.0	85.0	7108.0	48.0	104.755	17.083

IV. ENERGY SUPPLY PROBLEM

In Chapter III, only the demand side of the energy dilemma was discussed. In this chapter, the supply side will be emphasized: future energy resources will be reviewed, supply projections developed for the U. S., and some energy related issues will be discussed in light of projections. The U. S. has been gifted with a substantial share of the earth's fossil fuels (88). The actual amount of fossil fuel that exists is, of course, unknown, since the earth cannot be x-rayed and its exact composition assessed. Therefore, in this study estimates made by experts who render opinions on the extent of the earth's resources based on their geological knowledge and on exploratory work will be used.

A. Developments in Fuel Consumption

Figure 4.1 shows the developments in fuel consumption in the U. S. from 1850 through 1970 (11). As can be seen from the figure, the use of coal increased rapidly after 1850 and coal became the dominant energy source during the years from approximately 1870 to 1930. Its importance declined somewhat thereafter, and in 1970 it supplied only about 20 percent of the U. S. energy requirement. Some oil was used before 1900 and during the early part of this century, but only on a small scale until about 1920, when it began to replace coal for some purposes. By 1970, about 44 percent of the primary fuel used was oil, about 23 percent of which was imported (23, 31, 87). Use of natural gas has also increased in a relatively short time. It became a significant

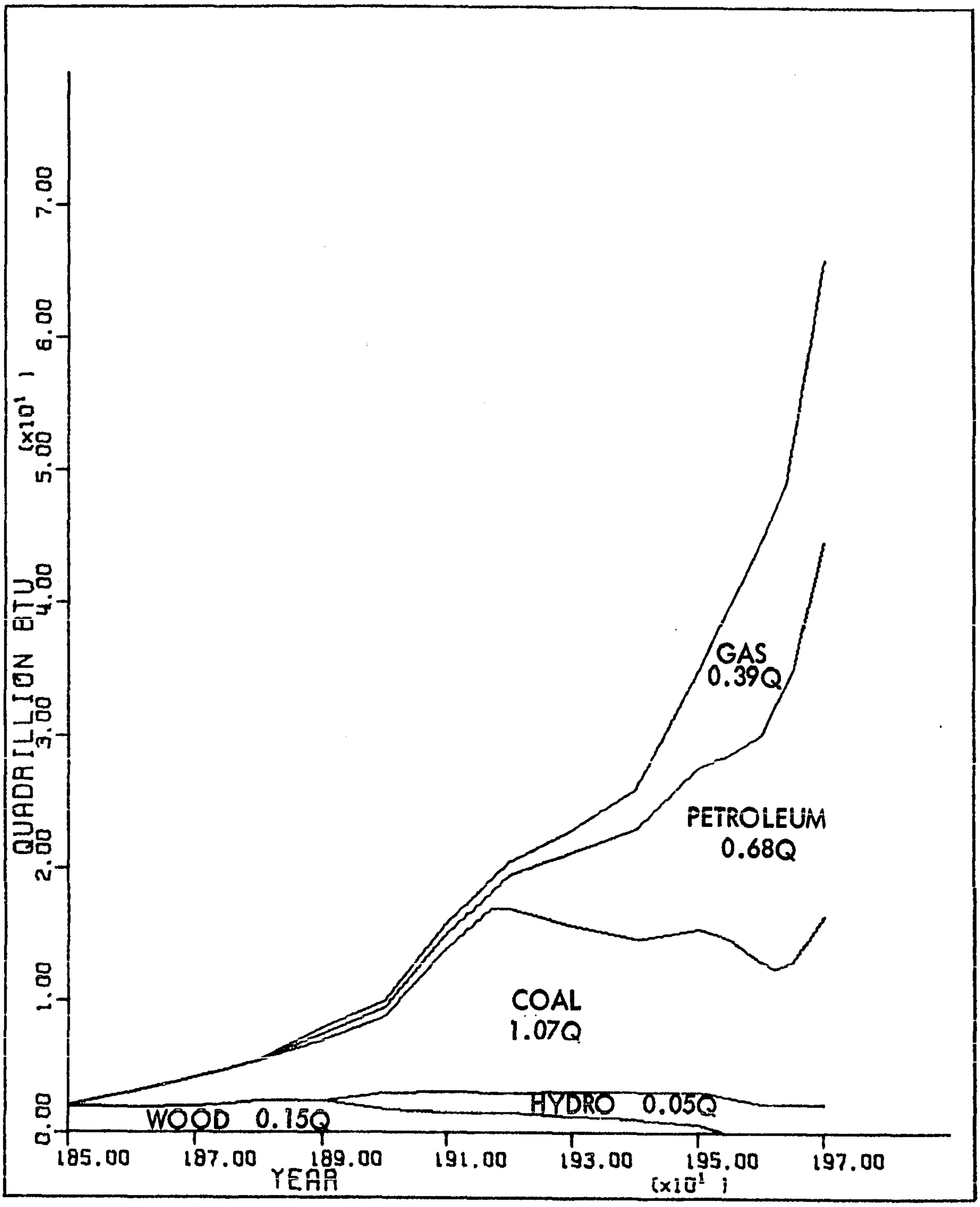

Figure 4.1. Historical U. S. consumption of energy resources (11)

primary fuel in the 1940's, and has been a major source of energy ever since. In 1970, about 32 percent of all energy expenditures were for natural gas. Hydro energy has been used since about 1890, but it has never supplied more than about 4 percent of the U. S. energy requirement, and will never be a major energy source. Nuclear reactors met about 0.3 percent of the energy need in 1970. Energy from other sources was negligible.

An estimate of the amount of energy derived from various fuels that was consumed in the period from 1850 to 1970 was obtained by using the computer program given in Appendix D to integrate the curves in Figure 4.1. The results, in units of Q (10^{18} Btu), are summarized in Table 4.1.

Table 4.1. U. S. energy consumption from 1850 to 1970

Fuel	Percentage of 1970 Energy Consumption	U. S. Energy Consumption from 1850 to 1970 (Q)
Coal	20	1.07
Oil	44	0.68
Gas	32	0.39
Wood	-	0.15
Hydro	3.7	0.05
Nuclear	0.3	-
Total	100	2.34

B. Energy Resources

1. With present technology

Accurate, or even approximate, estimates of amounts of available, or potentially available, fuels are extremely difficult to make due to the various uncertainties concerning the amounts of the fuels that actually exist. In order to examine energy resources, it is necessary to introduce some terminology. Reserves will be defined as the quantities that are known to exist and can be extracted at present cost levels using current technology. Resources will be defined as the quantities proven or unproven which can be extracted at or below a specified cost level using currently feasible or reasonably assured future technology. Finally, the resource base will be defined as all proven or unproven quantities that exist in a given geographical area regardless of whether they can be extracted or not (22). The most meaningful quantities for long term assessment are resources and the resource base, since proven reserves are relatively small, and of course they change as the result of further exploration.

Table 4.2 shows a summary of estimates of U. S. fossil fuel resources. The table, while by no means complete or exhaustive, covers the most authoritative estimates available today. These data can be converted to common energy units by using the following conversion factors (36)

$$1 \times 10^{15}\ \text{Btu} = 100 \times 10^{10}\ \text{ft}^3\ \text{of gas}$$

$$\text{"} \quad = 178 \times 10^{6}\ \text{Bbl of oil}$$

$$\text{"} \quad = 44 \times 10^{6}\ \text{tons of coal}$$

and by selecting the largest of the individual estimates in Table 4.2. The results of this conversion are shown in Table 4.3. The fossil resources in this table represent the initial supplies of fuel in the U. S. including the portion that has already been used.

Table 4.2. Estimates of U. S. fossil fuel resources, including Alaska

Source	Coal (10^9 metric tons)	Oil (10^9 Bbl)	Natural Gas (10^{12} ft^3)
Hubbert (Averitt) (144)	2972	200[a]	1075[b]
Scarlott (54)	-	250-750[c]	-
Schurr & Netschert (22)	-	500[b]	-
Landsberg & Fischman (145)	1700	250[a] 500[b]	1200-1700[a]
Hottel & Howard (10)	-	600[c]	-
Dept. of Interior (13)	-	-	1500[b]
Sartorius (36)	17-26Q[d]	5-9Q[c]	2Q[b]

[a] Recoverable resources.

[b] Resource base .

[c] Oil shale only.

[d] One Q = 10^{18} Btu.

Table 4.3. Conventional fuel resources in the U. S. (91, 92)

Type	Quantity	Energy Equivalent (10^{18} Btu)
Coal	1700×10^9 tons	38
Oil (without shale)	250[a] 500[b]	2.8
Natural Gas	1700×10^{12} ft^3	1.7
Hydro	90×10^6 KW (386×10^9 KWh/yr.)	0.004 (per yr.)

[a] Recoverable resources.

[b] Resource base.

Hydro power should be considered a conventional energy source. The maximum limit on U. S. hydro capacity is about 230-390 10^3 MW (22). However, Landsberg suggests that the practical maximum hydro capacity will not be more than 90 10^3 MW at any time in the future (89). Base on an equivalent power plant efficiency of 33.3 percent, this capacity is equivalent to a thermal input of 0.004×10^{18} Btu per year.

Nuclear power generation is still in the commercial development stage, however, it is expected to expand very rapidly in the next 10 to 15 years (46). Most nuclear reactors now in operation or on order are light water reactors (LWR). Therefore, uranium must be considered a conventional fuel to the extent that it can be utilized by present technology. Table 4.4 shows estimates of the quantities of U. S. uranium resources that have been estimated by the AEC to be recoverable at various costs (10, 91).

2. With future technology

Fission means the splitting of a nucleus into several nuclear fragments accompanied by the release of energy and neutrons. The fission reaction is triggered by the collision of a neutron with a U^{235} nucleus. The new neutrons released from the fission reaction produce more reactions if they collide with other nuclei. The continuation of this process is known as a "chain reaction." Today, only U^{235} can be used in the fission process. It is possible, however, to use the surplus neutrons released in the fission reaction to produce an artificial radioactive isotope that is fissionable. If U^{238} is placed in the reactor, for example, it is transformed into plutonium 239, which is fissionable and can be used as a nuclear fuel. Thorium 232 also becomes fissionable by absorbing neutrons. The process of producing fissionable material in the fission reactor is called "breeding" and the reactor in which this takes place is called the "breeder reactor" (170).

The need to generate enormous additional amounts of electric power while at the same time protecting the environment, is becoming one of the most important major social and technological problems that this society must resolve over the next few decades. Nuclear breeder reactors hold great promise as the solution to these problems. By producing more nuclear fuel than they consume, they would make it feasible to utilize enormous quantities of low-grade uranium and thorium ores dispersed in the rocks of the earth as sources of low-cost energy for thousands of years (92, 94).

Until such time that breeder reactors become a reality, coal will be by far the most abundant fuel. Moderately priced uranium is relatively scarce. Gas and oil, though readily used fuels of exceptional quality, are in short supply. Breeder reactors, if fully exploited commercially, would increase the ultimate effectiveness of uranium fuel one hundred fold and the total energy resource base at least tenfold. In that case, uranium would be the most abundant fuel, and it will be economically practical to extract even the most expensive ones, since the breeder will increase the utilization factor.

Because of this great potential effect on energy sources, the AEC, the nuclear industry and the electric utilities have launched large scale efforts to develop the technology whereby it will be possible to have a breeder reactor generating electric power on a commercial scale (94-96).

The basic types of breeder reactors under study in the U. S. are: 1) the Liquid Metal Fast Breeder Reactor (LMFBR), 2) the Gas Cooled Fast Reactor (GCFR), 3) the Molten Salt Breeder Reactor (MSBR) and 4) the Light Water Breeder Reactor (LWBR) (10). In the U. S. and several other countries, it was decided that the concept of the LMFBR was the most attractive to pursue. In the U. S., the LMFBR has been under active study for over 24 years (95).

Some proponents of breeder reactors consider the GCFR to be a better alternative than the LMFBR. They argue that the handling properties of the inert helium gas used in the GCFR are preferable to those of the liquid sodium used in the LMFBR. Furthermore, the gas turbines could possibly be used in a closed helium cycle (82, 94, 99). If used with gas turbines, it is argued that the GCFR could be easily adapted to dry cooling and would have a lower capital cost than the LMFBR (100, 101).

Since the GCFR fuel requirements are similar to those of the LMFBR, proponents believe that the cost of GCFR development would be relatively low (60). The cost of its development will probably be paid, in order to ensure the overall success of the national breeder development effort. By 1990, it is probable that, for the purpose of extending the energy resource base, there will be a fully coordinated energy program in the U. S. which will include breeders.

C. Fuel Supply Forecasts

In Chapter III, a total energy consumption forecast for the U. S. was presented. About 3.23×10^{18} Btu of all fuels will be consumed during the last three decades of this century, according to that forecast. However, it is difficult to predict a fuel mix since, in the long run, fuels can easily be substituted or interchanged. Even though the energy requirement in the years from 1970 to 2000 will be huge, any one of the conventional fuels will be able to provide a major part of it. Hence, there are many possible combinations of fuels which could meet the requirement. The composition of the future fuel mix will be a function of the evolving technology of the demand sectors, including new energy forms and conversion systems and the ability of resources to substitute for each other under various conditions of price and availability.

Considering the fact that proven oil reserves in this country are disturbingly low and domestic exploration is decreasing, the U. S. will have to increase its dependence on foreign oil in the near future (46). According to the National Petroleum Council estimates, the U. S. will import 40 percent of its oil by 1975 and 57 percent of it by 1985 (18).

Natural gas use cannot continue to grow as rapidly as it has since 1950 (See Figure 4.1), because the supply is limited. Environmental problems are blocking further domestic exploration for natural gas. In addition, there is a shortage of capital to finance this exploration, since the producer prices have historically been regulated (46). In the next several years, gas and liquid natural gas (LNG) imports will supplement the domestic supply. After 1980, Alaska pipeline imports and synthetic gas from coal will contribute to the supply.

Paradoxically, coal, the most polluting of the fossil fuels, is also the most plentiful source of energy. It appears to be the logical source for much of the future energy need. It is still used to fire boilers for the generation of 55 percent of all steam-electric power in the U. S., although it accounts for only 20 percent of the total energy. But, coal poses environmental problems at every stage, from mining to combustion. Strip mining creates an acid damage problem and deforms the landscape. The EPA restricts combustion of high sulfur coals and the supply of low sulfur coals is limited (80 percent of Eastern coal reserves are more than 1 percent sulfur by weight) (103). Although techniques to desulfurize stack gas are being developed, none are or will be available commercially until 1980 (46). Other desulfurization alternatives are being studied, but there is still much time consuming R & D left to do.

The Nuclear power share of the energy market is expected to grow, although forecasters disagree on just how rapidly. In recent years there have been delays, hopefully temporarily, in constructing nuclear plants and in licensing to build them. If, as has been discussed, commercial breeder reactors are in use by 1985 to 1990, there will be an ample supply of nuclear fuel.

A forecast of fuel demand for the years from the present to the year 2000 must take into account the interrelated factors of relative fuel prices, new technology, government regulation, environmental developments, etc. Several forecasts have been prepared and are summarized in the following tables. Many attempts at forecasting demand have been based on projections of recent trends in energy consumption and on the forecasters' knowledge of individual industries. While such forecasts do not enable one to estimate demand responses to changes in prices, they may still be useful as "boundary" projections for the relatively near future. Table 4.5 and Figure 4.2 show such forecasts of U. S. total energy consumption by major consuming sectors. In these judgemental estimates, energy demand is divided into three primary use sectors - residential and commercial; industrial; transportation - and one energy "transformation" sector, electric utilities, which transforms primary fuel into electrical energy, which then becomes an input which goes into the three primary sectors. Demand in each of the major sectors for a particular energy source is affected by fuel price and other economic and demographic variables. Table 4.6 and Figure 4.3 show forecasts of U. S. consumption of energy resources by major sources. The ranges of the forecasts and the "average" forecast are also shown in this table. The average forecast indicates that the percentage of the market supplied by natural gas and oil will decline gradually from the high of 76 percent in 1970, but will remain above 50 percent even as late as the year 2000.

For each fuel, a number of regression models were tested in order

Table 4.5. Forecasts of U. S. total energy consumption by major consuming sectors in percent

Source	Ref. No.	Year	Industrial	Residential and Commercial	Transportation	Electric Utilities
NAE	41	1980	-	-	-	33.0
		1990	-	-	-	41.7
		2000	-	-	-	45.5
EMUS	61	1970	31.6	21.5	24.2	22.6
		1980	28.3	19.7	24.5	27.7
		2000	19.3	12.5	25.3	43.0
EBASCO	23	1970	-	-	-	24.8
		1975	-	-	-	26.8
		1980	-	-	-	29.3
CMB	18	1970	32.0	19.0	24.0	25.0
		1985	26.0	16.0	21.0	37.0
USET	17	1971	29.4	20.7	24.6	25.3
		1975	28.5	19.9	23.8	27.9
		1980	26.8	18.2	23.8	31.2
		1985	25.9	16.2	23.2	34.6
		2000	24.5	11.4	22.2	41.9
H. & H.	10	1970	30.7	20.7	23.9	24.7
NPC	18	1970	26.2	19.2	24.0	24.6

Table 4.5. Continued.

Source	Ref. No.	Year	Industrial	Residential and Commercial	Transportation	Electric Utilities
		1980	21.8	16.3	23.3	32.0
		1985	19.7	15.0	22.5	35.4
Cook	7	1970	37.0	25.0	28.0	9.0
		2000	25.0	18.0	32.0	24.0
RANGE:						
		1970	26.2-37.0	19.0-25.0	23.9-28.0	9.0-25.0
		1975	28.5	19.9	23.8	26.8-27.9
		1980	21.8-28.3	16.3-19.7	23.3-24.5	29.3-33.0
		1985	19.7-26.0	15.0-16.2	21.0-23.2	34.6-37.0
		1990	-	-	-	41.7
		2000	19.3-25.0	11.4-18.0	22.2-32.0	24.0-45.5
MEAN:						
		1970	31.5	21.1	24.8	21.8
		1975	28.5	19.9	23.8	27.3
		1980	25.6	18.1	23.9	30.6
		1985	23.9	15.7	22.2	35.7
		1990	-	-	-	41.7
		2000	22.9	14.0	24.5	38.6

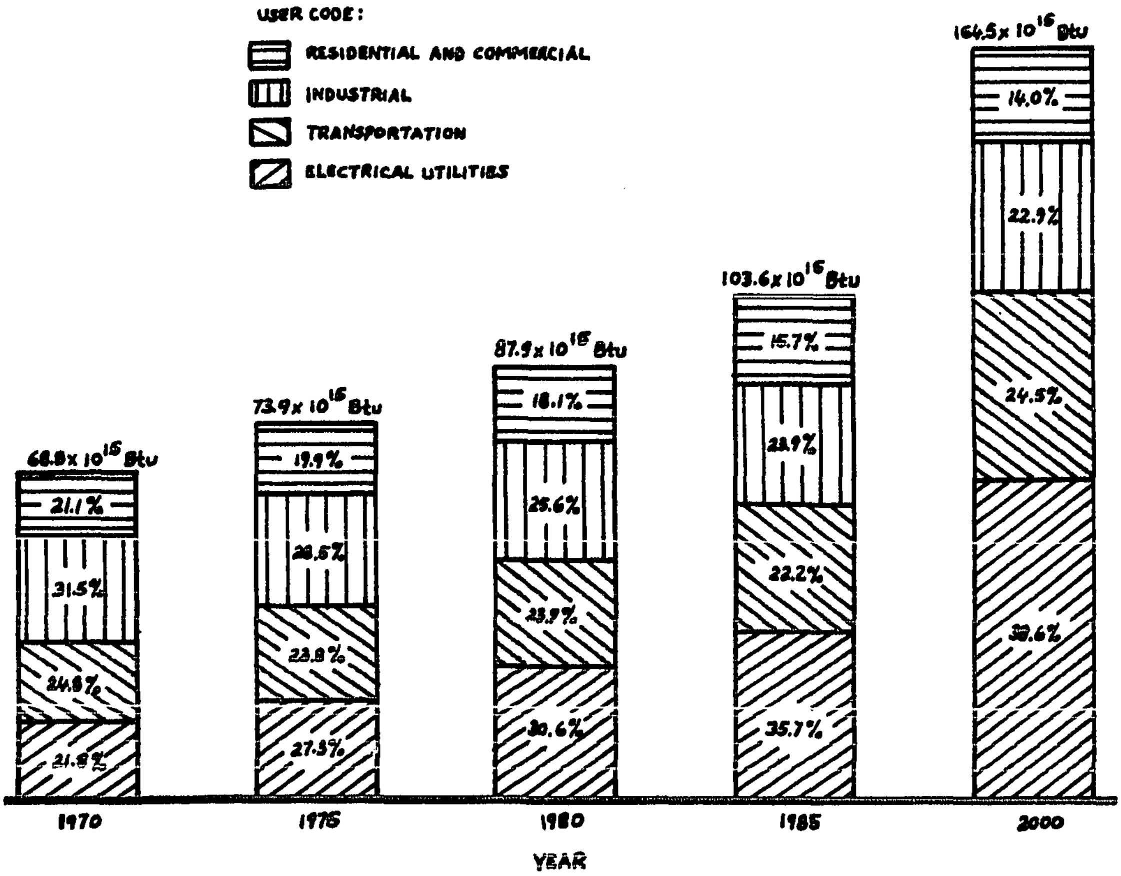

Figure 4.2. Projected U. S. total energy consumption by major consuming sectors

Table 4.6. Forecasts for U. S. consumption of energy resources by major sources in percent

Source	Ref. No.	Year	Coal	Oil	Gas	Hydro	Nuclear
CMB	18	1965	22.0	44.0	30.0	4.0	0
		1970	19.7	44.7	31.7	3.8	0.3
		1980	18.0	41.0	25.0	4.0	12.0
		1985	16.6	47.2	20.2	2.8	13.1
EBASCO	23	1970	20.0	43.4	32.6	3.8	0.29
		1980	16.0	41.3	30.8	3.2	8.7
EMUS	61	1980	21.8	40.8	28.9	3.4	4.6
		2000	13.3	34.2	24.7	3.0	25.8
PCCP	61	1980	20.7	34.7	31.5	-	9.4
		2000	18.0	35.0	28.9	-	15.9
FFF	61	1980	29.7	44.1	23.2	3.0	-
		2000	36.5	41.8	20.0	1.5	-
RAF	61	1980	19.9	41.6	30.5	3.3	4.0
		2000	13.3	45.6	25.0	2.1	14.1
USE	147	1970	20.0	43.0	32.8	3.9	0.3
		1975	18.2	41.0	32.4	3.2	5.5
		1985	16.7	35.6	29.6	2.6	15.6
		2000	13.7	34.6	26.4	2.6	22.7

Table 4.6. Continued.

Source	Ref. No.	Year	Coal	Oil	Gas	Hydro	Nuclear
USET	17	1971	18.2	44.2	33.0	4.0	0.6
		1975	17.2	43.7	31.4	4.4	3.2
		1980	16.8	43.9	28.0	4.2	7.0
		1985	18.4	43.5	24.3	3.7	10.1
		2000	16.3	37.2	17.7	3.1	25.7
LAIRD	36	1970	20.1	43.0	32.8	3.8	0.3
		2000	13.7	34.6	24.6	2.6	22.7
NASSIKAS	36	1970	20.1	43.0	32.8	3.8	0.3
		1980	18.9	40.0	27.9	3.2	10.0
		1990	13.2	35.7	25.5	2.6	23.0
MORTON	36	1970	20.1	43.0	32.8	3.8	0.3
		1985	16.7	35.6	29.5	2.6	15.6
		2000	13.7	34.6	26.4	2.6	22.7
NPC	18	1985	19.3	43.4	17.0	2.5	17.2
SPORN	60	1960	23.2	41.5	31.4	3.9	-
		1970	18.0	44.8	33.2	3.7	0.3
		1985	20.7	42.8	22.4	2.4	11.7
		2000	20.0	38.2	14.3	2.0	25.5

Table 4.6. Continued.

Source	Ref. No.	Year	Coal	Oil	Gas	Hydro	Nuclear
RANGE:							
		1960	23.2	41.5	31.4	3.9	-
		1965	22.0	44.0	30.0	4.0	0.0
		1970	18.0-20.1	43.0-44.8	31.7-33.2	3.7-3.9	0.29-0.3
		1975	17.2-18.2	41.0-43.7	31.4-32.4	3.2-4.4	3.2-5.5
		1980	16.0-21.8	40.8-44.8	23.2-31.5	3.0-4.2	4.0-12.0
		1985	16.6-20.7	35.6-47.2	17.0-29.6	2.4-3.7	11.7-17.2
		1990	13.2	35.7	25.5	2.6	23.0
		2000	13.3-36.5	34.2-45.6	14.3-28.9	1.5-3.1	14.1-25.8
MEAN:							
		1960	23.2	41.5	31.4	3.9	-
		1965	22.0	44.0	30.0	4.0	0.0
		1970	19.7	43.6	32.7	3.7	0.3
		1975	17.9	42.0	31.9	3.8	4.4
		1980	20.2	40.1	28.2	3.5	8.0
		1985	18.0	39.2	23.8	2.8	16.2
		1990	17.9	32.9	23.6	2.6	23.0
		2000	17.6	31.0	23.1	2.4	25.9

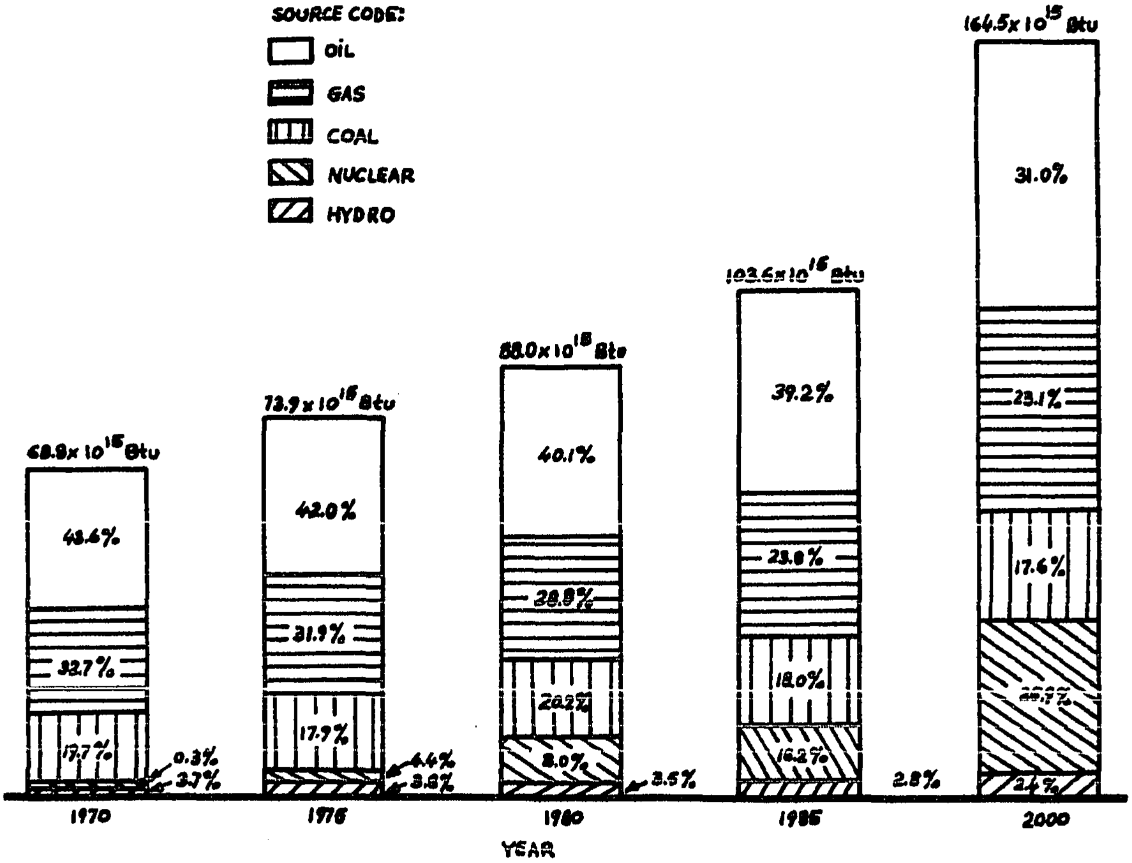

Figure 4.3. Projected U. S. consumption of energy resources by major sources

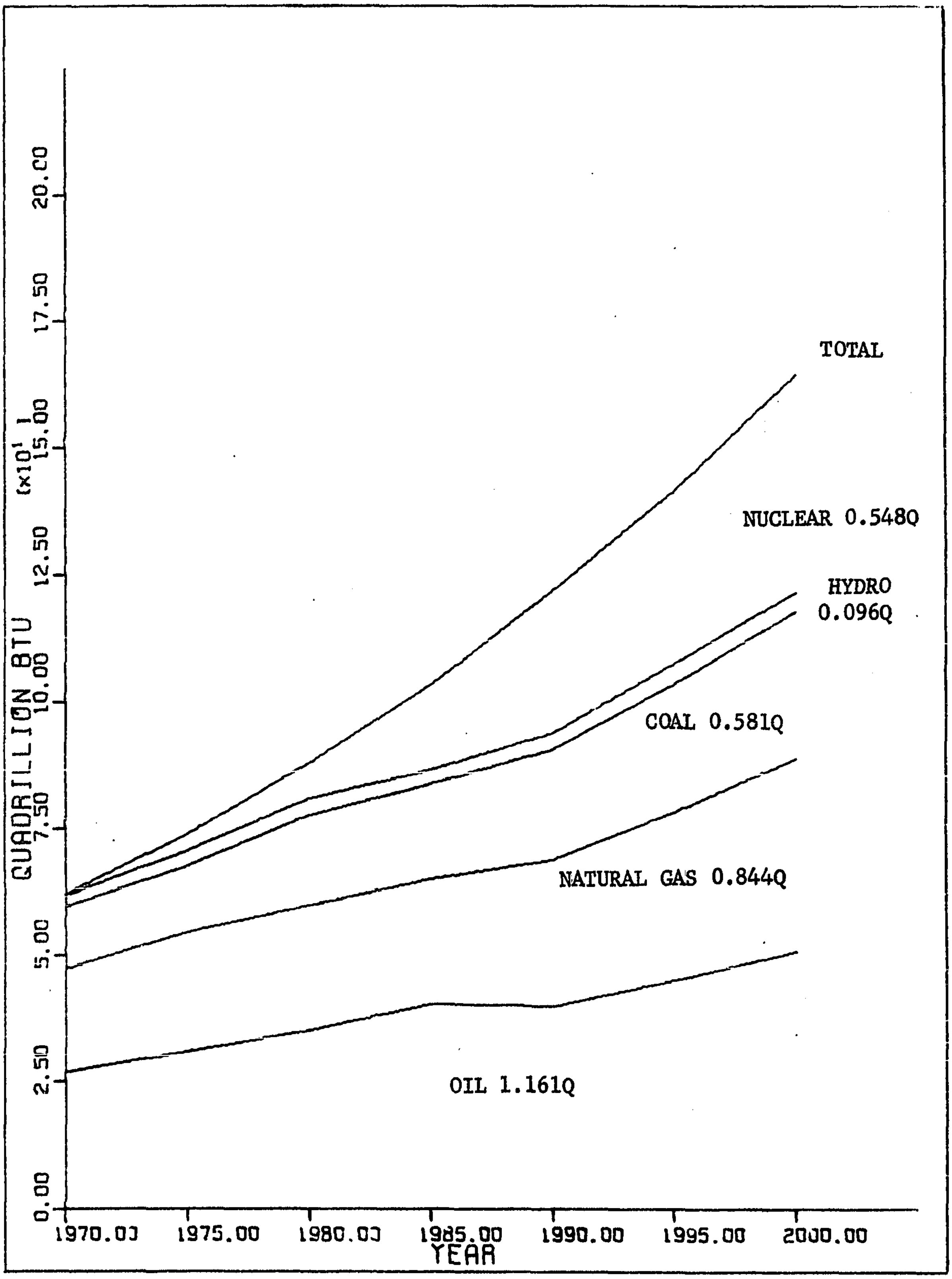

Figure 4.4. Projected U. S. consumption of energy resources by major sources

to estimate future fuel mix percentages. The following polynomial regression models proved to be the best with correlation coefficients of 0.850, 0.900, 0.960, 0.957 and 0.995 for coal, gas, oil, hydro and nuclear, respectively.

$$TFC = 23.885 - 0.512y + 0.0163y^2 - 0.00018y^3 + e \qquad (4.1)$$

$$TFC = 29.730 + 0.748y - 0.058y^2 + 0.00087y^3 + e \qquad (4.2)$$

$$TFC = 40.792 + 0.778y - 0.052y^2 + 0.0067y^3 + e \qquad (4.3)$$

$$TFC = 3.800 + 0.067y - 0.006y^2 + 0.00009y^3 + e \qquad (4.4)$$

$$TFC = 0.689 - 0.142y + 0.110y^2 - 0.0025y^3 + e \qquad (4.5)$$

The resultant "surprise-free forecast", shown in Figure 4.4, is an average fuel forecast to the year 2000. The market percentages which correspond to the figure are shown in Table 4.7, as is the total energy consumption forecast which was developed in Chapter III. Coal provides a declining percentage of the total fuel requirement in this average forecast. Gas and oil percentages exhibit more modest declines, and the nuclear energy percentage increases dramatically to 26 percent of total use in the year 20 2000.

Table 4.7. Future fuel mix estimations, in percent

Year	Energy Consumption (10^{15} Btu)	Coal (%)	Gas (%)	Oil (%)	Hydro (%)	Nuclear (%)
1970	68.8	20.0	33.0	43.0	3.7	0.3
1980	88.0	18.2	29.2	40.4	3.2	9.0
1990	122.0	15.7	26.2	37.2	2.6	18.3
2000	164.5	13.2	23.6	34.7	2.5	26.0

By integration of the fuel curves in Figure 4.4 from 1970 to the year 2000, using the computer program given in Appendix D, the projected energy supply of each fuel can be obtained for this period. The calculated values are shown on Figure 4.4 in units of Q, which is equal to 10^{18} Btu. They are also shown in Table 4.8 in 10^{18} Btu. Assuming domestic oil and gas production will remain constant, the domestic fossil fuel supply is estimated for the period of 1970 to 2000, and is shown in Table 4.8 (18). The balance of the oil demand is assumed to be met by imports, while the balance of gas demand either is met by imports or after 1980 is replaced by the synthetic gas from coal, which is called syngas. This syngas production after 1980 could possibly increase the demand for coal by 0.1×10^{18} Btu (18).

Table 4.8. Projected fuel supply for the U. S. for the period of 1970 to 2000

Fuel Type	Domestic Supply (10^{18} Btu)	Imported Supply (10^{18} Btu)	Consumption (10^{18} Btu)
Coal	0.581 + 0.100	-	0.681
Oil	0.591	0.570	1.161
Gas	0.536	0.208	0.744
Hydro	0.096	-	0.096
Nuclear	0.548	-	0.548
Total	2.452	0.778	3.230

Table 4.9 shows the estimated fossil fuel inventory for the U. S. in the year 2000, which is based on resources and forecasted comsumption.

Table 4.9. The U. S. fossil fuel inventory in the year 2000

Fuel Type	Initial Resources (10^{18} Btu)	Consumption 1850-1970 (10^{18} Btu)	Projected Consumption 10^{18} Btu)	Inventory in the year 2000 (10^{18} Btu)	Depleted (%)
Coal	38.0	1.07	0.681	36.249	4.60
Oil	2.8	0.68	0.591	1.529	45.39
Gas	1.7	0.39	0.536	0.774	45.53

As is evident in Table 4.9, the coal supply by the year 2000 will scarcely have been dented, while the original oil resource base will be half depleted; the presently estimated recoverable oil resources will be totally depleted, and the recoverable gas resources will be 60 percent depleted. In summary, the "premium" fuels which presently supply over three-fourths of the U. S. energy needs will be virtually exhausted by the year 2000.

D. The Impact of Advanced Technology

Today, the great bulk of our electric energy demand is met by converting kinetic (mechanical) energy into electrical energy in an engine with rotating or reciprocating parts, such as are associated with turbines, dynamos, and combustion engines. Most of the kinetic energy is in turn derived by conversion from chemical energy, through combustion. Recently, there has been rising interest in and much research concerning direct conversion of kinetic energy to electric energy, bypassing the intermediate step of mechanical energy. Table 4.10 shows the different types of energy and their interrelationships (16).

Research and development (R & D) on promising alternate energy sources and conversion technologies may develop practical substitutes for fossil and nuclear fuels or supplementary energy sources. Some of the new technologies will be discussed in terms of the primary energy sources with which they are associated: coal, nuclear fission, geothermal, oil, nuclear fusion, and solar. These techniques must be considered possible alternatives, not certainties.

1. Coal

Presently, coal is the major fuel used by utilities. Domestic coal reserves are significantly larger than the reserves of any other fossil fuel. The problems created by coal are primarily environmental. Since most of the coal in the U. S. contains over 1 percent sulfur (103), techniques are needed to desulfurize it so that it can be a clean energy source. The Clean Air Act of 1970 authorizes the Environmental Protection

Table 4.10. Energy conversion matrix

From To	Electromagnetic	Chemical	Nuclear	Thermal	Kinetic (Mechanical)	Electrical
Electromagnetic		Chemiluminescense	Gamma reactions	Thermal radiation	Accelerating charge (cyclotron) Phospher	Electromagnetic Electroluminescense
Chemical	Photosynthesis		Radiation catalysis Ionization	Boiling (water/steam) Dissociation	Dissociation by radiolysis	Electrolysis (aluminum production)
Nuclear	Gamma-neutron reactions	Unknown		Unknown	Unknown	Unknown
Thermal	Solar absorber	Combustion	Fission Fusion		Friction	Resistance-heating

Table 4.10. Continued.

From To	Electromagnetic	Chemical	Nuclear	Thermal	Kinetic (Mechanical)	Electrical
Kinetic (Mechanical)	Radiometer	Muscle	Radioactivity	Thermal expansion (turbines) Internal combustion (engines		Motors Electro-striction (Sonar transmitter)
Electrical Electrical	Photo-electricity Radio antenna Solar cell	Fuel cell Batteries	Nuclear battery	Thermo-electricity Thermoionics Thermo-magnetism Ferro-electricity	MHD Conventional generator	

Agency (EPA) to set maximum allowable sulfur oxide emission levels for coal burning electric power plants (46). Coal mining will probably be prohibited in some places only by land use restrictions. This makes it even more essential that the most accessible coal be delivered for use in energy production.

Utilities are presently testing about 13 stack gas desulfurization techniques. One or more of them will probably be commercially available by 1980 (46, 104, 105). Add on sulfur removal equipment probably will be of only limited value in the long run, as it fails to optimize the whole system. Some of the other processes being studied will probably reduce power plant thermal efficiency, and still others create problems with solid or liquid waste disposal (106).

One way to control pollution at ground level is to install very tall stacks. Tall stacks, here defined as stacks over 500 feet high, do not reduce overall emission, but do help disperse the effluent over a wider area. Peak ground level concentrations from the tall stacks are usually noticeable at lower levels than concentrations from short stacks. The trend toward larger power plants makes construction of tall stacks more feasible, but it also causes an increase in total emissions. More research is needed to determine the extent to which tall stacks improve local air quality under various meteorological and topographical conditions.

Sulfur can also be removed from the coal in the boiler during combustion. This could possibly be done by a fluidized bed boiler, which would also decrease the capital cost of the central power station (103, 107). Pressurized fluidized bed boilers may be operated commercially by the 1980's.

Another means by which coal would be utilized without producing sulfur pollutants is the process of coal gasification, by which coal would be converted into synthetic pipeline quality gas or low Btu "power gas" for electric power generation (108). Although the power gas could be made less expensively, it could not be economically piped over long distances. It could be used in utility boilers and in combined cycle plants which use a gas turbine in a topping cycle and a conventional steam cycle for bottoming. In this way, coal would provide energy in a cleaner way at a lower cost than if the boiler and steam turbine were used (108, 109). Condenser cooling requirement also would be reduced. If current estimates are correct, this gas turbine technology could, in the future, increase total plant efficiency to nearly 50 percent (110).

Small amounts of low-Btu power gas may be produced commercially by the late 1970's (112). By the 1980's, enough of it will be produced to make a significant contribution to the gas supply. Also, by the 1980's, high-Btu gas produced by coal gasification could be making a modest contribution to the U. S. natural gas supply (46, 111).

Another alternative for use in a combined cycle with the conventional steam boiler is the magnetohydrodynamic (MHD) generator. Numerous experimental MHD generators have been built, and a vigorous research program is underway to make them commercially feasible (114). The first application of the MHD to increase the efficiency of energy conversion will be in combination with conventional fossil fuel steam plants. The overall plant efficiency of such a combination could be as high as 60 percent, thus reducing waste heat twice as much as today's most efficient plants (113). The MHD generator has some characteristics which would possibly make it a desirable peaking unit. For example, it takes several hours to bring a fossil fuel or nuclear steam plant from a standstill to full capacity; an MHD peaking plant can do it in five seconds (106, 115). Research supported by the Edison Electric Institute (EEI) is being conducted to develop a single cycle MHD peaking unit which might possibly be used for a base-load design. However, there is some doubt as to whether the MHD generator will ever be a major source in this country (106).

Fuel cells present another possibility for the future utilization of fossil fuels. They convert stored chemical energy directly to electricity, skipping even the production of heat as an intermediate step. Present day fuel cells can operate at higher efficiencies than conventional fossil fuel or nuclear power plants. They operate on natural gas or syngas. Further development to reduce capital costs could produce substation size (10-20 MW) fuel cells for peaking power, using natural or synthetic gas (79, 114). The advantages of the fuel cells are many: they are clean and efficient; they operate quietly; they have a low space requirement, and have no need for water cooling, which makes it feasible to locate them at load centers (117). In this application, they would also reduce transmission system requirements. However, the natural gas shortage and anticipated high cost for substitutes will probably limit their use in electric power production to production of peaking energy (106).

2. Nuclear fission

Presently, nuclear reactors are not very efficient. Their efficiency is generally 32 to 33 percent, with the exception of the HTGR, which operates at an efficiency of 37 to 38 percent. Breeder reactors convert fertile isotopes into fissionable isotopes. In this way, the proportion of the nuclear fuel that is useful for energy production is vastly increased, which enlarges the energy resource base. In addition, the thermal efficiency of nuclear breeder reactors is about 40 percent, which is higher than that of today's light water reactors (93).

The LMFBR demonstration plant is scheduled to be completed in 1980 (60, 98). The 1980's may see the first LMFBR and possibly other breeders in commercial operation. If these are successful, there could be many commercial breeders in the 1990's, a situation which would fit well into a coordinated nuclear energy program using uranium resources to their maximum potential.

3. Geothermal energy

Heat from the earth's molten core and from chemical and nuclear reactions in the crust is carried to the surface by means of conduction, volcanoes, or hot springs. Under some circumstances, underground water, trapped in porous rock formations, is heated to extremely high temperatures by this geothermal energy. There are at least 1000 known hot springs in the U. S. (118-121). However, at the present time, there is only one geothermal power plant operating in the U. S. It is located north of San Francisco and is owned by the Pacific Gas and Electric Company. It has six generating units with a total capacity of 192 MW, using saturated steam. The ultimate power capacity of the geysers at this location may be as high as 1000 MW (121). The potential contribution of geothermal energy to the total energy supply will be very small (121). Estimates of total U. S. geothermal capacity range from 30,000 to 100,000 MW (118). These estimates assume full utilization of the potential at locations where steam or hot water are visible and near to the surface. About 85 percent of such locations are in the West (120).

The AEC's plowshare concept (120), which is still under study, could open an almost infinite supply of geothermal energy by tapping the vast heat in the hot rock deep in the earth. The hot rock would be fractured by small underground nuclear explosions. Then, water would be pumped into the fractured area, wherein it would become superheated. This superheated steam would rise to the surface where it could be used to drive turbines and thereby produce electric power. The condensed steam would be recycled back into the hot rock area. Hot rock, at the necessary depth and temperature, exists in many places in the U. S., most of which are in mountainous areas.

Conventional geothermal resources (steam and hot water) will probably be utilized as much as is advantageous economically without creating environmental problems. This will be possible for the most part in the western states and is unlikely to provide a large proportion of the future U. S. energy supply.

4. Oil

The U. S. oil supply is very limited, compared to the world's oil supply. The world oil supply is estimated to be 1,350 to 2,100 x 10^9

barrels, while the U. S. has about one-tenth of this amount (88). Within the bounds of any government restrictions on oil imports, the U. S. can import oil, particularly from the Middle East, where nearly one-third of the world's oil is located (86, 122). In 1971, the U. S. imported 28 percent of its oil requirement, partly because it could be imported more cheaply than it could be produced (87). The U. S. will very likely increase its dependence on foreign oil in the near future, at least to some extent.

Oil can also be produced from nonpetroleum fossil fuels like coal, tar sands, and oil shale. There are massive oil shale deposits in Colorado, Utah, and Wyoming. There are an estimated 600 billion barrels of raw oil contained in rock which has at least 25 gallons of oil in each ton. Much of this rock is on federally-owned land (10). This 600 billion barrels is approximately equivalent to three times the present U. S. petroleum resources. Heat at high temperatures is needed to separate the kerogen (oil) from the rock. The technology to do this has been developed by the U. S. Bureau of Mines and a number of companies. However, the process is an expensive one. The disposal of the spent shale after retorting also presents a problem. More research is needed to determine whether oil shale can ever be a practical commercial source of oil.

There are vast tar sands resources in Alberta (Canada) from which oil is already being produced. In contrast to the size of oil shale resources, U. S. tar sand resources are small, with less potential of contributing to the oil supply.

Obtaining oil from coal presents a greater technical challenge than does extracting it from shale. However, more oil can be obtained from coal than from shale and, consequently, there is less disposal problem. Research concerning the production of oil from coal is under way at a pilot plant at Cresap, West Virginia, which was built in 1967 with funds from the Office of Coal Research (103). The Gulf Oil Corporation is also studying solvent refining of coal, whereby a low sulfur, low ash liquid fuel for utility boilers could be produced (103, 123).

5. Fusion

Presently, two processes by which nuclear fusion can be used to produce power are being studied. One utilizes laser-ignited microbombs, and the other, magnetic confinement of an ultra-hot plasma. However, probably neither will be used for producing commercial power before the year 2000 (124, 125).

It has not yet been shown that nuclear fusion is scientifically feasible. One of the goals of the R & D Task Force of the Edison Electric Institute is to demonstrate such feasibility. Many scientists believe that fusion will be available during this decade (125). Nuclear fusion occurs when an atom of deuterium merges at very high temperatures (100 million degrees C.) with an atom of tritium, or when two deuterium atoms merge to form a helium atom in process releasing a great amount of heat (126). Both deuterium and tritium are isotopes of hydrogen. Deuterium is not scarce, but naturally, comprises about one part per 6,200 of water. Methods of separating deuterium from water are well-developed. Tritium, on the other hand, is very scarce and very expensive, as well as radioactive. A deuterium-tritium (D-T) fusion reactor, to be serviceable, must breed tritium, which requires a lithium-6 blanket. Neutron bombardment causes the lithium-6 to breed tritium. Both lithium and deuterium are consumed in the process. Hence, the amount of energy that can be produced by means of the D-T reaction is limited by the world's lithium supply. Because of this limitation, the energy production potential of the D-T reaction is little more than that of U. S. fossil fuels (125).

Because no raw materials are consumed, the Deuterium-Deuterium (D-D) reaction can potentially provide an infinite amount of energy. The D-D reaction is technically more difficult to induce than the D-T reaction because it proceeds at higher temperatures. Another drawback is that this reaction produces radioactive tritium, which would create a disposal problem (125). There would, of course, be no such disposal problem with a D-T reactor. One advantage of the D-D reaction is that it produces high velocity charged particles called protons, while the D-T reaction produces energetic neutrons (126). Because of this, the energy produced by the D-D reaction may be directly convertible to electricity, which the energy produced by the D-T reaction would not be. This direct conversion would make possible the elimination of the Carnot cycle, which decreases plant thermal efficiency.

Fusion reactors utilizing magnetic confinement will very likely be housed in huge central stations. Units could very likely have capacities of at least 1,000 MW (126) and probably up to 10,000 MW (127). Fusion reactors would be safer and would operate (up to 60 percent) more efficiently than fission reactors (126, 127). The laser fusion reactor could have a capacity much less than 1000 MW, about 100 MW. It would be just as safe and could be operated only when needed (124).

If commercial fusion reactors are to be developed, the necessary research will cost billions of dollars. The U. S. will undoubtedly make this investment, if indeed the process is shown to be scientifically feasible. Prototype fusion reactors may be in operation by the year 2000 or the early part of the 21st century.

6. Solar energy

The amount of solar energy which radiates to the U. S. is hundreds of times as much energy as is consumed. Based on the U. S. annual average solar incidence of about 1400 Btu per square foot day, the continental U. S. intercepts, annually, about 600 times the 1970 energy consumption of 69 x 10^{15} Btu (10). However, the energy is scattered and is not supplied continually. There is none supplied at night and very little on cloudy days. A method to cheaply convert solar energy into another, more useful form of energy, and a method to store that energy are needed. Various solar conversion processes have been proposed, but none has much potential for producing a major amount of energy.

Peter Glaser (47, 124) was the first to produce a synchronous orbiting satellite with an array of solar cells, which would "capture" solar energy. The solar energy would then be converted to microwave energy, which would continuously be transmitted to a receiver on earth, where the microwave energy would be converted to electricity.

A solar farm was suggested by Aden and Marjorie Meine (10, 127, 128).

Solar radiation would be entrapped by specially designed thin films and transferred to liquid sodium. Then, by means of an exchange mechanism, the heat would be conveyed to a secondary water cycle to be used for conventional steam generation. These solar farms could be 25-30 percent efficient. One major drawback is that the films for collecting the solar energy would require exceedingly large land areas. Also, if there were no way to store the energy, the supply would vary with the weather.

It may sometime be feasible to install flat collectors which convert solar energy to electrical energy on rooftops and similar surfaces (128). However, this will not be practical until solar cells are sharply reduced in price and a method is developed to store the energy.

Solar space heating has already been tested. In this system, solar heat is transferred from collectors on a roof to water or an air stream, and into a water tank where it is stored. Houses can be economically heated with such a system in certain sunny areas where fuel is expensive (10). However, the house has to be designed with solar heating in mind, and even so, supplemental heating will be necessary. Solar home heating will no doubt be used in the future in certain areas.

A 1000 MW (24-hr. average) power plant operating in a 1400 Btu/ft^2 per day solar climate with an efficiency of 5 percent would require 37 square miles of ground coverage, compared with a few hundred acres needed for a nuclear or fossil-fuel plant (10). Therefore, in practical terms, there is considerable doubt that solar energy will replace present power sources in the future.

E. The Limits to Energy Growth

As discussed in Chapter III, it is forecasted that future energy consumption will be vastly greater than present consumption. However, there are physical factors which may make such growth in the energy supply impossible - the availability of adequate resources, possible excessive pollution, and undesirable global climatic effects which could be created.

1. Resources

The energy resource base is expected to increase to well over 1000Q from today's level of 55Q in the next several decades (16). According to the projection discussed in Chapter III, 3.23×10^{18} Btu total energy will be used by the year 2000, and about 60×10^{18} Btu used by 2100 (See Table 3.20). Hence, fuel resources will presumably be adequate through and beyond that time.

Some types of energy production may be limited by the availability of nonfuel resources. For instance, the energy production potential of D-T fusion is limited by the lithium supply (125). A deficit of platinum may limit fuel cell development unless another usable catalyst is found (42). Some of these limitations can be overcome, though. It may be possible, for example, to recycle rare resources. Since indications are that there are more than adequate potential resources to meet projected demand, it is unlikely that energy growth in the next century will be impeded by resource limitations.

2. Pollution

Pollution is unavoidable, as it is produced by most industrial processes. Production of enormous amounts of solid waste is a problem in a society such as this which has a "throw away" mentality and finds "no-deposit-no-return" packages most economical. Pollution will undoubtedly increase exponentially as long as industrial and energy production do so, although this cannot continue indefinitely, as there is a point beyond which more pollution would be intolerable. The crux of the problem is economic. It is costly to eliminate or dispose of pollution produced as a by-product of an industrial process. The least expensive way to deal with pollution, the one which has been used in the past, is to not deal with it at all. But, it is possible to design industrial processes which produce essentially no pollution, excepting waste heat, if the public is willing to pay the price.

Energy production creates basically the same types of pollution problems as do other industrial processes. The level of pollution which the environment can safely tolerate must be determined. The industry must find practical methods to collect, recycle, or safely dispose of pollutants. All this may at times be technically challenging, but it no doubt is possible, although probably expensive. Hence, pollution control is unlikely to impede growth of the energy supply, though it will make energy production more costly.

3. Climatic effects

The sun's energy supports the life cycle of the earth. Variations in the amount of radiant energy from time to time and from region to region result in different and changing atmospheric conditions, seasons, and climatic conditions. If man's energy production ultimately were to produce an amount of waste heat that was significant compared to the amount radiated from the sun, it certainly would seriously alter climatic conditions. For this reason, energy production cannot increase indefinitely. However, there will probably be no climatic problem until the amount of heat added to the atmosphere is equivalent to about 1 percent of that radiated from the sun, though this is only a speculation (10, 42).

Utilization of most forms of energy ultimately produces waste heat, which increases the thermal burden on the biosphere. This is not true for an invariant energy resource like hydropower, because it basically circulates through the terrestrial water cycle. Unfortunately, hydropower will never be able to meet a major portion of energy needs. Solar energy could also be an invariant energy resource if either the solar cells or the converters were located on the earth's surface. The Glaser approach to solar energy utilization does not include this future. All other means of energy utilization, other than hydropower and solar conversion are noninvariant and so would result in the release of waste heat into the environment. This is even true of geothermal energy, which originates in the earth itself. This being the case, it is possible, to evaluate the overall thermal situation in the U. S. An average of 1400 Btu/ft^2 of solar energy radiates to the U. S. land area each day (10), which is equivalent to 51 x 10^{18} Btu per year. According to the energy forecast discussed in Chapter III, Section G, the rate of growth of Btu per capita will be 2 percent by the year 2040, and almost 0.2

percent by the year 2100. The energy, naturally, will not be equally distributed, so the thermal load will be greater in some areas than in others. Even so, thermal pollution is unlikely to cause global climatic problems even as far in the future as the year 2100, largely because over two-thirds of the earth's surface is water. Even if man generates heat at a rate of 3 percent of the solar input on all land areas, the overall worldwide heat generation rate would still be 1 percent. The northeastern region of the U. S., which consumes 40 percent of the nation's energy, locally produces waste heat at a level equivalent to 1 percent of that provided by the sun. The 4,000 square-mile Los Angeles basin area suffers no ill climatic effects, even though it generates heat at a 5 percent level (129).

There is much concern about the long range effect that human activities may have on the earth's temperature and thereby on its climate and atmospheric heat balance (50). The overall problem is complex and difficult to quantify. There are at least five ways in which man could change the earth's temperature, some of which are not directly related to energy utilization.

1. Fossil fuel combustion produces CO_2 and therefore increases the CO_2 concentration in the atmosphere. This CO_2 blocks the long-wave radiation from the earth's surface to space, and so raises the average temperature by this "greenhouse effect." If the entire U. S. fossil fuel supply were eventually burned for fuel, the atmospheric CO_2 concentration could double, thereby possibly increasing the average earth temperature by 2.4 degrees C.

2. Combustion of fossil or nuclear fuel releases heat directly into the atmosphere, thereby raising the earth's temperature.
3. Aerosols produced by industry, automobiles, etc., make the atmosphere less pervious to incoming solar radiation, which tends to lower the earth's temperature.
4. Incorrect agricultural procedures produce dust, which has the same effect as do aerosols.
5. Urbanization and deforestation on the earth increase the proportion of incoming solar radiation that is reflected outward again as soon as it hits the earth's surface (albedo). This tends to decrease the earth's temperature.

The long range effect of the interaction of these factors on the earth's temperature is still a matter of speculation (50). Until further research is completed, the probable impact of growing energy consumption on global climatic conditions will remain uncertain.

F. Fuel Supply Forecast for the 21st Century

According to the forecast presented in Chapter III, Section G, the energy requirement in the decades after the year 2000 will be enormous, as shown by Table 4.11.

Table 4.11. Forecasted U. S. energy demand for the 21st century

Ten-Year Interval	(10^{18} Btu)
2000-2010	1.912825
2010-2020	2.563244

Table 4.11. Continued.

Ten-Year Interval	(10^{18} Btu)
2020-2030	3.395954
2030-2040	4.358086
2040-2050	5.326945
2050-2060	6.297757
2060-2070	7.200201
2070-2080	7.890642
2080-2090	8.376136
2090-2100	8.673228
Total	55.995018

In the first decade alone, about 1.913 x 10^{18} Btu will be required. Part of this may be provided by oil - some of which will be imported, and some of which will certainly be kerogen from shale oil. Domestic oil will make only a minor contribution as it will be almost depleted.

Domestic natural gas will also be almost totally depleted by the year 2000, as shown in Table 4.9. However, Alaska pipeline gas or LNG from the Middle East or Africa will still be imported. Syngas from coal, although expensive, will be available. Hence, gas will be used only for purposes which merit the high cost.

Coal resources will be only slightly depleted by the year 2000 - coal equivalent to 36 x 10^{18} Btu will still be available. Because breeder reactors will be in operation by that time, optimum utilization of uranium will be possible, and, therefore, uranium energy resources will be immense. By the first decade of the 21st century, prototype fusion reactors may be in operation, hopefully paving the way for commercial plants in the second decade. Solar and geothermal sources will be utilized to a relatively small degree. Thus, in the years from 2000 to 2020, much of the U. S. energy need will have to be met by coal and uranium. The degree to which the various forms of nuclear power and coal contribute to the energy supply will depend on their comparative costs.

The cost of both nuclear power and coal will be determined primarily by the necessary capital investment, some of which will be for pollution control equipment. Both uranium and coal fairly certainly will be major sources of energy in the early part of the 21st century.

Some scientists believe that nuclear fusion will be a viable energy source by the yeat 2000 (126), which may be the case if the necessary research and development are adequately funded. But, since research effort must be allocated among a number of important projects, the first commercial fusion plants will probably not be in operation until the second decade of the 21st century. Hydropower will never be more than 4×10^{15} Btu per year because of limited number of potential sites and water capacity.

Because nuclear power will supply an increasing proportion of the energy supply after the year 2000, growth of electric power's share of the energy market will be accelerated. Electricity's share of the market will keep growing until it reaches 85 percent and the market is saturated.

V. DEVELOPMENT OF AN ELECTRICAL ENERGY MODEL FOR IOWA UTILITIES

A. Introduction

Recent developments in the energy field indicate that the United States cannot simultaneously continue its rapid growth in energy usage, maintain low energy prices, protect the environment, and remain relatively independent of foreign suppliers. Because changes in the price availability of electrical energy affects everybody and the whole economy, a need for the development of an electrical energy model is apparent.

In order to evaluate rapidly the consequences of different proposed energy policies, a computerized electrical energy model has been developed in this study. The necessary mechanism is built into the model in order to capture accurately the dynamics of changes. Furthermore, if one wishes to answer the many "what if" questions, the computerized model has a consistent framework within which to investigate a wide variety of policies rapidly and economically.

The model can be used to investigate the impact of a wide range of factors on the regional energy situation. The following list indicates the type of factors that can be considered: new technology, environmental restrictions, fuel import quotas, fuel availability, energy conservation measures, and price increases and decreases.

The model is basically built for the electric power industry to minimize the cost of energy used for electric generation through optimum allocation of various fuel mixes over a period of n years, where the energy is subject to a large number of physical and environmental constraints.

In order to keep the size of the model within reasonable bounds (because of a limited computer budget, difficulties involved in obtaining the necessary coefficients, and a time limitation) the model is applied to the State of Iowa rather than to the whole country. Thus, Iowa, 95 percent of which is electrified by a group of utilities referred to here as the "Iowa Pool",[1] was chosen as the region for the application of the model (134).

B. Structure of the Model

1. General discussion

One approach to analyzing complex energy problems which are related to the electric power industry is to use mathematical "models". By means of a model, one attempts to represent the interactions between supply, demand, prices, and other variables through mathematical relationships. In a general sense a model can be defined as an intellectual construction bearing some relation to reality, which can be discussed and analyzed in and of itself (135).

The electrical energy model developed in this study is a useful tool for minimizing overall fuel costs by optimum allocation of various fuel mixes among generating units, not only for the Iowa Pool as a whole, but also for the individual utilities. It is applied to the Pool under the assumption that the Pool members will act as a united group to minimize their overall fuel costs.

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[1] The name "Iowa Pool" is not intended to imply any official consortium of companies; it is merely a convenient name used for the identified group of Iowa utilities.

A functional block diagram of the electrical energy model is shown in Figure 5.1. It consists of a main fuel allocation model (FAM) and three forecasting submodels, namely: the fuel supply forecasting submodel, the fuel cost forecasting submodel, and the electrical energy demand forecasting submodel. The initial data input is composed of information on all of the submodels.

Additional inputs concerning new technology and policy will modify the parameters within the FAM. The FAM uses the mathematical techniques of Linear Programming (LP) in order to obtain the optimum fuel mixes which minimize the fuel costs of the pool or an individual company.

The electrical energy demand forecasting submodel projects the electrical energy demands of the region into the future for each company and/or for the Iowa Pool in total. A computer subroutine program was prepared to project the future electrical energy demands. This subroutine is presented in Appendix E.

The fuel supply forecast gives the future fuel supply for each fuel, and the fuel cost forecast provides the future costs for each type of fuel. These forecasts have been provided by the individual companies in light of their long-term contracts with the fuel supply companies.

The purpose of the new technology inputs is to investigate the impact of future major developments with respect to electrical energy supply and demand. From new technologies under investigation, input constraints to the LP on supply and demand can be developed to reflect the new technologies' effect on consumption over the appropriate time period. The specification of substitutions and price constraints can provide addi-

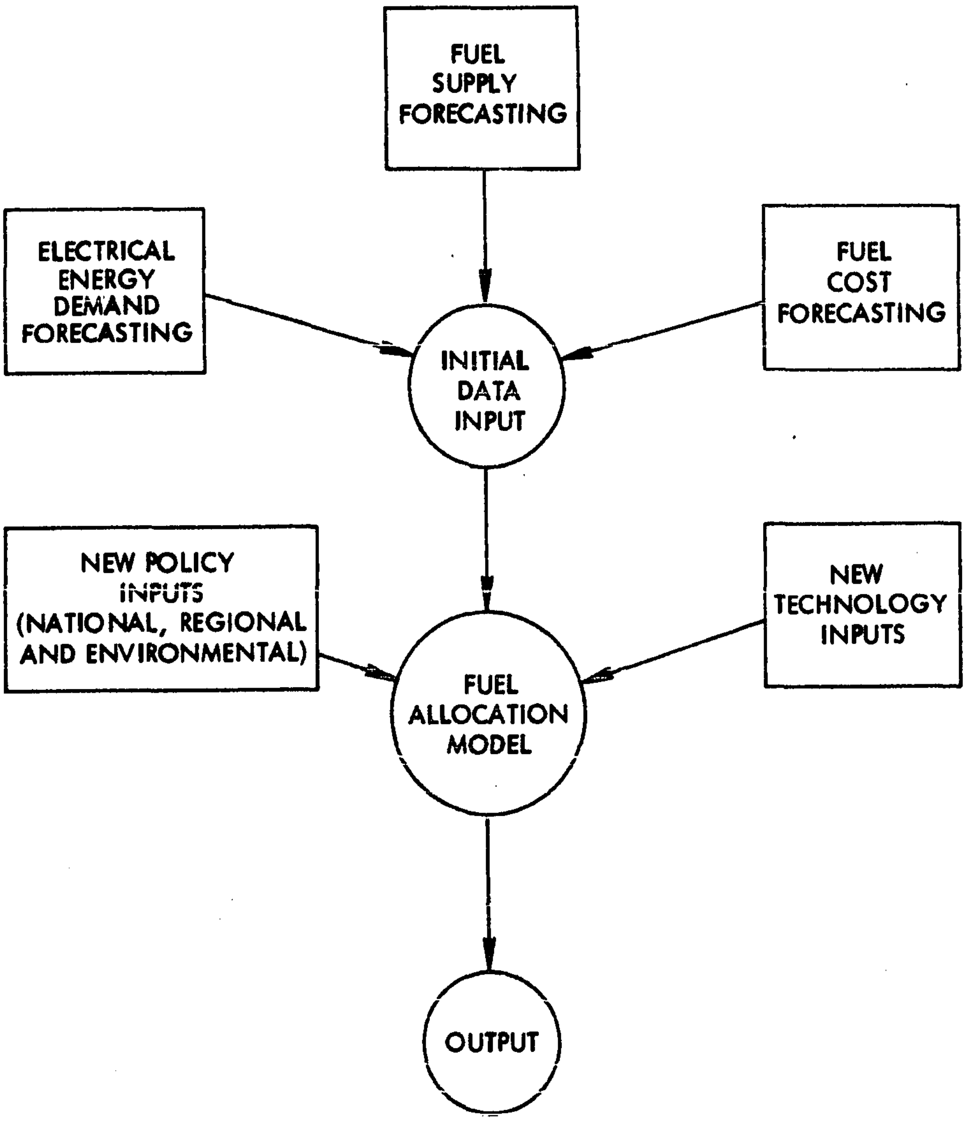

Figure 5.1. A functional block diagram of the electrical energy model

tional means of reflecting the effects of new technologies.

The investigation of national, regional, and environmental policies also requires manipulation of the FAM parameter inputs. From the new policies under investigation, LP input constraints on supply, demand, and cost can be modified.

2. Mathematical model

As explained before, the FAM uses a mathematical technique called Linear Programming. The LP is a mathematical process which seeks to minimize or maximize a linear function, called the objective function, in which the variables are subject to linear constraints.

The objective function takes the linear form

$$Z = \sum_{i=1}^{n} C_i X_i \qquad (5.1)$$

where Z is the value to be optimized. In our model, Z is the total fuel cost which is to be minimized. The X_i represents n unknown quantities, and the C_i are the costs associated with one unit of X_i. The C_i may be positive or negative, whereas the X_i must be defined in such a manner as to assume only positive values.

The constraints, or restrictions, are limitations on the values that the unknowns may assume and must be a linear combination of the unknowns. The constraints assume the form

$$\sum_{i=1}^{n} a_{ji} x_i = , \geq , \leq b_j \qquad (5.2)$$

$$x_i \geq 0$$

or

$$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = , \geq , \leq b_1$$

$$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n = , \geq , \leq b_2$$

$$\vdots$$

$$a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{m1}x_n = , \geq , \leq b_m$$

$$x_1 \geq 0,\ x_2 \geq 0,\ \ldots,\ x_n \geq 0 \qquad \begin{array}{l} \text{where } j = 1, 2, \ldots, m \\ \phantom{\text{where }} i = 1, 2, \ldots, n \end{array}$$

where there are m constraints of which any number may be equalities or inequalities. Also, the number of constraints, m, may be greater than, less than, or equal to the number of unknowns, n. The coefficients of the unknowns, a_{ji}, may be positive, negative, or zero, but must be constants. The b_j are also constants, which may be positive, negative, or zero. The constraints in our model, as formulated, express the energy requirements, the generation limitations of specific units, and other restrictions which are described in the following sections.

The constraints define a region of solution feasibility in n dimensional space. The optimum solution is the point within this space whose x_i values minimize or maximize the objective function Z. In general, the solutions obtained are real and positive.

In our model the objective function is used to find the minimum overall fuel costs of the Iowa Pool or of an individual utility by optimum allocation of various fuel mixes among generating units over a period of n years. Therefore, the objective function takes the linear form

$$Z = \sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} C_{ijk} F_{ijk} + \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} C^p_{ik} P_{ik} - \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} C^s_{ik} S_{ik} \qquad (5.3)$$

where $i = 1, 2, \ldots, N_u$

$j = 1, 2, \ldots, N_f$

$k = 1, 2, \ldots, N_y$

where i gives the serial number of utilities in the Iowa Pool in order to represent them in the computations. There are nine electrical utilities in the Pool, therefore $N_u = 9$. The serial numbers of the companies are given according to the code which is shown in Table 5.1.

Table 5.2 and Figure 5.2 show the annual gross electrical energy requirement forecast for the Iowa Pool according to 1975 MARCA report for the period of 1975 - 1985 (137). Figure 5.3 represents the annual gross electrical energy requirement forecast for one company (IPL) for the years from 1975 to 1985. These nine utility companies account for about 95 percent of the electricity generated in the State of Iowa. The remaining 5 percent of the electricity is produced by municipal utilities (134). The index j represents the serial number of the generating units of each company of the Pool, where generating units may use different types of fuel, such as oil, coal, natural gas, and nuclear fuel, to produce energy. Because of its very small contribution, hydro is neglected in this study.

Index k represents the number of years which are covered. In our study we covered only the eleven-year period from 1975 through 1985, because of a limited computer budget, difficulties involved in obtaining

Table 5.1. The serial number of the companies in the Iowa Pool

Serial Number	Company Name	Code Name
1	Iowa Power and Light	IPL
2	Iowa Southern Utilities	ISU
3	Iowa Public Service	IPS
4	Interstate Power	ISP
5	Iowa Electric Light and Power	IELP
6	Central Iowa Power Cooperative	CIPC
7	Iowa-Illinois Gas and Electric	IIGE
8	Corn Belt Power Cooperative	CPA
9	Eastern Iowa Light and Power Cooperative	EILP

Table 5.2. The annual gross electrical energy requirement of the Iowa Pool in GWh for the years from 1975 to 1985 (137)

Year	IPL (1)	ISU (2)	IPS (3)	ISP (4)	IELP(CIPC) (5-6)	IIGE (7)	CPA (8)	EILP (9)	Total
1975	4111	1488	2896	3178	4840	3810	1919	285	22,527
1976	4423	1706	3293	3369	5143	4111	2087	300	24,432
1977	4769	1907	3729	3571	5538	4446	2306	325	26,591
1978	5152	2039	4142	3785	5925	4801	2506	360	28,710
1979	5534	2176	4432	4013	6340	5185	2723	395	30,798
1980	5945	2324	4742	4253	6786	5600	2959	410	33,019
1981	6396	2482	5116	4508	7262	6048	3217	430	35,459
1982	6877	2652	5516	4779	7775	6532	3499	445	38,075
1983	7353	2835	5929	5065	8320	7054	3785	475	40,816
1984	7893	3031	6392	5369	8960	7619	4094	475	43,833
1985	8466	3242	6893	5692	9534	8828	4428	475	46,963

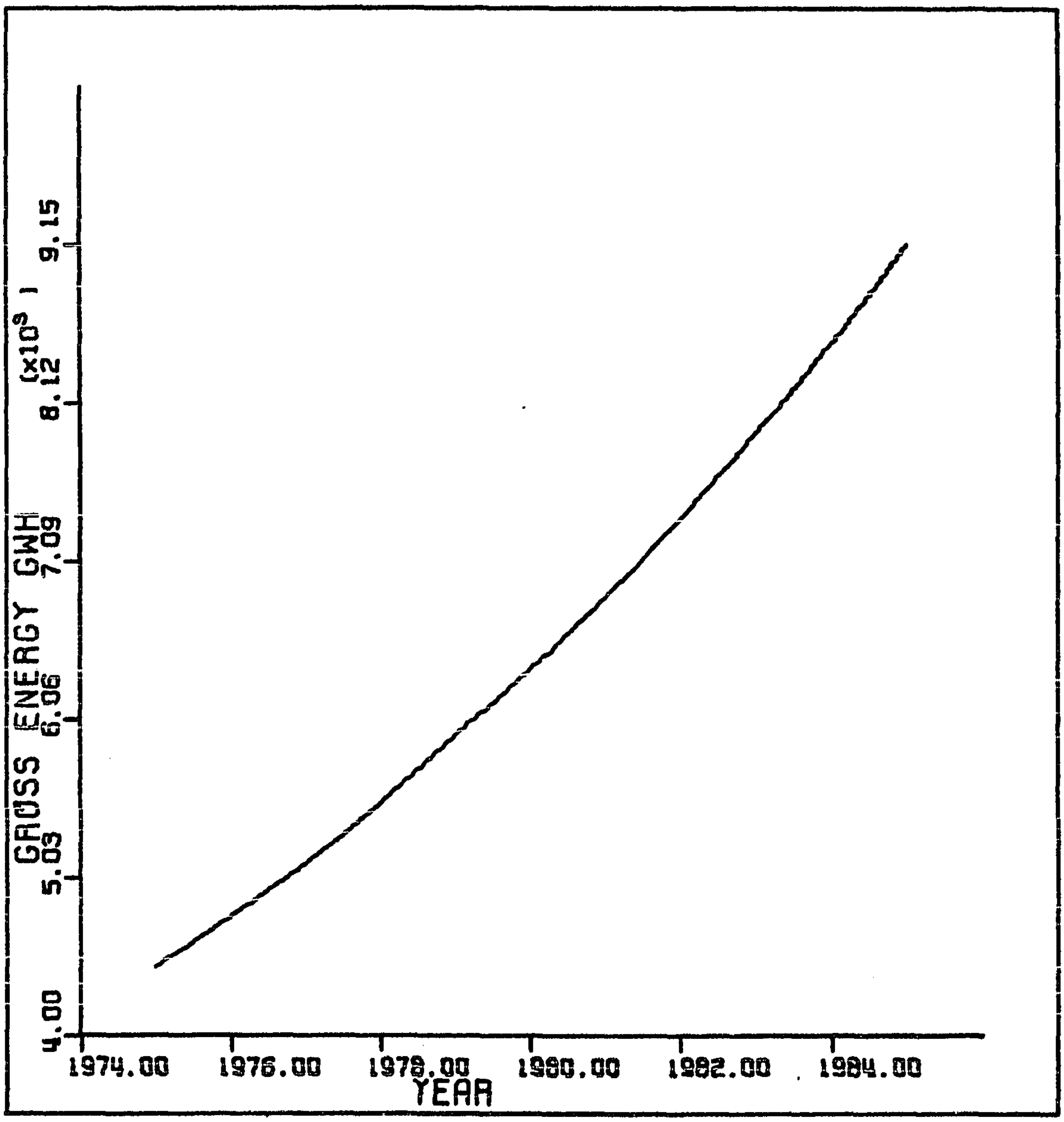

Figure 5.2. The annual gross electrical energy requirement of the Iowa Pool in GWh for the years from 1975 to 1985

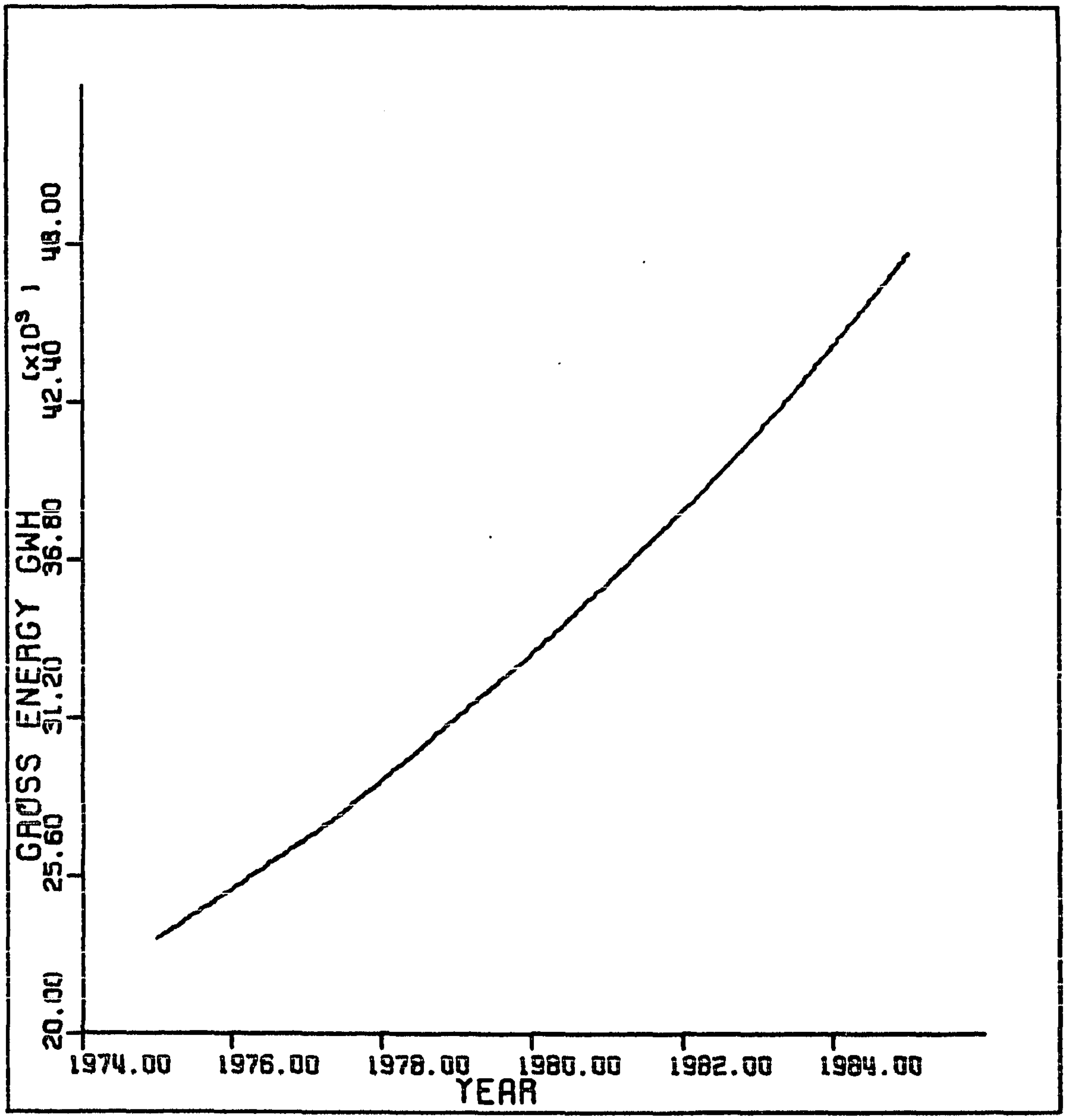

Figure 5.3. The annual gross electrical energy requirement of a single utility company (IPL) for the years 1975 to 1985

the necessary coefficients, and a time limit.

Also define

C_{ijk} = cost of fuel used to produce electrical energy from jth generating unit of the ith utility during the kth year in dollars per MBtu.

F_{ijk} = amount of fuel used to produce electrical energy from jth generating unit of the ith utility during the kth year in MBtu.

P_{ik} = amount of annual electrical energy purchases by the ith utility during the kth year in MWh.

C^p_{ik} = cost of electrical energy purchases by the ith utility during the kth year in dollars per MWh.

S_{ik} = amount of annual electrical energy sales by the ith utility during the kth year in MWh.

C^s_{ik} = cost of electrical energy sales by the ith utility during the kth year in dollars per MWh.

Fuel costs of a generating unit are proportional to the inclusive cost of heat and inversely proportional to the thermal efficiency. The cost of heat, in turn, depends on the sources of fuel and the transportation and fuel handling costs, which are themselves affected by the total fuel consumption of the utility companies.

There may be a larger number of physical and environmental restrictions affecting the model in the long run than at the present. For example, the fuel imported for all purposes into the State of Iowa might be restricted by transportation capacity, e.g., rail capacity, barge capacity, etc. The total electric generation might be restricted by the water available to energy generation for cooling purposes in the State of Iowa. Furthermore, the needed transmission line capacity might be restricted by the corridor capacity available for the energy transmission lines. However, in our study, which covers only the eleven-year time period through 1985, we assumed that the above restrictions and many others which might apply were not of great importance; therefore they were neglected. Some of the currently significant physical and environmental restrictions are presented below.

3. Energy requirement restriction

The electrical energy generated by the individual generating units of the Pool plus the electrical energy purchased minus the electrical energy sold by the Pool through out-of-Pool transactions is equal to the annual gross electrical energy demand of the Pool.

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} n_{ij} \times F_{ijk} + \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} K_1 \times P_{ik} - \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} K_1 \times P_{ik}$$

$$= \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} AGE_{ik} \qquad (5.4)$$

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} n_{ij} \times F_{ijk} + \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} K_1 \times S_{ik} - \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} K_1 \times S_{ik}$$

$$= \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} K_1 \times PD_{ik} \times 8760 \times ALF_{ik} \qquad (5.5)$$

where

n_{ij} = efficiency of jth generating unit of ith company of the Pool. It can be calculated by using the formula

$$n_{ij} = \frac{(3413\ \text{Btu/kWh}) \times 100}{(\text{Heat rate of the unit Btu/kWh})_{ij}}$$

K_1 = 3.413 MBtu/MWh. It is the heat energy equivalent to 1 MWh of the electrical energy.

AGE_{ik} = annual gross electrical energy demand of the ith utility for the kth year, in which system losses and energy uses of the plants themselves are included in MWh.

PD_{ik} = annual peak demand of the ith utility during the kth year.

ALF_{ik} = annual load factor of the ith utility during the kth year.

8760 = number of hours in a year.

4. Energy capacity restriction

The total electrical energy generated by each individual generating unit of the Pool will not exceed the total maximum available generating capacity of the Pool

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} n_{ij} \times F_{ijk} \leq \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} K_1 \times MAC_{ik} \times 8760 \qquad (5.6)$$

or

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} n_{ij} \times F_{ijk}$$

$$\le \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} K_1 \times C_{ik} \times K_2 \times (1 - K_3) \times K_4 \times 8760 \qquad (5.7)$$

or

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} n_{ij} \times F_{ijk} \le \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} C_{ik} \times AF \times 8760 \qquad (5.8)$$

where

$AF = K_1 \times K_2 \times (1 - K_3) \times K_4)$

= an average overall factor.

MAC_{ik} = maximum available generating capacity of the ith utility during the kth year in MW.

C_{ik} = maximum installed generating capacity of the ith utility during the kth year in MW.

K_2 = an average cruise rating factor. In the electric power industry, the general practice is not to run generating units at their maximum capacity in order to avoid certain operational problems. Throughout this study, K_2 is set equal to 0.9, but any value could be used.

K_3 = a reserve factor. According to the Mid-Continent Area Realiability Coordination Agreement (MARCA), each utility company shall reserve 15 percent of its generating units' capacity for reliability purposes. Therefore, K_3 was accepted as equal to 0.15 (137).

K_4 = an average availability factor of a unit. It covers scheduled and unscheduled outage rates of the generating units. In this study, the average plant availability factor was assumed to be 0.964 for fossil fuel burning generating units and 0.900 for nuclear generating units because of lack of data (146).

5. Sulfur emission restriction

The main fossil fuels used for steam electric power generation are bituminous coal, residual oil, and natural gas, each with its own spectrum of air pollutants. Typical emissions of these pollutants are carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates, and hydrocarbons. In this study, because of a lack of necessary data, the only environmental restriction applied was that of sulfur emission. Other pollution restrictions could be added, however, using the technique used for sulfur emissions.

The oxides of sulfur, principally SO_2, are released primarily from residual oil and coal plants. The sulfur contained in oil and coal is oxidized to SO_2, which in turn may be oxidized to SO_3.

To control sulfur dioxide emission, four approaches are being used, none of which are complete answers to the problem: 1) using coal that naturally has lower sulfur content, 2) removing sulfur from the fuel before it is burned, 3) installing devices to collect sulfur dioxide after the fuel is burned, 4) blending high-sulfur coal with low-sulfur coal in order to obtain a coal mix which has a permissibly low sulfur content.

Low-sulfur coal (about one percent sulfur as compared to the nominal three percent) is available, especially in Wyoming and Montana, and is being used. However, other industries, especially the metallurgical industry, also show a high demand for this coal. Therefore, it is important to recognize that one-percent-sulfur coal provides only a short-term limited solution to the problem for two reasons: 1) with electrical energy production doubling every ten years, the total emission from increasing quantities of low-sulfur coal will become greater than that now emitted from smaller quantities of higher-sulfur coal; and 2) present U. S. reserves of low-sulfur coal cannot meet total demands indefinitely.

Some sulfur can be removed from coal before burning using existing technology. Sulfur occurs in coal in the pyrite form (FeS_2) and as complex organic compounds. The pyrite form can be removed by washing and grinding, leaving only the organic compounds, which are more difficult to remove. Preliminary results of research supported by the National Air Pollution Control Administration show that the washing technique can be used for about 20 percent of the coal consumed by the utility industry and can reduce the sulfur content to approximately one percent (136).

The process of SO_2 collection after the fuel is burned applies to both coal and residual oil fuels. Of the many collection processes under development, few have reached the successful stage (136).

For power plant applications, there are no existing systems for the control or recovery of the oxides of nitrogen. Presently, power plants are being built with higher stacks, depending on broader dispersal of the pollutants as the main method of reducing regional concentration. Also, methods are being developed to improve the combustion control and to reduce the fire-box temperature in utility boilers as a means of greatly reducing the production of nitrogen oxides.

Federal proposed performance standards (40 Code of Federal Regulations, Part 60, Section 43) have been issued for sulfur dioxide emissions from fossil fuel burning steam generators of 250 MBtu per hour or more heat output. The standards state that emissions shall not exceed 0.80 pound per MBtu derived from liquid fossil fuel and 1.2 pound per MBtu derived from solid fossil fuel.

In the State of Iowa these standards have been relaxed, according to the Rules and Regulations of the Air Quality Commission (136). After July 13, 1975, no fossil fuel burning generating units of 250 MBtu per hour or more heat input will be allowed to cause the emission of sulfur dioxide into the atmosphere in an amount greater than six pounds of sulfur dioxide per MBtu of heat input from any solid fuel burning generating unit for any combination of fuels burned. For liquid fuel burning generator units, the emission of sulfur dioxide into the atmosphere in an amount greater than 2.5 pounds of sulfur dioxide per MBtu of heat input is prohibited. After July 31, 1978, the emission of sulfur dioxide into the air will not exceed 5 pounds for any solid fuel burning generating unit.

The demand for a fuel is a function of the price of the fuel and an average cost penalty for meeting sulfur regulations. This demand may be expressed as

$$D = f(R_j, ACP_j) \qquad j = 1, 2, \ldots, r$$

where

D = demand for fuel in MBtu per year.

R_j = price of fuel j in dollars per MBtu.

ACP_j = average cost penalty for fuel j in dollars per MBtu.

j = index number of competing fuels.

In the case when available fuels have a higher sulfur content, then the real cost of the fuel will be increased by an extra cost of satisfying sulfur regulations. This can be formulated such that

$$TC_p = TC_d + TC_{sc} \tag{5.9}$$

where

TC_p = total cost of satisfying sulfur regulations in dollars.

TC_d = total cost of desulfurization in dollars.

TC_{sc} = total cost of stack controls in dollars.

where

$$TC_{sc} = \sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} C_{sc_{ijk}} \times TF_{ijk} \tag{5.10}$$

$C_{sc_{ijk}}$ = cost of stack control of the fuel used by the jth type of generating unit of the ith utility during the kth year in dollars per MBtu.

TF_{ijk} = total fuel used by the jth type of generating unit of the ith utility during the kth year in MBtu.

For the purpose of our study, the restriction on sulfur dioxide emission was formulated such that

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} F_{ijk} \times SP_{ijk}$$

$$\leq \sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} TF_{ijk} \times PSP_{ijk} \qquad (5.11)$$

where

SP_{ijk} = sulfur content of the fuel used by the jth energy generating unit of the ith utility during the kth year in pounds.

PSP_{ijk} = permissible sulfur content of the fuel which should be used by the jth energy generating unit of the ith utility during the kth year in pounds.

6. Fuel availability restriction

Fuel availability is an important restriction in long range energy planning. It applies not only to oil and natural gas, but also to the low-sulfur coal supply, which is limited. In general, this restriction can be formulated as

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} F_{ijk} \leq \sum_{k=1}^{N_y} \sum_{j=1}^{N_u} AFEG_{jk} \qquad (5.12)$$

or

$$\sum_{k=1}^{N_y} \sum_{j=1}^{N_f} \sum_{i=1}^{N_u} F_{ijk}$$

$$\leq \sum_{k=1}^{N_y} \sum_{j=1}^{N_u} K_5 \times K_6 \times (FPIA_{jk} + FITI_{jk}) \qquad (5.13)$$

where

$AFEG_{jk}$ = total available fuel for the jth type energy generating units of the Iowa Pool during the kth year in MBtu.

$FPIA_{jk}$ = total fuel production in Iowa which can be consumed by the jth type energy generating units in the total region of Iowa during the kth year in MBtu.

$FITI_{jk}$ = total fuel imports to Iowa which can be consumed by the jth type energy generating units in the total region of Iowa during the kth year in MBtu.

K_5 = a per unit electric market factor. Since nine member utilities of the Iowa Pool account for about 95 percent of the electricity generated in the State of of Iowa, this factor is assumed equal to 0.95 (for studies applied to the entire pool).

K_6 = a per unit fuel consumption factor for each type of fuel for electric generation in the State of Iowa. According to the statistics of the 1975 Iowa Energy Council's Annual Report (134), this factor K_6 is equal to

K_6 = 0.692 for coal
K_6 = 0.203 for natural gas
K_6 = 0.102 for fuel oil
K_6 = 1.000 for nuclear.

Even though the above factors may vary throughout the years, they are, for the purpose of our study, assumed to be constants. They could be easily adjusted, however, if more accurate data becomes available.

Historical and forecasted total fuel consumption for the State of Iowa in 10^{12} Btu, has been calculated using a least square regression analysis of the historical data with a 0.96 correlation coefficient. These results are shown in Table 5.3 and Figure 5.4.

For convenient reference, some nomographs have been developed so that one can calculate the amount of fuel consumed annually by one installed KW of capacity of generating units with various heat rates at plant factors of 0.80, 0.85, and 1.00. These are presented in Appendix G.

7. Annual electrical energy purchases and sales restrictions

The total annual electrical energy purchased and sold, and consequently transmitted between the utilities of the Pool and the out-of-state utilities, shall be restricted by the capacity of tie lines between the Iowa Pool and out-of-State utilities such that

$$\sum_{k=1}^{N_y} \sum_{i=1}^{N_u} P_{ik} \leq \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} TTLC_{ik} \times 8760 \qquad (5.14)$$

and

$$\sum_{k=1}^{N_y} \sum_{i=1}^{N_u} S_{ik} \leq \sum_{k=1}^{N_y} \sum_{i=1}^{N_u} TTLC_{ik}\ 8760 \qquad (5.15)$$

where

$TTLC_{ik}$ = total tie line capacity between the ith utility of the Iowa Pool and out-of-State utilities for the kth year in MWh.

Table 5.3. Historical and forecasted total fuel consumption for the State of Iowa in 10^{12} Btu

HISTORICAL (138)		FORECASTED	
Year	10^{12} Btu	Year	10^{12} Btu
1953	400.8	1974	878.4
1954	419.7	1975	901.4
1955	463.9	1976	924.5
1956	488.3	1977	947.5
1957	504.0	1978	970.6
1958	513.0	1979	993.7
1959	554.8	1980	1016.7
1960	554.9	1981	1039.8
1961	553.3	1982	1062.9
1962	583.2	1983	1085.9
1963	599.0	1984	1108.9
1964	616.0	1985	1132.0
1965	641.2		
1966	646.6		
1967	701.0		
1968	720.6		
1969	749.1		
1970	810.2		
1971	828.9		
1972	903.5		
1973	866.1		

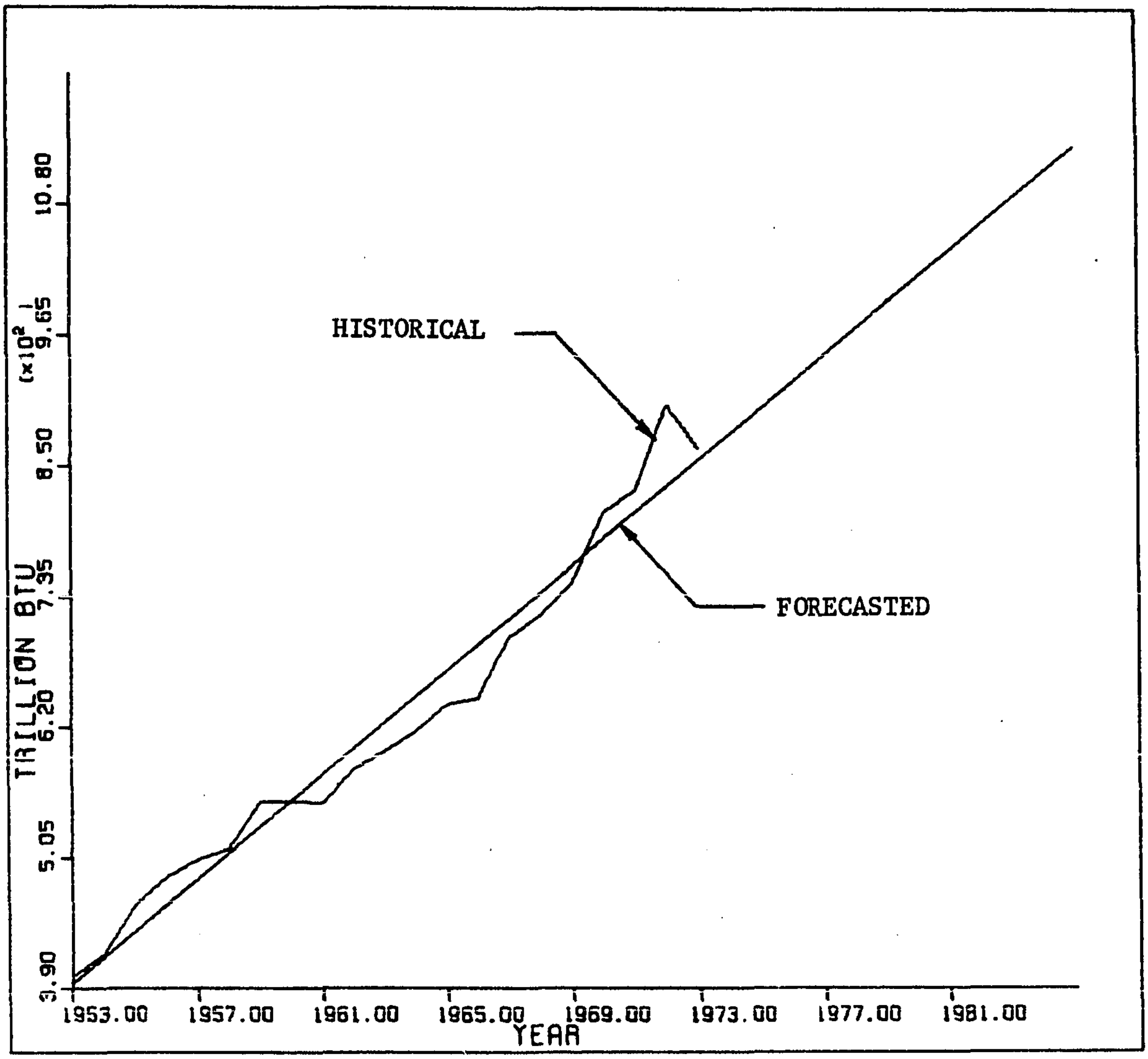

Figure 5.4. Historical and forecasted total fuel consumption for the State of Iowa in 10^{12} Btu

8. General restrictions

There are also some restrictions on the variables as a result of the nature of the linear programming, such as

$$F_{ijk} \geq 0 \tag{5.16a}$$

$$P_{ik} \geq 0 \tag{5.16b}$$

$$S_{ik} \geq 0 \tag{5.16c}$$

In general, the constraint matrix of the program has a simple form. The coefficients are mostly zeros and ones, but they do not fall into regular patterns because each utility has a different number of generating units.

Appendix H explains the procedure for performing the LP computations using the MPSX system.

C. The Application of Demand Duration Curves in the Model

Different types of electrical energy generating units have different functions in modern interconnected power systems. The main unit types are: 1) fossil fueled units which run basically on fuel oil, coal, and gas; 2) hydro units; 3) nuclear reactor units; and 4) special-purpose peaking units which are usually combustion turbine or pumped storage units.

Generally, combustion turbine units have low capital but high generation costs; nuclear reactor units have high capital but low generating costs; and hydro units have high or low capital costs depending on the site of the hydro units, with almost no generation costs.

Therefore, combustion turbine units are usually used for peak load periods, fossil fueled units for intermediate load periods, nuclear reactor units for base loads, and hydro units used as required, depending on costs, unit availability, and the energy constraint. However, because of its very small contribution in Iowa, hydro is neglected in this study. Consequently, the optimum balance of the units in the system at any time will depend on the relative capital and generation costs of the various electrical energy generating units.

In a given power system, the cheapest way of meeting the demand at any time is to run the generating units which have the lowest operating costs, which is largely dependent on fuel costs. The system dispatcher tabulates the generating units in ascending order of marginal operating costs, and loads or unloads the units sequentially as the demand rises and falls. Figure 5.5 gives a typical table of available plant capacities and an annual demand duration curve. In this figure, the system is represented by four different types of power generating units. They are, in ascending order of marginal operating costs, nuclear, new fossil, old fossil, and combustion turbine units. By projecting the plant capacities horizontally through the annual demand duration curve, one can find the total operating time of each plant for the period represented by the curve. By estimating the areas slices out of the load duration curve, one can estimate the energy delivered by each generating unit and thus the total fuel costs, and consequently the total system operating costs. These costs will be at a minimum when this method is used, because the generating units with the highest fuel costs, such as old fossil fueled units or combustion turbines, will be operated the least.

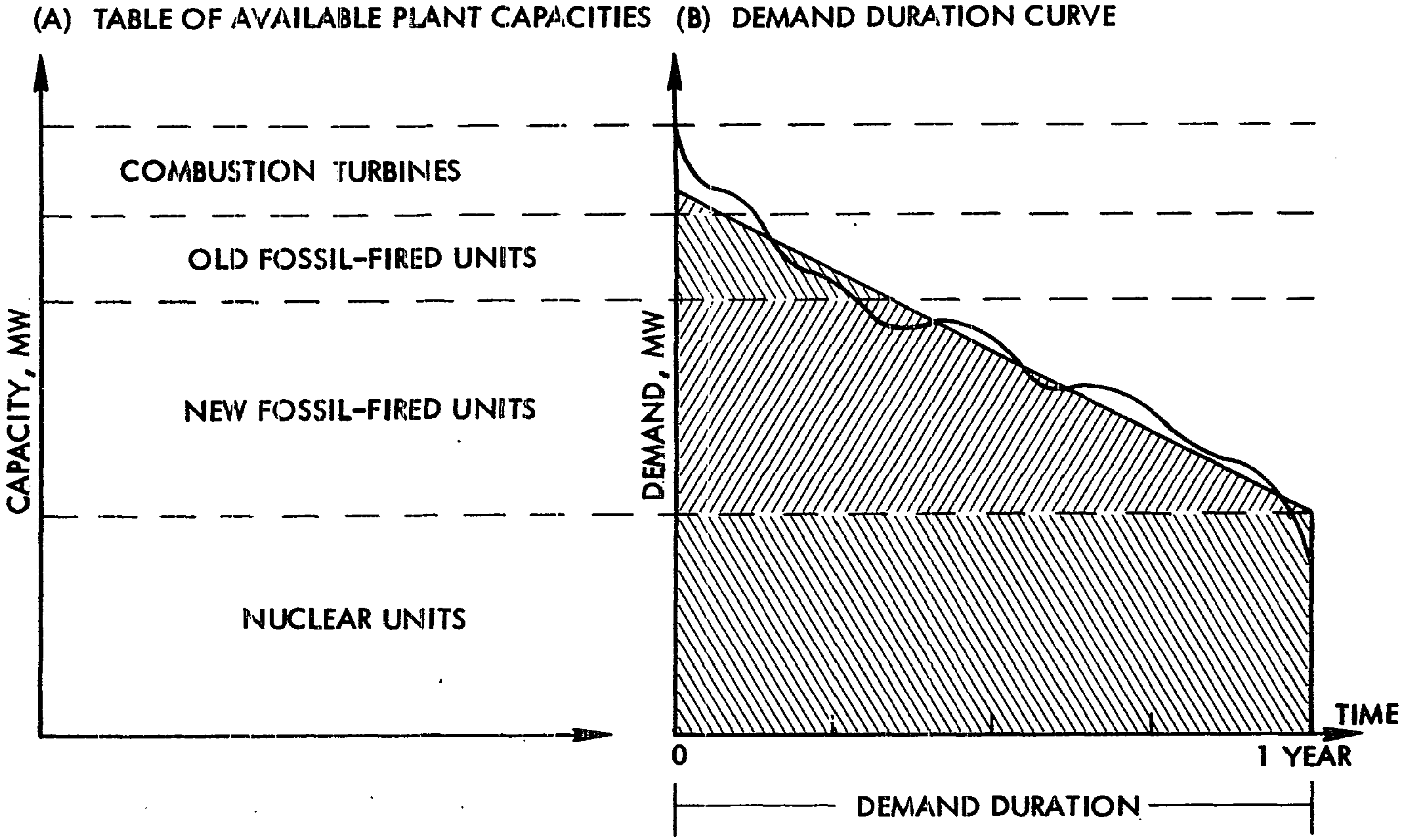

Figure 5.5. A typical table of available plant capacities and an annual demand duration curve

The FAM, which uses the LP technique, not only minimizes the fuel costs of the Pool or of an individual company for a given period in a computerized fashion, but it also gives an optimized solution. According to the definition, an optimal solution is a feasible solution which minimizes the objective function.

In view of the general uncertainties associated with long term power systems planning, it is reasonable to make some simplifying assumptions. Therefore, because of lack of precise data, demand duration curves are assumed for each company and for the Iowa Pool. The assumed demand duration curve for the Iowa Pool is shown in Figure 5.6 as an example.

Usually each operating utility has records of the actual load duration curve experienced by that utility on a yearly, monthly, weekly, or even a daily basis. Such detailed information could be projected for each utility for future years and used in the optimization study. The method of obtaining the optimum would be the same, however, and the assumed average load duration was chosen as a compromise for this study.

D. Input Data

Some of the input data for the FAM model, needed to minimize overall fuel costs of the Iowa Pool or of an individual utility by optimum allocation of various fuel mixes among generating units over a period of n years, are presented in the tables shown on the following pages.

The capacity data of the generating units of the nine companies involved in this study are shown in Tables 5.4 to 5.12. These data have been provided by the individual companies.

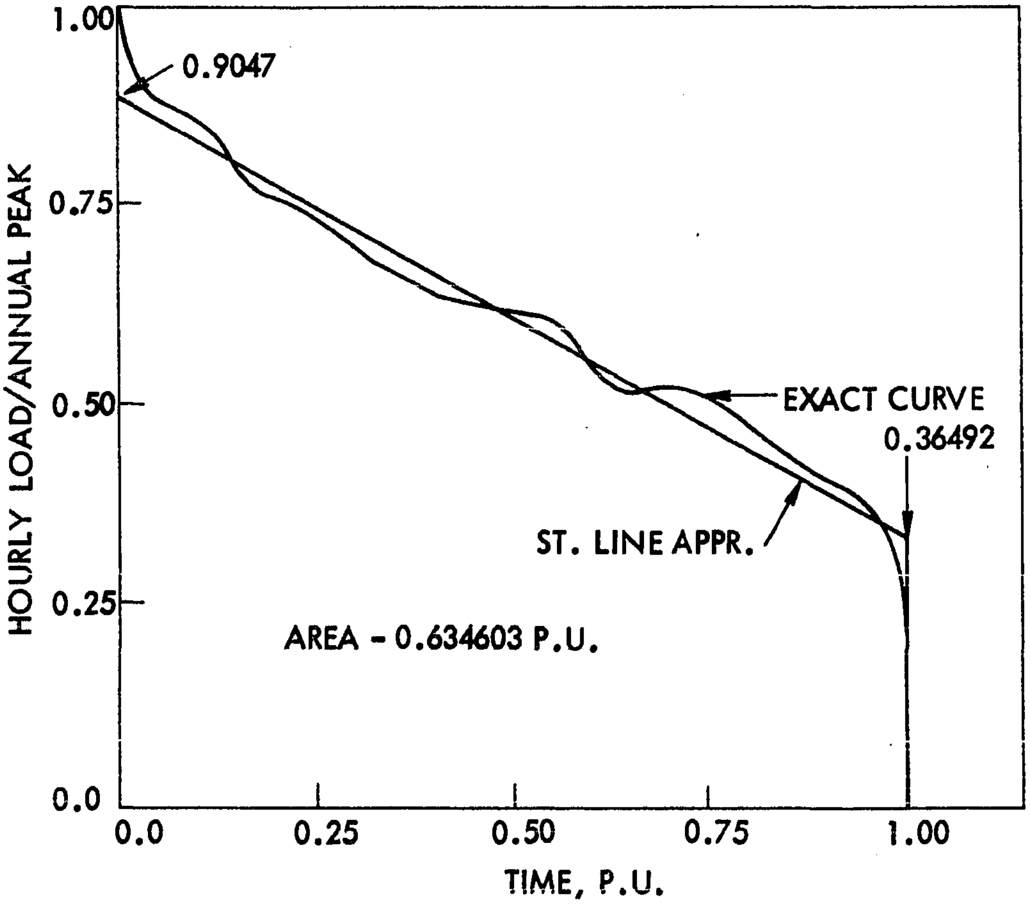

Figure 5.6. An assumed demand duration curve for the Iowa Pool (141)

Table 5.4. Capacity data for the generating units of company number 1 (IPL)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	DPS	7	40	90	10,400	0.3281	Coal (0.5 Wyo. + 0.5 Iowa)
2	"	6	20	60	11,500	0.2967	" " " "
3	"	5	20	50	14,000	0.2437	Oil
4	Council Bluffs	3	75	280	9,500	0.3592	Coal (Wyo.)
5	" "	2	30	80	10,600	0.3220	" "
6	" "	1	20	40	11,500	0.2968	" "
7	Neal	1	30	105	9,500	0.3592	" "
8	Sycamore	1	35	70	12,000	0.2844	Oil
9	"	2	35	70	12,000	0.2844	"
10	River Hills	1	15	15	16,000	0.2133	"
11	" "	2	15	15	"	"	"
12	" "	3	15	15	"	"	"
13	" "	4	15	15	"	"	"
14	" "	5	15	15	"	"	"
15	" "	6	15	15	"	"	"
16	" "	7	15	15	"	"	"
17	" "	8	15	15	"	"	"

Table 5.4. Continued.

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
	PURCHASES:						
18	Cinus	1	50	150	-	-	Nuclear
19	Cooper	1	100	350	-	-	"
20	Firm	1	0	75	-	-	Coal
21	Firm	2	0	70	-	-	"
22	Econ.	1	0	500	-	-	"
	SALES:						
23	Firm	1	0	85	-	-	Coal
24	Firm	2	0	150	-	-	"
25	Firm	3	0	75	-	-	"

Table 5.5. Capacity data for the generating units of company 2 (ISU)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	Bridgeport	1	5	20.1	15,700	0.2173	Oil, Coal
2	"	2	5	20.1	"	"	" "
3	"	3	5	20.9	"	"	" "
4	Burlington	1	70	207	10,082	0.3385	Coal
5	Centerville	1-3	0	6	12,000[a]	0.2844	Oil
6	Creston	3,4	0	2.5	"	"	"
7	Washington	1,2	0	2.5	"	"	"
8	Neal	3	70[a]	145.6	9,500[a]	0.3592	Coal
PURCHASES:							
9	Firm	-	-	20	-	-	-
10	Firm	-	-	1	-	-	-
11	Econ.	-	-	150[a]	-	-	-
SALES:							
12	Firm	-	-	5	-	-	-
13	Firm	-	-	8	-	-	-
14	Firm	-	-	10	-	-	-

[a] Assumed value.

Table 5.6. Capacity data for the generating units of company 3 (IPS)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	Big Sioux	1	4	12	18,000	0.1896	Gas
2	" "	2	4	12	"	"	"
3	" "	3	4	12	"	"	"
4	" "	4	4	13	16,000	0.2133	"
5	Carroll	1	3	5	"	"	"
6	"	2	3	5	"	"	Coal
7	Eagle Gr.	1	4	10	15,000	0.2275	"
8	Hawkeye	1	4	10	"	"	"
9	"	2	4	13	14,000	0.2437	"
10	Kirk	1	3	10	15,000	0.2275	Oil
11	"	5	2	9	"	"	"
12	Maynard	4	4	11	"	"	Gas
13	"	5	4	12	"	"	"
14	"	6	5	24	12,000	0.2844	"
15	"	7	7	57	10,500	0.3250	Coal
16	Neal	1	50	147	10,000	0.3413	"
17	"	2	100	330	9,700	0.3518	"
18	"	3	150	415	9,500	0.3592	"
19	"	4	150	226	"	"	"

Table 5.6. Continued.

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
20	Parr Ct.	1	10	17	16,000	0.2133	Oil
21	" "	2	10	17	"	"	"
22	Waterloo Ct.	1	40	60	11,000	0.3102	"
23	" "	2	40	65	"	"	"
	Diesel	1	1	26	10,000	0.3413	"

Table 5.7. Capacity data for the generating units of company 4 (ISP)

Unit Serial No.	Station Name	Station Unit No.	Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
1	A. Lea	2	2	4.7	22,000	0.1551	Gas
2	" "	3	2	6.0	19,000	0.1796	Oil
3	" "	4	3	8.3	15,500	0.2201	"
4	Kapp	1	6	18.5	14,000	0.2437	Gas
5	"	2	55	220	10,300	0.3313	Oil
6	Dubuque	2	6	15	18,000	0.1896	Coal
7	"	3	10	30	12,800	0.2666	Gas
8	"	4	18	35	12,000	0.2844	Oil
9	Fox Lake	1	4	12	13,700	0.2491	Coal
10	" "	2	4	12	13,700	"	Gas
11	" "	3	19	84	10,700	0.3189	Oil
12	Lansing	1	8	17.5	13,300	0.2566	"
13	"	2	4	10.7	13,600	0.2509	Coal
14	"	3	10	33.8	12,000	0.2844	"
15	Mason City	2	3	5.5	19,500	0.1750	Gas
16	" "	3	4	10.5	18,000	0.1896	Oil
17	" "	4	4	9	15,000	0.2275	"
18	Montgy. G.T.	1	22	22.2	14,000	0.2437	"

Table 5.7. Continued.

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
19	Fox Lake G.T.	4	21	21.3	14,000	0.2437	Oil
20	Lansing	4	70[a]	260	9,500	0.3592	Coal

[a] Assumed value.

Table 5.8. Capacity data for the generating units of company 5 (IELP)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	Sutherland	1	10	31.5	12,309	0.2772	Coal
2	"	2	10	31.5	12,301	0.2774	"
3	"	3	45	82.5	10,197	0.3347	"
4	Prairie Creek	1	7	23.5	12,659	0.2696	"
5	" "	2	7	23.5	12,662	0.2695	"
6	" "	3	19	49.5	11,121	0.3069	"
7	" "	4	55	120	9,945	0.3031	"
8	6th St.	2	3	3	9,034	0.3778	"
9	" "	4	5	19	16,265	0.2098	"
10	" "	7	5	19	15,297	0.2231	"
11	" "	8	8	28	14,566	0.2343	"
12	" "	9	0	23	17,200	0.1984	"
13	Boone	1,2	10	29	14,044	0.2430	"
14	"	3	0	7	16,800	0.2031	"
15	Iowa Falls	4	3	9	14,956	0.2282	"
16	DAEC	--	220	476	10,278	0.3320	Nuclear
17	Diesel	--	0	37.5	12,500	0.2730	Oil

Table 5.9. Capacity data for the generating units of company 6 (CIPC)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	DAEC	-	-	106	10,278	0.3320	Nuclear
2	P. C.	1	-	20	12,600	0.2708	Coal
3	" "	2	-	20	"	"	"
4	" "	3	-	48	11,200	0.3047	"
5	S. L.	1-4	-	4	12,000	0.2844	Oil
6	G. T.	1	-	29	14,100	0.2420	"
7	" "	2	-	28	"	"	"
8	H. R.	1	-	24	10,200	0.3346	"

Table 5.10. Capacity data for the generating units of company 7 (IIGE)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	Coralville	1	0	83	17,000	0.2007	Oil, Gas
2	M	3	0	14	24,000	0.1422	" "
3	"	5	0	21	13,000	0.2625	" "
4	"	6	-	27	12,000	0.2844	" "
5	"	7	-	28	13,000	0.2625	" "
6	Moline	1	-	78	17,000	0.2007	" "
7	Q. C.	1	60	192	11,000	0.3102	Nuclear
8	" "	2	"	"	"	"	"
9	R.	1	0	24	19,000	0.1796	Gas
10	"	3	0	26	14,000	0.2437	Coal, Gas
11	"	4	15	51	12,000	0.2844	" "
12	"	5	15	143	9,700	0.3518	" "
13	Riverside	1	0	75	17,000	0.2007	" "
14	Neal	3	50	151	9,300	0.3670	Coal
15	M	8	0	40	10,000	0.3413	Oil, Gas
16	C. B.	3	60	211	9,300	0.3670	Coal
17	Ott.	1	40	125	"	"	"
18	Carroll	1	50	165	11,000	0.3102	Nuclear

Table 5.10. Continued.

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
PURCHASES:							
19	I. P.	-	-	25	-	-	-

Table 5.11. Capacity data for the generating units of company 8 (CPA)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	Humboldt	1	2	10	14,500	0.2353	Gas, Coal
2	"	2	2	10	15,000	0.2275	" "
3	"	3	3	13	13,500	0.2528	" "
4	"	4	5	19	13,000	0.2625	" "
5	Wisdom	1	10	39	11,800	0.2892	" "
6	DAEC	-	-	200	10,278	0.3320	Nuclear
PURCHASES:							
7	USBR[a]	1	-	29	-	-	Hydro

[a] Assumed values.

Table 5.12. Capacity data for the generating units of company 9 (EILP)

Unit Serial No.	Station		Minimum Load (MW)	Maximum Load (MW)	Heat Rate (Btu/KWh)	Unit Efficiency (η)	Fuel Type
	Name	Unit No.					
1	Fair	1	8	25	11,500	0.2967	Coal
2	"	2	12	40	11,200	0.3046	"

Fuel and energy cost forecasts of the companies for the years between 1975 and 1985 are shown in Tables 5.13 to 5.21. The average fuel cost increase is forecast to be about 7 percent from 1975 until 1985. Fuel cost and energy purchase cost forecasts, in cents per MBtu and in mills per kWh, have been provided by the companies, which considered their long term contracts with the supplying companies in making the forecasts. In order to construct the model more efficiently, the costs involved are converted into dollars per MWh.

The following tables show the sulfur emissions and restrictions for the generating units of company 1 (IPL). Table 5.22 shows the maximum level of permissible sulfur emissions, according to EPA Standards and State of Iowa regulations, for the coal-burning units of company 1 in pounds per MBtu and in pounds per MWh. Also, Table 5.23 indicates the maximum level of permissible sulfur emissions for the oil-burning units of company 1 in pounds per MBtu and in pounds per MWh.

Table 5.24 and Table 5.25 give the projected level of sulfur emissions resulting from the operation of the coal-burning and oil-burning units of company 1 for the years from 1975 to 1985 in pounds per MBtu and in pounds per MWh, according to projected fuel qualities.

In Tables 5.24 and 5.25, column 1 gives the years which are covered in this study. Column 2 shows the unit serial numbers of company 1. Column 3 indicates, in MBtu, the heat input needed to generate one MWh electrical energy from each unit. Column 4 gives information on the fuel types used in each unit of company 1 for the years from 1975 to 1985. Column 5 reveals the heat value of the fuel used in MBtu per ton or MBtu per barrel, while column 6 shows the sulfur content of the fuel, in percent. Column 7 gives the sulfur content of the fuel in pounds per ton or in pounds per barrel. Column 8 shows the level of sulfur emission from each unit, in pounds per MBtu, which is calculated by dividing each value in column 7 by the related value in column 5. Column 9 gives the same sulfur emission data in pounds per MWh, which are calculated by dividing the values in column 3 by the values in column 8.

Table 5.13. Forecasted fuel and energy costs for company 1 (IPL) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	7.69	8.23	8.81	9.43	-	-	-	-	-	-	-
2	8.51	9.10	9.74	10.42	11.15	11.93	12.77	13.66	14.62	15.64	16.74
3	44.11	47.20	50.50	54.04	57.82	61.87	66.20	70.84	75.79	81.10	86.78
4	-	-	-	-	8.41	9.86	10.55	11.28	12.08	12.92	13.83
5	7.84	8.39	8.98	9.60	-	-	-	-	-	-	-
6	8.51	9.10	9.74	10.42	11.15	11.93	12.77	13.66	14.62	15.64	16.73
7	-	6.30	6.74	7.21	7.72	8.26	8.84	9.45	10.12	10.83	11.58
8	37.80	40.44	43.27	46.30	49.55	53.01	56.73	60.70	64.95	69.49	74.36
9	"	"	"	"	"	"	"	"	"	"	"
10	50.40	53.93	57.70	61.74	66.06	70.69	75.64	80.93	86.60	92.66	99.15
11	"	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	"	"	"	"	"	"
13	"	"	"	"	"	"	"	"	"	"	"
14	"	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"	"
16	"	"	"	"	"	"	"	"	"	"	"
17	"	"	"	"	"	"	"	"	"	"	"

Table 5.13. Continued.

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
PURCHASES:											
18	-	-	-	-	-	-	-	-	-	3.70	3.88
19	1.93	2.02	2.12	2.23	2.34	2.46	2.58	3.05	3.20	3.36	3.53
20	-	-	-	6.20	6.20	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	10.10	10.10	-
22	40.00	42.80	45.79	49.00	52.43	56.10	60.02	64.23	68.72	73.53	78.68
SALES:											
23	-	5.50	5.50	-	-	-	-	-	-	-	-
24	-	-	-	-	6.20	6.20	-	-	-	-	-
25	-	-	-	-	-	6.60	6.60	-	-	-	-

Table 5.14. Forecasted fuel and energy costs for company 2 (ISU) for the years from 1975 to 1985 in dollars per MWh[a]

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	26.53	28.39	30.37	32.50	34.77	37.21	39.81	42.60	45.58	48.77	52.19
2	"	"	"	"	"	"	"	"	"	"	"
3	"	"	"	"	"	"	"	"	"	"	"
4	6.04	6.47	6.92	7.41	7.92	8.48	9.07	9.71	10.39	11.12	11.89
5	25.20	26.96	28.85	30.74	32.89	35.20	37.66	40.40	43.12	47.03	50.32
6	"	"	"	"	"	"	"	"	"	"	"
7	"	"	"	"	"	"	"	"	"	"	"
8	-	6.30	6.74	7.21	7.72	8.26	8.83	9.45	10.12	10.82	11.58
PURCHASES:											
9	5.5	5.88	-	-	-	-	-	-	-	-	-
10	5.5	5.88	6.29	6.73	7.20	7.71	8.25	8.83	9.45	10.11	10.82
11	50.40	53.93	57.70	61.74	66.06	70.69	75.66	80.93	86.60	92.66	99.15
SALES:											
12	6.2[b]	-	-	-	-	-	-	-	-	-	-
13	-	6.6[b]	-	-	-	-	-	-	-	-	-
14	-	-	6.9[b]	-	-	-	-	-	-	-	-

[a] 7 percent annual cost increase is assumed.

[b] Assumed values.

Table 5.15. Forecasted fuel and energy costs for company 3 (IPS) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	9.00	-	-	-	-	-	-	-	-	-	-
2	9.00	-	-	-	-	-	-	-	-	-	-
3	9.00	-	-	-	-	-	-	-	-	-	-
4	8.00	-	-	-	-	-	-	-	-	-	-
5	15.52	17.12	18.72	20.64	22.72	24.96	-	-	-	-	-
6	"	"	"	"	"	"	-	-	-	-	-
7	15.84	17.44	19.20	21.12	23.30	25.44	-	-	-	-	-
8	16.16	17.76	19.52	21.44	23.68	26.08	-	-	-	-	-
9	14.14	15.54	17.08	18.76	20.72	22.82	-	-	-	-	-
10	34.20	37.65	41.40	45.45	-	-	-	-	-	-	-
11	34.20	37.65	41.40	45.45	-	-	-	-	-	-	-
12	7.65	8.40	-	-	-	-	-	-	-	-	-
13	7.65	8.40	-	-	-	-	-	-	-	-	-
14	6.12	6.72	33.12	36.43	40.07	44.08	48.49	53.34	58.67	64.54	71.00
15	11.13	12.24	13.46	14.81	16.29	17.92	19.71	21.69	23.86	26.24	28.87
16	5.90	6.49	7.13	7.85	8.63	9.50	10.45	11.49	12.64	13.91	15.30
17	5.72	6.29	6.92	7.61	8.37	9.21	10.13	11.15	12.26	13.49	14.84
18	-	6.16	6.78	7.46	8.20	9.02	9.93	10.92	12.01	13.21	14.53
19	-	-	-	-	"	"	"	"	"	"	"

Table 5.15. Continued.

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
20	36.48	40.13	44.14	48.55	53.41	58.75	64.63	71.09	78.20	86.02	94.62
21	"	"	"	"	"	"	"	"	"	"	"
22	25.08	27.58	30.34	33.38	36.71	40.39	44.43	48.87	53.76	59.13	65.05
23	"	"	"	"	"	"	"	"	"	"	"
24	22.80	25.08	27.58	30.34	33.38	36.71	40.39	44.43	48.87	53.76	59.13

Table 5.16. Forecasted fuel and energy costs for company 4 (ISP) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	12.32	13.18	14.10	15.09	16.15	17.28	18.49	19.78	21.17	22.65	24.24
2	45.36	48.53	51.93	55.56	59.45	63.09	67.50	72.23	77.29	82.70	88.49
3	32.56	34.84	37.28	39.73	42.51	45.48	48.67	52.08	55.72	60.78	65.03
4	7.84	8.39	8.97	9.60	10.27	10.99	11.77	12.59	13.47	14.41	15.42
5	21.63	23.14	24.76	26.39	28.24	30.22	32.33	34.60	37.02	40.38	43.20
6	12.87	13.77	14.73	15.76	17.06	18.25	19.53	20.90	22.36	23.93	25.60
7	7.16	7.67	8.20	8.78	9.39	10.05	10.75	11.51	12.31	13.17	14.10
8	25.20	26.96	28.85	30.74	32.90	35.20	37.67	40.30	43.12	47.04	50.33
9	9.79	10.48	11.21	12.00	12.98	13.89	14.87	15.91	17.02	18.21	19.49
10	7.67	8.21	8.78	9.40	10.05	10.76	11.51	12.32	13.18	14.10	15.09
11	25.54	27.33	29.24	31.29	33.48	35.83	38.33	41.02	43.89	46.96	50.25
12	27.93	29.88	31.97	34.08	36.46	39.01	41.75	44.67	47.79	52.13	55.78
13	9.72	10.40	11.13	11.91	12.89	13.79	14.76	15.79	16.90	19.08	19.34
14	8.58	9.18	9.82	10.51	11.37	12.17	13.02	13.93	14.91	15.95	17.07
15	10.92	11.68	12.50	13.37	14.31	15.31	16.38	17.53	18.76	20.07	21.48
16	42.96	45.97	49.19	52.63	56.31	60.26	64.47	68.99	73.82	78.99	84.52
17	31.50	33.70	36.06	38.43	41.12	44.00	47.08	50.37	53.90	58.79	62.91
18	29.40	31.45	33.65	35.87	38.38	41.06	43.94	47.02	50.31	54.87	58.71

Table 5.16. Continued.

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
19	29.40	31.45	33.65	35.87	38.38	41.06	43.94	47.02	50.31	54.87	58.71
20	-	-	7.77	8.32	9.00	9.63	10.31	11.03	11.80	12.63	13.51

Figure 5.17. Forecasted fuel and energy costs for company 5 (IELP) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	13.05	13.83	14.66	15.54	16.47	17.46	18.51	19.62	20.80	22.04	23.37
2	13.04	13.82	14.65	15.53	16.46	17.45	18.50	19.61	20.79	22.03	23.35
3	10.80	11.45	12.14	12.87	13.64	14.46	15.33	16.25	17.22	18.26	19.35
4	13.41	14.22	15.07	15.98	16.94	17.95	19.03	20.17	21.38	22.67	24.03
5	13.42	14.23	15.08	15.99	16.95	17.96	19.04	20.18	21.39	22.68	24.04
6	11.78	12.49	13.24	14.03	14.88	15.77	16.72	17.72	18.78	19.91	21.11
7	11.93	12.65	13.41	14.21	15.06	15.97	16.93	17.94	19.02	20.16	21.37
8	9.57	-	-	-	-	-	-	-	-	-	-
9	17.24	18.27	19.37	20.53	21.76	23.07	24.46	25.92	27.48	29.13	30.88
10	16.21	17.18	18.22	19.31	20.47	21.70	23.00	24.38	25.84	27.39	29.04
11	15.44	16.36	-	-	-	-	-	-	-	-	-
12	18.23	19.32	20.48	21.71	23.02	24.40	25.86	27.41	29.06	30.80	32.65
13	16.15	17.12	18.14	19.23	20.39	21.61	22.91	24.28	25.74	27.28	28.92
14	19.32	20.48	21.71	23.01	24.39	25.86	27.41	29.05	30.80	32.64	34.60
15	17.19	18.23	19.32	20.48	21.71	23.01	24.39	25.86	27.41	29.05	30.80
16	2.71	2.82	2.93	3.05	3.17	3.30	3.45	3.57	3.71	3.86	4.01
17	29.75	31.57	33.43	35.43	37.56	39.81	42.20	44.73	47.42	50.26	53.28

Table 5.18. Forecasted fuel and energy costs for company 6 (CIPC) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	2.23	2.38	2.55	2.73	2.92	3.12	3.34	3.58	3.83	4.10	4.38
2	12.41	13.28	14.21	15.20	16.26	17.40	18.62	19.93	21.32	22.81	24.41
3	"	"	"	"	"	"	"	"	"	"	"
4	11.03	11.80	12.63	13.51	14.46	15.47	16.55	17.71	18.95	20.28	21.70
5	22.57	24.15	25.84	27.65	29.59	31.66	33.88	36.25	38.79	41.50	44.41
6	26.52	28.38	30.37	32.49	34.77	37.20	39.81	42.59	45.58	48.77	52.18
7	"	"	"	"	"	"	"	"	"	"	"
8	19.19	20.53	21.97	23.50	25.15	26.91	28.79	30.81	32.97	35.97	37.75

Table 5.19. Forecasted fuel and energy costs for company 7 (IIGE) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	32.30	33.92	35.61	37.38	39.27	41.22	43.28	45.44	47.72	50.10	52.61
2	45.60	47.88	-	-	-	-	-	-	-	-	-
3	24.70	25.93	27.23	28.58	30.03	31.52	33.10	34.75	36.49	38.31	40.26
4	22.80	23.94	25.14	26.37	27.72	29.10	30.55	32.07	33.68	35.36	37.16
5	24.70	25.93	27.23	28.58	30.03	31.52	33.10	34.75	36.49	38.31	40.26
6	32.30	33.92	35.61	37.38	39.27	41.22	43.28	45.44	47.72	50.10	52.61
7	2.31	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70	2.76	2.81
8	"	"	"	"	"	"	"	"	"	"	"
9	11.40	11.97	12.57	13.20	13.85	14.55	15.27	16.04	16.84	17.68	18.57
10	9.80	10.29	10.80	11.34	11.91	12.50	13.13	13.79	14.48	15.20	15.96
11	8.40	8.82	9.26	9.72	10.21	10.72	11.25	11.82	12.41	13.03	13.68
12	6.79	7.13	7.49	7.86	8.25	8.66	9.10	9.55	10.03	10.53	11.06
13	10.20	10.71	11.24	11.80	12.40	13.01	13.66	14.35	15.07	15.82	16.61
14	-	5.37	5.64	5.92	6.21	6.52	6.85	7.19	7.55	7.93	8.33
15	-	19.95	20.95	21.99	23.10	24.25	25.46	26.73	28.07	29.47	30.95
16	-	-	-	-	6.78	7.12	7.47	7.85	8.24	8.65	9.09
17	-	-	-	-	-	-	"	"	"	"	"
18	-	-	-	-	-	-	-	-	-	-	2.81

Table 5.19. Continued.

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
PURCHASES:											
19	-	-	5.00	5.00	-	-	-	-	-	-	-

Table 5.20. Forecasted fuel and energy costs for company 8 (CPA) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	12.40	13.34	19.28	21.17	22.48	23.92	25.37	26.82	28.56	30.16	32.04
2	12.82	13.80	19.95	21.90	23.25	24.75	26.25	27.75	29.55	31.20	33.15
3	11.54	12.42	17.95	19.71	20.92	22.27	23.62	24.97	26.59	28.08	29.83
4	11.11	11.96	17.29	18.98	20.15	21.45	22.75	24.05	25.61	27.04	28.73
5	10.09	10.86	15.69	17.23	18.29	19.47	20.65	21.83	23.24	24.54	26.07
6	2.71	2.82	2.93	3.05	3.17	3.30	3.43	3.57	3.71	3.80	4.01
PURCHASES:											
7	2.61	2.71	2.81	2.91	3.01	3.11	3.21	3.31	3.41	3.51	3.61

Table 5.21. Forecasted fuel and energy costs for company 9 (EILP) for the years from 1975 to 1985 in dollars per MWh

Unit Serial No.	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	8.62	9.20	9.77	10.80	11.50	12.30	13.22	14.14	15.06	16.21	17.25
2	"	"	"	"	"	"	"	"	"	"	"

Table 5.22. Maximum permissable sulfur emissions for the coal burning units of company 1 according to EPA standards and State of Iowa regulations in lbs per MBtu and in lbs per MWh

Unit Serial No. Col. 1	Unit Efficiency (η) Col. 2	K_1/η_j (MBtu/MWh) Col. 3	Permissible Sulfur Emission			
			EPA Standard		Iowa Regulation	
			(lb/MBtu) Col. 4	(lb/MBtu) Col. 5 = Col. 3 x Col. 4	(lb/MBtu) Col. 6	(lb/MBtu) Col. 7 = Col. 3 x Col. 6
1	0.3281	10.4	1.2	12.48	5.0	52.0
2	0.2967	11.5	"	13.80	"	57.5
4	0.3592	9.5	"	11.40	"	47.5
5	0.3220	10.6	"	12.72	"	53.0
6	0.2968	11.5	"	13.80	"	57.5
7	0.3592	9.5	"	11.40	"	47.5

Table 5.23. Maximum permissable sulfur emissions for the oil burning units of company 1 according to EPA standards and State of Iowa regulations in lbs per MBtu and in lbs per MWh

Unit Serial No. Col. 1	Unit Efficiency (η) Col. 2	K_1/η_j (MBtu/MWh) Col. 3	Permissible Sulfur Emission			
			EPA Standard		Iowa Regulation	
			(lb/MBtu) Col. 4	(lb/MBtu) Col. 5 = Col. 3 x Col. 4	(lb/MBtu) Col. 6	(lb/MBtu) Col. 7 = Col. 3 x Col. 6
3	0.2437	14.0	0.8	11.2	2.5	35.0
8	0.2844	12.0	"	9.6	"	30.0
9	"	"	"	"	"	30.0
10	0.2133	16.0	"	12.8	"	40.0
11	"	"	"	"	"	"
12	"	"	"	"	"	"
13	"	"	"	"	"	"
14	"	"	"	"	"	"
15	"	"	"	"	"	"
16	"	"	"	"	"	"
17	"	"	"	"	"	"

Table 5.24. Projected sulfur emissions resulting from the operation of the coal burning units of company 1 for the years from 1975 to 1985 in pounds per MBtu and in pounds per MWh, according to project coal qualities

Year	Unit Serial No.	K_1/η_j (MBtu/MWh)	Coal Type	Heat Value of Coal (MBtu/ton)	Sulfur Content of Coal		Sulfur Emission from the Unit	
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	(%) Col. 6	(lb/ton) Col. 7	(lb/MBtu) Col. 8 =Col. 7/Col. 5	(lb/MWh) Col. 9 =Col. 3/Col. 8
1975	1	10.4	0.5 Iowa + 0.5 Wyo.	17.6	1.925	38.5	2.187	22.75
"	2	11.5	"	17.6	1.925	38.5	2.187	25.15
"	4	9.5	Wyoming	20.6	0.9	18.0	0.874	8.3
"	5	10.6	"	20.6	0.9	18.0	0.874	9.26
"	6	11.5	"	20.6	0.9	18.0	0.874	10.05
1976	1	10.4	0.5 Iowa + 0.5 Wyo.	17.6	1.925	38.5	2.1875	22.75
"	2	11.5	"	17.6	1.925	38.5	2.187	22.75
"	4	9.5	Wyoming	20.6	0.55	11.0	0.679	6.45
"	5	10.6	"	20.6	0.55	11.0	0.679	6.45
"	6	11.5	"	20.6	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1977	1	10.4	0.5 Iowa + 0.5 Wyo.	17.6	1.925	38.5	2.1875	22.75
"	2	11.5	"	17.6	1.925	38.5	2.187	22.75
"	4	9.5	Wyoming	20.6	0.55	11.0	0.679	6.45
"	5	10.6	"	20.6	0.55	11.0	0.679	6.45

Table 5.24. Continued.

Year	Unit Serial No.	K_1/η_j (MBtu/MWh)	Coal Type	Heat Value of Coal (MBtu/ton)	Sulfur Content of Coal		Sulfur Emission from the Unit	
					(%)	(lb/ton)	(lb/MBtu)	(lb/MWh)
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8 =Col. 7/Col. 5	Col. 9 =Col. 3/Col. 8
1977	6	11.5	Wyoming	20.6	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1978	1	10.4	0.5 Iowa + 0.5 Wyo.	17.6	1.925	38.5	2.187	22.75
"	2	11.5	"	17.6	1.925	38.5	2.187	22.75
"	4	9.5	Wyoming	20.6	0.55	11.0	0.679	6.45
"	5	10.6	"	20.6	0.55	11.0	0.679	6.45
"	6	11.5	"	20.6	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1979	1	10.4	0.5 Iowa + 0.5 Wyo.	18.4	2.1	42.0	2.282	23.74
"	2	11.5	"	18.4	2.1	42.0	2.282	26.25
"	4	9.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	5	10.6	"	16.2	0.55	11.0	0.679	6.45
"	6	11.5	"	16.2	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1980	1	10.4	0.5 Iowa + 0.5 Wyo.	18.4	2.1	42.0	2.282	23.74
"	2	11.5	"	18.4	2.1	42.0	2.282	26.25

Table 5.24. Continued.

Year Col. 1	Unit Serial No. Col. 2	K_1/η_j (MBtu/MWh) Col. 3	Coal Type Col. 4	Heat Value of Coal (MBtu/ton) Col. 5	Sulfur Content of Coal		Sulfur Emission from the Unit	
					(%) Col. 6	(lb/ton) Col. 7	(lb/MBtu) Col. 8 =Col. 7/Col. 5	(lb/MWh) Col. 9 =Col. 3/Col. 8
1980	4	9.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	5	10.6	"	16.2	0.55	11.0	0.679	6.45
"	6	11.5	"	16.2	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1981	1	10.4	0.5 Iowa + 0.5 Wyo.	18.4	2.1	42.0	2.282	23.74
"	2	11.5	"	18.4	2.1	42.0	2.282	26.25
"	4	9.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	5	10.6	"	16.2	0.55	11.0	0.679	6.45
"	6	11.5	"	16.2	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1982	1	10.4	0.5 Iowa + 0.5 Wyo.	18.4	2.1	42.0	2.282	23.74
"	2	11.5	"	18.4	2.1	42.0	2.282	26.25
"	4	9.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	5	10.6	"	16.2	0.55	11.0	0.679	6.45
"	6	11.5	"	16.2	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3

Table 5.24. Continued.

Year Col. 1	Unit Serial No. Col. 2	K_1/η_j (MBtu/MWh) Col. 3	Coal Type Col. 4	Heat Value of Coal (MBtu/ton) Col. 5	Sulfur Content of Coal		Sulfur Emission from the Unit	
					(%) Col. 6	(lb/ton) Col. 7	(lb/MBtu) Col. 8 =Col. 7/Col. 5	(lb/MWh) Col. 9 =Col. 3/Col. 8
1983	1	10.4	0.5 Iowa + 0.5 Wyo.	18.4	2.1	42.0	2.282	23.74
"	2	11.5	"	18.4	2.1	42.0	2.282	26.25
"	4	9.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	5	10.6	"	16.2	0.55	11.0	0.679	6.45
"	6	11.5	"	16.2	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1984	1	10.4	0.5 Iowa + 0.5 Wyo.	18.4	2.1	42.0	2.282	23.74
"	2	11.5	"	18.4	2.1	42.0	2.282	26.25
"	4	9.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	5	10.6	"	16.2	0.55	11.0	0.679	6.45
"	6	11.5	"	16.2	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3
1985	1	10.4	0.5 Iowa + 0.5 Wyo.	18.4	2.1	42.0	2.282	23.74
"	2	11.5	"	18.4	2.1	42.0	2.282	26.25
"	4	9.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	5	10.6	"	16.2	0.55	11.0	0.679	6.45

Table 5.24. Continued.

Year	Unit Serial No.	K_1/η_j	Coal Type	Heat Value of Coal	Sulfur Content of Coal		Sulfur Emission from the Unit	
		(MBtu/MWh)		(MBtu/ton)	(%)	(lb/ton)	(lb/MBtu)	(lb/MWh)
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8 =Col. 7/Col.5	Col. 9 =Col. 3/Col.8
1985	6	11.5	Wyoming	16.2	0.55	11.0	0.679	6.45
"	7	9.5	"	20.6	0.9	18.0	0.874	8.3

Table 5.25. Projected sulfur emissions resulting from the operation of the oil burning units of company 1 for the years from 1975 to 1985 in pounds per MBtu and in pounds per MWh, according to projected oil qualities

Year Col. 1	Unit Serial No. Col. 2	K_1/η_j (MBtu/MWh) Col. 3	Oil Type Col. 4	Heat Value of Oil (MBtu/Bbl) Col. 5	Sulfur Content of Oil		Sulfur Emission from the Unit	
					(%) Col. 6	(lb/Bbl) Col. 7	(lb/MBtu) Col. 8 = Col. 7/Col. 5	(lb/MWh) Col. 9 = Col. 3 x Col. 8
1975	3	14.0	#2	5.67	0.4	1.34	0.237	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1976	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1977	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1978	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1979	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1980	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84

Table 5.25. Continued.

Year Col. 1	Unit Serial No. Col. 2	K_1/η_j (MBtu/MWh) Col. 3	Oil Type Col. 4	Heat Value of Oil (MBtu/Bbl) Col. 5	Sulfur Content of Oil		Sulfur Emission from the Unit	
					(%) Col. 6	(lb/Bbl) Col. 7	(lb/MBtu) Col. 8 = Col. 7/Col. 5	(lb/MWh) Col. 9 = Col. 3 x Col. 8
1980	10-17	16.0	#2	5.67	0.4	1.34	0.237	3.79
1981	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1982	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1983	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1984	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79
1985	3	14.0	"	5.67	"	"	"	3.32
"	8,9	12.0	"	5.67	"	"	"	2.84
"	10-17	16.0	"	5.67	"	"	"	3.79

VI. THE RESULTS OF ELECTRICAL ENERGY MODEL APPLICATIONS

In this chapter a number of the application results are presented which illustrate the usefulness of the electrical energy model which is presented in Chapter V.

The model has been applied to each of the nine utility companies individually in order to minimize their overall fuel costs through optimum allocation of various fuel mixes among generating units of each utility. The results are shown in Table 6.1. The table reveals the present worth of annual optimum total fuel costs in dollars for each company with independent optimum operation of its generation units for the years from 1975 to 1985.

The model has also been applied to the Iowa Pool under the assumption that the Pool members will act as a united group in order to minimize their overall fuel costs by optimum allocation of various fuel mixes among generating units of the Pool. Table 6.2 shows the optimum annual energy generation in MWh and the present worth of total fuel costs, in dollars, of optimum energy generation for the companies, with optimum Iowa Pool operation, for the years from 1975 to 1985. Table 6.3 shows the comparison of the forecasted results of independent operation with those of Pool operation. It shows the total optimum energy generation for the whole Pool in MWh and the present worth of annual optimum total fuel costs, in dollars, for the optimum independent operation of the companies, and for their cooperative optimum operation as the Iowa Pool for the years from 1975 to 1985. The results have been plotted on Figure 6.1 As can be seen from Table 6.3 and Figure 6.1, there is a considerable savings to the com-

Table 6.1. Forecasted present worth of annual optimum total fuel costs, in dollars, for the companies with independent optimum operation for the years from 1975 to 1985

Company No.	Year	Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
1	1975	4,111,000.0	43,199,182.7	0.9259	39,998,123.3
	1976	4,423,000.0	50,787,970.2	0.8573	43,540,526.9
	1977	4,769,000.0	61,539,257.3	0.7938	48,849,862.4
	1978	5,152,000.0	64,288,429.4	0.7350	47,251,995.6
	1979	5,534,000.0	88,589,663.0	0.6806	60,294,124.6
	1980	5,945,000.0	126,830,113.0	0.6302	79,928,337.2
	1981	6,396,000.0	134,375,298.2	0.5835	78,407,986.5
	1982	6,877,000.0	159,266,829.8	0.5403	86,051,868.1
	1983	7,353,000.0	164,168,590.1	0.5002	82,117,128.8
	1984	7,893,000.0	210,527,705.3	0.4632	97,516,433.1
	1985	8,466,000.0	256,690,856.7	0.4289	110,094,708.4
Total		66,919,000.0	1,380,850,679.7	-	774,051,094.9
2	1975	1,488,000.0	12,251,601.1	0.9259	11,343,757.5
	1976	1,706,000.0	14,525,175.9	0.8573	12,452,433.3
	1977	1,907,000.0	17,205,297.9	0.7938	13,657,565.5
	1978	2,039,000.0	20,541,137.0	0.7350	15,097,735.7
	1979	2,176,000.0	23,220,984.8	0.6806	15,804,202.3
	1980	2,324,000.0	26,310,212.9	0.6302	16,580,696.2
	1981	2,482,000.0	32,221,790.3	0.5835	18,801,414.6
	1982	2,652,000.0	41,774,310.3	0.5403	22,570,659.9
	1983	2,835,000.0	56,703,426.4	0.5002	28,363,053.9
	1984	3,031,000.0	78,891,076.7	0.4632	36,542,346.7
	1985	3,242,000.0	105,329,077.8	0.4289	45,175,641.5
Total		25,882,000.0	428,011,555.5	-	236,389,507.1
3	1975	2,896,000.0	24,060,496.3	0.9259	22,277,613.5
	1976	3,293,000.0	27,178,610.2	0.8573	23,300,222.5
	1977	3,729,000.0	35,369,290.0	0.7938	28,076,142.4

Table 6.1. Continued.

Company No.	Year	Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
	1978	4,124,000.0	39,943,010.1	0.7350	29,358,112.4
	1979	4,432,000.0	45,759,035.5	0.6806	31,144,212.1
	1980	4,742,000.0	54,504,213.7	0.6302	34,348,555.5
	1981	5,116,000.0	60,807,657.4	0.5835	35,481,268.1
	1982	5,516,000.0	71,632,133.7	0.5403	38,702,841.8
	1983	5,929,000.0	84,990,860.4	0.5002	42,512,428.4
	1984	6,392,000.0	101,373,117.1	0.4632	46,956,027.8
	1985	6,898,000.0	120,083,720.2	0.4289	51,503,907.6
Total		53,085,000.0	665,644,354.6		383,661,332.1
4	1975	3,178,000.0	61,779,607.2	0.9259	57,201,738.3
	1976	3,369,000.0	71,976,832.7	0.8573	61,705,738.7
	1977	3,571,000.0	57,684,841.3	0.7938	45,790,227.0
	1978	3,785,000.0	64,491,834.8	0.7350	47,401,498.6
	1979	4,013,000.0	72,667,958.7	0.6806	49,457,812.7
	1980	4,253,000.0	85,103,182.7	0.6302	53,632,025.7
	1981	4,508,000.0	99,509,699.0	0.5835	58,063,909.4
	1982	4,779,000.0	116,261,979.9	0.5403	62,816,347.7
	1983	5,065,000.0	137,915,424.9	0.5002	68,985,295.5
	1984	5,363,000.0	171,884,571.2	0.4632	79,616,933.4
	1985	5,692,000.0	215,929,802.4	0.4289	92,612,292.3
Total		47,576,000.0	1,155,205,739.2		677,283,819.3
5	1975	3,802,855.1	19,910,254.8	0.9259	18,434,904.9
	1976	4,101,635.3	21,760,422.2	0.8573	18,655,210.0
	1977	4,488,260.4	26,253,422.2	0.7938	20,839,966.5
	1978	5,308,937.9	39,000,801.8	0.7350	28,665,589.3
	1979	5,050,422.2	37,308,114.0	0.6806	25,391,902.4
	1980	5,492,763.8	46,509,380.7	0.6302	29,310,211.7
	1981	5,963,225.3	57,379,376.7	0.5835	33,480,866.3

Table 6.1. Continued.

Company No.	Year	Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
	1982	6,363,543.8	69,026,460.3	0.5403	37,294,936.5
	1983	6,674,182.6	97,170,171.1	0.5002	48,604,519.6
	1984	7,105,690.8	98,466,497.3	0.4632	45,609,681.6
	1985	7,679,690.8	179,357,073.8	0.4289	76,926,249.0
Total		62,031,208.0	692,141,974.8		383,214,097.8
6	1975	1,037,144.9	6,013,273.0	0.9259	5,567,683.5
	1976	1,041,364.7	6,499,356.7	0.8573	5,571,898.5
	1977	1,049,739.6	7,089,517.3	0.7938	5,627,658.8
	1978	616,062.1	8,981,029.9	0.7350	6,601,057.0
	1979	1,289,577.8	11,702,539.8	0.6806	7,964,746.6
	1980	1,293,236.2	12,606,901.0	0.6302	7,944,869.0
	1981	1,298,774.7	13,651,152.0	0.5835	7,965,447.2
	1982	1,411,456.2	16,951,145.0	0.5403	9,158,703.6
	1983	1,645,817.4	27,415,397.3	0.5002	13,713,181.7
	1984	1,854,309.2	39,505,074.9	0.4632	18,298,750.7
	1985	1,854,309.2	42,264,429.8	0.4289	18,127,213.9
Total		14,391,792.0	153,175,137.3		106,541,216.5
7	1975	3,810,000.0	19,229,380.0	0.9259	17,804,482.9
	1976	4,111,000.0	21,274,970.9	0.8573	18,239,032.6
	1977	4,446,000.0	24,072,030.7	0.7938	19,108,378.0
	1978	4,801,000.0	28,044,675.9	0.7350	20,612,836.8
	1979	5,185,000.0	32,012,400.1	0.6806	21,787,639.5
	1980	5,600,000.0	36,285,218.9	0.6302	22,866,945.0
	1981	6,048,000.0	42,247,440.1	0.5835	24,651,381.3
	1982	6,532,000.0	48,341,906.7	0.5403	26,119,132.2
	1983	7,054,000.0	56,225,060.0	0.5002	28,123,775.0
	1984	7,619,000.0	67,245,772.8	0.4632	31,148,242.0

Table 6.1. Continued.

Company No.	Year	Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
	1985	8,828,000.0	87,267,057.0	0.4289	37,428,840.8
Total		64,034,000.0	462,744,313.1	-	267,890,840.8
8	1975	1,919,000.0	9,339,519.7	0.9259	8,647,461.3
	1976	2,087,000.0	14,714,907.0	0.8573	12,615,089.8
	1977	2,306,000.0	30,815,533.7	0.7938	24,461,370.7
	1978	2,506,000.0	45,472,099.8	0.7350	33,421,993.4
	1979	2,723,000.0	62,761,414.9	0.6806	42,715,419.0
	1980	2,959,000.0	83,641,969.4	0.6302	52,711,169.1
	1981	3,217,000.0	108,749,941.7	0.5835	63,455,591.0
	1982	3,499,000.0	133,765,202.4	0.5403	72,273,338.9
	1983	3,785,000.0	178,579,173.9	0.5002	89,325,302.8
	1984	4,094,000.0	213,501,967.4	0.4632	98,894,111.3
	1985	4,428,000.0	261,275,680.2	0.4289	112,061,139.2
Total		33,523,000.0	1,142,617,410.3	-	610,581,986.5
9	1975	285,000.0	2,456,700.0	0.9259	2,357,989.5
	1976	300,000.0	2,760,000.0	0.8573	2,366,148.0
	1977	325,000.0	3,175,250.0	0.7938	2,520,513.5
	1978	360,000.0	3,888,000.0	0.7350	2,857,680.0
	1979	395,000.0	4,542,500.0	0.6806	3,091,625.5
	1980	410,000.0	5,043,000.0	0.6302	3,178,098.6
	1981	430,000.0	5,684,600.0	0.5835	3,316,964.1
	1982	445,000.0	6,292,300.0	0.5403	3,399,729.7
	1983	475,000.0	7,153,500.0	0.5002	3,578,180.7
	1984	475,000.0	7,699,750.0	0.4632	3,566,524.2
	1985	475,000.0	8,193,750.0	0.4289	3,514,299.4
Total		4,375,000.0	56,889,350.0	-	33,747,753.2

Table 6.2. Forecasted present worth of annual optimum total fuel costs, in dollars, for the companies with optimum Iowa Pool operation for the years from 1975 to 1985

Company No.	Year	Optimum Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
1	1975	3,986,816.6	41,089,020.6	0.09259	38,044,324.2
	1976	4,684,006.8	49,570,240.6	0.8573	42,496,567.3
	1977	4,694,083.1	53,383,863.7	0.7938	42,376,111.0
	1978	5,016,601.3	59,283,747.0	0.7350	43,573,554.0
	1979	5,630,027.3	68,281,833.5	0.6806	46,472,615.9
	1980	5,643,158.4	75,585,160.2	0.6302	47,633,768.0
	1981	5,653,302.2	81,445,742.1	0.5835	47,523,590.5
	1982	5,848,348.1	99,755,307.6	0.5403	53,897,792.7
	1983	6,518,557.9	98,778,658.5	0.5002	49,409,085.0
	1984	6,796,212.0	130,311,706.7	0.4632	60,360,382.5
	1985	9,230,328.0	316,828,181.9	0.4289	135,887,607.2
Total		63,701,909.7	1,074,342,356.0	-	607,675,398.3
2	1975	1,564,101.4	12,521,013.9	0.9259	11,593,206.8
	1976	1,169,756.0	10,797,673.5	0.8573	9,256,845.5
	1977	2,359,017.3	19,897,344.6	0.7938	15,794,512.1
	1978	2,389,631.0	23,139,312.8	0.7350	17,007,394.9
	1979	2,395,006.0	24,955,512.3	0.6806	16,984,721.7
	1980	2,398,922.9	26,945,533.2	0.6302	16,981,075.0
	1981	2,402,979.3	29,104,983.8	0.5835	16,982,758.0
	1982	2,418,453.7	31,846,037.3	0.5403	17,206,414.0
	1983	2,483,307.4	48,985,192.7	0.5002	24,502,393.4
	1984	2,746,851.8	52,471,384.9	0.4632	24,304,745.5
	1985	2,749,165.0	56,138,274.2	0.4289	24,077,705.8
Total		25,077,191.8	336,802,263.1	-	194,691,772.7
3	1975	4,079,800.8	31,502,253.9	0.9259	29,167,936.9
	1976	5,792,580.3	42,757,171.3	0.8573	36,655,723.0

Table 6.2. Continued.

Company No.	Year	Optimum Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
	1977	6,270,588.8	53,031,688.3	0.7938	42,096,554.2
	1978	6,077,120.5	55,147,016.6	0.7350	40,533,057.2
	1979	7,156,472.3	71,776,164.2	0.6806	48,850,857.4
	1980	7,541,337.5	79,915,323.1	0.6302	50,362,636.6
	1981	7,410,128.3	84,114,871.2	0.5835	49,081,027.4
	1982	7,612,856.8	97,145,853.7	0.5403	52,487,904.8
	1983	7,632,739.0	108,075,548.2	0.5002	54,059,389.2
	1984	8,560,859.6	174,564,928.0	0.4632	80,858,474.7
	1985	8,563,351.2	191,301,374.6	0.4289	82,049,159.6
Total		75,272,230.0	989,332,193.1	-	556,202,721.0
4	1975	1,985,395.4	38,799,746.0	0.9259	35,924,684.8
	1976	1,816,125.5	40,646,351.7	0.8573	34,846,117.3
	1977	1,843,182.7	44,221,003.0	0.7938	35,102,632.2
	1978	3,672,982.7	51,148,802.5	0.7350	37,594,369.8
	1979	2,459,124.7	57,877,409.3	0.6806	39,391,364.8
	1980	3,986,377.7	77,472,487.0	0.6302	48,823,161.3
	1981	4,018,402.4	83,820,799.4	0.5835	48,909,436.5
	1982	4,038,593.5	90,338,322.1	0.5403	48,809,795.4
	1983	4,905,725.9	130,037,050.9	0.5002	65,044,532.9
	1984	4,938,626.8	156,654,733.0	0.4632	72,562,472.3
	1985	5,196,643.9	167,734,301.8	0.4289	71,941,242.0
Total		38,861,181.2	938,751,006.7	-	538,949,809.3
5	1975	4,268,346.0	21,237,596.5	0.9259	19,663,890.6
	1976	4,256,201.4	22,265,568.5	0.8573	19,088,271.9
	1977	4,236,296.4	23,194,579.1	0.7938	18,411,856.9
	1978	4,252,257.0	23,730,223.3	0.7350	17,441,714.1
	1979	4,266,950.5	26,240,101.4	0.6806	17,859,013.0
	1980	4,284,712.8	27,994,115.5	0.6302	17,641,891.6

Table 6.2. Continued

Company No.	Year	Optimum Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
	1981	4,977,233.9	40,443,596.1	0.5835	23,598,838.3
	1982	6,471,837.0	71,660,593.7	0.5403	38,718,218.8
	1983	6,924,422.4	93,284,370.2	0.5002	46,660,842.0
	1984	6,918,123.1	98,466,497.3	0.4632	45,609,681.6
	1985	6,911,823.8	103,921,870.1	0.4289	44,572,090.1
Total		57,768,204.3	552,439,111.7	-	309,266,308.9
6	1975	1,040,830.9	6,033,912.0	0.9259	5,586,799.1
	1976	1,044,191.5	6,516,289.2	0.8573	5,586,414.7
	1977	1,049,739.6	7,089,514.7	0.7938	5,627,656.8
	1978	388,494.4	5,906,590.2	0.7350	4,341,343.8
	1979	1,062,888.8	7,714,104.7	0.6806	5,250,219.7
	1980	1,047,139.6	9,770,971.8	0.6302	6,157,666.4
	1981	1,298,774.7	13,635,496.3	0.5835	7,956,312.1
	1982	1,411,456.2	16,951,145.0	0.5403	9,158,703.6
	1983	1,854,309.2	36,918,453.5	0.5002	18,466,610.4
	1984	1,854,309.2	39,505,074.9	0.4632	18,298,750.7
	1985	1,854,309.2	42,264,429.7	0.4289	18,127,213.9
Total		13,906,443.3	192,305,982.0	-	104,557,691.2
7	1975	3,878,235.5	19,692,699.1	0.9259	18,233,470.1
	1976	4,211,134.6	21,812,693.7	0.8573	18,700,022.3
	1977	4,538,600.8	24,765,610.8	0.7938	19,658,941.9
	1978	5,064,779.7	30,117,991.9	0.7350	22,136,724.0
	1979	6,277,068.0	40,382,856.8	0.6806	27,484,572.3
	1980	6,437,928.1	44,213,754.8	0.6302	27,863,508.3
	1981	7,479,280.1	57,590,784.6	0.5835	33,604,222.8
	1982	7,751,723.6	62.714,092.3	0.5403	33,884,424.0
	1983	8,320,335.5	84,735,330.3	0.5002	42,384,612.2
	1984	9,241,096.4	134,911,307.4	0.4632	62,490,917.6

Table 6.2. Continued.

Company No.	Year	Optimum Annual Energy Generation (MWh)	Total Fuel Costs ($)	Present Worth Factor	Present Worth of Total Fuel Costs ($)
	1985	9,934,020.7	144,084,686.0	0.4289	61,797,921.8
Total		73,134,203.0	665,021,807.7	-	368,239,337.3
8	1975	1,854,909.7	8,421,481.7	0.9259	7,797,449.9
	1976	1,865,359.9	9,050,569.8	0.8573	7,759,053.5
	1977	1,840,965.3	11,019,501.8	0.7938	8,747,280.5
	1978	1,848,138.6	11,994,372.3	0.7350	8,815,863.6
	1979	1,854,980.5	12,776,886.6	0.6806	8,695,949.0
	1980	1,864,488.9	12,787,086.3	0.6302	8,058,421.8
	1981	1,871,806.0	14,606,780.5	0.5835	8,523,056.4
	1982	1,973,608.0	17,681,298.2	0.5403	9,553,205.4
	1983	2,162,040.0	19,357,008.4	0.5002	9,682,375.6
	1984	2,015,781.8	20,937,061.6	0.4632	9,698,046.9
	1985	2,015,781.8	22,107,211.7	0.4289	9,481,783.1
Total		21,167,860.5	160,739,258.9	-	96,812,485.7
9	1975	-	-	-	-
	1976	-	-	-	-
	1977	-	-	-	-
	1978	-	-	-	-
	1979	-	-	-	-
	1980	404,896.2	4,980,223.2	0.6302	3,138,536.7
	1981	504,576.0	6,670,494.7	0.5835	3,892,233.7
	1982	504,576.0	7,134,704.6	0.5403	3,854,880.9
	1983	504,576.0	7,598,914.5	0.5002	3,800,977.0
	1984	504,576.0	8,179,176.9	0.4632	3,788,594.7
	1985	504,576.0	8,703,936.0	0.4289	3,733,118.2
Total		2,927,776.2	43,267,449.9	-	22,208,341.2

Table 6.3. Forecasted present worth of annual optimum total fuel costs, in dollars, for optimum independent operation of the companies, and for their cooperative optimum operation as the Iowa Pool for the years from 1975 to 1985

Year	Total Optimum Energy Generation (MWh)	Companies Operating Independently		Companies Operating as a Pool	
		Total Fuel Costs ($)	Present Worth of Total Fuel Costs ($)	Total Fuel Costs ($)	Present Worth of Total Fuel Costs ($)
1975	22,527,000.0	198,240,011.8	183,633,760.7	179,297,723.7	166,011,762.4
1976	24,432,000.0	231,478,245.8	198,446,300.3	203,416,558.3	174,389,015.5
1977	26,591,000.0	263,204,440.4	208,931,684.8	236,603,106.0	187,815,545.6
1978	28,710,000.0	314,651,018.7	231,268,798.8	260,468,056.6	191,444,021.3
1979	30,798,000.0	378,565,510.8	257,651,684.7	310,004,868.8	210,953,313.8
1980	33,019,000.0	476,834,192.3	300,500,908.0	359,664,655.1	226,660,665.7
1981	35,459,000.0	554,626,355.4	323,624,828.5	411,433,548.7	240,080,475.7
1982	38,075,000.0	663,312,268.1	358,387,617.9	495,227,354.5	267,571,339.6
1983	40,816,000.0	810,321,604.1	405,322,866.4	627,770,527.2	314,010,817.7
1984	43,833,000.0	989,095,532.7	458,149,050.8	816,001,870.7	377,972,066.5
1985	46,963,000.0	1,276,391,447.0	547,444,292.1	1,053,084,266.0	451,667,841.7

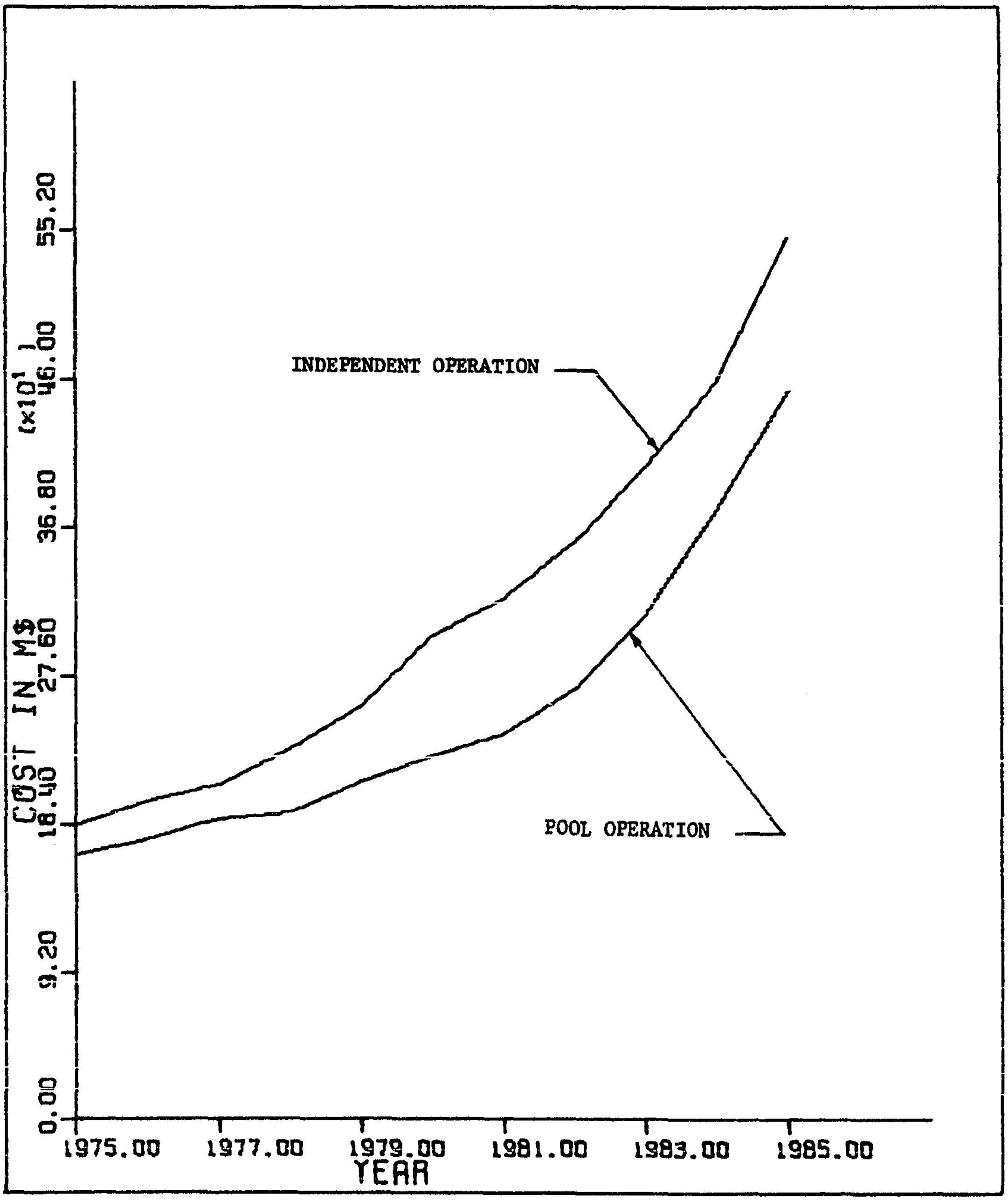

Figure 6.1. Forecasted present worth of annual optimum total fuel costs for optimum independent operation of the companies and for their cooperative optimum operation as the Iowa Pool for the years from 1975 to 1985, in millions of dollars per year

panies and, finally, to the consumer, if the companies act as a united group to meet their customers' electrical energy demand in an optimum fashion. Table 6.4 and Figure 6.2 show, in percent per year, the annual total fuel cost savings of optimum operation of the generating units of the companies as the Iowa Pool, compared to optimum independent operation of the generating units for each company. The computer outputs for the Iowa Pool application of the model are presented in Appendix H.

In the Iowa Pool's optimum operation, each company generates electrical energy according to the efficiency of its generating units and the costs and qualities of the fuels used. While, in some years some of the companies generate less electrical energy than with their independent operations, some others generate more energy than they normally would. Again, the energy generation totally depends on the efficiency of the units and on the cost and quality of the fuels used throughout the years, which are changeable. For example, Figure 6.3 shows the annual optimum electrical energy generation in GWh by company 1 as a result of independent operation and Iowa Pool operation for the years from 1975 to 1985. As can be seen from this figure, company 1 produces much less energy with Pool operation than with independent operation for the years from 1979 to 1984. But, after the year 1984, it generates much more energy under Pool operation than under independent operation, because of planned new nuclear units. Figure 6.4 shows the present worth of annual optimum total fuel costs for company 1 with independent operation and with Iowa Pool operation for the years from 1975 to 1985 in millions of dollars. Nevertheless, under the Pool operation, since each company shares the total fuel costs of the Pool

Table 6.4. Forecasted annual total fuel cost savings of optimum operation of the companies as the Iowa Pool compared to optimum independent operation of the companies, in percent per year

Year	Total Fuel Cost Savings (%)
1975	9.6
1976	12.1
1977	10.1
1978	17.2
1979	18.1
1980	24.6
1981	25.8
1982	25.3
1983	22.5
1984	17.5
1985	17.5

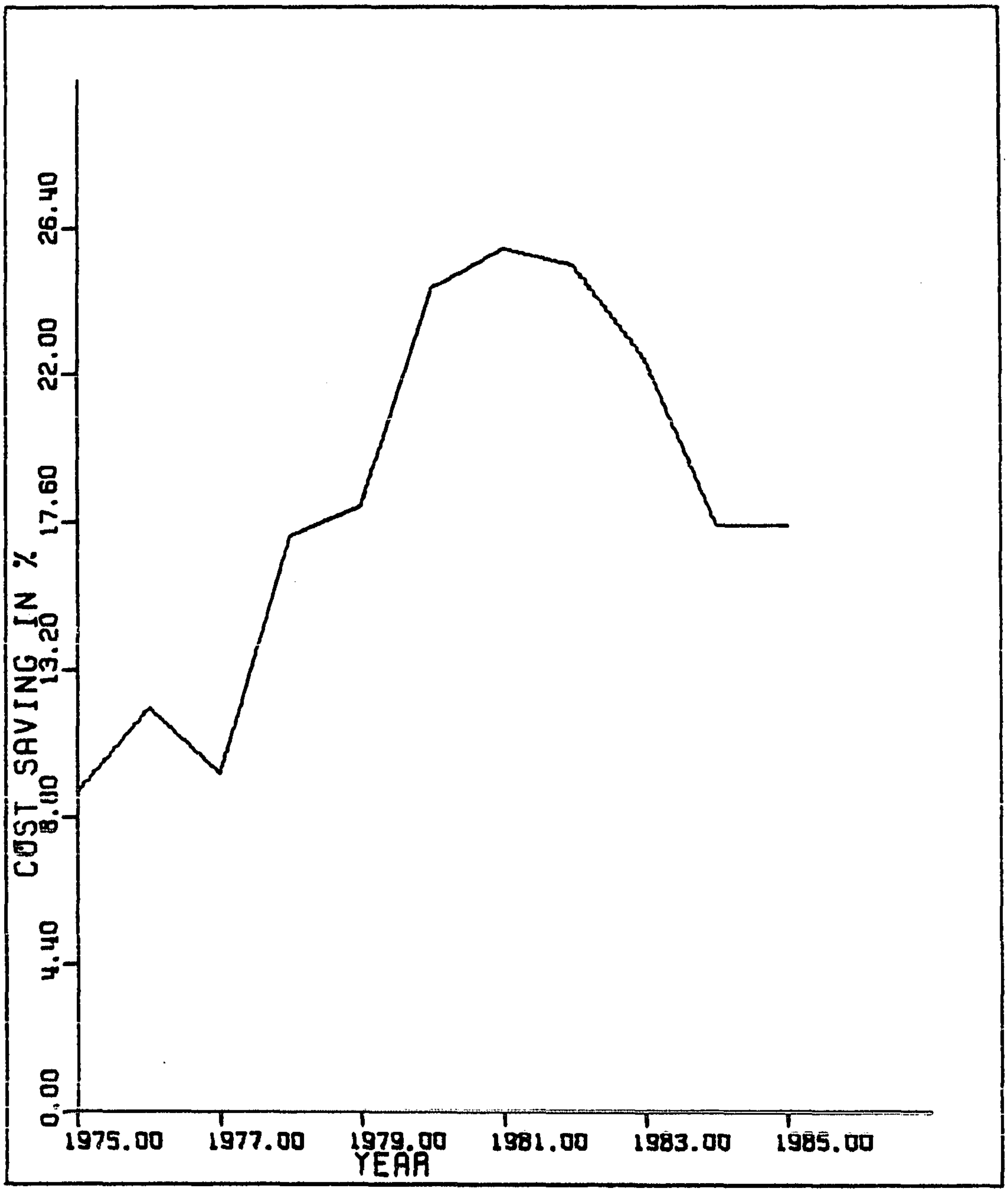

Figure 6.2. Forecasted annual total fuel cost savings of cooperative optimum operation of the companies as the Iowa Pool, compared to optimum independent operation of the companies in percent per year

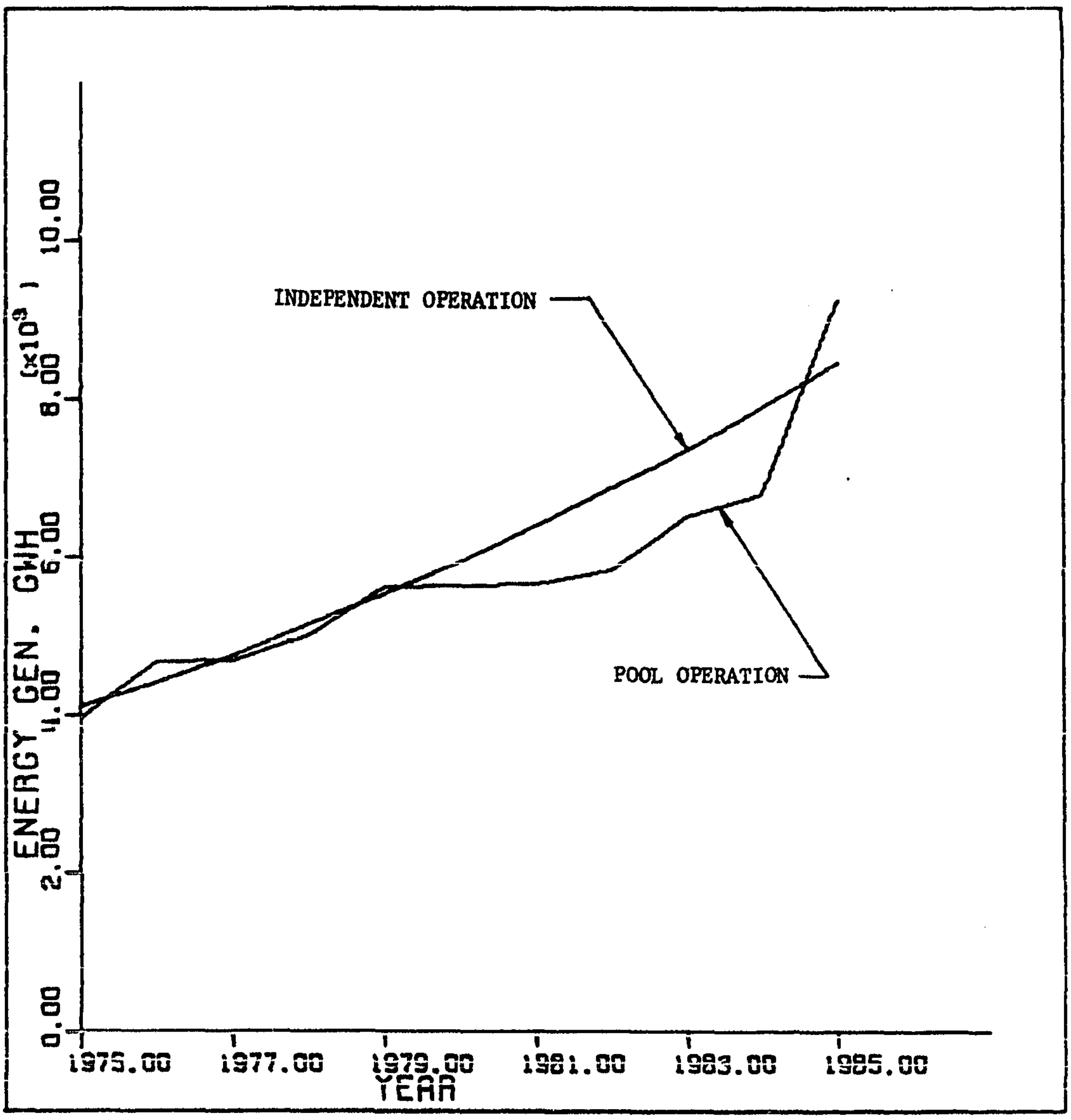

Figure 6.3. Forecasted annual optimum electrical energy generation by company 1 as a result of independent operation and Iowa Pool operation for the years from 1975 to 1985, in GWh

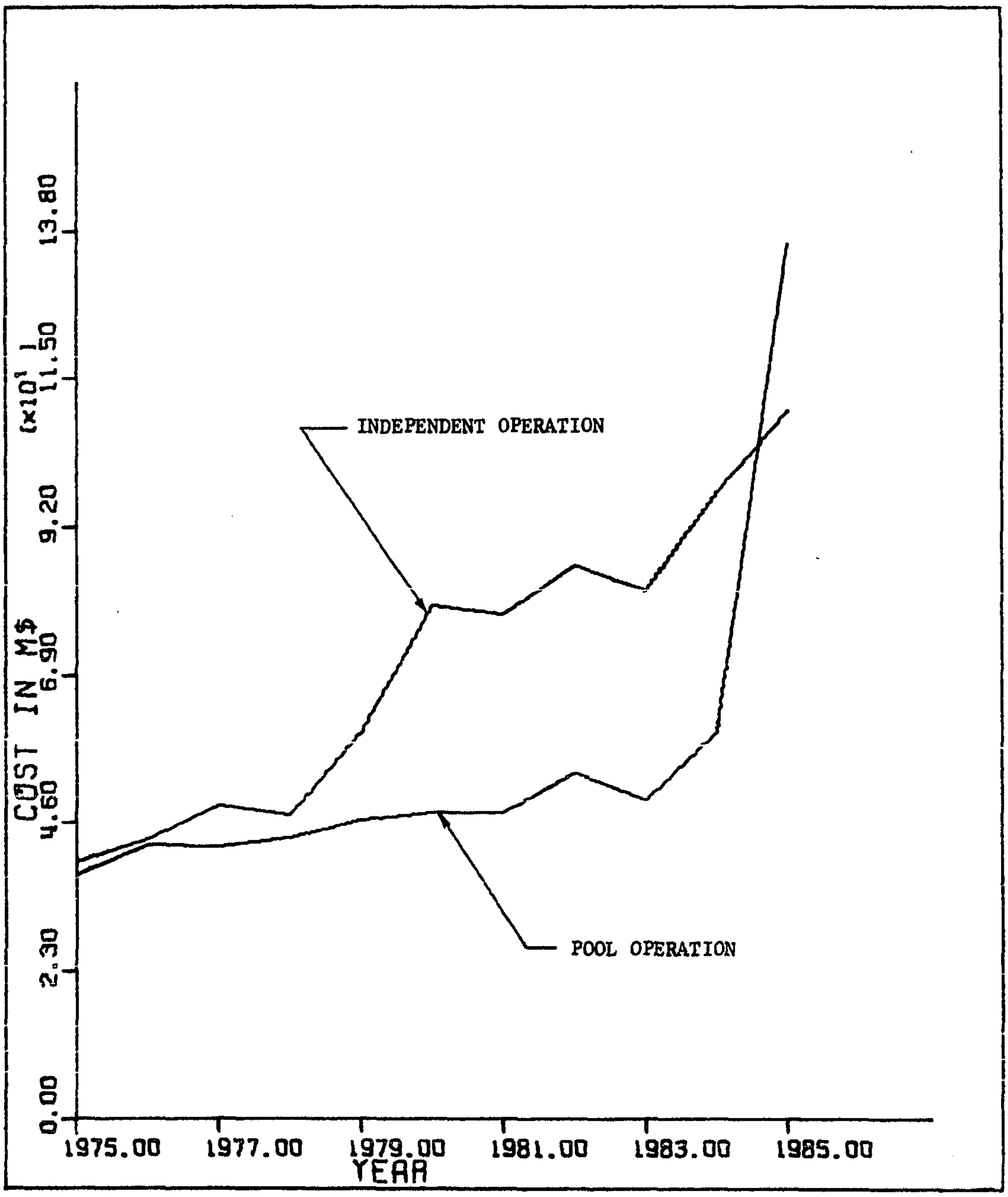

Figure 6.4. Forecasted present worth of annual optimum total fuel costs for optimum usage of the units of company 1 with independent operation, and with Iowa Pool operation, from 1975 to 1985, in millions of dollars

according to its own energy demands, the fuel cost savings of each company, in dollars per MWh, will be the same (See Table 6.4 and Figure 6.2).

Some considerable savings can be achieved in energy and in the total cost of energy by conservation measures. The recent emphasis on voluntary measures of energy conservation in response to potential energy shortages created by the cut-off of oil supplies from the Middle East, yielded a 5 percent reduction in energy demand by simple conservation measures (134). Table 6.5 and Figure 6.5 show the annual electrical energy requirements in MWh for company 1 with various conservation levels.

As an example to illustrate the usefulness of the computerized model to investigate a wide variety of policies rapidly and economically, the following study has been made. In this study, the possible savings in energy costs have been investigated with decreasing crude oil prices at various conservation levels, applying the model to company 1. In this study, three crude oil prices have been assumed, as previously studied in the Project Independence Report (21). These prices are four dollars per barrel, seven dollars per barrel, and the present price of eleven dollars per barrel. While the crude oil prices are changing, the other fuel prices have been assumed to remain the same. The results of this application are summarized in Table 6.6. The table shows the total fuel costs of optimum electrical energy generation using the generating units of company 1 for various fuel prices and for various conservation levels, in dollars, over an 11 year period from 1975 to 1985. These results are plotted in Figure 6.6. Table 6.7 shows total fuel cost savings, in percent, for optimum electrical energy generation for company 1 for various fuel prices

Table 6.5. Annual electrical energy generation of company 1 for various conservation levels, in MWh

Year	Annual Electrical Energy Generations (MWh)					
	0%	5%	10%	15%	20%	25%
1975	4,111,000	3,905,450	3,699,900	3,494,350	3,288,800	3,083,250
1976	4,423,000	4,201,850	3,980,700	3,759,550	3,538,400	3,317,250
1977	4,769,000	4,530,550	4,292,100	4,053,650	3,815,200	3,576,750
1978	5,152,000	4,893,450	4,635,900	4,378,350	4,120,800	3,863,250
1979	5,534,000	5,257,300	4,980,600	4,703,900	4,427,200	4,150,500
1980	5,945,000	5,647,750	5,350,500	5,053,250	4,756,000	4,458,750
1981	6,396,000	6,076,200	5,756,400	5,436,600	5,116,800	4,797,000
1982	6,877,000	6,533,150	6,189,300	5,845,300	5,501,600	5,157,750
1983	7,353,000	6,985,350	6,617,700	6,250,050	5,882,400	5,512,750
1984	7,893,000	7,498,350	7,103,700	6,709,050	6,314,400	5,919,750
1985	8,466,000	8,042,700	7,619,400	7,196,100	6,772,800	6,349,500

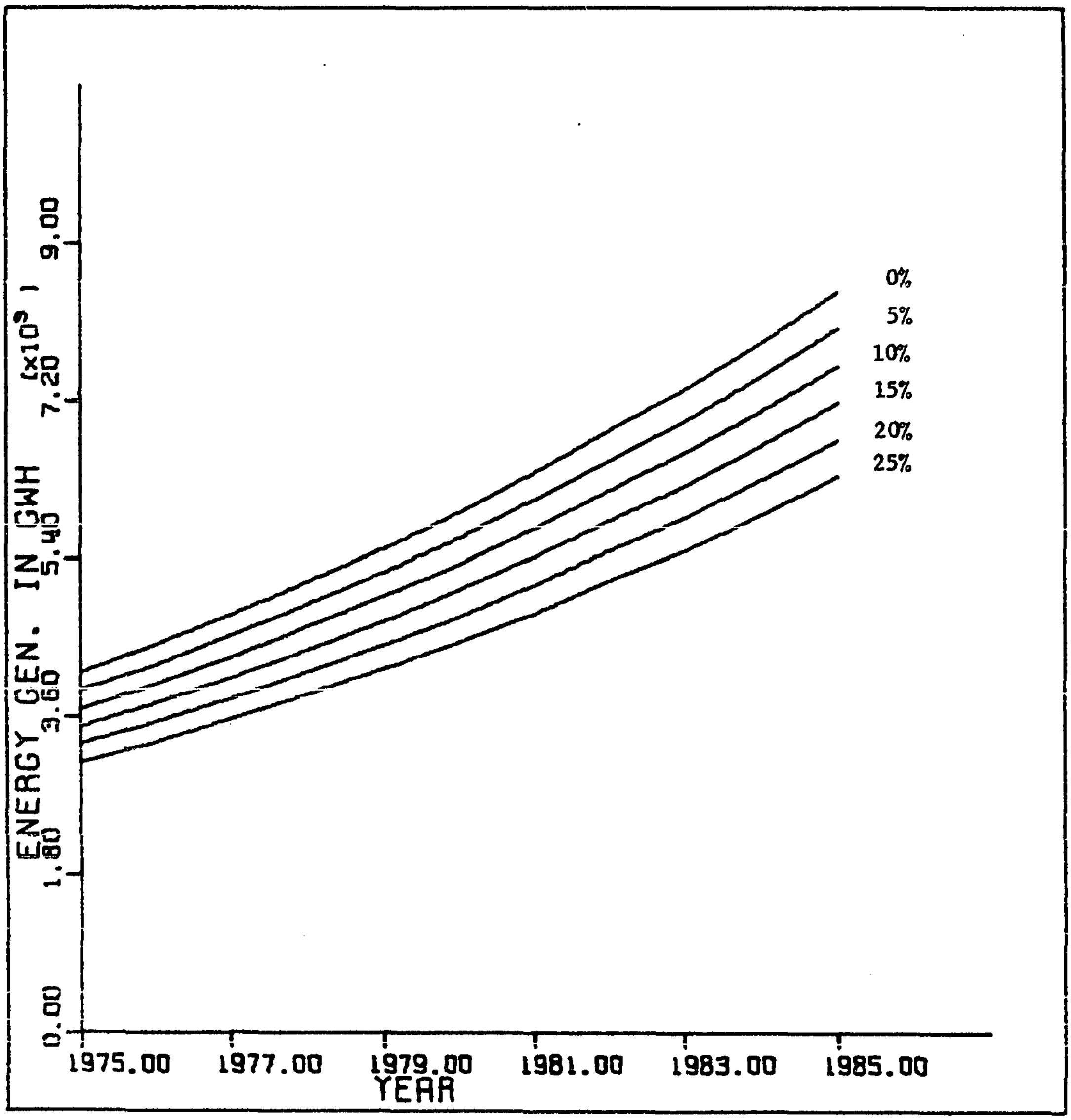

Figure 6.5. Annual electrical energy generation of company 1 for various conservation levels, in MWh

Table 6.6. Total fuel costs, in dollars, of optimum electrical energy generation for company 1 for various fuel prices and conservation levels, in percent, over an 11 year period from 1975 to 1985

B's	Conserved Energy (%)	Total Optimum Fuel Costs for Various Future Fuel Prices		
		(at 11 $/Bbl oil) ($)	(at 7 $/Bbl oil) ($)	(at 4 $/Bbl oil) ($)
B	0.0	1,382,359,757.9	1,128,322,565.8	801,714,076.7
B2	5.0	1,020,026,912.2	821,801,704.9	606,111,030.3
B3	10.0	869,987,888.6	709,448,667.0	545,116,529.1
B4	15.0	756,815,755.3	626,832,609.2	494,179,540.9
B5	20.0	688,535,352.3	567,652,738.8	444,279,046.0
B6	25.0	645,224,043.3	531,896,376.4	416,233,325.6

Table 6.7. Total fuel cost savings, in percent, for optimum electrical energy generation for company 1, for various fuel prices and conservation levels, in percent, over an 11 year period from 1975 to 1985

B's	Conserved Energy (%)	Total Fuel Cost Savings for Various Future Fuel Prices		
		(at 11 $/Bbl oil) (%)	(at 7 $/Bbl oil) (%)	(at 4 $/Bbl oil) (%)
B	0.0	0.0	18.4	42.0
B2	5.0	26.2	40.6	56.2
B3	10.0	37.0	48.7	60.5
B4	15.0	45.3	54.7	64.3
B5	20.0	50.2	58.9	67.9
B6	25.0	53.3	61.5	69.9

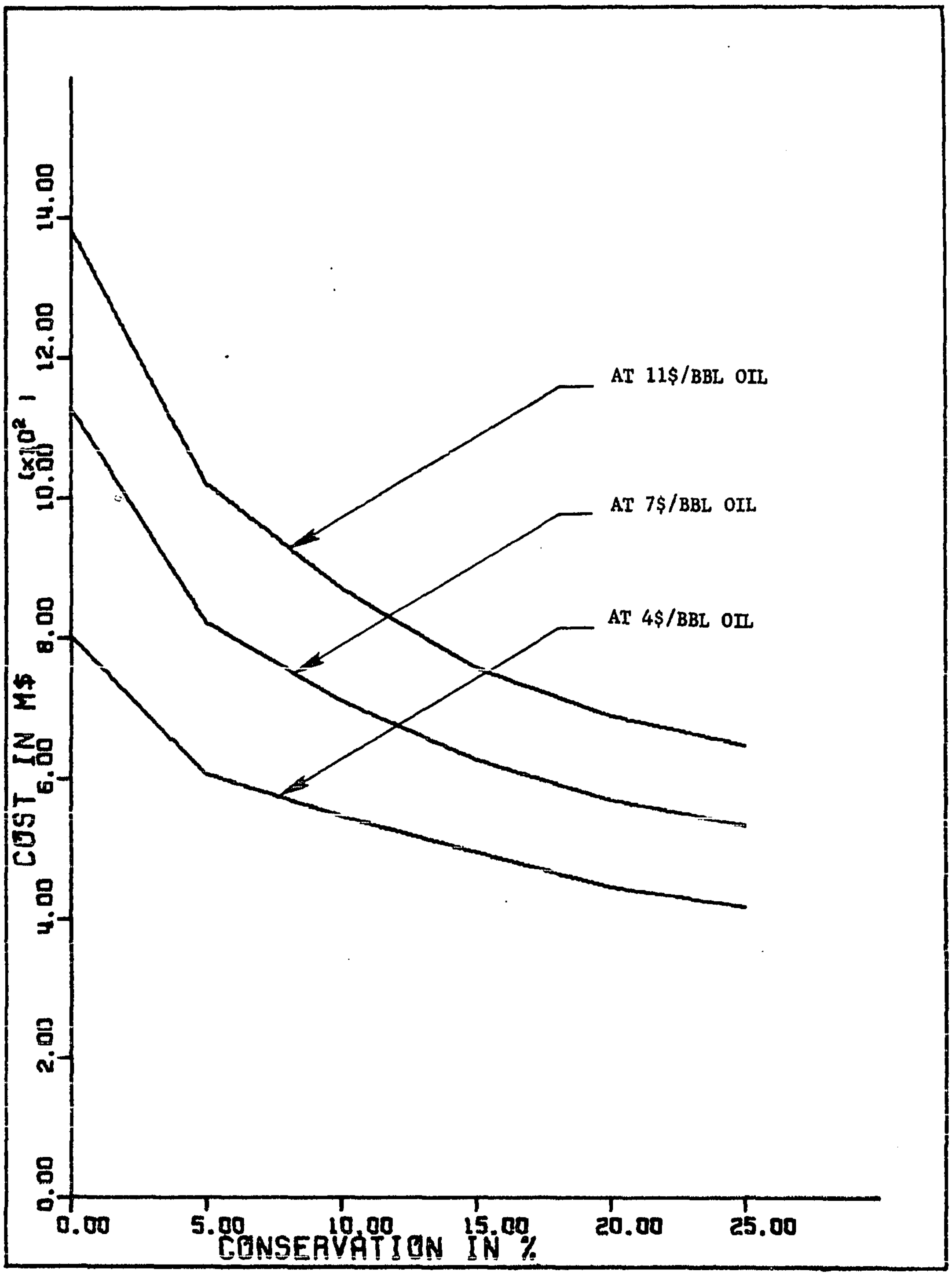

Figure 6.6. Total optimum fuel costs for various fuel prices and conservation levels for company 1 over an 11 year period from 1975 to 1985, in millions of dollars

and conservation levels in percent, compared to present fuel prices and a zero conservation level, over an 11 year period from 1975 to 1985. The results are plotted on Figure 6.7.

Table 6.7 and Figure 6.7 show that, if a 5 percent conservation level is achieved, at the present crude oil prices, the total fuel cost savings of company 1 is 26.2 percent. If 25 percent conservation level is achieved, then the total fuel cost savings is 53.3 percent. If the crude oil prices decrease to seven dollars per barrel, at a 5 percent conservation level, the total fuel cost savings is 40.6 percent; at a 25 percent conservation level the total fuel cost savings is 61.5 percent. The main reason for these savings is that the decreasing demand for electrical energy decreases the necessity of operation of the less efficient or more expensively fueled generating units.

Because of the number of assumptions involved, the results of this application of the model may not be precisely accurate. Nevertheless, the usefulness of the model as a tool for making comparative studies for sensitivity analyses is well illustrated by these examples.

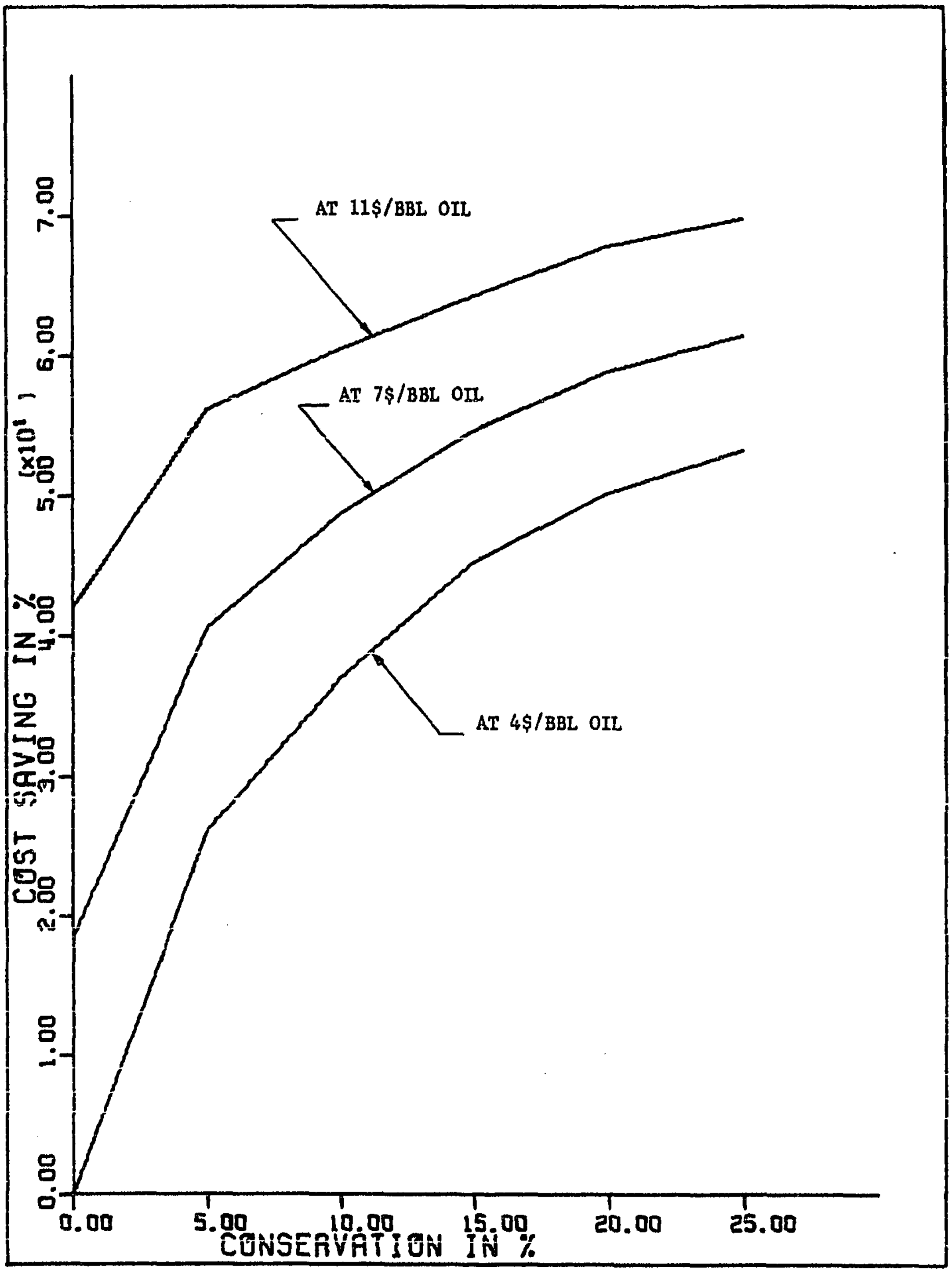

Figure 6.7. Total optimum fuel cost savings for various fuel prices and conservation levels for company 1, compared to present fuel prices and a zero conservation level over an 11 year period from 1975 to 1985, in percent

VII. SUMMARY AND CONCLUSIONS

This study covers the entire energy field with special emphasis on electric power. The sources of energy and the projected energy supply and demand to the year 2000 on the basis of statistical data have been reviewed, and a survey of U. S. energy forecasts has been made in order to make a comparison between projections. Some energy related issues are discussed in the light of these projections.

In order to evaluate rapidly the consequences of different proposed energy policies, a computerized electrical energy model has been developed in this thesis. The necessary mechanism is built into the model to capture accurately the dynamics of changes. Furthermore, if one wishes to answer the many "what if" questions, the computerized electrical energy model has a consistent framework within which to investigate a wide variety of policies rapidly and economically.

The model is basically built for the electric power industry to minimize the cost of energy used for electric generation through optimum allocation of various fuel mixes over a period of n years, where the energy is subject to a large number of physical and environmental constraints.

The model has been applied to each of the nine utility companies in the State of Iowa individually and together as an Iowa Pool.

The results show that the computerized model is a promising tool in long range power systems planning. It is also demonstrated that there can be a considerable savings to the companies and, finally, to the consumer, if the companies act as a united group to meet their customers' electrical energy demand in an optimum fashion.

The FAM model is quite efficient and economical. For example, the program requires 96K words of computer core storage, 1.18 minutes of computer CPU time, and 1063 iterations to reach an optimum solution for the Iowa Pool program which has 1287 real variables, 45 LP rows, and 3713 LP elements, at a cost of only 15.14 dollars.

VIII. RECOMMENDED FUTURE WORK

In order to make this model a more useful tool in long range power system planning, capitalization costs, operating and maintenance costs should be added to the fuel cost to determine the optimum generation plans with the lowest annual cost. The model can be improved easily to evaluate long range generation patterns not only for the units which are already installed but for those to be installed in the future. Of course, there may be a better way to formulate the optimization model than we have used, nevertheless, this study presents a valuable start in this direction.

Some further work is needed to apply the model into a pool arrangement. For example, in order to distribute the economic benefits of shared generation, in a manner which all can accept as fair and equitable, an allocation method should be developed. Also, a fair penalty system should be established among the pool members to fairly penalize those who, for private or internal reasons, choose to not cooperate in optimum pool development. A method should also be developed to determine the allocation of capacity benefits and costs resulting from the additional installation of transmission facilities among the pool members.

Finally, it should be recognized that pool planning studies of this kind require both a commitment to cooperate in this work and a willingness to share information. To this end it is recommended that the Iowa utilities establish an "Iowa Energy Data System" which can be used to collect, store, and evaluate data which would be available to all utilities for the contribution of optimal growth plans.

IX. REFERENCES

1. Quinn, J. B. "Technological Forecasting." Harvard Business Review, 39 (March 1967): 106-115.

2. Dalal, W. "Environmental Energy and the Need for New Technology." Science, 40 (1972): 63-76.

3. Guyol, N. B. The World Electric Power Industry. Berkeley, California: University of California Press, 1969.

4. Darmstadter, J. Energy in the World Economy. Baltimore: The Johns Hopkins Press, 1971.

5. Felix, F. World Markets of Tomorrow. New York, New York: Harper & Row, Co., 1972.

6. Freeman, S. I. "Technical Alternatives for Energy Management." Science, 41 (1972): 57-65.

7. Cook, E. "The Flow of Energy in an Industrialized Society." Scientific American, 224 (1971): 134-144.

8. Meadows, D. H., Meadows, D. L. and Randers, J. The Limits to Growth. New York, New York: Universe Books Co., 1972.

9. Altman, M., Wolf, M. and Telkes, M. "The Energy Resources and Electric Power Situation in the United States." Energy Conversion, 12 (1971): 53-64.

10. Hottel, H. C. and Howard, J. B. New Energy Technology - Some Facts and Assessments. Cambridge, Mass.: The MIT Press, 1971.

11. Starr, C. "Energy and Power." Scientific American, 224 (1971): 39-45.

12. Gaucher, L. P. "Energy in Perspective." Chemical Technology, 3 (March 1971): 153-158.

13. Morrison, W. E. and Readling, C. L. An Energy Model for the United States. U. S. Dept. of the Interior, Bureau of Mines, No. 8384, 1968.

14. Ritchings, F. A. "Trends in Energy Needs." A paper presented at the Annual ASME Meeting, New York, 1971.

15. Cook, C. S. "Energy: Planning for the Future." American Scientist, 61 (1973): 61-65.

16. Landsberg, H. H. and Schurr, S. H. Energy in the United States, Sources, Uses and Policy Issues. New York, New York: Random House, 1968.

17. Dupree, W. G. and West, J. A. United States Energy Through the Year 2000. U. S. Department of the Interior, Washington, D.C.: U. S. Government Printing Office, 1972.

18. U. S. Energy Outlook - An Initial Appraisal, 1971-1985. An Interim Report by the National Petroleum Council's Committee on U. S. Energy Outlook, Vol. 2, 1971.

19. A Time to Choose - America's Energy Future. The Energy Policy Project of the Ford Foundation. Cambridge, Mass.: Ballinger Publishing Co., 1974.

20. Megastar - The Meaning of Energy Growth: An Assessment of Systems, Technologies and Requirements. NASA CR-120338, Auburn University Engineering Systems Design Summer Faculty Fellows, Auburn University, Auburn, Alabama, 1974.

21. Project Independence Report. Federal Energy Administration, Washington, D.C.: U. S. Government Printing Office, 1974.

22. Schurr, S. H. and Netschert, B. S. Energy in the American Economy, 1850-1975. Baltimore: Johns Hopkins Press, 1960.

23. 1972 Business and Economic Charts. Statistical Reference Book. Chicago: Ebasco Service, Inc., 1972.

24. Gonen, T. and Anderson, P. M. "Energy Dilemma in the U. S. and Economical Production of Electric Energy from Western Coal." Annual Progress Report of the Electric Power Affiliate Research Program. Ames, Iowa: Engineering Experiment Station, Iowa State University of Science and Technology, 1974.

25. Anderson, P. M. "The World's Energy Supply." Unpublished Class Notes. Ames, Iowa: Department of Electrical Engineering, I.S.U., 1966.

26. Hammond, R. P. "Nuclear Power Risks." American Scientist, 62 (1974): 155-160.

27. Cheney, E. S. "U. S. Energy Resources: Limits and Future Outlook." American Scientist, 62 (1974): 14-22.

28. Szego, G. C. The U. S. Energy Problem. Vol. 2, Appendices Part A. Warrenton, Virginia: Inter Technology Co., 1971.

29. *Outlook for Energy in the United States to 1985.* New York: Chase Manhattan Bank, Energy Economics Division, 1972.

30. Szego, G. C. *The U. S. Energy Problem.* Vol. 1. Warrenton, Virginia: Inter Technology Co., 1972.

31. Hauser, L. G., Comtois, W. H. and Boyle, R. R. "The Effect of Fuel Availability on Future R & D Programs in Power Generation." Proc. of the American Power Conference, 34 (1972): 382-393.

32. "If You are a Businessman, This Chart May be the Shape of Your Future." U. S. News and World Report, 110 (May 1972): 37-44.

33. "Population and the American Future." A Summary of the Final Report and Recommendations by the U. S. Commission on Population Growth and the American Future. *New York Times,* (April 30, 1972).

34. "The Surprising Decline in the Birthrate." *Business Week,* 2231 (1972): 66-67.

35. U. S. Department of Commerce, Bureau of Census. *Statistical Abstract of the U. S., 1971.* Washington, D.C.: U. S. Government Printing Office, 1971.

36. *Energy, The Ultimate Resource.* Washington, D.C.: U. S. Government Printing Office, 1971.

37. Drucker, P. F. "Saving the Crusade." *Harper's Magazine,* 244 (1972): 66-69.

38. Bright, J. R. *Technological Forecasting for Industry and Government.* Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1968.

39. Landsberg, H. H. *Natural Resources for U. S. Growth.* Baltimore: Johns Hopkins Press, 1964.

40. Kahn, H. and Wiener, A. J. *The Year 2000 - A Framework for Speculation on the Next Thirty-three Years.* New York, New York: Macmillan Co., 1968.

41. National Academy of Engineering. *Engineering for the Resolution of the Energy-Environment Dilemma.* Washington, D.C.: National Academy of Sciences, 1972.

42. Summers, C. M. "The Conversion of Energy." *Scientific American,* 224 (March 1971): 151-155.

43. "The High Price of More Electric Power." *Business Week,* 2242 (1972): 54-56.

44. "EEI President Criticizes EPA's Sulfur Oxide Emission Standard." Statement by W. Donham Crawford before the Subcommittee on Air and Water Pollution, U. S. Senate Committee on Public Works. News Release, (February 25, 1972).

45. Netschert, B. C. "The Year 2000 - Living with Growth." Electric Light and Power, 50, No. 17 (1972): 67-71.

46. Stelzer, I. M. "The Fuel Situation." EEI Bulletin, 40, No. 4 (1973): 178-181.

47. Lessing, L. "Why the U. S. Lags in Technology." Fortune, 85, No. 4 (1972): 69-73.

48. Salihi, J. T. "The Electric Car, Fact and Fancy." Electric Light and Power, 50, No. 18 (1972): 45-49.

49. Sporn, J. T. "Options on the Way to the Future." Special Publication of the IEEE Power Engineering Society. 71-M-31-PWR, 1971.

50. Berkowitz, D. A. and Squires, A. M. Power Generation and Environmental Change. Cambridge, Massachusetts: MIT Press, 1971.

51. Heydinger, E. R. "Outlook for the U. S. Economy, Energy and Oil to 1980." Electric Light and Power, 50, No. 9 (1973): 47-51.

52. Toffler, A. Future Shock. New York, New York: Random House, Inc., 1970.

53. Hayakawa, S. I. "Talking - Is Anyone Listening?" EEI Bulletin, 40, No. 4 (1972): 228-231.

54. The Foreign Policy Association. Toward the Year 2018. New York, New York: Cowles Education Corp., 1968.

55. Heer, J. E. and Hagerty, J. D. "Refuse Turns Resource." IEEE Spectrum, 11, No. 7 (July 1974): 83-86.

56. Nagel, T. J. "Electric Power's Role in the U. S. Energy Crisis." IEEE Spectrum, 11, No. 7 (July 1974): 69-72.

57. Christiansen, D. "The Critical Years." IEEE Spectrum, 11, No. 6 (June 1974): 38-42.

58. Jurgen, R. K. and Friedlander, G. D. "The Energy Outlook: Ways to Go." IEEE Spectrum, 11, No. 3 (March 1974): 83-92.

59. Friedlander, G. D. "The Fast-Breeder Reactor: When, Where, Why, and How?" IEEE Spectrum, 11, No. 2 (February 1974): 85-92.

60. Sporn, P. "The Indispensability of Research." A paper presented at the IEEE Conference on Research for the Electric Power Industry, Washington, D.C., December 11-14, 1972.

61. Battelle Memorial Institute. *A Review and Comparison of Selected* U. S. Energy Forecasts. Washington, D.C.: U. S. Government Printing Office, 1970.

62. Gambs, G. C. *The Twentieth Century Fossil Fuel Crisis: Current and Projected Requirements*. New York, New York: Ford, Bacon and Davis, Inc., 1971.

63. Cook, D. C. "Providing a Reliable and Economic Future Power Supply." A paper presented at IEEE Winter Power Meeting, New York, New York, January 27, 1970.

64. Olmstead, L. M. "22nd Annual Electrical Industry Forecast." *Electrical World*, 176, No. 6 (1971): 41-45.

65. Federal Power Commission. *The 1970 National Power Survey, Part I.* Washington, D.C.: U. S. Government Printing Office, 1971.

66. Neter, J. and Wasserman, W. *Fundamental Statistics for Business and Economics*. Boston, Massachusetts: Allyn and Bacon, Inc., 1961.

67. Gregory, D. P. "A New Concept in Energy Transmission." *Public Utilities Fortnightly*, 89, No. 3 (1972): 27-31.

68. Bockris, O. M. "A Hydrogen Economy." *Science*, 176, No. 4041 (1972): 1323-1327.

69. Tanner, E. C. and Huse, R. A. "A Hydrogen-Electric Utility System with Particular Reference to Fusion as the Energy Source." 7th Intersociety Energy Conversion Engineering Conference Proceedings, p. 1323, 1972.

70. DeBeni, G. and Marchetti, C. "Hydrogen, Key to the Energy Market." *Euro Spectra*, 9, No. 2 (1970): 46-49.

71. Federal Power Commission. *Statistics of Privately Owned Electric Utilities in the United States, 1969.* Washington, D.C.: U. S. Government Printing Office, 1971.

72. *Statistical Yearbook of the Electric Utility Industry for 1970.* EEI Publication No. 71-25, 1971.

73. Gregory, D. P. "The Hydrogen Economy." *Scientific American*, 228, No. 1 (1973): 13-18.

74. Lessing, L. "The Coming Hydrogen Economy." Fortune, 86, No. 5 (1972): 138-143.

75. "Eco-Energy Studies and TEMPO." Nuclear Engineering International, 17, No. 198 (1972): 942-946.

76. Heredy, L. A. and Parkins, W. E. "Lithium-Sulfur Battery Plant for Power Peaking." IEEE Conference Paper C72-234-8. Presented at the IEEE Winter Power Meeting, New York, New York, February 4, 1972.

77. "EEI Sponsors Research on Advanced Storage Battery." EEI Bulletin, 40, No. 3 (1972): 117-123.

78. "High Energy Battery Promising for Electric Cars." Electric Review, 190, No. 21 (1972): 720-724.

79. Lueckel, W. J., Eklund, L. G., and Law, S. H. "Fuel Cells for Dispersed Power Generation." IEEE Transactions, PAS-92, No. 1 (1973): 230-235.

80. "Swedes to Build Air Storage Plant." Electrical Review, 190, No. 23 (1972): 800-807.

81. Olsson, E. K. A. "220 MW Air Storage Power Plant." Mechanical Engineering, 92, No. 11 (1970): 20-24.

82. "Gas Turbines: Increasingly Important." Electrical World, 173, No. 24, (1970): 38-42.

83. Electric Energy Association. The Comparative Environmental Impact in 1980 of Fossil Fuel Space Heating Systems Versus Electric Space Heating, Executive Summary. New York, New York: Gordian Associates, Inc., 1972.

84. Nicholas, F. "Electric Heat Conserves Energy." Contractors' Electrical Equipment, 24, No. 8 (1972): 8-12.

85. "All-Electric Residence Conserves Energy." Electrical World, 178, No. 3 (1972): 54-57.

86. "Pollution Level Cut with Electrical Heat Use." Electrical World, 177, No. 9 (1972): 48-51.

87. Kidd, I. C., Jr. "Of Time and Energy." EEI Bulletin, 40 (1972): 167-172.

88. Hubbert, M. K. "The Energy Resources of the Earth." Scientific American, 224, No. 3 (1971): 61-67.

89. Landsberg, H. H. Resources in America's Future. Baltimore: Johns Hopkins Press, 1963.

90. Smock, R. W. "Let's Face it - There's a Fuel Crisis." Electric Light and Power, 50, No. 13 (1972): 27-31.

91. Sherman, J. T. "Uranium 1971." Engineering and Mining Journal, 173, No. 3 (1972): 67-71.

92. Benedict, M. "Electric Power from Nuclear Fission." Technical Review, 74 (October 1971): 37-42.

93. Benedict, M. "Electric Generating Prospects for Nuclear Power." IEEE Spectrum, 7, No. 7 (1970): 27-32.

94. "The Fast Breeder Reactor: Signs of a Critical Reaction." Science, 176, No. 4033 (1972): 391-397.

95. Bueche, A. M. "Electric Utility R & D Goals Through the Year 2000." Public Utilities Fortnightly, 89, No. 8 (1972): 40-46.

96. Behnke, W. B. "Status Report: U. S. LMFBR Program." Combustion, 43, No. 12 (1972): 24-27.

97. "Commonwealth Edison and TVA will Build and Operate LMFBR Demonstration Plant." EEI Bulletin, 40, No. 1 (1972): 11-17.

98. "The Who, What, Why, When, and Where of Fast Breeder Reactors," Combustion, 43, No. 12 (1972): 20-26.

99. "Nuclear Power Engineering." Power Engineering, 76, No. 7 (1972): 24-27.

100. Fortescue, P. "A Reactor Strategy: FBR's and HTGR's." Power Engineering, 75, No. 8 (1971): 45-49.

101. Fortescue, P. "Tomorrow's Plant: Gas Turbines, Nuclear Power, Dry Cooling." Power Engineering, 75, No. 8 (1971): 45-49.

102. Papamarcas, J. "Fossil Fuels." Power Engineering, 76, No. 5 (1972): 35-39.

103. Office of Coal Research. Annual Report - 1972. Washington, D.C.: U. S. Government Printing Office, 1972.

104. Atkins, R. S. "Scrubbing SO_2 and Particulates Demonstrated on Industrial Boiler." Power Engineering, 76, No. 5 (1972): 50-56.

105. "SO_2: More Questions than Answers." Electrical World, 176, No. 12 (1971): 50-56.

106. Baker, B. S. "Power for Tomorrow" What are Our Options?" Power Engineering, 74, No. 10 (1970): 30-34.

107. "Catching Sulfur Before it Goes up the Stack." Business Week, No. 2221 (1972): 72-73.

108. Matthews, C. W. "Coal Gasification for Electric Power." Proceedings of the American Power Conference, 34 (1972): 505-511.

109. Priddy, A. P. "Engineering Considerations of Combined Cycles." Proceedings of the American Power Conference, 34 (1972): 282-289.

110. Squires, A. M. "Clean Power from Dirty Fuels." Scientific American, 227, No. 4 (1972): 26-31.

111. "Ready to Turn Coal Into Gas." Business Week. No. 2225 (1972): 44-47.

112. "Commonwealth Edison May Seek Industry Money for Gassification R & D Project." Electrical Week, April 19, 1972.

113. "MHD Research Gets Backing of Industrial Group." Electrical World, 173, No. 2 (1970): 20-24.

114. Friedlander, G. D. "A Comeback for Ready Kilowatt." IEEE Spectrum, 9, No. 4 (1972): 44-47.

115. Jackson, W. D. "Critique of MHD Power Generation." Power Engineering, 76, No. 10 (1972): 68-72.

116. "EEI Supports Research Project on MHD Energy Conversion." EEI Bulletin, 40, No. 3 (1972): 121-129.

117. Mathusa, P. D. "Can Urban Power Systems Use Fuel Cells?" Electric Light and Power, 50, No. 7 (1972): 57-61.

118. Bowen, R. G. "Geothermal: Earth's Primordial Energy." Technology Review, 74 (October 1971): 48-51.

119. Lessing, L. "Power from the Earth's Own Heat." Fortune, 79, No. 7 (1969): 138-142.

120. Horvath, J. C. "Geothermal Energy, Its Future and Economics." Electric Light and Power, 50, No. 8 (1972): 63-69.

121. "Turning Turbines with Geothermal Steam." Power Engineering, 76, No. 3 (1972): 36-39.

122. "Why Saudi Arabia Wants a U. S. Oil Deal." Business Week, No. 2249 (1972): 32-33.

123. "A Way to Clean the Dirtiest Fuel." Business Week, No. 2249 (1972): 72-75.

124. Balzhiser, R. E. "The Energy Horizon: Technology's Contribution." Proceedings of the American Power Conference, 34 (1972): 23-31.

125. Olds, E. E. "Fusion Power." Power Engineering, 74, No. 10 (1970): 37-41.

126. Mills, R. G. "The Promise of Controlled Fusion." IEEE Spectrum, 8, No. 11 (1971): 24-29.

127. "The Year 2000: Living with Growth." Electric Light and Power, 50, No. 17 (1972): 55-57.

128. Strother, J. A. "New Power Sources." IEEE Spectrum, 9, No. 5 (1972): 12-17.

129. Harleman, D. R. and Parsons, R. M. "Heat: The Ultimate Waste." Technology Review, 74 (December 1971): 44-49.

130. Council on Environmental Quality. Energy and the Environment - Electric Power. Washington, D.C.: U. S. Government Printing Office, 1973.

131. Nasser, E. The Structure of the Electric Energy System, Part I - Generation. Department of Electrical Engineering, Engineering Research Institute, Iowa State University, Ames, Iowa, 1974.

132. Distributive Systems, Electric Utility Engineering Reference Book. East Pittsburgh, Pennsylvania: Westinghouse Electric Corporation, 1965.

133. Edison Electric Institute. Statistical Year Book of the Electric Utility Industry for 1973. New York, New York: Author, 1974.

134. Energy: 1975. The First Annual Report of the Iowa Energy Policy Council, DesMoines, Iowa, 1975.

135. Lanford, H. W. Technological Forecasting Methodologies. Washington, D.C.: American Management Association, 1972.

136. Rules and Regulations. State of Iowa, Department of Environmental Quality, Air Quality Commission, Des Moines, Iowa, December 1973.

137. Annual MARCA Report to the Federal Power Commission. Mid-Continent Area Reliability Coordination Agreement (MARCA), Minneapolis, Minnesota, 1975.

138. Energy Facts for Iowa. State of Iowa, Iowa Geological Survey, Iowa City, Iowa, 1973.

139. Driebeek, N. J. Applied Linear Programming. Reading, Massachusetts: Addison-Wesley Publishing Co., 1969.

140. IBM Program Product. "Introduction to Mathematical Programming System-Extended (MPSX)." White Plains, New York: IBM Publications, 1972.

141. El-Tablawy, T. A. "Digital Optimization of Long-Range Power System Planning Using the Dynamic Programming Technique." Unpublished Ph.D. thesis, Iowa State University, Ames, Iowa, 1970.

142. North Central Power Study. Report of Phase I, Volume II. Committee of North Central Power Study, Billings, Montana, October 1971.

143. Weekly Energy Report, 3, No. 1 (Jan 1975): 4-8.

144. Hubbert, M. K. "The Energy Resources of the Earth." Scientific American, 224, No. 3 (1971): 61-70.

145. Landsberg, H. H. and Fischman, L. L. Resources in America's Future. Baltimore: Johns Hopkins Press, 1963.

146. The 1970 National Power Survey. Part I, Federal Power Commission. Washington, D.C.: U. S. Government Printing Office, 1971.

147. U. S. Energy - A Summary Review. U. S. Department of the Interior, Washington, D.C.: U. S. Government Printing Office, 1972.

148. "Electric Industry Sets 1970 Records in Generation, Capacity, Sales, Revenues." EEI Bulletin, 39, No. 1 (1971): 4-11.

149. 48th Semi-Annual Electric Power Survey. A report of the Electric Power Survey Committee of the Edison Electric Institute, New York, October 1970.

150. Bibliography & Digest of U. S. Electric & Total Energy Forecasts 1970-2050. Edison Electric Institute, Publication No. 69-23, New York, 1971.

151. The Economy, Energy, & the Environment. Joint Economic Committee, Congress of the U.S. By the Environmental Policy Division, Legislative Reference Service, Washington, D.C.: U. S. Government Printing Office, 1970.

152. Environmental Effects of Producing Electric Power. Hearings before the Joint Committee on Atomic Energy, Congress of the U. S., Washington, D.C.: U. S. Government Printing Office, 1969.

153. Conklin, E. R. 19th Annual Electrical Industry Forecast. New York, New York: McGraw-Hill, Inc., 1968.

154. Olmstead, L. M. 21st Annual Electrical Industry Forecast. New York, New York: McGraw-Hill, Inc., 1970.

155. Dole, H. M. "American Energy Needs & Resources." A Paper Presented at Stanford University, Palo Alto, California, January 12, 1971.

156. 49th Annual Report for Congress, 1969. Federal Power Commission, Washington, D.C.: U. S. Government Printing Office, 1970.

157. "Fuels Management in an Environmental Age." Environmental Science & Technology, 5, No. 1 (1971): 30-36.

158. Rocks, L. and Runyon, R. P. The Energy Crisis. New York, New York: Crown Publishers, Inc., 1972.

159. Felix, F. "Annual Growth on Downward Trend." Electrical World, 174, No. 22 (July 1970): 22-26.

160. Potential Nuclear Power Growth Patterns. Division of Reactor Development & Technology, U. S. Atomic Energy Commission, Washington, D.C.: U. S. Government Printing Office, 1970.

161. Evans, R. K. and Strauss, S. D. "Energy Demands." Power, 112, No. 6 (1968): 51-53.

162. Kohn, J. P. "Energy for the Seventies." A Paper Presented at the Utility Executive Conference, Washington, D.C., January 14-15, 1971.

163. Wright, J. H. "Electric Power Generation & Environment." Westinghouse Engineer, 26, No. 5 (May 1970): 66-80.

164. Ross, P. N. and Hauser, L. G. "Some Future Dimensions of Electric Power Generation, Circa 1970-1990." Westinghouse Engineer, 27, No. 1 (January 1971): 2-7.

165. 1971 Statistical Year Book. Statistical Office of the United Nations, New York: United Nations Publication, 1971.

166. Statistical Abstract of the U. S., 1971. U. S. Department of Commerce, Bureau of Census, Washington, D.C.: U. S. Government Printing Office, 1971.

167. Mayer, A. L. "It's a Beer Market for Babies, Too." Fortune, 89, No. 12 (December 1974): 134-137.

168. Minerals Yearbook, 1972. U. S. Department of the Interior, Bureau of Mines, Washington, D.C.: U. S. Government Printing Office, 1972.

169. Statistical Year Book of the Electric Utility Industry for 1973. Edison Electric Institute, New York, New York: EEI Publication, 1974.

170. Steam-Electric Plant Construction Cost and Annual Production Expenses, 1972. Federal Power Commission, Washington, D.C.: U. S. Government Printing Office, 1974.

171. Inglis, D. R. Nuclear Energy: Its Physics and Its Social Challenge. Reading, Massachusetts: Addison-Wesley Publishing Co., 1973.

X. ACKNOWLEDGMENTS

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XI. APPENDIX A: ANNUAL LOAD FACTOR

The load factor is the ratio of the average load over a given period of time to the peak load occurring in that period (132). Therefore, the system annual load factor (LF), as viewed from the terminals of all generating units, is:

$$LF = \frac{\text{(Average Load, kW)}}{\text{(Peak Load, kW)}} = \frac{\text{(Ann. Energy Output, kWh)}}{\text{(Peak Load, kW)(8760)}}$$

In 1973, annual electrical energy output, peak load, and energy sales data for total electric utility industry in the United States, according to Edison Electric Institute, were (133):

Peak Load: 343,900 MW

Electric Energy Output: $1{,}868.8 \times 10^6$ MWh

Energy Sales = $1{,}703.203 \times 10^6$ MWh

Therefore, in 1973 the annual load factor for the USA was:

$$LF = \frac{1{,}868.8 \times 10^6 \text{ MWh}}{(343{,}900 \text{ MW})(8760)} = 62\%$$

Figure A.1 shows that in 1968 the world average load factor was much lower than the United States' load factor, although several nations had better (higher) load factors (28). There is no direct correlation between GNP and load factor.

The difference between annual energy output and energy sales is transmission and distribution system losses and miscellaneous use, which amounted to 8.86 percent of the average system load in 1973. Thus, on an energy basis the aggregate U. S. electric power transmission system was

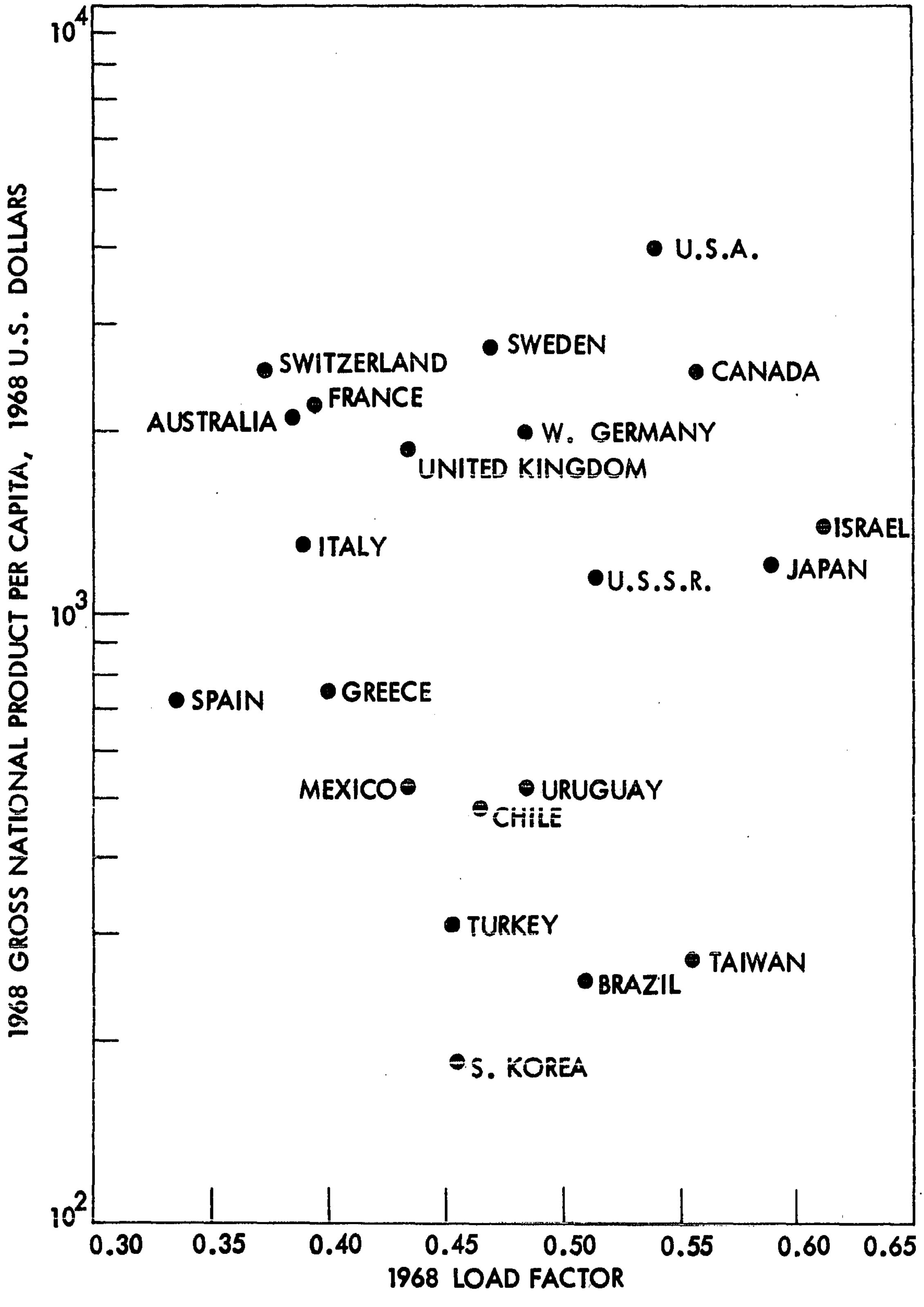

Figure A.1. Load factor versus GNP for various countries, in 1968 about 91 percent efficient.

The peak load loss (portion of the peak demand consumed in the transmission system) is not readily measured, but can be calculated from the energy loss factor and the system annual load factor with the following equations (132):

$$\text{LS} = (0.25)(\text{LF}) + (0.75)(\text{LF})^2$$

where LS is loss factor in per unit, and LF is load factor in per unit.

Therefore,

$$\text{LS} = (0.25)(0.62) + (0.75)(0.62)^2 = 0.443$$

$$\text{Peak Loss} = \frac{(\text{Electric Energy Output, MWh}) - (\text{Energy Sales, MWh})}{(\text{Loss Factor})(8760)}$$

$$= \frac{(1{,}868.8 \times 10^6 - 1{,}703.203 \times 10^6)}{(0.443)(8760)} = 42{,}672.16 \text{ MW}$$

Hence, the peak load loss for the total electric utility industry in the United States was 12.4 percent in 1973. The load factor calculations above are based on viewing the system and load from the generator busses. However, the load factor as viewed from the customer terminals is:

$$(\text{LF})_{\substack{\text{customer}\\ \text{bus}}} = \frac{(\text{Energy Sales, MWh})}{(\text{Peak Customer Load, MW})(8760)}$$

$$= \frac{(\text{Energy Sales, MWh})}{(\text{Peak Load, MW})(1 - \text{Peak Loss in p.u.})(8760)}$$

$$= \frac{(1{,}703.203 \times 10^6 \text{ MWh})}{(343{,}900 \text{ MW})(1 - 0.124)(8760)} = 64.53\%$$

The ratio of load factor to load factor of customer bus is:

$$\frac{LF}{(LF)_{\text{customer bus}}} = \frac{0.62}{0.6453} = 0.96$$

Therefore, it is found that, using 1973 data for the United States, $(LF)_{\text{customer bus}} = (1.04)LF$.

XII. APPENDIX B: THE EXPONENTIAL GROWTH

Fitting trends after transformation of data is a common practice in technical forecasting. An arithmetic straight line that will not fit the original data may fit, for example, the logarithms of the data as typified by the exponential trend,

$$y_t = ab^x \tag{B.1}$$

This expression is sometimes called a growth equation, since it is often used to explain the phenomenon of growth through time. For example, the compound-interest formula is:

$$P_n = P_o(1 + i)^n \tag{B.2}$$

where P_o is the initial capital, i is the rate of interest, and P_n is the capital value after n years. Now, if we set $P_n = y_t$, $P_o = a$, $1 + i = b$, and $n = x$, then the equation is identical to the exponential trend equation (B.1).

A quantity exhibits exponential growth when it increases by a constant percentage of the whole in a constant time period (8). The process proceeds in exponential fashion until something limits the growth process. Shortage of food or resources, natural enemies, and perhaps other checks to growth cannot be ignored. In a realistic environment, no process can or will grow exponentially forever, although it may experience exponential growth for a limited period. Many processes have been properly characterized in terms of an exponential growth curve by forecasters considering bounded study periods. The assumption is that natural limitations to the growth process will not be strong or dominant during the study period.

A realistic model of growth would be that of fruit flies in a jar. Assume a fixed amount of air and food are injected daily. The fruit flies would multiply in number, and their growth would be exponential at first, until the air and food became limited resources. Then competition for the resources would leave some flies without the means for survival, and the population would level off, rather than fill the jar completely. Growth would cease rather abruptly, since the restraining forces cannot be avoided or altered.

Most growth processes are much more complicated than those discussed above. In particular, the restraining forces are usually numerous and interrelated, and are present even in the earliest stages of growth. As a result, growth processes are usually multistage, beginning often in exponential fashion, followed by growth at a diminishing rate, followed by ultimate stopping of growth. Let us consider an example of the growth of some generalized quantity, which is normalized to a value of 1.0 at time zero. Consider exponential growth at 2.0 percent per year, compounded annually, for an unbounded time period. Next, consider a modified exponential growth pattern for the same quantity, governed by the growth rates indicated in Table B.1.

Table B.1. Modified exponential growth rates

Time Period (Years)	Compound Growth Rate (Percent)
0-30	10
30-60	8

Table B.1. Continued.

Time Period (Years)	Compound Growth Rate (Percent)
60-70	6
70-80	4
80-90	3
90-100	2
100-110	1
110-160	0.5
160-200	0.3
200-300	0.1
300-400	0.05

Both growth curves are plotted in Figure B.1. Note that the modified exponential growth curve rises more rapidly at first, then "saturates", and continues to grow modestly. It passes through a phase of rapid exponential growth, and then later grows at a steadily diminishing rate until absolute growth becomes very moderate. This is typical of the growth of natural processes, and the modified exponential growth curve in Figure B.1 resembles the Gompertz and Pearl-Reed growth curves used by economists (66). On the other hand, the true exponential growth curve seems to grow modestly at first, but eventually reaches staggering proportions. Not only does the total amount grow exponentially, but the slope of the curve also grows exponentially. It is noteworthy that all true exponential growth curves have the same shape. Only the time scale changes as the compound growth rate is modified. Alternatively, exponential growth can be plotted in doubling periods instead of years. The

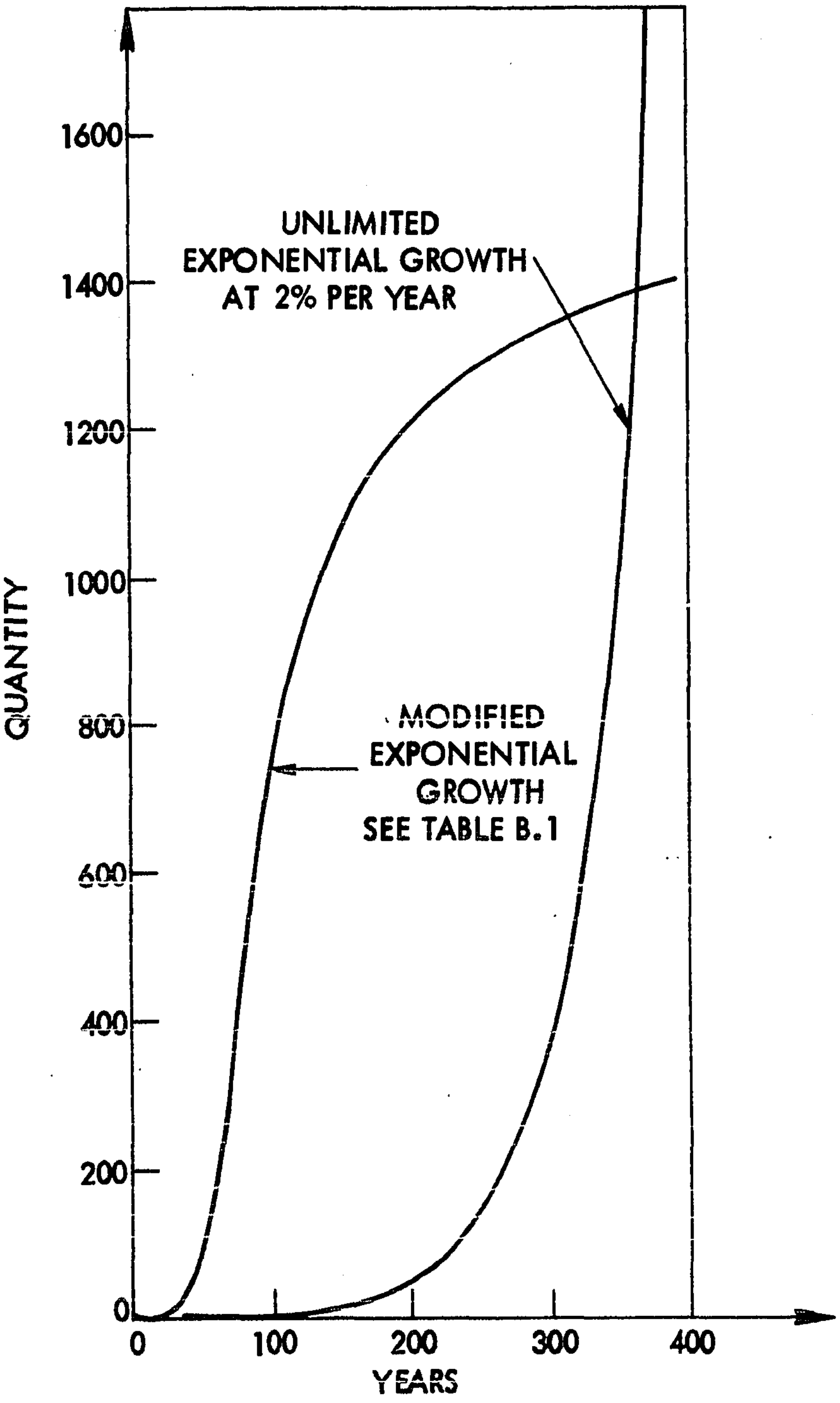

Figure B.1. Growth curves

length of the doubling period is directly related to the compound growth rate, and in the present case (2% growth), it is 35 years. Other doubling periods are noted in Table B.2 for comparison.

Table B.2. Doubling periods for various annual growth rates

Annual Growth Rate (%)	Doubling Period (Years)
1	69.4
2	35
5	14.2
7.2	10
10	7.3

No natural or man-made process can experience exponential growth indefinitely. Eventually some limitation, or several limitations, will present opposing forces which diminish the intensity of growth or even reverse it. Natural enemies, competition, resource and food limitations, and space limitations are examples of possible forces opposing exponential growth. Processes involving human decisions are not exceptions to this rule. Although human ingenuity can sometimes extend the period of exponential growth by weakening or removing the opposing forces, that same ingenuity can substitute alternative processes which may also limit the growth of the original process.

XIII. APPENDIX C: THE IMPACT OF ELECTRIC CARS ON LOAD FACTOR

In the United States in 1973, the load factor for all power systems combined was approximately 62 percent. This figure takes into account a simultaneous peak demand of 343,900 MW and energy production of 1,866.8 x 10^6 MWh (See Appendix A). The load factor is a measure of equipment utilization. Therefore, since electric power systems are capital intensive, electric power industry strive for high load factors. For this reason, off-peak energy utilization is advantageous. Since such utilization requires no additional capital investment in system facilities, it benefits both electric power companies and their customers. Load growth, on the other hand, is undesirable. It causes an increase in peak load, which necessitates new investment in production, transmission, and distribution facilities.

At present, the battery powered electric vehicles that are in service are far outnumbered by gasoline powered vehicles. Today the impact of these electric vehicles on electric power demand is relatively insignificant. This situation will probably not change until better high energy density batteries become feasible to use on a large scale (48). If, at some future time, electric cars do become popular, electric power systems will supply the energy they need. Since most cars would be in use during peak periods, their batteries could easily be energized during off-peak periods, in which case no new power plants or transmission facilities would need to be built. Although the future popularity of electric cars cannot be predicted precisely, their possible impact on the system load factor can be estimated by making certain assumptions.

To present an extreme example, it will be assumed that electric cars become extremely popular in the early 1980's. There are presently 90 million cars on the road. It is expected that 180 million cars will be by the year 2000 (48). Assuming range and performance similar to those of contemporary automobiles, a 1,430 kilogram electric car with an energy consumption rate of 0.40 kWh per kilometer, including energy needed to overcome vehicle inertia and road friction, to charge and discharge the battery, energy lost in the transmission line, and that needed for heating and air conditioning (48). Approximately 1.16 x 10^{12} kWh of energy would be consumed yearly by 180 million such cars, assuming an average driving distance of 16,100 kilometers (10,000 miles).

It is quite possible that electric cars alone will supply the "second car" market by the year 2000. At that time, there very possibly may be 90 million cars (half of total cars sold) on the second car market, assuming there will be more than two cars per family of four and a U. S. population of 279 million. If those 90 million cars were electric cars, they would use 0.58 x 10^{12} kWh of electrical energy per year, which would significantly increase the load factor for combined power systems.

XIV. APPENDIX D: A COMPUTER PROGRAM TO CALCULATE THE AREA UNDER A GIVEN CONSUMPTION CURVE

```
C.......................................................
C
C A PROGRAM TO CALCULATE THE AREA UNDER A GIVEN
C              CONSUMPTION CURVE
C
C.......................................................
C
C
//C269TG   JOB    I4375,GONEN
//STEP1  EXEC  WATFIV
//GO.SYSIN  DD  *
$JOB       'GONEN',TIME=5,PAGES=10
      DIMENSION Y(30)
C N IS THE NUMBER OF GIVEN CONSUMPTION VALUES MINUS ONE.
C DELTAX IS THE NUMBER OF THE YEARS BETWEEN INTERVALS.
      READ,N
      READ,DELTAX
      NN=N+1
      READ,(Y(I),I=1,NN)
      PRINT,NN,DELTAX,(Y(I),I=1,NN)
      SUM=Y(1)+Y(NN)
      NM=N-2
      DO 1 I=2,NM,2
      SUM=SUM+4.*Y(I)+2.*Y(I+1)
      IF((I+1).EQ.(N-1)) GO TO 20
    1 CONTINUE
   20 SUM=SUM+4.*Y(N)
    2 AREA=DELTAX*SUM/3.
      PRINT,AREA
      STOP
      END
$ENTRY
DATA
      N
      DELTAX.
Y.
/*
```

XV. APPENDIX E: A COMPUTER PROGRAM FOR DEMAND FORECASTING SUBMODEL

```
C.................................................
C
C            DEMAND FORECASTING SUBMODEL.
C
C.................................................
C
C
//C269TG  JOB   I4375,GONEN
      DIMENSION RLXD(50),RLXC(50),Y(50)
C RLXD=READ PAST DEMAND VALUES IN MW.
C RLXC=PREDICTED FUTURE DEMAND VALUES IN MW.
C NP=NUMBER OF YEARS IN THE PAST UP TO THE PRESENT
C NF=NUMBER OF YEARS FROM THE PRESENT TO THE FUTURE THAT
C     WILL BE PREDICTED.
      READ,NP,NF
      READ,(RLXD(I),I=1,NP)
      SXIYI=0.
      SXISQ=0.
      SXI=0.
      SYI=0.
      SYISQ=0.
      DO 1 I=1,NP
      XI=I-1
      Y(I)=ALOG(RLXD(I))
      SXIYI=SXIYI+XI*Y(I)
      SXI=SXI+XI
      SYI=SYI+Y(I)
      SXISQ=SXISQ+XI**2
      SYISQ=SYISQ+Y(I)**2
    1 CONTINUE
      A=(SXIYI-(SXI*SYI)/NP)/(SXISQ-(SXI**2)/NP)
      B=SYI/NP-A*SXI/NP
C A=ALOG(R);R=1+RATE OF GROWTH
      R=EXP(A)
C B=ALOG(RLXC(1))
      RLXC(1)=EXP(B)
C RG=RATE OF GROWTH
```

```
      RG=R-1.
      PRINT,'RATE OF GROWTH=',RG
      NN=NP+NF
      DO 2 I=2,NN
      XI=I-1
      DY=A*XI+B
      RLXC(I)=EXP(DY)
    2 CONTINUE
      PRINT,'RLXD              RLXC'
      DO 4 I=1,NP
      PRINT,RLXD(I),RLXC(I)
    4 CONTINUE
      DO 3 I=1,NF
      IP=I+NP
      PRINT,'                  ',RLXC(IP)
    3 CONTINUE
      STOP
      END
$ENTRY
DATA
      NP
      NF
RLXD.
/*
```

XVI. APPENDIX F: COMPUTER OUTPUTS OF THE FAM MODEL FOR THE IOWA POOL APPLICATION

The following pages show a summary of the input data and the optimum solution of the FAM model for the Iowa Pool application. (See Appendix H for the interpretation of the output.)

```
                 EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

SOLUTION    (OPTIMAL)

TIME =    1.18 MINS. ITERATION NUMBER =  1063

          ...NAME...     ...ACTIVITY...        DEFINED AS

          FUNCTIONAL     4953459326.97         C
          RESTRAINTS                           B
          BOUNDS....                           BND1
```

```
                    EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

SECTION 1 - ROWS

NUMBER  ...ROW..  AT  ...ACTIVITY...  SLACK ACTIVITY  ..LOWER LIMIT.  ..UPPER LIMIT.  .DUAL ACTIVITY

     1  C         BS  4953459326.97   4953459326.97-            NONE            NONE         1.00000
     2  R1        EQ  22527000.0000          .         22527000.0000   22527000.0000        7.67000-
     3  R2        EQ  24432000.0000          .         24432000.0000   24432000.0000        6.30000-
     4  R3        EQ  26591000.0000          .         26591000.0000   26591000.0000        7.49000-
     5  R4        EQ  28710000.0000          .         28710000.0000   28710000.0000        8.78000-
     6  R5        EQ  30798000.0000          .         30798000.0000   30798000.0000        9.00000-
     7  R6        EQ  33019000.0000          .         33019000.0000   33019000.0000       12.30000-
     8  R7        EQ  35459000.0000          .         35459000.0000   35459000.0000       16.72000-
     9  R8        EQ  38074999.9998          .         38074999.9998   38074999.9998       24.38000-
    10  R9        EC  40815999.9998          .         40815999.9998   40815999.9998       47.72000-
    11  R10       EQ  43832999.9999          .         43832999.9999   43832999.9999       69.49000-
    12  R11       EQ  46962999.9995          .         46962999.9995   46962999.9995       78.68000-
    13  R12       BS  19742956.9000   18325374.4999             NONE   38068331.3999         .
    14  R13       BS  22018413.2000   20988161.8995             NONE   43006575.0995         .
    15  R14       BS  24022076.9000   20324465.6995             NONE   44346542.5995         .
    16  R15       BS  25517787.1000   19167422.0997             NONE   44685209.1997         .
    17  R16       BS  28573749.2000   19063716.5995             NONE   47637465.7995         .
    18  R17       BS  30912948.1000   16620735.4997             NONE   47533683.5997         .
    19  R18       BS  32875794.4000   14905662.3996             NONE   47781456.7996         .
    20  R19       BS  35287969.7998   12749659.7998             NONE   48037629.5996         .
    21  R20       BS  37816375.3998   10508922.2997             NONE   48325297.6996         .
    22  R21       BS  40820125.2999   7981820.69997             NONE   48801945.9999         .
    23  R22       BS  41942192.7998   7714360.29982             NONE   49656553.0996         .
    24  R23       BS    519459.39999    75867.10000             NONE    595326.50000         .
    25  R24       BS    522611.00000    72715.50000             NONE    595326.50000         .
    26  R25       BS    523759.00000    71567.50000             NONE    595326.50000         .
    27  R26       BS    525686.50000    69640.00000             NONE    595326.50000         .
    28  R27       BS    152521.00000   162839.00000             NONE    315360.00000         .
    29  R28       UL    315360.00000         .                  NONE    315360.00000          .37000
    30  R29       UL    315360.00000         .                  NONE    315360.00000         3.95000
    31  R30       UL    315360.00000         .                  NONE    315360.00000        10.72000
    32  R31       UL    315360.00000         .                  NONE    315360.00000        33.10000
    33  R32       UL    315360.00000         .                  NONE    315360.00000        53.85000
    34  R33       UL    315360.00000         .                  NONE    315360.00000        61.94000
    35  R34       BS    555669.80000    10000.20000             NONE    565670.00000         .
    36  R35       BS    555669.80000    10000.20000             NONE    565670.00000         .
    37  R36       BS    555669.80000    10000.20000             NONE    565670.00000         .
    38  R37       BS    555669.79999    10000.20001             NONE    565670.00000         .
    39  R38       UL   1681919.99998         .                  NONE   1681919.99998          .59000
    40  R39       UL   1681919.99998         .                  NONE   1681919.99998         2.44000
    41  R40       UL   1681919.99998         .                  NONE   1681919.99998         6.17000
    42  R41       UL   1681919.99999         .                  NONE   1681919.99999        13.10000
    43  R42       UL   1681919.99999         .                  NONE   1681919.99999        35.64000
    44  R43       UL   1681920.00000         .                  NONE   1681920.00000        56.57000
    45  R44       UL   1681920.00000         .                  NONE   1681920.00000        64.85000
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                    EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

SECTION 2 - COLUMNS

 NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

     46  F175      LL   366938.40000         7.69000    366938.40000    566938.40000          .02000
     47  F275      LL   152521.00000         8.51000    152521.00000    377959.00000          .84000
     48  F375      LL    45813.30000        44.11000     45813.30000    314966.80000        36.44000
     49  F575      LL   313697.40000         7.84000    313697.40000    503945.30000          .17000
     50  F675      LL   241972.40000         8.51000    241972.40000    251972.60000          .84000
     51  F875      EQ   440952.10000        37.80000    440952.10000    440952.10000        30.13000
     52  F975      LL    72126.00000        37.80000     72126.00000    440952.10000        30.13000
     53  F1075     LL    82591.40000        50.40000     82591.40000     94489.70000        42.73000
     54  F1175     LL         .             50.40000          .          94489.70000        42.73000
     55  F1275     LL         .             50.40000          .          94489.70000        42.73000
     56  F1375     LL         .             50.40000          .          94489.70000        42.73000
     57  F1475     LL         .             50.40000          .          94489.70000        42.73000
     58  F1575     LL         .             50.40000          .          94489.70000        42.73000
     59  F1675     LL         .             50.40000          .          94489.70000        42.73000
     60  F1775     LL         .             50.40000          .          94489.70000        42.73000
     61  P1975     UL  2204760.60000         1.93000          .        2204760.60000         5.74000-
     62  P2275     LL    65444.20000        40.00000     65444.20000   3149658.00000        32.33000
     63  F176      LL   370090.00000         8.23000    370090.00000    566938.40000         1.93000
     64  F276      LL   152521.00000         9.10000    152521.00000    377959.00000         2.80000
     65  F376      LL    46100.00000        47.20000     46100.00000    314966.80000        40.90000
     66  F576      LL   313697.40000         8.39000    313697.40000    503945.30000         2.09000
     67  F676      LL   241972.40000         9.10000    241972.40000    251972.60000         2.80000
A    68  F776      UL   661428.20000         6.30000    238193.80000    661428.20000           .
     69  F876      EQ   440952.10000        40.44000    440952.10000    440952.10000        34.14000
     70  F976      LL    86810.00000        40.44000     86810.00000    440952.10000        34.14000
     71  F1076     EQ    94489.70000        53.93000     94489.70000     94489.70000        47.63000
     72  F1176     LL     1868.60000        53.93000      1868.60000     94489.70000        47.63000
     73  F1276     LL         .             53.93000          .          94489.70000        47.63000
     74  F1376     LL         .             53.93000          .          94489.70000        47.63000
     75  F1476     LL         .             53.93000          .          94489.70000        47.63000
     76  F1576     LL         .             53.93000          .          94489.70000        47.63000
     77  F1676     LL         .             53.93000          .          94489.70000        47.63000
     78  F1776     LL         .             53.93000          .          94489.70000        47.63000
     79  P1976     UL  2204760.60000         2.02000          .        2204760.60000         4.28000-
     80  P2276     LL    69316.60000        42.80000     69316.60000   3149658.00000        36.50000
     81  S2376     EQ   356961.20000         5.50000-   356961.20000    356961.20000          .80000
     82  F177      LL   371238.00000         8.81000    371238.00000    566938.40000         1.32000
     83  F277      LL   152521.00000         9.74000    152521.00000    377959.00000         2.25000
     84  F377      LL    46895.90000        50.50000     46895.90000    314966.80000        43.01000
     85  F577      LL   313697.40000         8.98000    313697.40000    503945.30000         1.49000
     86  F677      LL   241972.40000         9.74000    241972.40000    251972.60000         2.25000
     87  F777      UL   661428.20000         6.74000    241225.00000    661428.20000          .75000-
     88  F877      EQ   440952.10000        43.27000    440952.10000    440952.10000        35.78000
     89  F977      LL    91668.00000        43.27000     91668.00000    440952.10000        35.78000
     90  F1077     EQ    94489.70000        57.70000     94489.70000     94489.70000        50.21000
     91  F1177     LL     3819.70000        57.70000      3819.70000     94489.70000        50.21000
     92  F1277     LL         .             57.70000          .          94489.70000        50.21000
     93  F1377     LL         .             57.70000          .          94489.70000        50.21000
     94  F1477     LL         .             57.70000          .          94489.70000        50.21000
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                    EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

    95  F1577     LL         .            57.70000           .          94489.70000      50.21000
    96  F1677     LL         .            57.70000           .          94489.70000      50.21000
    97  F1777     LL         .            57.70000           .          94489.70000      50.21000
    98  P1977     UL  2204760.60000        2.12000           .        2204760.60000       5.37000-
    99  P2277     LL    70639.90000       45.79000     70639.90000    3149658.00000      38.30000
   100  S2377     EQ   178480.60000        5.50000-   178480.60000     178480.60000       1.99000
   101  F178      LL   373165.50000        9.43000    373165.50000     566938.40000        .65000
   102  F278      LL   152521.00000       10.42000    152521.00000     377959.00000       1.64000
   103  F378      LL    47118.50000       54.04000     47118.50000     314966.80000      45.26000
   104  F578      LL   313697.40000        9.60000    313697.40000     503945.30000        .82000
   105  F678      LL   241972.40000       10.42000    241972.40000     251972.60000       1.64000
   106  F778      UL   661428.20000        7.21000    248129.70000     661428.20000       1.57000-
   107  F878      EQ   440952.10000       46.30000    440952.10000     440952.10000      37.52000
   108  F978      LL    94957.00000       46.30000     94957.00000     440952.10000      37.52000
   109  F1078     EQ    94489.70000       61.74000     94489.70000      94489.70000      52.96000
   110  F1178     LL     4684.00000       61.74000      4684.00000      94489.70000      52.96000
   111  F1278     LL         .            61.74000           .          94489.70000      52.96000
   112  F1378     LL         .            61.74000           .          94489.70000      52.96000
   113  F1478     LL         .            61.74000           .          94489.70000      52.96000
   114  F1578     LL         .            61.74000           .          94489.70000      52.96000
   115  F1678     LL         .            61.74000           .          94489.70000      52.96000
   116  F1778     LL         .            61.74000           .          94489.70000      52.96000
   117  P1978     UL  2204760.60000        2.23000           .        2204760.60000       6.55000-
   118  P2078     UL   314965.90000        6.20000    265196.50000     314965.90000       2.58000-
   119  P2278     LL    71888.10000       49.00000     71888.10000    3149658.00000      40.22000
   120  F279      LL   152521.00000       11.15000    152521.00000     377959.00000       2.15000
   121  F379      LL    47764.40000       57.82000     47764.40000     314966.80000      48.82000
   122  F479      BS  1439947.60000        8.41000    663889.00000    1763808.50000        .
   123  F679      LL   241972.40000       11.15000    241972.40000     251972.60000       2.74000
   124  F779      UL   661428.20000        7.72000    251000.00000     661428.20000       1.28000-
   125  F879      EQ   440952.10000       49.55000    440952.10000     440952.10000      40.55000
   126  F979      LL   106654.00000       49.55000    106654.00000     440952.10000      40.55000
   127  F1079     EQ    94489.70000       66.06000     94489.70000      94489.70000      57.06000
   128  F1179     LL     6734.50000       66.06000      6734.50000      94489.70000      57.06000
   129  F1279     LL         .            66.06000           .          94489.70000      57.06000
   130  F1379     LL         .            66.00000           .          94489.70000      57.06000
   131  F1479     LL         .            66.06000           .          94489.70000      57.06000
   132  F1579     LL         .            66.06000           .          94489.70000      57.06000
   133  F1679     LL         .            66.00000           .          94489.70000      57.06000
   134  F1779     LL         .            66.06000           .          94489.70000      57.06000
   135  P1979     LL  2204760.60000        2.30000           .        2204760.60000       6.66000-
   136  P2079     UL   157482.90000        6.20000    147844.00000     157482.90000       2.80000-
   137  P2279     LL    75319.90000       52.43000     75319.90000    3149658.00000      43.43000
   138  S2479     EQ   629931.60000        6.20000-   629931.60000     629931.60000       2.80000
   139  F280      BS   315360.00000       11.93000    152521.00000     377959.00000        .
   140  F380      LL    48119.30000       61.87000     48119.30000     314966.80000      49.57000
   141  F480      BS  1439947.60000        9.86000    672217.70000    1763808.50000        .
   142  F680      LL   241972.40000       11.93000    241972.40000     251972.60000       2.07000
   143  F780      UL   661428.20000        8.26000    253775.00000     661428.20000       4.04000-
   144  F880      EQ   440952.10000       53.01000    440952.10000     440952.10000      40.71000
   145  F980      LL   108420.20000       53.01000    108420.20000     440952.10000      40.71000
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          EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  146   F1080     EQ     94489.70000      70.69000       94489.70000     94489.70000        14.59000
  147   F1180     LL     10412.20000      70.69000       10412.20000     94489.70000        14.59000
  148   F1280     LL          .           70.69000            .          94489.70000        14.59000
  149   F1380     LL          .           70.69000            .          94489.70000        14.59000
  150   F1480     LL          .           70.69000            .          94489.70000        14.59000
  151   F1580     LL          .           70.69000            .          94489.70000        14.59000
  152   F1680     LL          .           70.69000            .          94489.70000        14.59000
  153   F1780     LL          .           70.69000            .          94489.70000        14.59000
  154   P1980     LL   2204760.60000       2.40000            .        2204760.60000        53.64000-
  155   F2280     ES    676537.40002      56.10000       77296.70000   3149658.00000          .
  156   S2480     EQ    314965.80000       6.20000-     314965.80000    314965.80000        49.90000
  157   S2580     EQ    314965.80000       6.60000-     314965.80000    314965.80000        49.50000
  158   F281      BS    315360.00000      12.77000      152521.00000    377959.00000          .
  159   F381      LL     51003.00000      66.20000       51003.00000    314966.80000         6.18000
  160   F481      BS   1439947.60000      10.55000      678539.00000   1763808.50000          .
  161   F681      LL    241972.40000      12.77000      241972.40000    251972.60000         2.22000
  162   F781      UL    661428.20000       8.84000      286998.00000    661428.20000        51.18000-
  163   F881      EQ    440952.10000      56.73000      440952.10000    440952.10000         3.29000-
  164   F981      UL    440952.10000      56.73000      110764.00000    440952.10000         3.29000-
  165   F1081     EQ     94489.70000      75.64000       94489.70000     94489.70000        15.62000
  166   F1181     LL     14089.00000      75.64000       14089.00000     94489.70000        15.62000
  167   F1281     LL          .           75.64000            .          94489.70000        15.62000
  168   F1381     LL          .           75.64000            .          94489.70000        15.62000
  169   F1481     LL          .           75.64000            .          94489.70000        15.62000
  170   F1581     LL          .           75.64000            .          94489.70000        15.62000
  171   F1681     LL          .           75.64000            .          94489.70000        15.62000
  172   F1781     LL          .           75.64000            .          94489.70000        15.62000
  173   P1981     UL   2204760.60000       2.58000            .        2204760.60000        57.44000-
  174   F2281     ES    648528.20003      60.02000       78535.60000   3149658.00000          .
  175   S2581     EQ    157482.90000       6.60000-     157482.90000    157482.90000        53.42000
  176   F282      BS    315360.00000      13.66000      152521.00000    377959.00000          .
  177   F382      LL     57025.00000      70.84000       57025.00000    314966.80000         6.61000
  178   F482      ES   1439947.60000      11.28000      701985.00000   1763808.50000          .
  179   F682      LL    241972.40000      13.66000      241972.40000    251972.60000         2.38000
  180   F782      UL    661428.20000       9.45000      301222.00000    661428.20000        54.78000-
  181   F882      EQ    440952.10000      60.70000      440952.10000    440952.10000         3.53000-
  182   F982      LL    440952.10000      60.70000      293293.60000    440952.10000         3.53000-
  183   F1082     EQ     94489.70000      80.93000       94489.70000     94489.70000        16.70000
  184   F1182     LL     10994.60000      80.93000       10994.60000     94489.70000        16.70000
  185   F1282     LL          .           80.93000            .          94489.70000        16.70000
  186   F1382     LL          .           80.93000            .          94489.70000        16.70000
  187   F1482     LL          .           80.93000            .          94489.70000        16.70000
  188   F1582     LL          .           80.93000            .          94489.70000        16.70000
  189   F1682     LL          .           80.93000            .          94489.70000        16.70000
  190   F1782     LL          .           80.93000            .          94489.70000        16.70000
  191   F1982     UL   2204760.60000       3.05000            .        2204760.60000        61.18000-
  192   P2282     BS    968117.70001      64.23000       80124.40000   3149658.00000          .
  193   F283      BS    315360.00000      14.62000      152521.00000    377959.00000          .
  194   F383      LL     57841.00000      75.73000       57841.00000    314966.80000         7.61000
  195   F483      BS   1439947.60000      12.08000      723260.00000   1763808.50000          .
  196   F683      LL    241972.40000      14.62000      241972.40000    251972.60000         2.54000
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              EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   197  F783      UL    661428.20000        10.12000    336719.90000    661428.20000       37.60000-
   198  F883      EQ    440952.10000        64.95000    440952.10000    440952.10000       17.23000
   199  F983      LL    117852.00000        64.95000    117852.00000    440952.10000       17.23000
   200  F1083     EQ     94489.70000        86.60000     94489.70000     94489.70000       38.88000
   201  F1183     LL     20812.00000        86.60000     20812.00000     94489.70000       38.88000
   202  F1283     LL          .             86.60000          .          94489.70000       38.88000
   203  F1383     LL          .             86.60000          .          94489.70000       38.88000
   204  F1483     LL          .             86.60000          .          94489.70000       38.88000
   205  F1583     LL          .             86.60000          .          94489.70000       38.88000
   206  F1683     LL          .             86.60000          .          94489.70000       38.88000
   207  F1783     LL          .             86.60000          .          94489.70000       38.88000
   208  P1983     UL   2204760.60000         3.20000          .        2204760.60000       44.52000-
   209  P2183     UL    293968.10000        10.10000    241133.00000    293968.10000       37.62000-
   210  P2283     LL     85247.00000        68.72000     85247.00000   3149658.00000       21.00000
   211  F284      BS    315360.00000        15.64000    152521.00000    377959.00000         .
   212  F384      LL     58477.00000        81.10000     58477.00000    314966.80000       11.61000
   213  F484      BS   1439947.60001        12.92000    734678.90000   1763808.50000         .
   214  F684      LL    241972.40000        15.64000    241972.40000    251972.60000        2.72000
   215  F784      UL    661428.20000        10.83000    341232.70000    661428.20000       58.66000-
A  216  F884      EQ    440952.10000        69.49000    440952.10000    440952.10000         .
   217  F984      BS    334312.80010        69.49000    122868.00000    440952.10000         .
   218  F1084     EQ     94489.70000        92.66000     94489.70000     94489.70000       23.17000
   219  F1184     LL     26041.00000        92.66000     26041.00000     94489.70000       23.17000
   220  F1284     LL          .             92.66000          .          94489.70000       23.17000
   221  F1384     LL          .             92.66000          .          94489.70000       23.17000
   222  F1484     LL          .             92.66000          .          94489.70000       23.17000
   223  F1584     LL          .             92.66000          .          94489.70000       23.17000
   224  F1684     LL          .             92.66000          .          94489.70000       23.17000
   225  F1784     LL          .             92.66000          .          94489.70000       23.17000
   226  N1884     UL    629931.60000         3.70000    586742.70000    629931.60000       65.79000-
   227  P1984     UL   2204760.60000         3.36000          .        2204760.60000       66.13000-
   228  P2184     UL    146984.00000        10.10000    125777.00000    146984.00000       59.39000-
   229  P2284     LL    201555.00000        73.53000    201555.00000   3149658.00000        4.04000
   230  F285      BS    315360.00000        16.74000    152521.00000    377959.00000         .
   231  F385      LL     61232.70000        86.78000     61232.70000    314966.80000        8.10000
   232  F485      BS   1439947.60000        13.83000    741536.40000   1763808.50000         .
   233  F685      LL    241972.40000        16.73000    241972.40000    251972.60000        2.90000
   234  F785      UL    661428.20000        11.58000    347888.70000    661428.20000       67.10000-
   235  F885      EQ    440952.10000        74.36000    440952.10000    440952.10000        4.32000-
   236  F985      UL    440952.10000        74.36000    143009.00000    440952.10000        4.32000-
   237  F1085     EQ     94489.70000        99.15000     94489.70000     94489.70000       20.47000
   238  F1185     LL     30176.90000        99.15000     30176.90000     94489.70000       20.47000
   239  F1285     LL          .             99.15000          .          94489.70000       20.47000
   240  F1385     LL          .             99.15000          .          94489.70000       20.47000
   241  F1485     LL          .             99.15000          .          94489.70000       20.47000
   242  F1585     LL          .             99.15000          .          94489.70000       20.47000
   243  F1685     LL          .             99.15000          .          94489.70000       20.47000
   244  F1785     LL          .             99.15000          .          94489.70000       20.47000
   245  N1885     UL    944897.40000         3.88000    725422.20000    944897.40000       74.80000-
   246  P1985     UL   2204760.60000         3.53000          .        2204760.60000       75.15000-
   247  P2285     BS   2354158.29971        78.68000    272114.50000   3149658.00000         .
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                 EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT   ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   248  F2175     LL    14641.00000        26.53000      14641.00000    126616.30000        18.86000
   249  F2275     LL    17890.70000        26.53000      17890.70000    126616.30000        18.86000
   250  F2375     LL    16616.30000        26.53000      16616.30000    131655.70000        18.86000
   251  F2475     UL  1303958.40000         6.04000     385553.20000   1303958.40000         1.63000-
   252  F2575     LL    25681.00000        25.20000      25681.00000     37795.90000        17.53000
   253  F2675     LL    14649.20000        25.20000      14649.20000     15748.30000        17.53000
   254  F2775     LL    13372.80000        25.20000      13372.80000     15748.30000        17.53000
   255  P2975     UL   125986.30000         5.50000           .        125986.30000         2.17000-
   256  P21075    UL     6299.30000         5.50000           .          6299.30000         2.17000-
   257  P21175    LL    25006.40000        50.40000      25006.40000    944897.40000        42.73000
   258  S21275    EQ    31496.60000         6.20000-     31496.60000     31496.60000         1.47000
   259  F2176     LL    15423.00000        28.39000      15423.00000    126616.30000        22.09000
   260  F2276     LL    16452.30000        28.39000      16452.30000    126616.30000        22.09000
   261  F2376     LL    17263.10000        28.39000      17263.10000    131655.70000        22.09000
   262  F2476     LL   393236.50000         6.47000     393236.50000   1303958.40000          .17000
   263  F2576     LL    27331.10000        26.96000      27331.10000     37795.90000        20.66000
   264  F2676     LL    14649.20000        26.96000      14649.20000     15748.30000        20.66000
   265  F2776     LL     9689.90000        26.96000       9689.90000     15748.30000        20.66000
   266  F2876     BS   516808.40013         6.30000           .        917180.40000          .
   267  P2976     UL   125986.30000         5.88000           .        125986.30000          .42000-
   268  P21076    UL     6299.30000         5.88000           .          6299.30000          .42000-
   269  P21176    LL    26536.80000        53.93000      26536.80000    944897.40000        47.63000
   270  S21376    EQ    50394.50000         6.60000-     50394.50000     50394.50000          .30000-
   271  F2177     LL    16742.20000        30.37000      16742.20000    126616.30000        22.88000
   272  F2277     LL    16862.00000        30.37000      16862.00000    126616.30000        22.88000
   273  F2377     LL    18281.10000        30.37000      18281.10000    131655.70000        22.88000
   274  F2477     UL  1303958.40000         6.92000     586732.30000   1303958.40000          .57000-
   275  F2577     LL    27936.20000        28.85000      27936.20000     37795.90000        21.36000
   276  F2677     LL    14925.20000        28.85000      14925.20000     15748.30000        21.36000
   277  F2777     LL     9879.00000        28.85000       9879.00000     15748.30000        21.36000
   278  F2877     UL   917180.40000         6.74000           .        917180.40000          .75000-
   279  P21077    UL     6299.30000         6.29000           .          6299.30000         1.20000-
   280  P21177    LL    26953.50000        57.70000      26953.50000    944897.40000        50.21000
   281  S21477    EQ    62993.20000         6.90000-     62993.20000     62993.20000          .59000
   282  F2178     LL    15943.00000        32.50000      15943.00000    126616.30000        23.72000
   283  F2278     LL    16925.50000        32.50000      16925.50000    126616.30000        23.72000
   284  F2378     LL    19385.60000        32.50000      19385.60000    131655.70000        23.72000
   285  F2478     UL  1303958.40000         7.61000     591113.70000   1303958.40000         1.37000-
   286  F2578     LL    28520.00000        30.74000      28520.00000     37795.90000        21.96000
   287  F2678     LL    15026.30000        30.74000      15026.30000     15748.30000        21.96000
   288  F2778     LL    10136.40000        30.74000      10136.40000     15748.30000        21.96000
   289  F2878     UL   917180.40000         7.21000           .        917180.40000         1.57000-
   290  P21078    UL     6299.30000         6.73000           .          6299.30000         2.05000-
   291  P21178    LL    56256.10000        61.74000      56256.10000    944897.40000        52.96000
   292  F2179     LL    17462.50000        34.77000      17462.50000    126616.30000        25.77000
   293  F2279     LL    16925.50000        34.77000      16925.50000    126616.30000        25.77000
   294  F2379     LL    21301.90000        34.77000      21301.90000    131655.70000        25.77000
   295  F2479     UL  1303958.40000         7.92000     597222.80000   1303958.40000         1.08000-
   296  F2579     LL    28563.00000        32.89000      28563.00000     37795.90000        23.89000
   297  F2679     LL    15026.30000        32.89000      15026.30000     15748.30000        23.89000
   298  F2779     LL    11425.00000        32.89000      11425.00000     15748.30000        23.89000
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             EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  299   F2879     UL   917180.40000         7.72000          .          917180.40000         1.28000-
  300   P21079    UL     6299.30000         7.20000          .            6299.30000         1.80000-
  301   P21179    LL    56863.70000        66.06000    56863.70000      944897.40000        57.06000
  302   F2180     LL    17642.50000        37.21000    17642.50000      126616.30000        24.91000
  303   F2280     LL    16926.00000        37.21000    16926.00000      126616.30000        24.91000
  304   F2380     LL    21445.90000        37.21000    21445.90000      131655.70000        24.91000
  305   F2480     UL  1303958.40000         8.48000   601057.90000     1303958.40000         3.82000-
  306   F2580     LL    29223.00000        35.20000    29223.00000       37795.90000        22.90000
  307   F2680     LL    15026.30000        35.20000    15026.30000       15748.30000        22.90000
  308   F2780     LL    11638.00000        35.20000    11638.00000       15748.30000        22.90000
  309   F2880     UL   917180.40000         8.26000          .          917180.40000         4.04000-
  310   P21080    UL     6299.30000         7.71000          .            6299.30000         4.59000-
  311   P21180    LL    59584.00000        70.69000    59584.00000      944897.40000        58.39000
  312   F2181     LL    17692.80000        39.81000    17692.80000      126616.30000        23.09000
  313   F2281     LL    17001.00000        39.81000    17001.00000      126616.30000        23.09000
  314   F2381     LL    21996.70000        39.81000    21996.70000      131655.70000        23.09000
  315   F2481     UL  1303958.40000         9.07000   612258.30000     1303958.40000         7.65000-
  316   F2581     LL    28289.00000        37.66000    28289.00000       37795.90000        20.94000
  317   F2681     LL    15526.30000        37.66000    15526.30000       15748.30000        20.94000
  318   F2781     LL    11985.30000        37.66000    11985.30000       15748.30000        20.94000
  319   F2881     UL   917180.40000         8.83000          .          917180.40000         7.89000-
  320   P21081    UL     6299.30000         8.25000          .            6299.30000         8.47000-
  321   P21181    LL    63050.10000        75.64000    63050.10000      944897.40000        58.92000
  322   F2182     LL    18532.00000        42.60000    18532.00000      126616.30000        18.22000
  323   F2282     LL    19090.60000        42.60000    19090.60000      126616.30000        18.22000
  324   F2382     LL    28887.70000        42.60000    28887.70000      131655.70000        18.22000
  325   F2482     UL  1303958.40000         9.71000   632338.00000     1303958.40000        14.67000-
  326   F2582     LL    29111.00000        40.30000    29111.00000       37795.90000        15.92000
  327   F2682     LL    15526.30000        40.30000    15526.30000       15748.30000        15.92000
  328   F2782     LL    15612.00000        40.30000    15612.00000       15748.30000        15.92000
  329   F2882     UL   917180.40000         9.45000          .          917180.40000        14.93000-
  330   P21082    UL     6299.30000         8.83000          .            6299.30000        15.55000-
  331   P21182    LL    64256.00000        80.93000    64256.00000      944897.40000        56.55000
  332   F2183     UL   126616.30000        45.58000    18632.50000      126616.30000         2.14000-
  333   F2283     UL   126616.30000        45.58000    19865.10000      126616.30000         2.14000-
  334   F2383     UL   131655.70000        45.58000    29216.90000      131655.70000         2.14000-
  335   F2483     UL  1303958.40000        10.39000   671832.00000     1303958.40000        37.33000-
  336   F2583     UL    37795.90000        43.12000    29678.30000       37795.90000         4.60000-
  337   F2683     UL    15748.30000        43.12000    15526.30000       15748.30000         4.60000-
  338   F2783     UL    15748.30000        43.12000    15173.00000       15748.30000         4.60000-
  339   F2883     UL   917180.40000        10.12000          .          917180.40000        37.60000-
  340   P21083    UL     6299.30000         9.45000          .            6299.30000        38.27000-
  341   P21183    LL    64853.70000        86.60000    64853.70000      944897.40000        38.88000
  342   F2184     UL   126616.30000        48.77000    19003.00000      126616.30000        20.72000-
  343   F2284     UL   126616.30000        48.77000    20063.00000      126616.30000        20.72000-
  344   F2384     UL   131655.70000        48.77000    29480.60000      131655.70000        20.72000-
  345   F2484     UL  1303958.40000        11.12000   678345.00000     1303958.40000        58.37000-
  346   F2584     UL    37795.90000        47.03000    30048.50000       37795.90000        22.46000-
  347   F2684     UL    15748.30000        47.03000    15526.30000       15748.30000        22.46000-
  348   F2784     UL    15748.30000        47.03000    14583.90000       15748.30000        22.46000-
  349   F2884     UL   917180.40000        10.82000          .          917180.40000        58.67000-
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              EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   350  P21084    UL     6299.30000       10.11000          .            6299.30000       59.38000-
   351  F21184    LL    65232.90000       92.66000     65232.90000     944897.40000       23.17000
   352  F2185     UL   126616.30000       52.19000     18732.60000     126616.30000       26.49000-
   353  F2285     UL   126616.30000       52.19000     20105.80000     126616.30000       26.49000-
   354  F2385     UL   131655.70000       52.19000     30468.00000     131655.70000       26.49000-
   355  F2485     UL  1303958.40000       11.89000    683537.80000    1303958.40000       66.79000-
   356  F2585     UL    37795.90000       50.32000     31542.00000      37795.90000       28.36000-
   357  F2685     UL    15748.30000       50.32000     15526.30000      15748.30000       28.36000-
   358  F2785     UL    15748.30000       50.32000     14985.00000      15748.30000       28.36000-
   359  F2885     UL   917180.40000       11.58000          .          917180.40000       67.10000-
   360  P21085    UL     6299.30000       10.82000          .            6299.30000       67.86000-
   361  P21185    LL    67546.10000       99.15000     67546.10000     944897.40000       20.47000
   362  F3175     LL    13645.90000        9.00000     13645.90000      75591.80000        1.33000
   363  F3275     LL    13645.00000        9.00000     13645.00000      75591.80000        1.33000
   364  F3375     LL     6523.00000        9.00000      6523.00000      75591.80000        1.33000
   365  F3475     LL    25003.60000        8.00000     25003.60000      81891.10000         .33000
   366  F3575     LL    21496.60000       15.52000     21496.60000      31496.60000        7.85000
   367  F3675     LL    21496.60000       15.52000     21496.60000      31496.60000        7.85000
   368  F3775     LL    42993.10000       15.84000     42993.10000      62993.10000        8.17000
   369  F3875     LL    42993.10000       16.16000     42993.10000      62993.10000        8.49000
   370  F3975     LL    64432.00000       14.14000     64432.00000      81891.10000        6.47000
   371  F31075    LL    13645.40000       34.20000     13645.40000      62993.10000       26.53000
   372  F31175    LL    13645.00000       34.20000     13645.00000      56693.80000       26.53000
   373  F31275    UL    69292.50000        7.65000     60292.50000      69292.50000         .02000-
   374  F31375    UL    75591.80000        7.65000     72591.80000      75591.80000         .02000-
   375  F31475    UL   151183.60000        6.12000     98564.70000     151183.60000        1.55000-
   376  F31575    LL   259061.00000       11.13000    259061.00000     359061.00000        3.46000
   377  F31675    UL   925999.50000        5.90000    425999.50000     925999.50000        1.77000-
   378  F31775    UL  2078774.30000        5.72000          .         2078774.30000        1.95000-
   379  F32075    LL    26453.80000       36.48000     26453.80000     107088.40000       28.81000
   380  F32175    LL     4685.00000       36.48000      4685.00000     107088.40000       28.81000
   381  F32275    LL    35375.60000       25.08000     35375.60000     377959.00000       17.41000
   382  F32375    LL    10095.00000       25.08000     10095.00000     409455.50000       17.41000
   383  F32475    LL    63829.40000       22.80000     63829.40000     163782.20000       15.13000
   384  F3576     LL    21496.60000       17.12000     21496.60000      31496.60000       10.82000
   385  F3676     LL    21496.60000       17.12000     21496.60000      31496.60000       10.82000
   386  F3776     LL    32993.10000       17.44000     32993.10000      62993.10000       11.14000
   387  F3876     LL    32993.10000       17.76000     32993.10000      62993.10000       11.46000
   388  F3976     LL    64432.00000       15.54000     64432.00000      81891.10000        9.24000
   389  F31076    LL    13546.00000       37.65000     13546.00000      62993.10000       31.35000
   390  F31176    LL    15849.00000       37.65000     15849.00000      56693.80000       31.35000
   391  F31276    LL    60292.50000        8.40000     60292.50000      69292.50000        2.10000
   392  F31376    LL    72591.80000        8.40000     72591.80000      75591.80000        2.10000
   393  F31476    LL    98564.70000        6.72000     98564.70000     151183.60000         .42000
   394  F31576    LL   259061.00000       12.24000    259061.00000     359061.00000        5.94000
   395  F31676    LL   325999.50000        6.49000    325999.50000     925999.50000         .19000
   396  F31776    UL  2078774.30000        6.29000    685333.00000    2078774.30000         .01000-
   397  F31876    UL  2614216.10000        6.10000          .         2614216.10000         .14000-
   398  F32076    LL    18600.00000       40.13000     18600.00000     107088.40000       33.83000
   399  F32176    LL     9300.00000       40.13000      9300.00000     107088.40000       33.83000
   400  F32276    LL    19863.70000       27.58000     19863.70000     377959.00000       21.28000
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               EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   401  F32376    LL     9865.00000      27.58000      9865.00000     409455.50000      21.28000
   402  F32476    LL    22645.30000      25.08000     22645.30000     163782.20000      18.78000
   403  F3577     LL    21496.60000      18.72000     21496.60000      31496.60000      11.23000
   404  F3677     LL    21496.60000      18.72000     21496.60000      31496.60000      11.23000
   405  F3777     LL    32993.10000      19.20000     32993.10000      62993.10000      11.71000
   406  F3877     LL    32993.10000      19.52000     32993.10000      62993.10000      12.03000
   407  F3977     LL    71891.10000      17.08000     71891.10000      81891.10000       9.59000
   408  F31077    LL    14865.00000      41.40000     14865.00000      62993.10000      33.91000
   409  F31177    LL    16023.80000      41.40000     16023.80000      56693.80000      33.91000
   410  F31477    LL    98564.50000      33.12000     98564.50000     151183.60000      25.63000
   411  F31577    LL   259061.00000      13.46000    259061.00000     359061.00000       5.97000
   412  F31677    UL   925999.50000       7.13000    396853.00000     925999.50000        .36000-
   413  F31777    UL  2078774.30000       6.92000    327164.20000    2078774.30000        .57000-
   414  F31877    UL  2614216.10000       6.78000          .         2614216.10000        .71000-
   415  F32077    LL    17253.60000      44.14000     17253.60000     107088.40000      36.65000
   416  F32177    LL    21863.50000      44.14000     21863.50000     107088.40000      36.65000
   417  F32277    LL    18645.00000      30.34000     18645.00000     377959.00000      22.85000
   418  F32377    LL     4589.00000      30.34000      4589.00000     409455.50000      22.85000
   419  F32477    LL    19863.00000      27.58000     19863.00000     163782.20000      20.09000
   420  F3578     LL    27869.30000      20.68000     27869.30000      31496.60000      11.90000
   421  F3678     LL    26385.60000      20.68000     26385.60000      31496.60000      11.90000
   422  F3778     LL    33463.80000      21.12000     33463.80000      62993.10000      12.34000
   423  F3878     LL    29635.30000      21.44000     29635.30000      62993.10000      12.66000
   424  F3978     LL    53465.00000      18.76000     53465.00000      81891.10000       9.98000
   425  F31078    LL    14985.00000      45.45000     14985.00000      62993.10000      36.67000
   426  F31178    LL    16765.00000      45.45000     16765.00000      56693.80000      36.67000
   427  F31478    LL    65645.00000      36.43000     65645.00000     151183.60000      27.65000
   428  F31578    LL   105061.00000      14.81000    105061.00000     359061.00000       6.03000
   429  F31678    UL   925999.50000       7.85000    325999.50000     925999.50000        .93000-
   430  F31778    UL  2078774.30000       7.61000    685854.00000    2078774.30000       1.17000-
   431  F31878    UL  2614216.10000       7.46000          .         2614216.10000       1.32000-
   432  F32078    LL    16253.00000      48.55000     16253.00000     107088.40000      39.77000
   433  F32178    LL    22863.90000      48.55000     22863.90000     107088.40000      39.77000
   434  F32278    LL    18890.30000      33.38000     18890.30000     377959.00000      24.60000
   435  F32378    LL     6849.70000      33.38000      6849.70000     409455.50000      24.60000
   436  F32478    LL    19998.70000      30.34000     19998.70000     163782.20000      21.56000
   437  F3579     LL    28369.00000      22.72000     28369.00000      31496.60000      13.72000
   438  F3679     LL    27401.60000      22.72000     27401.60000      31496.60000      13.72000
   439  F3779     LL    34586.90000      23.20000     34586.90000      62993.10000      23.20000
   440  F3879     LL    31531.10000      23.68000     31531.10000      62993.10000      14.68000
   441  F3979     LL    55463.70000      20.72000     55463.70000      81891.10000      11.72000
   442  F31479    LL    68345.70000      40.07000     68345.70000     151183.60000      31.07000
   443  F31579    LL   121033.00000      16.29000    121033.00000     359061.00000       7.29000
   444  F31679    UL   925999.50000       8.63000    331251.80000     925999.50000        .37000-
   445  F31779    UL  2078774.30000       8.63000    331251.80000    2078774.30000        .37000-
   446  F31879    UL  2614216.10000       8.20000    685596.00000    2614216.10000        .80000-
   447  F31979    UL  1423645.40000       8.20000    685596.00000    1423645.40000        .80000-
   448  F32079    LL     9457.00000      53.41000      9457.00000     107088.40000      44.41000
   449  F32179    LL     6325.00000      53.41000      6325.00000     107088.40000      44.41000
   450  F32279    LL    36456.00000      36.71000     36456.00000     377959.00000      27.71000
   451  F32379    LL    13863.00000      36.71000     13863.00000     409455.50000      27.71000
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                 EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   452  F32479    LL     41005.30000        33.38000     41005.30000    163782.20000        24.38000
   453  F3580     LL     28690.50000        24.96000     28690.50000     31496.60000        12.66000
   454  F3680     LL     27401.60000        24.96000     27401.60000     31496.60000        12.66000
   455  F3780     LL     35637.80000        25.44000     35637.80000     62993.10000        13.14000
   456  F3880     LL     33891.60000        26.08000     33891.60000     62993.10000        13.78000
   457  F3980     LL     57892.00000        22.82000     57892.00000     81891.10000        10.52000
   458  F31480    LL     71585.00000        44.08000     71585.00000    151183.60000        31.78000
   459  F31580    LL    131487.10000        17.92000    131487.10000    359061.00000         5.62000
   460  F31680    UL    925999.50000         9.50000    501000.60000    925999.50000         2.80000-
   461  F31780    UL   2078774.30000         9.21000    550000.80000   2078774.30000         3.09000-
   462  F31880    UL   2614216.10000         9.02000    563008.00000   2614216.10000         3.28000-
   463  F31980    UL   1423645.40000         9.02000    563008.00000   1423645.40000         3.28000-
   464  F32080    LL     17825.60000        58.75000     17825.60000    107088.40000        46.45000
   465  F32180    LL     25893.00000        58.75000     25893.00000    107088.40000        46.45000
   466  F32280    LL     36865.30000        40.39000     36865.30000    377959.00000        28.09000
   467  F32380    LL      9536.70000        40.39000      9536.70000    409455.50000        28.09000
   468  F32480    LL     41996.00000        36.71000     41996.00000    163782.20000        24.41000
   469  F31481    LL     75869.50000        48.49000     75869.50000    151183.60000        31.77000
   470  F31581    LL    161831.60000        19.71000    161831.60000    359061.00000         2.99000
   471  F31681    UL    925999.50000        10.45000    521005.00000    925999.50000         6.27000-
   472  F31781    UL   2078774.30000        10.13000    563865.90000   2078774.30000         6.59000-
   473  F31881    UL   2614216.10000         9.93000    675396.10000   2614216.10000         6.79000-
   474  F31981    UL   1423645.40000         9.93000    675396.10000   1423645.40000         6.79000-
   475  F32081    LL     16849.00000        64.63000     16849.00000    107088.40000        47.91000
   476  F32181    LL     23750.80000        64.03000     23750.80000    107088.40000        47.31000
   477  F32281    LL     36963.60000        44.43000     36963.60000    377959.00000        27.71000
   478  F32381    LL      9863.50000        44.43000      9863.50000    409455.50000        27.71000
   479  F32481    LL     42365.00000        40.39000     42365.00000    163782.20000        23.67000
   480  F31482    LL     77353.10000        53.34000     77353.10000    151183.60000        28.96000
   481  F31582    UL    359061.00000        21.69000    165132.00000    359061.00000         2.69000-
   482  F31682    UL    925999.50000        11.49000    597465.30000    925999.50000        12.89000-
   483  F31782    UL   2078774.30000        11.15000    599801.00000   2078774.30000        13.23000-
   484  F31882    UL   2614216.10000        10.92000    623698.40000   2614216.10000        13.46000-
   485  F31982    UL   1423645.40000        10.92000    623698.00000   1423645.40000        13.46000-
   486  F32082    LL     17845.00000        71.09000     17845.00000    107088.40000        46.71000
   487  F32182    LL     25836.50000        71.09000     25836.50000    107088.40000        46.71000
   488  F32282    LL     37085.00000        48.87000     37085.00000    377959.00000        24.49000
   489  F32382    LL     10365.30000        48.87000     10365.30000    409455.50000        24.49000
   490  F32482    LL     42675.60000        44.43000     42675.60000    163782.20000        20.05000
   491  F31483    LL     81666.60000        58.67000     81666.60000    151183.60000        10.95000
   492  F31583    UL    359061.00000        23.86000    179378.00000    359061.00000        23.86000-
   493  F31683    UL    925999.50000        12.64000    629881.50000    925999.50000        35.08000-
   494  F31783    UL   2078774.30000        12.26000    628645.00000   2078774.30000        35.46000-
   495  F31883    UL   2614216.10000        12.01000    681536.70000   2614216.10000        35.71000-
   496  F31983    UL   1423645.40000        12.01000    681223.00000   1423645.40000        35.71000-
   497  F32083    LL     19985.80000        78.20000     19985.80000    107088.40000        30.48000
   498  F32183    LL     29536.20000        78.20000     29536.20000    107088.40000        30.48000
   499  F32283    LL     37265.00000        53.76000     37265.00000    377959.00000         6.04000
   500  F32383    LL     19863.80000        53.76000     19863.80000    409455.50000         6.04000
   501  F32483    LL     42725.30000        48.87000     42725.30000    163782.20000         1.15000
   502  F31484    UL    151183.60000        64.54000     85347.60000    151183.60000         4.95000-
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            EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   503  F31584    UL    359061.60000        26.24000    181749.00000    359061.00000       43.25000-
   504  F31684    UL    925099.50000        13.91000    635112.00000    925999.50000       55.58000-
   505  F31784    UL   2078774.30000        13.91000    671915.60000   2078774.30000       55.58000-
   506  F31884    UL   2614216.10000        13.21000    701581.30000   2614216.10000       56.28000-
   507  F31984    UL   1423645.40000        13.21000    691131.60000   1423645.40000       56.28000-
   508  F32084    LL     25006.00000        86.02000     25006.00000    107088.40000       16.53000
   509  F32184    LL     31777.00000        86.02000     31777.00000    107088.40000       16.53000
   510  F32284    UL    377959.00000        59.13000     38006.00000    377959.00000       10.36000-
   511  F32384    UL    409455.50000        59.13000     25676.90000    409455.50000       10.36000-
   512  F32484    UL    163782.20000        53.76000     43925.30000    163782.20000       15.73000-
   513  F31485    UL    151183.60000        71.00000     91555.30000    151183.60000        7.68000-
   514  F31585    UL    359061.00000        28.87000    223663.50000    359061.00000       49.8[illegible]0-
   515  F31685    UL    925999.50000        15.30000    673846.00000    925999.50000       63.38000-
   516  F31785    UL   2078774.30000        14.84000    685111.20000   2078774.30000       63.84000-
   517  F31885    UL   2614216.10000        14.53000    721090.00000   2614216.10000       64.15000-
   518  F31985    UL   1423645.40000        14.53000    699523.60000   1423645.40000       64.15000-
   519  F32085    LL     27008.00000        94.62000     27008.00000    107088.40000       15.94000
   520  F32185    LL     35266.60000        94.62000     35266.60000    107088.40000       15.94000
   521  F32285    UL    377959.00000        65.05000     39685.00000    377959.00000       13.63000-
   522  F32385    UL    409455.50000        65.05000     27786.70000    409455.50000       13.63000-
   523  F32485    UL    163782.20000        59.13000     45685.30000    163782.20000       19.55000-
   524  F4175     LL     21346.00000        12.32000     21346.00000     29606.80000        4.65000
   525  F4275     LL      8189.40000        45.36000      8189.40000     37795.90000       37.69000
   526  F4375     LL     16253.00000        32.56000     16253.00000     52284.30000       24.89000
   527  F4475     LL          .              7.84000          .          116537.30000         .17000
   528  F4575     LL    653879.20000        21.63000    653879.20000   1385849.50000       13.96000
   529  F4675     LL     71689.50000        12.87000     71689.50000     94489.70000        5.20000
   530  F4775     UL    188979.50000         7.16000          .          188979.50000         .51000-
   531  F4875     LL    163475.00000        25.20000    163475.00000    220476.10000       17.53000
   532  F4975     LL     56591.80000         9.79000     56591.80000     75591.80000        2.12000
   533  F41075    BS     71630.60014         7.67000     58590.20000     75591.80000         .
   534  F41175    LL    385677.10000        25.54000    385677.10000    529142.50000       17.87000
   535  F41275    LL     42683.70000        27.93000     42683.70000    110238.00000       20.26000
   536  F41375    LL     58332.90000         9.72000     58332.90000     67402.70000        2.05000
   537  F41475    LL    125897.00000         8.58000    125897.00000    212916.90000         .91000
   538  F41575    LL     24543.70000        10.92000     24543.70000     34646.20000        3.25000
   539  F41675    LL     12345.60000        42.96000     12345.60000     66142.80000       35.29000
   540  F41775    LL     18999.30000        31.50000     18999.30000     58693.80000       23.83000
   541  F41875    LL     28351.00000        29.40000     28351.00000    139844.80000       21.73000
   542  F41975    LL     36531.20000        29.40000     36531.20000    134175.40000       21.73000
   543  F4176     LL     21673.90000        13.18000     21673.90000     29606.80000        6.88000
   544  F4276     LL      8453.10000        48.53000      8453.10000     37795.90000       42.23000
   545  F4376     LL     17009.00000        34.84000     17009.00000     52284.30000       28.54000
   546  F4476     LL          .              8.39000          .          116537.30000        2.09000
   547  F4576     LL    657235.40000        23.14000    657235.40000   1385849.50000       16.84000
   548  F4676     LL     73873.50000        13.77000     73873.50000     94489.70000        7.47000
   549  F4776     LL          .              7.67000          .          188979.50000        1.37000
   550  F4876     LL    167745.00000        26.96000    167745.00000    220476.10000       20.66000
   551  F4976     LL     58431.80000        10.48000     58431.80000     75591.80000        4.18000
   552  F41076    LL     61200.00000         8.21000     61200.00000     75591.80000        1.91000
   553  F41176    LL    388788.00000        27.33000    388788.00000    529142.50000       21.03000
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            EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   554  F41276    LL    43532.70000        29.88000     43532.70000   110238.00000        23.58000
   555  F41376    LL    63477.80000        10.40000     63477.80000    67402.70000         4.10000
   556  F41476    LL   127546.00000         9.18000    127546.00000   212916.90000         2.88000
   557  F41576    LL    26348.90000        11.68000     26348.90000    34646.20000         5.38000
   558  F41676    LL    14879.50000        45.97000     14879.50000    66142.80000        39.67000
   559  F41776    LL    19250.00000        33.70000     19250.00000    56693.80000        27.40000
   560  F41876    LL    29125.70000        31.45000     29125.70000   139844.80000        25.15000
   561  F41976    LL    37555.20000        31.45000     37555.20000   134175.40000        25.15000
   562  F4177     LL    23781.60000        14.10000     23781.60000    29606.80000         6.61000
   563  F4277     LL     8979.40000        51.93000      8979.40000    37795.90000        44.44000
   564  F4377     LL    18045.30000        37.28000     18045.30000    52284.30000        29.79000
   565  F4477     LL          .             8.97000           .        116537.30000         1.48000
   566  F4577     LL   659108.20000        24.76000    659108.20000  1385849.50000        17.27000
   567  F4677     LL    74333.60000        14.73000     74333.60000    94489.70000         7.24000
   568  F4777     LL          .             8.20000           .        188979.50000          .71000
   569  F4877     LL   168256.00000        28.85000    168256.00000   220476.10000        21.36000
   570  F4977     LL    59453.20000        11.21000     59453.20000    75591.80000         3.72000
   571  F41077    LL    63400.00000         8.78000     63400.00000    75591.80000         1.29000
   572  F41177    LL   392377.70000        29.24000    392377.70000   529142.50000        21.75000
   573  F41277    LL    45272.50000        31.97000     45272.50000   110238.00000        24.48000
   574  F41377    LL    63987.60000        11.13000     63987.60000    67402.70000         3.64000
   575  F41477    LL   128187.30000         9.82000    128187.30000   212916.90000         2.33000
   576  F41577    LL    27238.50000        12.50000     27238.50000    34646.20000         5.01000
   577  F41677    LL    15763.10000        49.19000     15763.10000    66142.80000        41.70000
   578  F41777    LL    21100.00000        36.06000     21100.00000    56693.80000        28.57000
   579  F41877    LL    31273.40000        33.65000     31273.40000   139844.80000        26.16000
   580  F41977    LL    42625.30000        33.65000     42625.30000   134175.40000        26.16000
   581  F42077    LL          .             7.77000           .       1637822.10000          .28000
   582  F4178     LL    25237.40000        15.09000     25237.40000    29606.80000         6.31000
   583  F4278     LL     9121.20000        55.56000      9121.20000    37795.90000        46.78000
   584  F4378     LL    19273.90000        39.73000     19273.90000    52284.30000        30.95000
   585  F4478     LL          .             9.60000           .        116537.30000          .82000
   586  F4578     LL   673213.10000        26.39000    673213.10000  1385849.50000        17.61000
   587  F4678     LL    77286.70000        15.76000     77286.70000    94489.70000         6.98000
   588  F4778     BS   138595.80016         8.78000           .        188979.50000          .
   589  F4878     LL   172108.00000        30.74000    172108.00000   220476.10000        21.96000
   590  F4978     LL    62530.70000        12.00000     62530.70000    75591.80000         3.22000
   591  F41078    LL    64893.70000         9.40000     64893.70000    75591.80000          .62000
   592  F41178    LL   397426.40000        31.29000    397426.40000   529142.50000        22.51000
   593  F41278    LL    49326.00000        34.08000     49326.00000   110238.00000        25.30000
   594  F41378    LL    64273.60000        11.91000     64273.60000    67402.70000         3.13000
   595  F41478    LL   132207.30000        10.51000    132207.30000   212916.90000         1.73000
   596  F41578    LL    29432.80000        13.37000     29432.80000    34646.20000         4.59000
   597  F41678    LL    17342.60000        52.63000     17342.60000    66142.80000        43.85000
   598  F41778    LL    23222.20000        38.43000     23222.20000    56693.80000        29.65000
   599  F41878    LL    33282.50000        35.87000     33282.50000   139844.80000        27.09000
   600  F41978    LL    46386.40000        35.87000     46386.40000   134175.40000        27.09000
   601  F42078    UL  1637822.10000         8.32000           .       1637822.10000          .46000-
   602  F4179     LL    26389.00000        16.15000     26389.00000    29606.80000         7.15000
   603  F4279     LL     9863.40000        59.45000      9863.40000    37795.90000        50.45000
   604  F4379     LL    21863.70000        42.51000     21863.70000    52284.30000        33.51000
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                EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   605  F4479     LL          .           10.27000          .          116537.30000        1.27000
   606  F4579     LL   693416.70000       28.24000   693416.70000     1385849.50000       19.24000
   607  F4679     LL    82473.50000       17.06000    82473.50000       94489.70000        8.06000
   608  F4779     LL          .            9.39000          .          188979.50000         .39000
   609  F4879     LL   173025.00000       32.90000   173025.00000      220476.10000       23.90000
   610  F4979     LL    63645.80000       12.98000    63645.80000       75591.80000        3.98000
   611  F41079    LL    65267.30000       10.05000    65267.30000       75591.80000        1.05000
   612  F41179    LL   397426.40000       33.48000   397426.40000      529142.50000       24.48000
   613  F41279    LL    49483.00000       36.46000    49483.00000      110238.00000       27.46000
   614  F41379    LL    65148.90000       12.89000    65148.90000       67402.70000        3.89000
   615  F41479    LL   135998.10000       11.37000   135998.10000      212916.90000        2.37000
   616  F41579    LL    30040.00000       14.31000    30040.00000       34646.20000        5.31000
   617  F41679    LL    17781.80000       56.31000    17781.80000       66142.80000       47.31000
   618  F41779    LL    23673.70000       41.12000    23673.70000       56693.80000       32.12000
   619  F41879    LL    35432.60000       38.38000    35432.60000      139844.80000       29.38000
   620  F41979    LL    47563.20000       38.38000    47563.20000      134175.40000       29.38000
   621  F42079    BS   520632.70011        9.00000          .         1637822.10000          .
   622  F4180     LL    26833.00000       17.28000    26833.00000       29606.80000        4.98000
   623  F4280     LL    10102.70000       63.09000    10102.70000       37795.90000       50.79000
   624  F4380     LL    22222.30000       45.48000    22222.30000       52284.30000       33.18000
   625  F4480     UL   116537.30000       10.99000          .          116537.30000        1.31000-
   626  F4580     LL   695386.70000       30.22000   695386.70000     1385849.50000       17.92000
   627  F4680     LL    83192.40000       18.25000    83192.40000       94489.70000        5.95000
   628  F4780     UL   188979.50000       10.05000          .          188979.50000        2.25000-
   629  F4880     LL   174287.00000       35.02000   174287.00000      220476.10000       22.72000
   630  F4980     LL    64897.00000       13.89000    64897.00000       75591.80000        1.59000
   631  F41080    UL    75591.80000       10.76000    66783.20000       75591.80000        1.54000-
   632  F41180    LL   398222.50000       35.83000   398222.50000      529142.50000       23.53000
   633  F41280    LL    52326.80000       39.01000    52326.80000      110238.00000       26.71000
   634  F41380    LL    66476.90000       13.79000    66476.90000       67402.70000        1.49000
   635  F41480    UL   212916.90000       12.17000   137399.20000      212916.90000         .13000-
   636  F41580    LL    30243.00000       15.31000    30243.00000       34646.20000        3.01000
   637  F41680    LL    18329.50000       60.26000    18329.50000       66142.80000       47.96000
   638  F41780    LL    24893.80000       44.00000    24893.80000       56693.80000       31.70000
   639  F41880    LL    37238.40000       41.06000    37238.40000      139844.80000       28.76000
   640  F41980    LL    49878.10000       41.06000    49878.10000      134175.40000       28.76000
   641  F42080    UL  1637822.10000        9.63000          .         1637822.10000        2.67000-
   642  F4181     LL    28399.40000       18.49000    28399.40000       29606.80000        1.77000
   643  F4281     LL    10879.60000       67.50000    10879.60000       37795.90000       50.78000
   644  F4381     LL    24869.30000       48.67000    24869.30000       52284.30000       31.95000
   645  F4481     UL   116537.30000       11.77000          .          116537.30000        4.95000-
   646  F4581     LL   696235.20000       32.33000   696235.20000     1385849.50000       15.61000
   647  F4681     LL    84674.70000       19.53000    84674.70000       94489.70000        2.81000
   648  F4781     UL   188979.50000       10.75000          .          188979.50000        5.97000-
   649  F4881     LL   176673.60000       37.67000   176673.60000      220476.10000       20.95000
   650  F4981     UL    75591.80000       14.87000    66676.30000       75591.80000        1.85000-
   651  F41081    UL    75591.80000       11.51000    68973.80000       75591.80000        5.21000-
   652  F41181    LL   399000.60000       38.33000   399000.60000      529142.50000       21.61000
   653  F41281    LL    53535.80000       41.75000    53535.80000      110238.00000       25.03000
   654  F41381    UL    67402.70000       14.76000    66787.20000       67402.70000        1.96000-
   655  F41481    UL   212916.90000       13.02000   138878.80000      212916.90000        3.70000-
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           EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...    ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   656  F41581    UL      34646.20000        16.38000     31432.20000     34646.20000          .34000-
   657  F41681    LL      18978.50000        64.47000     18978.50000     66142.80000        47.75000
   658  F41781    LL      26322.70000        47.08000     26322.70000     56693.80000        30.36000
   659  F41881    LL      37999.60000        43.94000     37999.60000    139844.80000        27.22000
   660  F41981    LL      51345.10000        43.94000     51345.10000    134175.40000        27.22000
   661  F42081    UL    1637822.10000        10.31000          .        1637822.10000         6.41000-
   662  F4182     UL      29606.80000        19.78000     29133.30000     29606.80000         4.60000-
   663  F4282     LL      11343.80000        72.23000     11343.80000     37795.90000        47.85000
   664  F4382     LL      25277.70000        52.08000     25277.70000     52284.30000        27.70000
   665  F4482     UL     116537.30000        12.59000          .         116537.30000        11.79000-
   666  F4582     LL     697887.80000        34.60000    697887.80000   1385849.50000        10.22000
   667  F4682     UL      94489.70000        20.90000     86367.00000     94489.70000         3.48000-
   668  F4782     UL     188979.50000        11.51000          .         188979.50000        12.87000-
   669  F4882     LL     177277.80000        40.30000    177277.80000    220476.10000        15.92000
   670  F4982     UL      75591.80000        15.91000     67283.60000     75591.80000         8.47000-
   671  F41082    UL      75591.80000        12.32000     69386.10000     75591.80000        12.06000-
   672  F41182    LL     400109.00000        41.02000    400109.00000    529142.50000        16.64000
   673  F41282    LL      55558.00000        44.67000     55558.00000    110238.00000        20.29000
   674  F41382    UL      67402.70000        15.79000     66900.80000     67402.70000         8.59000-
   675  F41482    UL     212916.90000        13.93000    139324.50000    212916.90000        10.45000-
   676  F41582    UL      34646.20000        17.53000     31989.70000     34646.20000         6.85000-
   677  F41682    LL      19001.00000        68.99000     19001.00000     66142.80000        44.61000
   678  F41782    LL      27536.80000        50.37000     27536.80000     56693.80000        25.99000
   679  F41882    LL      38343.00000        47.02000     38343.00000    139844.80000        22.64000
   680  F41982    LL      52673.80000        47.02000     52673.80000    134175.40000        22.64000
   681  F42082    UL    1637822.10000        11.03000          .        1637822.10000        13.35000-
   682  F4183     UL      29606.80000        21.17000     28667.60000     29606.80000        26.55000-
   683  F4283     LL      11897.80000        77.29000     11897.80000     37795.90000        29.57000
   684  F4383     LL      25932.20000        55.72000     25932.20000     52284.30000         8.00000
   685  F4483     UL     116537.30000        13.47000          .         116537.30000        34.25000-
   686  F4583     UL    1385849.50000        37.02000    698334.70000   1385849.50000        10.70000-
   687  F4683     UL      94489.70000        22.36000     86338.80000     94489.70000        25.36000-
   688  F4783     UL     188979.50000        12.31000          .         188979.50000        35.41000-
   689  F4883     UL     220476.10000        43.12000    177865.10000    220476.10000         4.60000-
   690  F4983     UL      75591.80000        17.02000     67782.90000     75591.80000        30.70000-
   691  F41083    UL      75591.80000        13.18000     70010.30000     75591.80000        34.54000-
   692  F41183    UL     529142.50000        43.89000    461203.00000    529142.50000         3.83000-
   693  F41283    LL      56783.20000        47.79000     56783.20000    110238.00000          .07000
   694  F41383    UL      67402.70000        16.90000     66386.40000     67402.70000        30.82000-
   695  F41483    UL     212916.90000        14.91000    141343.00000    212916.90000        32.81000-
   696  F41583    UL      34646.20000        18.76000     32676.60000     34646.20000        28.96000-
   697  F41683    LL      19789.70000        73.82000     19789.70000     66142.80000        26.10000
   698  F41783    LL      28673.80000        53.90000     28673.80000     56693.80000         6.18000
   699  F41883    LL      39786.50000        50.31000     39786.50000    139844.80000         2.59000
   700  F41983    LL      53809.80000        50.31000     53809.80000    134175.40000         2.59000
   701  F42083    UL    1637822.10000        11.80000          .        1637822.10000        35.92000-
   702  F4184     UL      29606.80000        22.65000     28737.70000     29606.80000        46.84000-
   703  F4284     LL      12000.90000        82.70000     12000.90000     37795.90000        13.21000
   704  F4384     UL      52284.30000        60.78000     26382.70000     52284.30000         8.71000-
   705  F4484     UL     116537.30000        14.41000          .         116537.30000        55.08000-
   706  F4584     UL    1385849.50000        40.38000    702889.60000   1385849.50000        29.11000-
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               EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   707  F4684     UL     94489.70000        23.93000     87676.30000     94489.70000        45.56000-
   708  F4784     UL    188979.50000        13.17000          .         188979.50000        56.32000-
   709  F4884     UL    220476.10000        47.04000    179881.00000    220476.10000        22.45000-
   710  F4984     UL     75591.80000        18.21000     68349.00000     75591.80000        51.28000-
   711  F41084    UL     75591.80000        14.10000     70860.00000     75591.80000        55.39000-
   712  F41184    UL    529142.50000        46.96000    403893.00000    529142.50000        22.53000-
   713  F41284    UL    110238.00000        52.13000     57234.60000    110238.00000        17.36000-
   714  F41384    UL     67402.70000        18.08000     67088.50000     67402.70000        51.41000-
   715  F41484    UL    212916.90000        15.95000    142787.00000    212916.90000        53.54000-
   716  F41584    UL     34646.20000        20.07000     33733.60000     34646.20000        49.42000-
   717  F41684    LL     20900.00000        78.99000     20900.00000     66142.80000         9.50000
   718  F41784    UL     56693.80000        58.79000     29812.60000     56693.80000        10.70000-
   719  F41884    UL    139844.80000        54.87000     41121.00000    139844.80000        14.62000-
   720  F41984    UL    134175.40000        54.87000     54311.00000    134175.40000        14.62000-
   721  F42084    UL   1637822.10000        12.63000          .        1637822.10000        56.86000-
   722  F4185     UL     29606.80000        24.24000     29018.00000     29606.80000        54.44000-
   723  F4285     LL     12869.70000        88.49000     12869.70000     37795.90000         9.81000
   724  F4385     UL     52284.30000        65.03000     27234.00000     52284.30000        13.65000-
   725  F4485     UL    116537.30000        15.42000          .         116537.30000        63.26000-
   726  F4585     UL   1385849.50000        43.20000    708333.60000   1385849.50000        35.48000-
   727  F4685     UL     94489.70000        25.60000     88675.50000     94489.70000        53.08000-
   728  F4785     UL    188979.50000        14.10000          .         188979.50000        64.58000-
   729  F4885     UL    220476.10000        50.33000    181231.00000    220476.10000        28.35000-
   730  F4985     UL     75591.80000        19.49000     70777.50000     75591.80000        59.19000-
   731  F41085    UL     75591.80000        15.09000     71933.50000     75591.80000        63.59000-
   732  F41185    UL    529142.50000        50.25000    407977.00000    529142.50000        28.43000-
   733  F41285    UL    110238.00000        55.78000     59367.80000    110238.00000        22.90000-
   734  F41385    UL     67402.70000        19.30000     67371.30000     67402.70000        59.34000-
   735  F41485    UL    212916.90000        17.07000    145343.60000    212916.90000        61.61000-
   736  F41585    UL     34646.20000        21.40000     33789.00000     34646.20000        57.20000-
   737  F41685    LL     21485.00000        84.52000     21485.00000     66142.80000         5.84000
   738  F41785    UL     56693.80000        62.91000     31716.80000     56693.80000        15.77000-
   739  F41885    UL    139844.80000        58.71000     42334.00000    139844.80000        19.97000-
   740  F41985    UL    134175.40000        58.71000     55556.20000    134175.40000        19.97000-
   741  F42085    UL   1637822.10000        13.51000          .        1637822.10000        65.17000-
   742  F5175     LL     72533.00000        13.05000     72533.00000    220476.00000         5.38000
   743  F5275     LL     73377.00000        13.00000     73377.00000    220476.00000         5.37000
   744  F5375     LL     79331.60000        10.80000     79331.60000    566938.40000         3.13000
   745  F5475     LL     68008.70000        13.41000     68008.70000    163782.20000         5.74000
   746  F5575     LL     67010.50000        13.42000     67010.50000    163782.20000         5.75000
   747  F5675     LL    102400.00000        11.70000    102400.00000    346462.40000         4.11000
   748  F5775     LL     59333.00000        11.93000     59333.00000    850407.70000         4.26000
   749  F5875     LL     19000.00000         9.57000     19000.00000     22047.60000         1.90000
   750  F5975     LL     39555.00000        17.24000     39555.00000    132285.60000         9.57000
   751  F51075    LL     42778.30000        16.21000     42778.30000    132285.60000         8.54000
   752  F51175    LL     58252.00000        15.44000     58252.00000    195278.80000         7.77000
   753  F51275    LL     36248.00000        18.23000     36248.00000    157482.90000        10.56000
   754  F51375    LL     43115.80000        16.19000     43115.80000    201578.10000         8.48000
   755  F51475    LL     16773.50000        19.32000     16773.50000     50394.50000        11.65000
   756  F51575    LL     42388.20000        17.19000     42388.20000     62993.10000         9.52000
   757  F51675    UL   3332338.20000         2.71000          .        3332338.20000         4.96000-
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             EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   758  F51775    LL     9340.50000       29.75000      9340.50000    264571.30000        22.08000
   759  P51875    UL   108562.70000        5.60000     85773.30000    108562.70000         2.07000-
   760  F6175     UL   667727.50000        2.23000           .        667727.50000         5.44000-
   761  F6275     LL    65883.00000       12.41000     65883.00000    125986.30000         4.74000
   762  F6375     LL    66883.50000       12.41000     66883.50000    125986.30000         4.74000
   763  F6475     LL    72651.80000       11.03000     72651.80000    302367.20000         3.36000
   764  F6575     LL    12378.00000       22.57000     12378.00000     25197.30000        14.90000
   765  F6675     LL    10273.80000       26.52000     10273.80000    182680.20000        18.85000
   766  F6775     LL    10421.70000       26.52000     10421.70000    176380.80000        18.85000
   767  F6875     LL    37811.60000       19.19000     37811.60000    151183.60000        11.52000
   768  P6975     UL    96800.00000        5.60000     93114.00000     96800.00000         2.07000-
   769  F5176     LL    72883.90000       13.83000     72883.90000    220476.00000         7.53000
   770  F5276     LL    73631.70000       13.82000     73631.70000    220476.00000         7.52000
   771  F5376     LL    79881.60000       11.45000     79881.60000    566938.40000         5.15000
   772  F5476     LL    68556.00000       14.22000     68556.00000    163782.20000         7.92000
   773  F5576     LL    67430.50000       14.23000     67430.50000    163782.20000         7.93000
   774  F5676     LL   102873.60000       12.49000    102873.60000    346462.40000         6.19000
   775  F5776     LL    59772.80000       12.65000     59772.80000    850407.70000         6.35000
   776  F5976     LL    40028.30000       18.27000     40028.30000    125986.30000        11.97000
   777  F51076    LL    43125.40000       17.18000     43125.40000    132285.60000        10.88000
   778  F51176    LL    56712.30000       16.36000     56712.30000    195278.60000        10.06000
   779  F51276    LL    36973.10000       19.32000     36973.10000    157482.90000        13.02000
   780  F51376    LL    43766.50000       17.12000     43766.50000    201578.10000        10.82000
   781  F51476    LL    17107.00000       20.48000     17107.00000     50394.50000        14.18000
   782  F51576    LL    42787.30000       18.23000     42787.30000     62993.10000        11.93000
   783  F51676    UL  3332338.20000        2.82000           .       3332338.20000         3.48000-
   784  F51776    LL     9770.50000       31.57000      9770.50000    264571.30000        25.27000
   785  P51876    UL   108562.70000        5.99000     86711.00000    108562.70000          .31000-
   786  F6176     UL   667727.50000        2.38000           .        667727.50000         3.92000-
   787  F6276     LL    66667.40000       13.28000     66667.40000    125986.30000         6.98000
   788  F6376     LL    67340.00000       13.28000     67340.00000    125986.30000         6.98000
   789  F6476     LL    73115.80000       11.80000     73115.80000    302367.20000         5.50000
   790  F6576     LL    12730.70000       24.15000     12730.70000     25197.30000        17.85000
   791  F6676     LL    10787.00000       28.38000     10787.00000    182680.20000        22.08000
   792  F6776     LL    10809.60000       28.38000     10809.60000    176380.80000        22.08000
   793  F6876     LL    38213.50000       20.53000     38213.50000    151183.60000        14.23000
   794  P6976     UL    96800.00000        5.99000     93973.20000     96800.00000          .31000-
   795  F5177     LL    73119.00000       14.66000     73119.00000    220476.00000         7.17000
   796  F5277     LL    74794.00000       14.65000     74794.00000    220476.00000         7.16000
   797  F5377     LL    80311.50000       12.14000     80311.50000    566938.40000         4.65000
   798  F5477     LL    69277.60000       15.07000     69277.60000    163782.20000         7.58000
   799  F5577     LL    67973.40000       15.08000     67973.40000    163782.20000         7.59000
   800  F5677     LL   102999.00000       13.24000    102999.00000    346462.40000         5.75000
   801  F5777     LL    60121.30000       13.41000     60121.30000    850407.70000         5.92000
   802  F5977     LL    40233.00000       19.37000     40233.00000    119687.00000        11.88000
   803  F51077    LL    44319.70000       18.22000     44319.70000    132285.60000        10.73000
   804  F51277    LL    37902.00000       20.48000     37902.00000    157482.90000        12.99000
   805  F51377    LL    44788.30000       18.14000     44788.30000    201578.10000        10.65000
   806  F51477    LL    45717.10000       21.71000     45717.10000     50394.50000        14.22000
   8C7  F51577    LL    43855.60000       19.32000     43855.60000     62993.10000        11.83000
   808  F51677    UL  3332338.20000        2.93000           .       3332338.20000         4.56000-
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                    EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT   ...ACTIVITY...   ..INPUT COST..   ..LOWER LIMIT.   ..UPPER LIMIT.   .REDUCED COST.

   809  F51777    LL     10284.00000        33.43000      10284.00000     264571.30000        25.94000
   810  P51877    UL    108562.70000         6.41000      87411.60000     108562.70000         1.08000-
   811  F6177     UL    667727.50000         2.55000           .          667727.50000         4.94000-
   812  F6277     LL     67242.00000        14.21000      67242.00000     125986.30000         6.72000
   813  F6377     LL     68789.40000        14.21000      68789.40000     125986.30000         6.72000
   814  F6477     LL     73885.60000        12.63000      73885.60000     302367.20000         5.14000
   815  F6577     LL     13444.00000        25.84000      13444.00000      25197.30000        18.35000
   816  F6677     LL     11329.10000        30.37000      11329.10000     182680.20000        22.88000
   817  F6777     LL     11752.00000        30.37000      11752.00000     176380.80000        22.88000
   818  F6877     LL     38770.00000        21.97000      38770.00000     151183.60000        14.48000
   819  P6977     UL     96800.00000         6.41000      94271.00000      96800.00000         1.08000-
   820  F5178     LL     73324.60000        15.54000      73324.60000     220476.00000         6.76000
   821  F5278     LL     75631.80000        15.53000      75631.80000     220476.00000         6.75000
   822  F5378     LL     81876.30000        12.87000      81876.30000     566938.40000         4.09000
   823  F5478     LL     72000.00000        15.98000      72000.00000     163782.20000         7.20000
   824  F5578     LL     69334.60000        15.99000      69334.60000     163782.20000         7.21000
   825  F5678     LL    106201.70000        14.03000     106201.70000     346462.40000         5.25000
   826  F5778     LL     60877.30000        14.21000      60877.30000     850407.70000         5.43000
   827  F5978     LL     40742.60000        20.53000      40742.60000     113387.70000        11.75000
   828  F51078    LL     45834.40000        19.31000      45834.40000     132285.60000        10.53000
   829  F51278    LL     38426.00000        21.71000      38426.00000     157482.90000        12.93000
   830  F51378    LL     45590.00000        19.23000      45590.00000     201578.10000        10.45000
   831  F51478    LL     45922.80000        23.01000      45922.80000      50394.50000        14.23000
   832  F51578    LL     44860.00000        20.48000      44860.00000      62993.10000        11.70000
   833  F51678    UL   3332338.20000         3.05000           .         3332338.20000         5.73000-
   834  F51778    LL     10734.00000        35.43000      10734.00000     264571.30000        26.65000
   835  P51878    UL    108562.70000         6.86000      87939.70000     108562.70000         1.92000-
   836  F6178     LL          .              2.73000           .          667727.50000         2.73000
   837  F6278     LL     68345.00000        15.20000      68345.00000     125986.30000         6.42000
   838  F6378     LL     69666.00000        15.20000      69666.00000     125986.30000         6.42000
   839  F6478     LL     74799.50000        13.51000      74799.50000     302367.20000         4.73000
   840  F6578     LL     14587.90000        27.65000      14587.90000      25197.30000        18.87000
   841  F6678     LL     12090.00000        32.49000      12090.00000     182680.20000        23.71000
   842  F6778     LL     12373.00000        32.49000      12373.00000     176380.80000        23.71000
   843  F6878     LL     39833.00000        23.50000      39833.00000     151183.60000        14.72000
   844  P6978     UL     96800.00000         6.86000      95582.60000      96800.00000         1.92000-
   845  F5179     LL     74666.00000        16.47000      74666.00000     220476.00000         7.47000
   846  F5279     LL     77343.50000        16.46000      77343.50000     220476.00000         7.46000
   847  F5379     LL     82399.00000        13.64000      82399.00000     566938.40000         4.64000
   848  F5479     LL     72244.60000        16.94000      72244.60000     163782.20000         7.94000
   849  F5579     LL     71438.60000        16.95000      71438.60000     163782.20000         7.95000
   850  F5679     LL    107433.70000        14.88000     107433.70000     346462.40000         5.88000
   851  F5779     LL     61937.00000        15.06000      61937.00000     850407.70000         6.06000
   852  F5979     LL     41278.50000        21.76000      41278.50000     107088.40000        12.76000
   853  F51079    LL     46427.30000        20.47000      46427.30000     132285.60000        11.47000
   854  F51279    LL     39119.60000        23.02000      39119.60000     157482.90000        14.02000
   855  F51379    LL     47638.00000        20.39000      47638.00000     201578.10000        11.39000
   856  F51479    LL     47776.50000        24.39000      47776.50000      50394.50000        15.39000
   857  F51579    LL     45125.00000        21.71000      45125.00000      62993.10000        12.71000
   858  F51679    UL   3332338.20000         3.17000           .         3332338.20000         5.83000-
   859  F51779    LL     11222.30000        37.56000      11222.30000     264571.30000        28.56000
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              EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT   ...ACTIVITY...    ..INPUT COST..    ..LOWER LIMIT.   ..UPPER LIMIT.   .REDUCED COST.

   860  P51879    LL    108562.70000          7.34000      88660.90000     108562.70000          1.66000-
   861  F6179     UL    667727.50000          2.92000           .          667727.50000          6.08000-
   862  F6279     LL     69731.70000         16.26000      69731.70000     125986.30000          7.26000
   863  F6379     LL     70244.40000         16.26000      70244.40000     125986.30000          7.26000
   864  F6479     LL     75678.20000         14.46000      75678.20000     302367.20000          5.46000
   865  F6579     LL     15692.60000         29.59000      15692.60000      25197.30000         20.59000
   866  F6679     LL     12549.70000         34.77000      12549.70000     182680.20000         25.77000
   867  F6779     LL     12841.80000         34.77000      12841.80000     176380.80000         25.77000
   868  F6879     LL     41622.90000         25.15000      41622.90000     151183.60000         16.15000
   869  P6979     UL     96800.00000          7.30000      96777.40000      96800.00000          1.66000-
   870  F5180     LL     75278.60000         17.46000      75278.60000     220476.00000          5.16000
   871  F5280     LL     78635.60000         17.45000      78635.60000     220476.00000          5.15000
   872  F5380     LL     83465.90000         14.46000      83466.90000     566938.40000          2.16000
   873  F5480     LL     73639.20000         17.95000      73639.20000     163782.20000          5.65000
   874  F5580     LL     72540.00000         17.96000      72540.00000     163782.20000          5.66000
   875  F5680     LL    110125.60000         15.77000     110125.60000     346462.40000          3.47000
   876  F5780     LL     62678.90000         15.97000      62678.90000     850407.70000          3.67000
   877  F5980     LL     42877.50000         23.07000      42877.50000     100789.00000         10.77000
   878  F51080    LL     47388.60000         21.70000      47388.60000     132285.60000          9.40000
   879  F51280    LL     41280.00000         24.40000      41280.00000     157482.90000         12.10000
   880  F51380    LL     48474.30000         21.61000      48474.30000     201578.10000          9.31000
   881  F51480    LL     48883.00000         25.86000      48883.00000      50394.50000         13.56000
   882  F51580    LL     46287.30000         23.01000      46287.30000      62993.10000         10.71000
   883  F51680    UL   3332338.20000          3.30000           .         3332338.20000          9.00000-
   884  F51780    LL     12256.40000         39.81000      12256.40000     264571.30000         27.51000
   885  P51880    UL    108562.70000          7.85000      89785.00000     108562.70000          4.45000-
   886  F6180     UL    667727.50000          3.12000           .          667727.50000          9.18000-
   887  F6280     LL     70679.00000         17.40000      70679.00000     125986.30000          5.10000
   888  F6380     LL     71422.50000         17.40000      71422.50000     125986.30000          5.10000
   889  F6480     LL     76238.60000         15.47000      76238.60000     302367.20000          3.17000
   890  F6580     LL     15885.00000         31.66000      15885.00000      25197.30000         19.36000
   891  F6680     LL     13111.00000         37.20000      13111.00000     182680.20000         24.90000
   892  F6780     LL     13242.00000         37.20000      13242.00000     176380.80000         24.90000
   893  F6880     LL     42002.00000         26.91000      42002.00000     151183.60000         14.61000
   894  P6980     UL     96800.00000          7.85000      96543.00000      96800.00000          4.45000-
   895  F5181     LL     76832.00000         18.51000      76832.00000     220476.00000          1.79000
   896  F5281     LL     79211.50000         18.50000      79211.50000     220476.00000          1.78000
   897  F5381     UL    566938.40000         15.33000      84275.00000     566938.40000          1.39000-
   898  F5481     LL     74098.60000         19.03000      74098.60000     163782.20000          2.31000
   899  F5581     LL     73777.60000         19.04000      73777.60000     163782.20000          2.32000
   900  F5681     BS    309901.80015         16.72000     119250.00000     346462.40000           .
   901  F5781     LL     63802.40000         16.93000      63892.40000     850407.70000           .21000
   902  F5981     LL     43784.00000         24.46000      43784.00000      94489.70000          7.74000
   903  F51081    LL     48633.00000         23.00000      48633.00000     132285.60000          6.28000
   904  F51281    LL     42272.60000         25.86000      42272.60000     157482.90000          9.14000
   905  F51381    LL     49125.00000         22.91000      49125.00000     201578.10000          6.19000
   906  F51481    LL     49432.00000         27.41000      49432.00000      50394.50000         10.69000
   907  F51581    LL     47144.50000         24.39000      47144.50000      62993.10000          7.67000
   908  F51681    UL   3332338.20000          3.43000           .         3332338.20000         13.29000-
   909  F51781    LL     13389.60000         42.20000      13389.60000     264571.30000         25.48000
   910  P51881    UL    108562.70000          8.40000      92373.80000     108562.70000          8.32000-
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               EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  911   F6181     UL   667727.50000         3.34000          .          667727.50000       13.38000-
  912   F6281     LL    71525.30000        18.62000     71525.30000     125986.30000        1.90000
  913   F6381     LL    72623.00000        18.62000     72623.00000     125986.30000        1.90000
  914   F6481     UL   302367.20000        16.55000     76440.50000     302367.20000         .17000-
  915   F5581     LL    17234.60000        33.88000     17234.60000      25197.30000       17.16000
  916   F6681     LL    13789.70000        39.81000     13789.70000     182680.20000       23.09000
  917   F6781     LL    13970.40000        39.81000     13970.40000     176380.80000       23.09000
  918   F6881     LL    42737.00000        28.79000     42737.00000     151183.60000       12.07000
  919   P6981     UL    96800.00000         8.40000     96777.00000      96800.00000        8.32000-
  920   F5182     UL   220476.00000        19.62000     77232.00000     220476.00000        4.76000-
  921   F5282     UL   220476.00000        19.61000     81009.00000     220476.00000        4.77000-
  922   F5382     UL   566938.40000        16.25000     85341.00000     566938.40000        8.13000-
  923   F5482     UL   163782.20000        20.17000     75256.00000     163782.20000        4.21000-
  924   F5582     UL   163782.20000        20.18000     74875.60000     163782.20000        4.20000-
  925   F5682     UL   346462.40000        17.72000    123722.00000     346462.40000        6.66000-
  926   F5782     UL   850407.70000        17.94000     66423.00000     850407.70000        6.44000-
  927   F5982     LL    44688.50000        25.92000     44688.50000      88190.40000        1.54000
  928   F51082    BS    96870.49998        24.38000     49126.00000     132285.60000          .
  929   F51282    LL    42879.00000        27.41000     42879.00000     157482.90000        3.03000
  930   F51382    UL   201578.10000        24.28000     50344.70000     201578.10000         .10000-
  931   F51482    LL    50272.00000        29.05000     50272.00000      50394.50000        4.67000
  932   F51582    LL    48535.60000        25.86000     48535.60000      62993.10000        1.48000
  933   F51682    UL  3332338.20000         3.57000          .         3332338.20000       20.81000-
  934   F51782    LL    13787.50000        44.73000     13787.50000     264571.30000       20.35000
  935   P51882    UL   108562.70000         8.99000     93133.40000     108562.70000       15.39000-
  936   F6182     UL   667727.50000         3.58000          .          667727.50000       20.80000-
  937   F6282     UL   125986.30000        19.93000     72630.00000     125986.30000        4.45000-
  938   F6382     UL   125986.30000        19.93000     73732.60000     125986.30000        4.45000-
  939   F6482     UL   302367.20000        17.71000     77188.90000     302367.20000        6.67000-
  940   F6582     LL    18446.00000        36.25000     18446.00000      25197.30000       11.87000
  941   F6682     LL    15207.80000        42.59000     15207.80000     182680.20000       18.21000
  942   F6782     LL    15412.00000        42.59000     15412.00000     176380.80000       18.21000
  943   F6882     LL    43523.10000        30.81000     43523.10000     151183.60000        6.43000
  944   P6982     UL    96800.00000         8.99000     96777.00000      96800.00000       15.39000-
  945   F5183     UL   220476.00000        20.80000     77566.00000     220476.00000       26.92000-
  946   F5283     UL   220476.00000        20.79000     82447.50000     220476.00000       26.93000-
  947   F5383     UL   566938.40000        17.22000     86228.00000     566938.40000       30.50000-
  948   F5483     UL   163782.20000        21.38000     76361.20000     163782.20000       26.34000-
  949   F5583     UL   163782.20000        21.39000     75127.40000     163782.20000       26.33000-
  950   F5683     UL   346462.40000        18.78000    127232.70000     346462.40000       28.94000-
  951   F5783     UL   850407.70000        19.02000     67511.00000     850407.70000       28.70000-
  952   F5983     UL    81891.10000        27.48000     45770.00000      81891.10000       20.24000-
  953   F51083    UL   132285.60000        25.84000     49610.00000     132285.60000       21.88000-
  954   F51283    UL   157482.90000        29.06000     42973.40000     157482.90000       18.66000-
  955   F51383    UL   201578.10000        25.74000     51129.00000     201578.10000       21.98000-
  956   F51483    UL    50394.50000        30.80000     50284.30000      50394.50000       16.92000-
  957   F51583    UL    62993.10000        27.41000     49237.00000      62993.10000       20.31000-
  958   F51683    UL  3332338.20000         3.71000          .         3332338.20000       44.01000-
  959   F51783    UL   264571.30000        47.42000     14331.50000     264571.30000         .30000-
  960   P51883    UL   108562.70000         9.62000     93780.00000     108562.70000       38.10000-
  961   F6183     UL   667727.50000         3.83000          .          667727.50000       43.89000-
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              EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   962  F6283     UL   125986.30000        21.32000     73271.00000    125986.30000        26.40000-
   963  F6383     UL   125986.30000        21.32000     74342.70000    125986.30000        26.40000-
   964  F6483     UL   302367.20000        18.95000     78271.50000    302367.20000        28.77000-
   965  F6583     UL    25197.30000        38.79000     19118.60000     25197.30000         8.93000-
   966  F6683     UL   182680.20000        45.58000     15871.40000    182680.20000         2.14000-
   967  F6783     UL   176380.80000        45.58000     16923.80000    176380.80000         2.14000-
   968  F6883     UL   151183.60000        32.97000     44092.50000    151183.60000        14.75000-
   969  P6983     UL    95800.00000         9.62000     96777.00000     96800.00000        38.10000-
   970  F5184     UL   220476.00000        22.04000     78209.00000    220476.00000        47.45000-
   971  F5284     UL   220476.00000        22.03000     84007.50000    220476.00000        47.46000-
   972  F5384     UL   566938.40000        18.26000     88116.50000    566938.40000        51.23000-
   973  F5484     UL   163782.20000        22.67000     77408.00000    163782.20000        46.82000-
   974  F5584     UL   163782.20000        22.68000     76283.70000    163782.20000        46.81000-
   975  F5684     UL   346462.40000        19.91000    131421.90000    346462.40000        49.58000-
   976  F5784     UL   850407.70000        20.16000     69230.00000    850407.70000        49.33000-
   977  F5984     UL    75591.80000        29.13000     46119.00000     75591.80000        40.36000-
   978  F51084    UL   132285.60000        27.39000     51178.00000    132285.60000        42.10000-
   979  F51284    UL   157482.90000        30.80000     43682.00000    157482.90000        38.69000-
   980  F51384    UL   201578.10000        27.28000     51678.90000    201578.10000        42.21000-
   981  F51484    UL    50394.50000        32.64000          .          50394.50000        36.85000-
   982  F51584    UL    62993.10000        29.05000     50347.50000     62993.10000        40.44000-
   983  F51684    UL  3332338.20000         3.86000          .        3332338.20000        65.63000-
   984  F51784    UL   264571.30000        50.26000     15664.00000    264571.30000        19.23000-
   985  P51884    UL   108562.70000        10.30000     95212.00000    108562.70000        59.19000-
   986  F6184     UL   667727.50000         4.10000          .         667727.50000        65.39000-
   987  F6284     UL   125986.30000        22.81000     74347.80000    125986.30000        46.68000-
   988  F6384     UL   125986.30000        22.81000     75256.00000    125986.30000        46.68000-
   989  F6484     UL   302367.20000        20.28000     75482.00000    302367.20000        49.21000-
   990  F6584     UL    25197.30000        41.50000     21326.80000     25197.30000        27.99000-
   991  F6684     UL   182680.20000        48.77000     16997.20000    182680.20000        20.72000-
   992  F6784     UL   176380.80000        48.77000     17250.00000    176380.80000        20.72000-
   993  F6884     UL   151183.60000        35.28000     44751.60000    151183.60000        34.21000-
   994  P6984     UL    96800.00000        10.30000     96777.00000     96800.00000        59.19000-
   995  F5185     UL   220476.00000        23.37000     79247.70000    220476.00000        55.31000-
   996  F5285     UL   220476.00000        23.35000     85336.00000    220476.00000        55.33000-
   997  F5385     UL   566938.40000        19.35000     89344.50000    566938.40000        59.33000-
   998  F5485     UL   163782.20000        24.03000     78511.00000    163782.20000        54.65000-
   999  F5585     UL   163782.20000        24.04000     79607.40000    163782.20000        54.64000-
  1000  F5685     UL   346462.40000        21.11000    138119.00000    346462.40000        57.57000-
  1001  F5785     UL   850407.70000        21.37000     72345.60000    850407.70000        57.31000-
  1002  F5985     UL    69292.50000        30.88000     47122.00000     69292.50000        47.80000-
  1003  F51085    UL   132285.60000        29.04000     51324.60000    132285.60000        49.64000-
  1004  F51285    UL   157482.90000        32.65000     44766.80000    157482.90000        46.03000-
  1005  F51385    UL   201578.10000        28.92000     52348.90000    201578.10000        49.76000-
  1006  F51485    UL    50394.50000        34.60000     50377.00000     50394.50000        44.08000-
  1007  F51585    UL    62993.10000        30.80000     51530.00000     62993.10000        47.88000-
  1008  F51685    UL  3332338.20000         4.01000          .        3332338.20000        74.67000-
  1009  F51785    UL   264571.30000        53.28000     16337.00000    264571.30000        25.40000-
  1010  P51885    UL   108562.70000        11.01000     97558.00000    108562.70000        67.67000-
  1011  F6185     UL   667727.50000         4.38000          .         667727.50000        74.30000-
  1012  F6285     UL   125986.30000        24.41000     77279.50000    125986.30000        54.27000-
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              EXECUTOR.  MPSX  PELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT   ...ACTIVITY...   ..INPUT COST..   ..LOWER LIMIT.   ..UPPER LIMIT.   .REDUCED COST.

  1013  F6385     UL    125986.30000       24.41000       76131.70000     125986.30000        54.27000-
  1014  F6485     UL    302367.20000       21.70000       77990.00000     302367.20000        56.98000-
  1015  F6585     UL     25197.30000       44.41000       25137.80000      25197.30000        34.27000-
  1016  F6685     UL    182680.20000       52.18000       18375.10000     182680.20000        26.50000-
  1017  F6785     UL    176380.80000       52.18000       22184.00000     176380.80000        26.50000-
  1018  F6885     UL    151183.60000       37.75000       46957.00000     151183.60000        40.93000-
  1019  P6585     UL     96800.00000       11.01000       96777.00000      96800.00000        67.67000-
  1020  F7175     LL     16247.00000       32.30000       16247.00000     522843.20000        24.63000
  1021  F7275     LL      9763.50000       45.60000        9763.50000      88190.40000        37.93000
  1022  F7375     LL     32324.50000       24.70000       32324.50000     132285.60000        17.03000
  1023  F7475     LL     42119.60000       22.80000       42119.60000     170081.50000        15.13000
  1024  F7575     LL     35647.70000       24.70000       35647.70000     176380.80000        17.03000
  1025  F7675     LL     16247.30000       32.30000       16247.30000     491346.60000        24.63000
  1026  F7775     UL   1209468.70000        2.31000            .         1209468.70000         5.36000-
  1027  F7875     UL   1209468.70000        2.31000            .         1209468.70000         5.36000-
  1028  F7975     LL     56225.40000       11.40000       56225.40000     151183.60000         3.73000
  1029  F71075    LL    135240.80000        9.80000      135240.80000     163782.20000         2.13000
  1030  F71175    LL    167545.20000        8.40000      167545.20000     321265.10000          .73000
  1031  F71275    UL    900802.20000        6.79000      235779.50000     900802.20000          .88000-
  1032  F71375    LL     47134.90000       10.20000       47134.90000     472448.70000         2.53000
  1033  F7176     LL     18319.00000       33.92000       18319.00000     522843.20000        27.62000
  1034  F7276     LL     11321.50000       47.88000       11321.50000      29396.80000        41.58000
  1035  F7376     LL     35627.40000       25.93000       35627.40000     132285.60000        19.63000
  1036  F7476     LL     43244.10000       23.94000       43244.10000     170081.50000        17.64000
  1037  F7576     LL     37322.80000       25.93000       37322.80000     176380.80000        19.63000
  1038  F7676     LL     17856.60000       33.92000       17856.60000     491346.60000        27.62000
  1039  F7776     UL   1209468.70000        2.35000            .         1209468.70000         3.95000-
  1040  F7876     UL   1209468.70000        2.35000            .         1209468.70000         3.95000-
  1041  F7976     LL     58477.60000       11.97000       58477.60000     151183.60000         5.67000
  1042  F71076    LL    137119.70000       10.29000      137119.70000     163782.20000         3.99000
  1043  F71176    LL    171328.50000        8.82000      171328.50000     321265.10000         2.52000
  1044  F71276    LL    237455.00000        7.13000      237455.00000     900802.20000          .83000
  1045  F71376    LL     48244.30000       10.71000       48244.30000     472448.70000         4.41000
  1046  F71476    UL    951196.70000        5.37000      156589.70000     951196.70000          .93000-
  1047  F71576    LL     24684.00000       19.95000       24684.00000     167981.70000        13.65000
  1048  F7177     LL     19422.00000       35.61000       19422.00000     522843.20000        28.12000
  1049  F7377     LL     42879.50000       27.23000       42879.50000     132285.60000        19.74000
  1050  F7477     LL     45733.00000       25.14000       45733.00000     170081.50000        17.65000
  1051  F7577     LL     38112.20000       27.23000       38112.20000     176380.80000        19.74000
  1052  F7677     LL     18327.50000       35.61000       18327.50000     491346.60000        28.12000
  1053  F7777     UL   1209468.70000        2.40000            .         1209468.70000         5.09000-
  1054  F7877     UL   1209468.70000        2.40000            .         1209468.70000         5.09000-
  1055  F7977     LL     63324.00000       12.57000       63324.00000     151183.60000         5.08000
  1056  F71077    LL    142481.60000       10.80000      142481.60000     163782.20000         3.31000
  1057  F71177    LL    175432.00000        9.26000      175432.00000     321265.10000         1.77000
  1058  F71277    BS    422410.90007        7.49000      238538.90000     900802.20000          .
  1059  F71377    LL     52557.00000       11.24000       52557.00000     472448.70000         3.75000
  1060  F71477    UL    951196.70000        5.64000      158171.00000     951196.70000         1.85000-
  1061  F71577    LL     27787.00000       20.95000       27787.00000     251572.60000        13.46000
  1062  P71977    UL    120000.00000        5.00000      117666.00000     120000.00000         2.49000-
  1063  F7178     LL     22587.80000       37.38000       22587.80000     522843.20000        28.60000
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                EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT   ...ACTIVITY...   ..INPUT COST..   ..LOWER LIMIT.   ..UPPER LIMIT.   .REDUCED COST.

  1064  F7378     LL     43424.50000       28.58000       43424.50000     132285.60000        19.80000
  1065  F7478     LL     46874.60000       26.37000       46874.60000     170081.50000        17.59000
  1066  F7578     LL     39523.10000       28.58000       39523.10000     176380.80000        19.80000
  1067  F7678     LL     19263.00000       37.30000       19263.00000     491346.60000        28.60000
  1068  F7778     UL   1209468.70000        2.45000            .         1209468.70000         6.33000-
  1069  F7878     UL   1209468.70000        2.45000            .         1209468.70000         6.33000-
  1070  F7978     LL     64586.00000       13.20000       64586.00000     151183.60000         4.42000
  1071  F71078    LL    143687.90000       11.34000      143687.90000     163782.20000         2.56000
  1072  F71178    LL    177621.40000        9.72000      177621.40000     321265.10000          .94000
  1073  F71278    UL    900802.20000        7.86000      241578.30000     900802.20000          .92000-
  1074  F71378    LL     53629.00000       11.80000       53629.00000     472448.70000         3.02000
  1075  F71478    UL    951196.70000        5.92000      162321.70000     951196.70000         2.86000-
  1076  F71578    LL     32642.10000       21.90000       32642.10000     251972.60000        13.21000
  1077  P71978    UL    150000.00000        5.00000      149326.80000     150000.00000         3.78000-
  1078  F7179     LL     23842.60000       39.27000       23842.60000     522843.20000        30.27000
  1079  F7379     LL     44275.00000       30.03000       44275.00000     132285.60000        21.03000
  1080  F7479     LL     47326.80000       27.72000       47326.80000     170081.50000        18.72000
  1081  F7579     LL     48419.60000       30.03000       48419.60000     176380.80000        21.03000
  1082  F7679     LL     21819.40000       39.27000       21819.40000     491346.60000        30.27000
  1083  F7779     UL   1209468.70000        2.50000            .         1209468.70000         6.50000-
  1084  F7879     UL   1209468.70000        2.50000            .         1209468.70000         6.50000-
  1085  F7979     LL     67654.00000       13.85000       67654.00000     151183.60000         4.85000
  1086  F71079    LL    147542.30000       11.91000      147542.30000     163782.20000         2.91000
  1087  F71179    LL    183332.50000       10.21000      183332.50000     321265.10000         1.21000
  1088  F71279    UL    900802.20000        8.25000      243499.00000     900802.20000          .75000-
  1089  F71379    LL     57222.60000       12.40000       57222.60000     472448.70000         3.40000
  1090  F71479    UL    951196.70000        6.28000      187489.10000     951196.70000         2.79000-
  1091  F71579    LL     35541.20000       23.10000       35541.20000     251972.60000        14.10000
  1092  F71679    UL   1329155.70000        6.78000      656540.80000    1329155.70000         2.22000-
  1093  F7180     LL     25119.00000       41.22000       25119.00000     522843.20000        28.92000
  1094  F7380     LL     47320.50000       31.52000       47320.50000     132285.60000        19.22000
  1095  F7480     LL     49454.00000       29.10000       49454.00000     170081.50000        16.80000
  1096  F7580     LL     50521.00000       31.52000       50521.00000     176380.80000        19.22000
  1097  F7680     LL     23418.60000       41.22000       23418.60000     491346.60000        28.92000
  1098  F7780     UL   1209468.70000        2.55000            .         1209468.70000         9.75000-
  1099  F7880     UL   1209468.70000        2.55000            .         1209468.70000         9.75000-
  1100  F7980     LL     71322.10000       14.55000       71322.10000     151183.60000         2.25000
  1101  F71080    LL    152309.80000       12.50000      152309.80000     163782.20000          .20000
  1102  F71180    UL    321265.10000       10.72000      187100.00000     321265.10000         1.58000-
  1103  F71280    UL    900802.20000        8.66000      254587.30000     900802.20000         3.64000-
  1104  F71380    LL     59696.00000       13.01000       59696.00000     472448.70000          .71000
  1105  F71480    UL    951196.70000        6.52000      192492.70000     951196.70000         5.78000-
  1106  F71580    LL     37410.00000       24.25000       37410.00000     251972.60000        11.95000
  1107  F71680    UL   1329155.70000        7.12000      673477.00000    1329155.70000         5.18000-
  1108  F7181     LL     27347.00000       43.28000       27347.00000     522843.20000        26.56000
  1109  F7381     LL     48634.50000       33.10000       48634.50000     132285.60000        16.38000
  1110  F7481     LL     52004.90000       30.55000       52004.90000     170081.50000        13.83000
  1111  F7581     LL     51397.40000       33.10000       51397.40000     176380.80000        16.38000
  1112  F7681     LL     24870.00000       43.28000       24870.00000     491346.60000        26.56000
  1113  F7781     UL   1209468.70000        2.60000            .         1209468.70000        14.12000-
  1114  F7881     UL   1209468.70000        2.60000            .         1209468.70000        14.12000-
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            EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  1115  F7981     UL   151183.60000       15.27000      73764.20000   151183.60000         1.45000-
  1116  F71081    UL   163782.20000       13.13000     163540.00000   163782.20000         3.59000-
  1117  F71181    UL   321265.10000       11.25000     192233.50000   321265.10000         5.47000-
  1118  F71281    UL   900802.20000        9.10000     279997.00000   900802.20000         7.62000-
  1119  F71381    UL   472448.70000       13.66000      61007.00000   472448.70000         3.06000-
  1120  F71481    UL   951196.70000        6.85000     207811.00000   951196.70000         9.87000-
  1121  F71581    LL    41311.70000       25.46000      41311.70000   251972.60000         8.74000
  1122  F71681    UL  1329155.70000        7.47000     684533.00000  1329155.70000         9.25000-
  1123  F71781    UL   524943.00000        7.47000     522476.80000   524943.00000         9.25000-
  1124  F7182     LL    28949.00000       45.40000      28949.00000   522843.20000        21.06000
  1125  F7382     LL    52341.00000       34.75000      52341.00000   132285.60000        10.37000
  1126  F7482     LL    53118.00000       32.07000      53118.00000   170081.50000         7.69000
  1127  F7582     LL    52520.60000       34.75000      52520.60000   176380.80000        10.37000
  1128  F7682     LL    26175.30000       45.40000      26175.30000   491346.60000        21.06000
  1129  F7782     UL  1209468.70000        2.65000           .       1209468.70000        21.73000-
  1130  F7882     UL  1209468.70000        2.65000           .       1209468.70000        21.73000-
  1131  F7982     UL   151183.60000       16.00000      77971.00000   151183.60000         8.34000-
  1132  F71082    UL   163782.20000       13.79000     163646.80000   163782.20000        10.59000-
  1133  F71182    UL   321265.10000       11.82000     195554.00000   321265.10000        12.56000-
  1134  F71282    UL   900802.20000        9.55000     282039.60000   900802.20000        14.83000-
  1135  F71382    UL   472448.70000       14.35000      63545.10000   472448.70000        10.03000-
  1136  F71482    UL   951196.70000        7.10000     211929.00000   951196.70000        17.19000-
  1137  F71582    LL    42433.60000       26.73000      42433.60000   251972.60000         2.35000
  1138  F71682    UL  1329155.70000        7.85000     692489.40000  1329155.70000        16.53000-
  1139  F71782    UL   787414.50000        7.85000     637269.00000   787414.50000        16.53000-
  1140  F7183     BS    65147.30009       47.72000      32328.50000   522843.20000          .
  1141  F7383     UL   132285.60000       36.49000      54547.60000   132285.60000        11.23000-
  1142  F7483     UL   170081.50000       33.68000      55633.60000   170081.50000        14.04000-
  1143  F7583     UL   176380.80000       36.49000      53890.00000   176380.80000        11.23000-
A 1144  F7683     LL    28281.60000       47.72000      28281.60000   491346.60000          .
  1145  F7783     UL  1209468.70000        2.70000           .       1209468.70000        45.02000-
  1146  F7883     UL  1209468.70000        2.74000           .       1209468.70000        45.02000-
  1147  F7983     UL   151183.60000       16.84000      79814.70000   151183.60000        30.88000-
  1148  F71083    UL   163782.20000       14.48000     163338.00000   163782.20000        33.24000-
  1149  F71183    UL   321265.10000       12.41000     201879.60000   321265.10000        35.31000-
  1150  F71283    UL   900802.20000       10.03000     291616.50000   900802.20000        37.69000-
  1151  F71383    UL   472448.70000       15.07000      64328.00000   472448.70000        32.65000-
  1152  F71483    UL   951196.70000        7.55000     222737.40000   951196.70000        40.17000-
  1153  F71583    UL   251972.60000       28.07000      44756.80000   251972.60000        19.65000-
  1154  F71683    UL  1329155.70000        8.24000     694738.10000  1329155.70000        39.48000-
  1155  F71783    UL   787414.50000        8.24000     648111.00000   787414.50000        39.48000-
  1156  F7184     UL   522843.20000       50.10000      33678.90000   522843.20000        19.39000-
  1157  F7384     UL   132285.60000       38.31000      57381.00000   132285.60000        31.18000-
  1158  F7484     UL   170081.50000       35.36000      58292.70000   170081.50000        34.13000-
  1159  F7584     UL   176380.80000       38.31000      55666.80000   176380.80000        31.18000-
  1160  F7684     UL   491346.60000       50.10000      32519.20000   491346.60000        19.39000-
  1161  F7784     UL  1209468.70000        2.76000           .       1209468.70000        66.73000-
  1162  F7884     UL  1209468.70000        2.76000           .       1209468.70000        66.73000-
  1163  F7984     UL   151183.60000       17.68000      82510.00000   151183.60000        51.81000-
  1164  F71084    UL   163782.20000       15.20000     163647.50000   163782.20000        54.29000-
  1165  F71184    UL   321265.10000       13.03000     213190.70000   321265.10000        56.46000-
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              EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  1166  F71284    UL    900802.20000        10.53000    295535.80000    900802.20000        58.96000-
  1167  F71384    UL    472448.70000        15.82000     67589.30000    472448.70000        53.67000-
  1168  F71484    UL    951196.70000         7.93000    237310.80000    951196.70000        61.56000-
  1169  F71584    UL    251972.60000        29.47000     47191.20000    251972.60000        40.02000-
  1170  F71684    UL   1329155.70000         8.65000    701199.00000   1329155.70000        60.84000-
  1171  F71784    UL    787414.50000         8.65000    653329.50000    787414.50000        60.84000-
  1172  F7185     UL    522843.20000        52.61000     37777.50000    522843.20000        26.07000-
  1173  F7385     UL    132285.60000        40.26000     61498.20000    132285.60000        38.42000-
  1174  F7485     UL    170081.50000        37.16000     62323.80000    170081.50000        41.52000-
  1175  F7585     UL    176380.80000        40.26000     57749.40000    176380.80000        38.42000-
  1176  F7685     UL    491346.60000        52.61000     33840.00000    491346.60000        26.07000-
  1177  F7785     UL   1209468.70000         2.81000          .        1209468.70000        75.87000-
  1178  F7885     UL   1209468.70000         2.81000          .        1209468.70000        75.87000-
  1179  F7985     UL    151183.60000        18.57000     85349.60000    151183.60000        60.11000-
  1180  F71085    UL    163782.20000        15.96000    163116.70000    163782.20000        62.72000-
  1181  F71185    UL    321265.10000        13.68000    224633.50000    321265.10000        65.00000-
  1182  F71285    UL    900802.20000        11.06000    301412.70000    900802.20000        67.62000-
  1183  F71385    UL    472448.70000        16.01000     71744.40000    472448.70000        62.07000-
  1184  F71485    UL    951196.70000         8.33000    241248.90000    951196.70000        70.35000-
  1185  F71585    UL    251972.60000        30.95000     49322.10000    251972.60000        47.73000-
  1186  F71685    UL   1329155.70000         9.09000    723458.50000   1329155.70000        69.59000-
  1187  F71785    UL    787414.50000         9.09000    667948.40000    787414.50000        69.59000-
  1188  F71885    UL    692924.70000         2.81000          .         692924.70000        75.87000-
  1189  F8175     LL     29205.30000        12.40000     29205.30000     62993.10000         4.73000
  1190  F8275     LL     32314.70000        12.82000     32314.70000     62993.10000         5.15000
  1191  F8375     LL     71832.10000        11.84000     71832.10000     81891.10000         3.87000
  1192  F8475     LL    107687.40000        11.11000    107687.40000    119687.00000         3.44000
  1193  F8575     LL    171326.80000        10.09000    171326.80000    245673.30000         2.42000
  1194  F8675     UL   1259863.20000         2.71000          .        1259863.20000         4.96000-
  1195  P8775     UL    182680.20000         2.81000    182679.80000    182680.20000         5.06000-
  1196  F8176     LL     32422.20000        13.34000     32422.20000     62993.10000         7.04000
  1197  F8276     LL     33020.50000        13.80000     33020.50000     62993.10000         7.50000
  1198  F8376     LL     72377.80000        12.42000     72377.80000     81891.10000         6.12000
  1199  F8476     LL    109548.60000        11.96000    109548.60000    119687.00000         5.66000
  1200  F8576     LL    175447.40000        10.86000    175447.40000    245673.30000         4.56000
  1201  F8676     UL   1259863.20000         2.02000          .        1259863.20000         3.48000-
  1202  P8776     UL    182680.20000         2.71000    182679.00000    182680.20000         3.59000-
  1203  F8177     LL     34519.10000        19.28000     34519.10000     62993.10000        11.79000
  1204  F8277     LL     35110.60000        19.95000     35110.60000     62993.10000        12.46000
  1205  F8377     LL     74998.00000        17.95000     74998.00000     81891.10000        10.46000
  1206  F8477     LL     75338.40000        17.29000     75338.40000    119687.00000         9.80000
  1207  F8577     LL    178455.80000        15.49000    178455.80000    245673.30000         8.20000
  1208  F8677     UL   1259863.20000         2.93000          .        1259863.20000         4.56000-
  1209  P8777     UL    182680.20000         2.81000    182679.60000    182680.20000         4.68000-
  1210  F8178     LL     35897.20000        21.17000     35897.20000     62993.10000        12.39000
  1211  F8278     LL     36323.50000        21.90000     36323.50000     62993.10000        13.12000
  1212  F8378     LL     75114.60000        19.71000     75114.60000     81891.10000        10.93000
  1213  F8478     LL     76819.90000        18.98000     76819.90000    119687.00000        10.20000
  1214  F8578     LL    181440.00000        17.23000    181440.00000    245673.30000         8.45000
  1215  F8678     UL   1259863.20000         3.05000          .        1259863.20000         5.73000-
  1216  P8778     UL    182680.20000         2.91000    182679.80000    182680.20000         5.87000-
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                       EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  1217  F8179     LL    37414.00000       22.48000      37414.00000     62993.10000       13.48000
  1218  F8279     LL    38110.50000       23.25000      38110.50000     62993.10000       14.25000
  1219  F8379     LL    76257.40000       20.92000      76257.40000     81891.10000       11.92000
  1220  F8479     LL    77112.20000       20.15000      77112.20000    119687.00000       11.15000
  1221  F8579     LL   183543.00000       18.29000     183543.00000    245673.30000        9.29000
  1222  F8679     UL  1259863.20000        3.87000           .        1259863.20000        5.83000-
  1223  P8779     UL   182680.20000        3.01000     182679.00000    182680.20000        5.99000-
  1224  F8180     LL    39677.70000       23.92000      39677.70000     62993.10000       11.62000
  1225  F8280     LL    41322.10000       24.75000      41322.10000     62993.10000       12.45000
  1226  F8380     LL    77553.30000       22.27000      77553.30000     81891.10000        9.97000
  1227  F8480     LL    78119.90000       21.45000      78119.90000    119687.00000        9.15000
  1228  F8580     LL   185272.50000       19.47000     185272.50000    245673.30000        7.17000
  1229  F8680     UL  1259863.20000        3.30000           .        1259863.20000        9.00000-
  1230  P8780     UL   182680.20000        3.11000     182679.00000    182680.20000        9.19000-
  1231  F8181     LL    41322.10000       25.37000      41322.10000     62993.10000        8.65000
  1232  F8281     LL    42735.80000       26.25000      42735.80000     62993.10000        9.53000
  1233  F8381     LL    78664.40000       23.62000      78664.40000     81891.90000        6.90000
  1234  F8481     LL    79418.80000       22.75000      79418.80000    119687.00000        6.03000
  1235  F8581     LL   187121.50000       20.65000     187121.50000    245673.30000        3.93000
  1236  F8681     UL  1259863.20000        3.43000           .        1259863.20000       13.29000-
  1237  P8781     LL   182680.20000        3.21000     182679.40000    182680.20000       13.51000-
  1238  F8182     LL    42467.60000       26.82000      42467.60000     62993.10000        2.44000
  1239  F8282     LL    43594.70000       27.75000      43594.70000     62993.10000        3.37000
  1240  F8382     LL    79642.00000       24.97000      79642.00000     81891.90000         .59000
  1241  F8482     UL   119687.00000       24.05000      80420.30000    119687.00000         .33000-
  1242  F8582     UL   245673.30000       21.83000     190256.00000    245673.30000        2.55000-
  1243  F8682     UL  1259863.20000        3.57000           .        1259863.20000       20.81000-
  1244  P8782     UL   182680.20000        3.31000     182679.90000    182680.20000       21.07000-
  1245  F8183     LL    43547.00000       28.56000      43547.00000     62993.10000        4.18000
  1246  F8283     UL    62993.10000       29.55000      44779.10000     62993.10000       18.17000-
  1247  F8383     UL    81891.90000       26.59000      80432.00000     81891.90000       21.13000-
  1248  F8483     UL   119687.00000       25.61000      81528.40000    119687.00000       22.11000-
  1249  F8583     UL   245673.30000       23.24000     192427.50000    245673.30000       24.48000-
  1250  F8683     UL  1259863.20000        3.71000           .        1259863.20000       44.01000-
  1251  P8783     UL   182680.20000        3.41000     182679.60000    182680.20000       44.31000-
  1252  F8184     UL    62993.10000       30.16000      48600.00000     62993.10000       39.33000-
  1253  F8284     UL    62993.10000       31.20000      47813.50000     62993.10000       38.29000-
  1254  F8384     UL    81891.90000       28.08000      81890.50000     81891.90000       41.41000-
  1255  F8484     UL   119687.00000       27.04000      80347.40000    119687.00000       42.45000-
  1256  F8584     UL   245673.30000       24.54000     198546.00000    245673.30000       44.95000-
  1257  F8684     UL  1259863.20000        3.86000           .        1259863.20000       65.63000-
  1258  P8784     UL   182680.20000        3.51000     182679.10000    182680.20000       65.98000-
  1259  F8185     UL    62993.10000       32.04000      52527.50000     62993.10000       46.64000-
  1260  F8285     UL    62993.10000       33.15000      51789.60000     62993.10000       45.53000-
  1261  F8385     UL    81891.90000       29.83000      81477.50000     81891.90000       48.85000-
  1262  F8485     UL   119687.00000       28.73000      83690.20000    119687.00000       49.95000-
  1263  F8585     UL   245673.30000       26.07000     201117.70000    245673.30000       52.61000-
  1264  F8685     UL  1259863.20000        4.01000           .        1259863.20000       74.67000-
  1265  P8785     UL   182680.20000        3.61000     182679.10000    182680.20000       75.07000-
  1266  F9175     LL          .            8.62000           .         189216.00000         .95000
  1267  F9275     LL          .            8.62000           .         315360.00000         .95000
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              EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  1268   F9176    LL        .             9.20000          .          189216.00000      2.90000
  1269   F9276    LL        .             9.20000          .          315360.00000      2.90000
  1270   F9177    LL        .             9.77000          .          189216.00000      2.28000
  1271   F9277    LL        .             9.77000          .          315360.00000      2.28000
  1272   F9178    LL        .            10.80000          .          189216.00000      2.02000
  1273   F9278    LL        .            10.80000          .          315360.00000      2.02000
  1274   F9179    LL        .            11.50000          .          189216.00000      2.50000
  1275   F9279    LL        .            11.50000          .          315360.00000      2.50000
  1276   F9180    BS   89536.20018         12.30000          .          189216.00000       .
A 1277   F9280    UL  315360.00000         12.30000          .          315360.00000       .
  1278   F9181    UL  189216.00000         13.22000          .          189216.00000      3.50000-
  1279   F9281    UL  315360.00000         13.22000          .          315360.00000      3.50000-
  1280   F9182    UL  189216.00000         14.14000          .          189216.00000     10.24000-
  1281   F9282    UL  315360.00000         14.14000          .          315360.00000     10.24000-
  1282   F9183    UL  189216.00000         15.06000          .          189216.00000     32.66000-
  1283   F9283    UL  315360.00000         15.06000          .          315360.00000     32.66000-
  1284   F9184    UL  189216.00000         16.21000          .          189216.00000     53.28000-
  1285   F9284    UL  315360.00000         16.21000          .          315360.00000     53.28000-
  1286   F9185    UL  189216.00000         17.25000          .          189216.00000     61.43000-
  1287   F9285    UL  315360.00000         17.25000          .          315360.00000     61.43000-
```

XVII. APPENDIX G: FUEL CONSUMPTION AND COST NOMOGRAPHS

Heat values of fuels consumed by the utility companies vary over a broad range according to Weekly Energy Reports (143). For convenient reference, some nomographs have been developed so that one can calculate the amount of fuel consumed annually by one installed kW of capacity of generating units with various heat rates at plant factors of 0.80, 0.85, and 1.00. If the values obtained from the nomographs with a 1.00 plant factor are multiplied by any plant factor, the corresponding amount of fuel consumption per kW per year is obtained.

Figure G.1, Figure G.2, and Figure G.3 indicate the coal consumption of generating units with various heat rates in tons per kW of capacity per year for various coal heat values at various plant factors.

Figure G.4, Figure G.5, and Figure G.6 give the oil consumption of generating units with various heat rates in barrels per kW of capacity per year for various oil heat values at various plant factors.

Figure G.7, Figure G.8, and Figure G.9 show the natural gas consumption of generating units with various heat rates in cubic feet per kW of capacity per year for various natural gas heat values at various plant factors.

The following formulas are used to calculate the amount of fuel consumed annually by one installed kW of capacity of generating units at an assumed plant factor:

For coal-burning units:

$$\text{tons/kW/year} = \frac{(\text{Heat rate of the unit Btu/kWh}) \times 8760 \times (\text{Plant Factor})}{(\text{Heat value of coal Btu/ton}) \times (2000 \text{ lb/ton})}$$

For oil-burning units:

$$\text{Bbl/kW/year} = \frac{(\text{Heat rate of the unit Btu/kWh}) \times 8760 \times (\text{Plant Factor})}{(\text{Heat value of oil Btu/gal}) \times (42 \text{ gal/Bbl})}$$

For gas-burning units:

$$\text{cf/kW/year} = \frac{(\text{Heat rate of the unit Btu/kWh}) \times 8760 \times (\text{Plant Factor})}{(\text{Heat value of gas Btu/cf})}$$

Figure G.10 gives fuel costs in mills per kWh when fuel costs in cents per MBtu and the heat rate of the generating units in Btu per kWh are known.

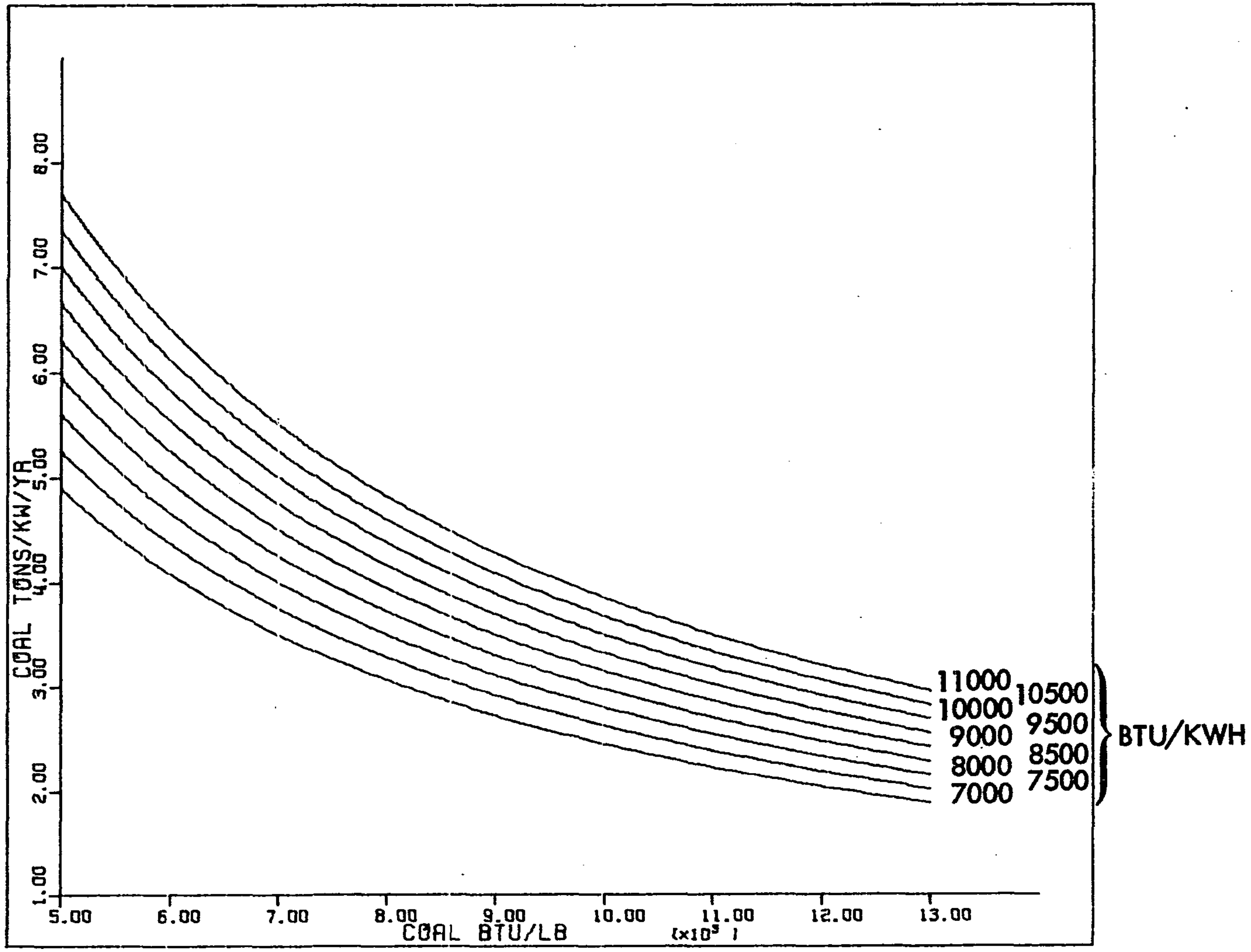

Figure G.1. Coal consumption of generating units with various heat rates for various coal heat values at a plant factor of 0.80 in tons/kW/year

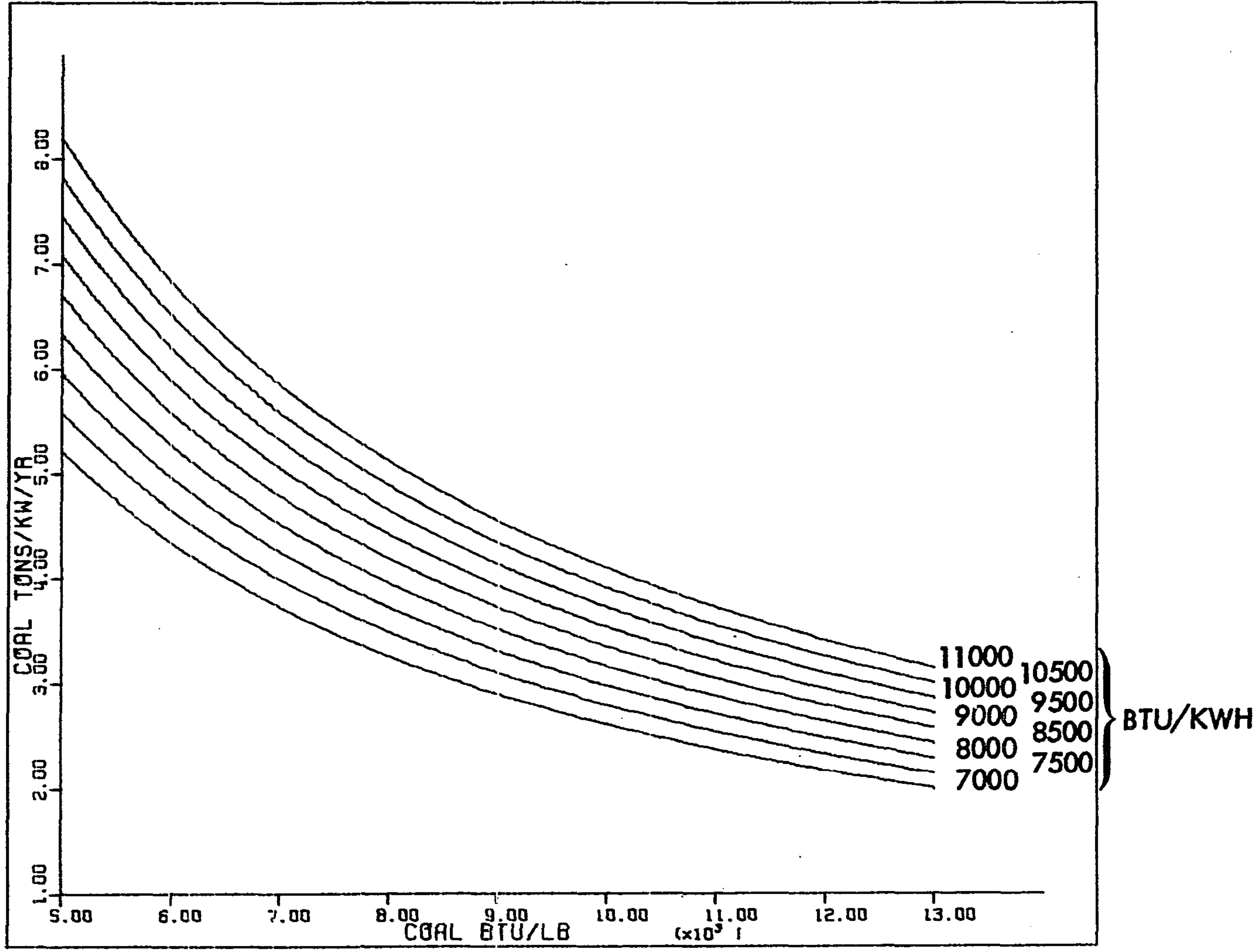

Figure G.2. Coal consumption of generating units with various heat rates for various coal heat values at a plant factor of 0.85 in tons/kW/year

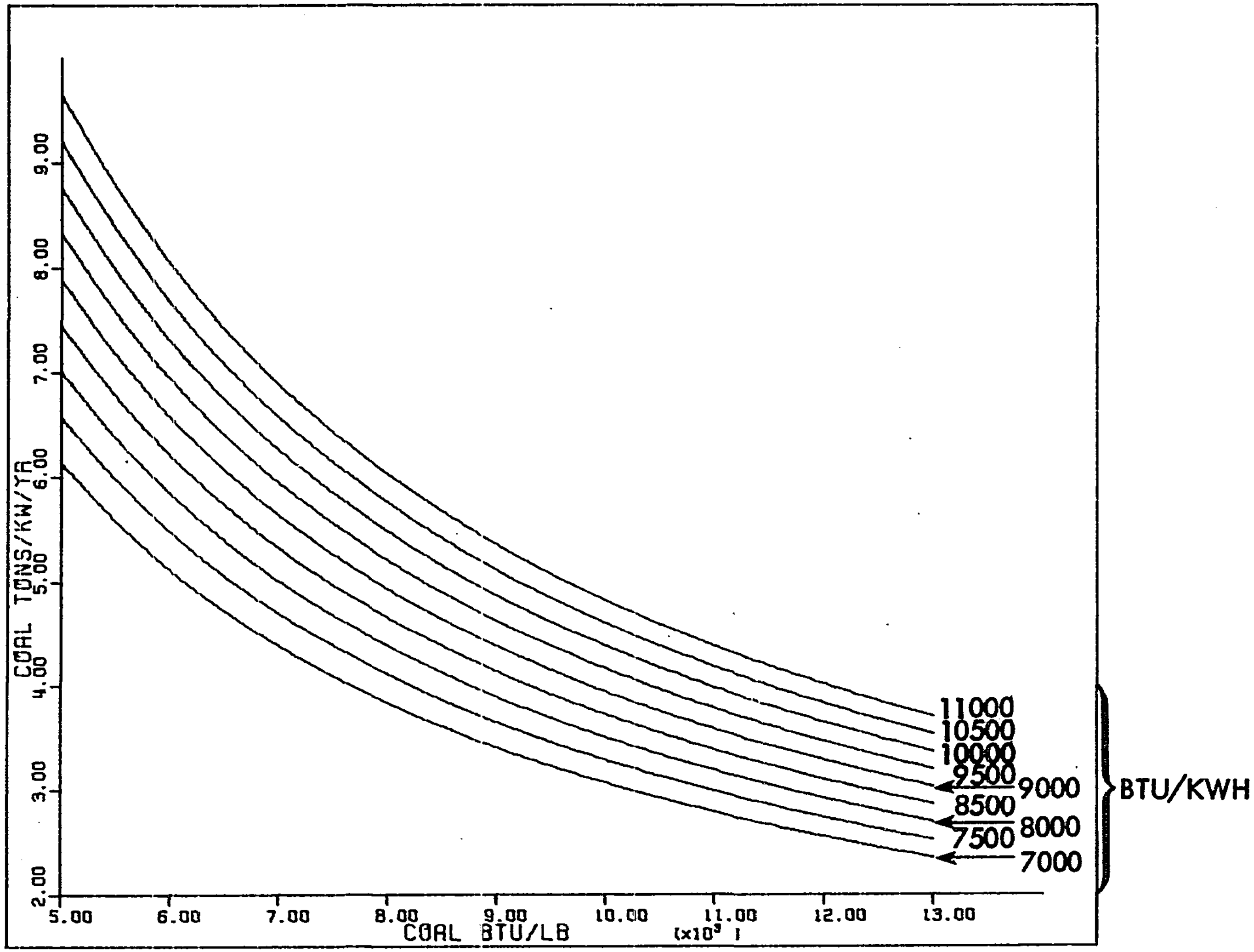

Figure G.3. Coal consumption of generating units with various heat rates for various coal heat values at a plant factor of 1.00 in tons/kW/year

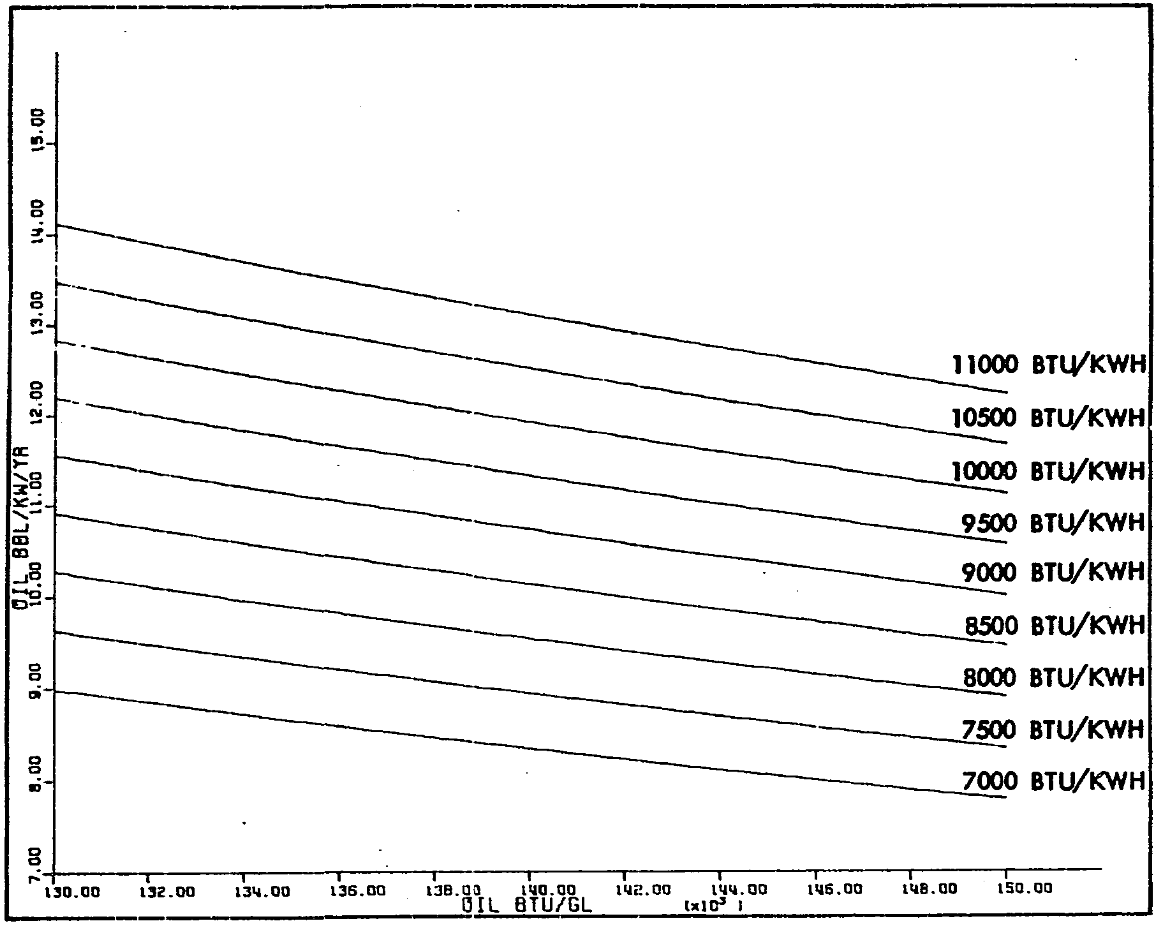

Figure G.4. Oil consumption of generating units with various heat rates for various oil heat values at a plant factor of 0.80 in barrels/kW/year

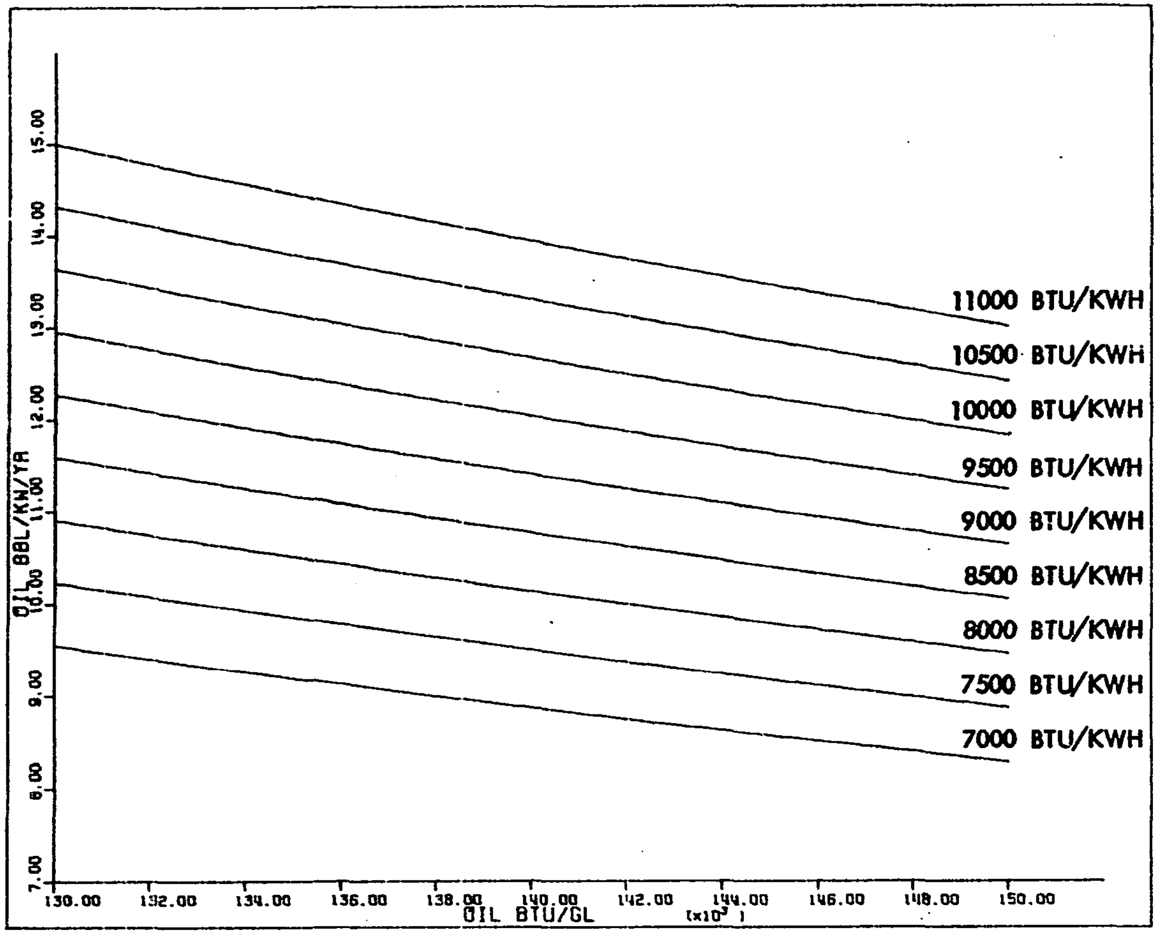

Figure G.5. Oil consumption of generating units with various heat rates for various oil heat values at a plant factor of 0.85 in barrels/kW/year

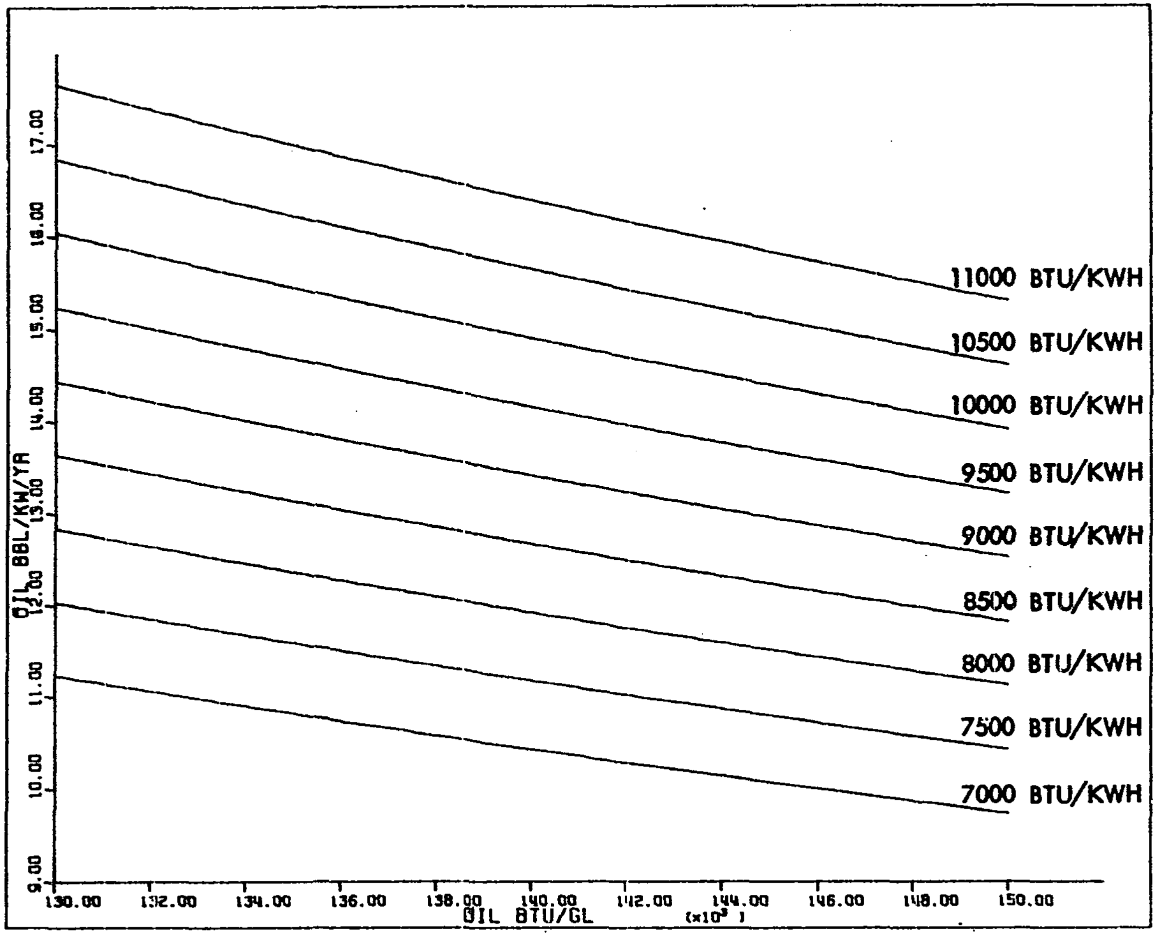

Figure G.6. Oil consumption of generating units with various heat rates for various oil heat values at a plant factor of 1.00 in barrels/kW/year

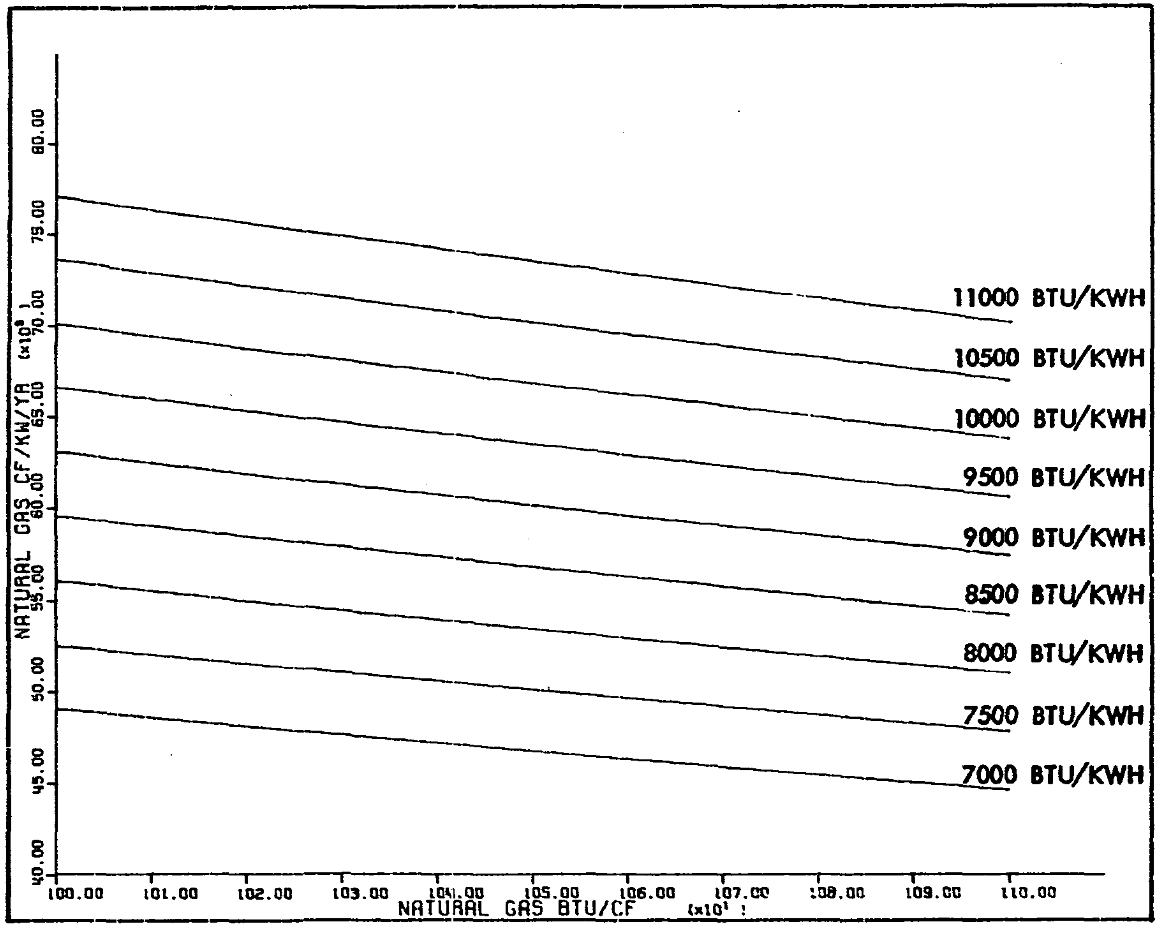

Figure G.7. Natural gas consumption of generating units with various heat rates for various natural gas heat values at a plant factor of 0.80 in cf/kW/year

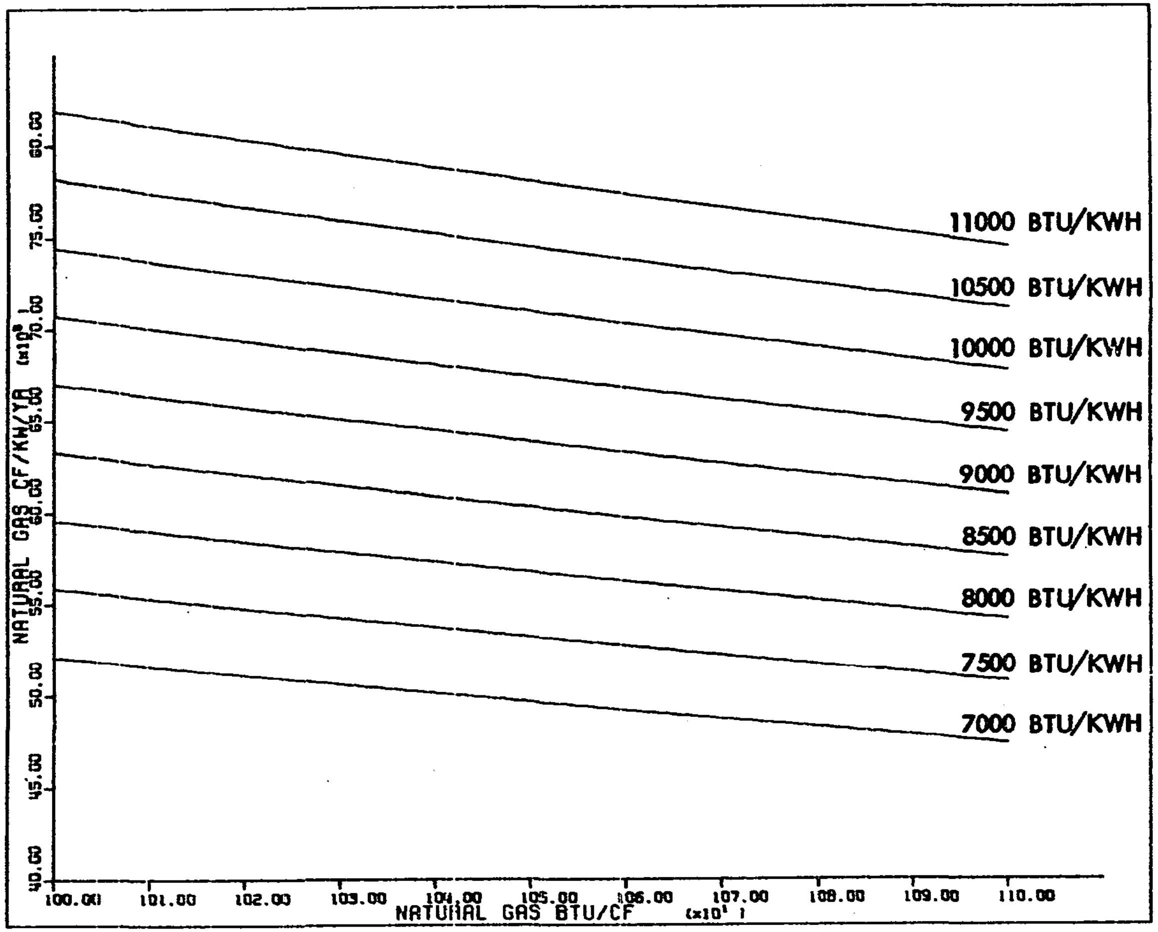

Figure G.8. Natural gas consumption of generating units with various heat rates for various natural gas heat values at a plant factor of 0.85 in cf/kW/year

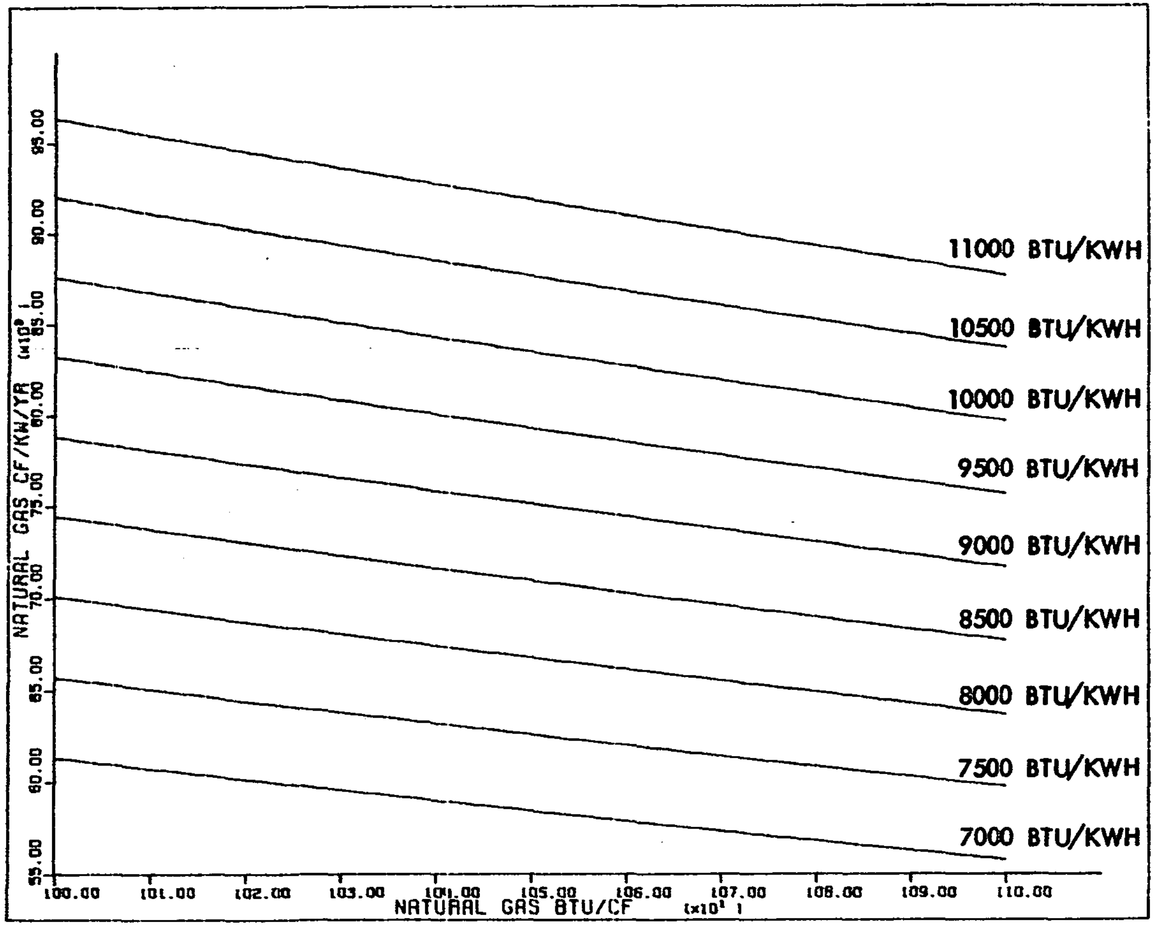

Figure G.9. Natural gas consumption of generating units with various heat rates for various natural gas heat values at a plant factor of 1.00 in cf/kW/year

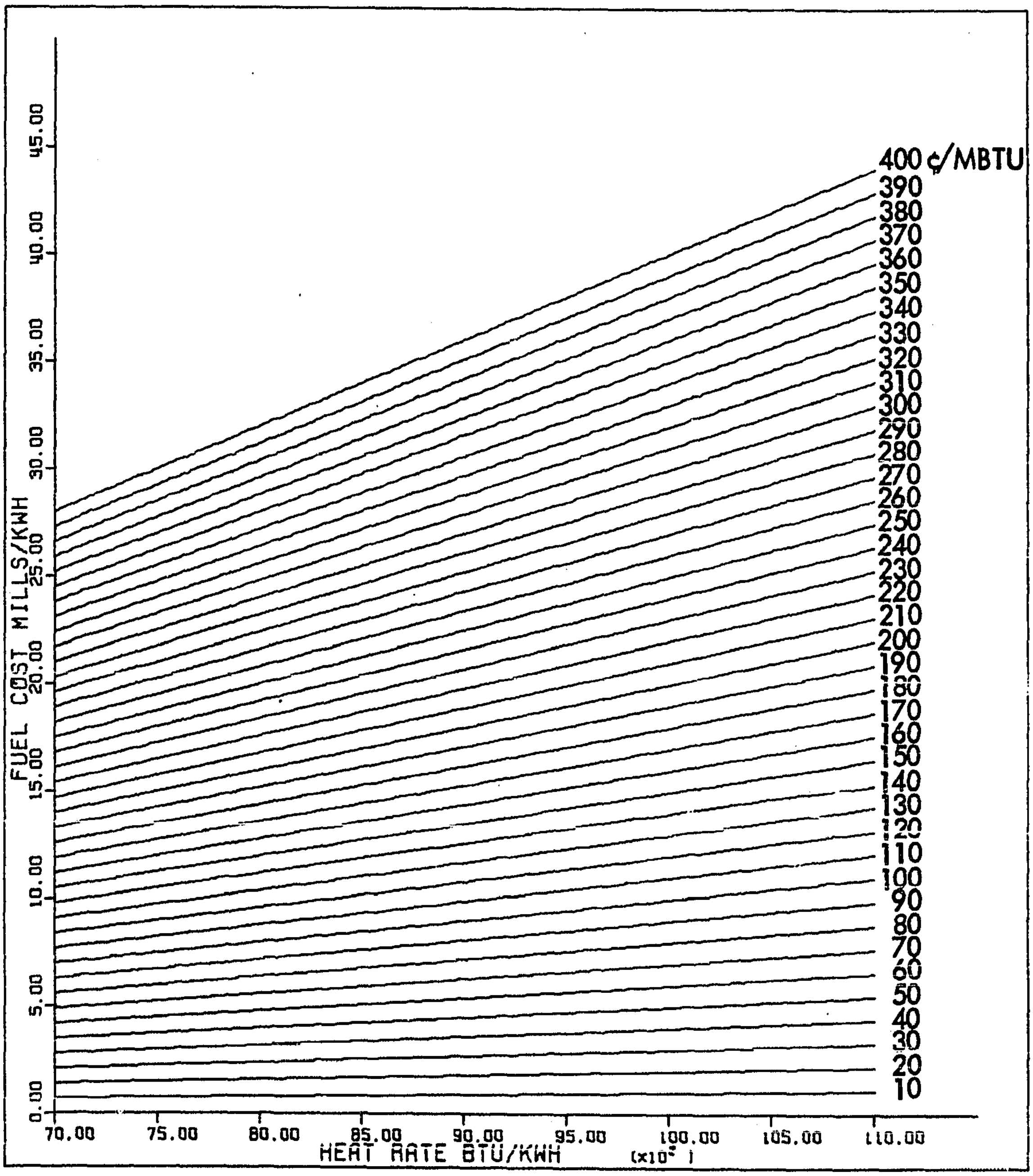

Figure G.10. Fuel costs in mills/kWh of generating units with various heat rates for various fuel costs in cents/MBtu

XVIII. APPENDIX H: LINEAR PROGRAMMING COMPUTATIONS USING MPSX SYSTEM

In Chapter V, we have explained the FAM which uses a Linear Programming optimization technique. There are many linear programming solution procedures available for the various makes and models of computers. The majority of these programs have been well-tested and are readily available for use. A major drawback that existed in the past was that the control language or the control commands to properly execute linear program solutions were difficult to learn and difficult to use properly (139). Although most linear programming computer programs have much in common, each has unique characteristics.

In this Appendix, we attempt to indicate and describe some of the options and procedures of MPSX (which is used in our energy model); and how to set up the input data and the control program to convey our solution strategy to MPSX.

The control program is composed of a set of procedures or commands for solving a linear programming problem in an orderly fashion (140).

A. Data Format

The input format of MPSX consists of two types of cards: (1) indicator cards and (2) data cards. The indicator cards specify the type of data that is to follow. Some of these are NAME, ROWS, COLUMNS, RHS, RANGES, BOUNDS, AND ENDATA, as shown in Figure H.1.

Each card is always punched so that its first character is in column 1. Each indicator card specifies a certain command and identifies a section or block data to the MPSX system. Command cards are placed

	F	1		Field 2	Field 3	Field 4	Field 5	Field 6
1	2	3		5 12	15 22	25 36	40 47	50 61
N	A	M	E		Data Set Name			
*	COMMENTS CARDS → 80							
R	O N G L E	W	S	Row Name				
C	O	L	U	M N S Column Name	Row Name 1	Value 1	Row Name 2	Value 2
R	H	S		RHS Name	Row Name 1	Value 1	Row Name 2	Value 2
R	A	N	G	E S Range Name	Row Name 1	Value 1	Row Name 2	Value 2
B	O L U F M P F	U O P X I L R	N	D S Bound Row Name	Column Name	Value		
E	N	D	A	T A				

Figure H.1. Input format

anywhere in the data deck by putting an asterisk (*) in column 1.

B. Data Preparation

A NAME card is always the first card in the input deck and an ENDATA is always the last card used to terminate the data deck. The NAME card contains a name (e.g., MODIPL 11, or MODPOOL) in field 3, which cannot have more than 8 characters, and is used to identify the data set to the MPSX.

The second data card contains the letters ROWS in the first four columns. The purpose of the row section is to define the type of row constraints that have been incorporated in the model. There are four indicators used to identify the type of row in the model followed by some name. The row type is specified according to the following code:

N = Objective function or nonrestrictive row
G = Minimum restraint (greater than or equal to)
L = Maximum restraint (less than or equal to)
E = Equality

The objective function or functions are labeled C or C2, C3, etc. in columns 5-12 of field 2. The other rows can have any name of not more than 8 characters entered in columns 5-12. The traditional R1, R2, ..., RX labeling system is used throughout in this study.

The column section specifies the restriction coefficients and the names to be labeled with each structural variable. The word COLUMNS is entered in the first 7 columns. Since the MPSX system will originally treat all coefficients in our model as zeros, we need only to declare nonzero entries in the data deck.

It should be noted that the matrix elements in the column section are specified by column. Hence, once a column name is specified, all other nonzero entries in that column must be declared before another column is defined. In order to do this, one must first enter the column name in columns 5-12 of field 3, and the coefficient values in columns 25-36 of field 4.

The resource vectors are specified in the right-hand side section. The input format is basically the same as defined in the column section, but a unique RHS name is declared for each resource vector defined.

The range section can be used to condense the input data. It has the effect of making more useful the interpretation of the shadow prices by providing an estimate of the range over which a shadow price is relevant. A RANGE card is added to the control deck immediately following the SOLUTION card.

The bound section is used to place bounds on the capacity of generating units. When bounds are not declared they are automatically set at zero and positive infinity. The bounds section of the data deck is preceded by the letters BOUNDS in columns 1-6. Because it is possible to obtain multiple solutions in the same computer run based upon different sets of bounds, names are given to the bound rows, e.g., BND1, BND2, ..., BNDX, to distinguish different bound sets.

Field 1 specifies the type of bound to be imposed on an activity. The following indicators are used:

UP = Upper bound or maximum

LO = Lower bound or minimum

FX = Fixed bound or minimum

MI = Lower bound of negative infinity

PL = Upper bound of positive infinity

FR = Free variable

C. Control Program

The control program is a set of procedures specified by the user to define the strategy to be used in solving the model. Table H.1 gives an example of a general control program used in our study.

The first command in the control program is PROGRAM which indicates to the MPSX system that the program is to follow and includes a listing of all coding errors if any are desired. If any errors are found in the program, the system will terminate before the input data is read. The second command is INITIALZ which establishes initial settings of all tolerances at their standard values (139).

The next two statements move the name of the data, MODEILP, into the MPSX cell XDATA and move the problem file name, PBFILE, into the cell XPBNAME. These two cells must be defined before such procedures as CONVERT and SETUP can be indicated in the control program (140). MVADR(XMAJERR,UNB) puts in the location XMAJERR the address of the first member of UNB. MVADR(XDONFS,NOF) puts in the location of XDONFS the address of the first member of UNB.

The CONVERT statement instructs the MPSX system to check the input data for proper specifications and to convert the data into internal representation onto the PROBFILE device with a problem name of PBFILE.

The next instruction SETUP('MIN','BOUNDS','BND1') will allocate

```
C.......................................................................
C
C TABLE H.1. A GENARAL CONTROL PROGRAM.
C
C.......................................................................
          PROGRAM
          INITIALZ
          MOVE(XDATA,'MODEILP')
          MOVE(XPENAME,'PBFILE')
          MVADR(XMAJERR,UNB)
          MVADR(XCONFS,NOF)
          CONVERT
          SETUP('MIN','BOUNDS','BND1')
          MOVE(XRHS,'B')
          MOVE(XOBJ,'C')
          PRIMAL
          PICTURE
          SOLUTION
          EXIT
NOF       TRACE
UNB       EXIT
          PEND
/*
```

memory space within the computer and add appropriate slack variables. The added parameter 'MIN' specifies that the problem is to be minimized. The parameters 'BOUNDS' and 'BND1' imply that in the bound section the vector BND1 is to be used in solving the problem. If these parameters are omitted, the solution given will be obtained without these restrictions. Since there may exist many objective functions (C's) or resource vectors (B's) in the input deck, the following two instructions specify which vectors are relevant. In this example, the resource vector, B, is moved into the MPSX XRHS cell and the objective function name, C, is moved into the cell XOBJ.

PRIMAL instructs MPSX to apply a variant of the simplex algorithm to solve the problem. PICTURE creates a pictorial representation of the specified portion of the current matrix. All numbers other than ±1 are converted to alphabetic codes that indicate magnitude.

In order to get the output for the solution the command SOLUTION is used. After the solution the commands EXIT and PEND are given. They terminate the program and turn over control to the IBM system. TRACE creates a report of those vectors that may be related to the cause of an infeasibility.

Table H.2 gives a typical set of job control language cards which instruct the computer where to find the MPSX program. The control program follows the //MPSCOMP.SYSIN DD * card and the input data follows the //MPSEXEC.SYSIN DD * card.

D. Multiple C Rows

The convention of labeling the original objective function C and

```
C......................................................................
C
C TABLE H.2. JOB CONTROL LANGUAGE CARDS.
C
C......................................................................
//C26STG   JOB    I4375.GONEN
//STEP1       EXEC     MPSX
//MPSCOMP.SYSIN DD *
(CONTROL PROGRAM)
/*
//MPSEXEC.SYSIN DD *
(DATA)
/*
```

subsequent functions C2, C3, ..., CX has been followed in preparing control cards. Each C row contained in the model is labeled in the ROWS section in the data deck. All C rows are preceded by the letter N in the field 1. The name of the row (e.g., C, C2, C3, etc.) appears in field 2, left-justified.

In entering the coefficients C row data are treated the same as data from other rows. The column name is given in field 3, and the coefficient in field 4. A second row, for example, C2, may be named in field 5 and its coefficient in field 6. A control program for the multiple C rows is shown in Table H.3.

E. Combination of Multiple C Rows and Multiple B Rows

The control program can be extended to include any number of B columns by reproducing (with the appropriate B column label for each B column intended) the control cards from MOVE through SOLUTION. The B column names and coefficients are always entered on the data sheet under the RHS section.

The names given B columns on the data sheet correspond exactly to those contained on the control cards. Because of the convention of naming B columns B, B2, B3, ..., BX has been followed in preparing the control program, the labeling of the B columns in the RHS section of the data deck follows the same system.

Any combination of B columns and C rows may be included in one model and a single computer run. Table H.4 shows a control program for the combination of multiple C rows and multiple B columns and bounds.

```
C................................................
C
C TABLE H. 3. A CONTROL PROGRAM FOR THE MULTIPLE C'S.
C
C................................................
//C269TG   JOB    I4375,GONEN
//*MAIN CRG=ANYLCCAL
//STEP1       EXEC     MPSX
//MFSCCMF.SYSIN CD *
              FRCGRAM
              INITIALZ
              MOVE(XDATA,'MCDIPLII')
              MOVE(XPBNAME,'PBFILE')
              MVADR(XMAJERR,UNB)
              MVACR(XCONFS,NOF)
              CCNVERT
              SETUP('MIN','BOUNCS','BND1')
              MOVE(XRHS,'B')
              MCVE(XOBJ,'C')
              PICTURE
              PRIMAL
              SAVE
              SOLUTICN
              MOVE(XOBJ,'C2')
              PICTURE
              RESTORE
              PRIMAL
              SAVE
              SCLUTION
              MOVE(XOBJ,'C3')
              PICTURE
              RESTORE
              PRIMAL
              SCLUTION
              EXIT
NCF           TRACE
UNB           EXIT
```

```
          FEND
/*
//MPSEXEC.SYSIN DD *
```

```
C......................................................................
C
C TABLE H.4. A CONTROL PROGRAM FOR THE MULTIPLE C'S AND MULTIPLE B'S
C AND BOUNDS.
C
C......................................................................
//C269TG  JOB   I4378,GONEN
//STEP1      EXEC     MPSX,TIME.MPSEXEC=1
//*MAIN LINES=50
//MPSCOMP.SYSIN DD *
          PROGRAM
          INITIALZ
          MOVE(XDATA,'MODIPL11')
          MOVE(XPENAME,'PBFILE')
          MVADR(XMAJERR,UNB)
          MVADR(XCONFS,NCF)
          CONVERT
          SETUP('MIN','BOUNDS','BND1')
          MOVE(XRHS,'B')
          MOVE(XOBJ,'C')
          PRIMAL
          SAVE
          SOLUTION
          MOVE(XRHS,'B2')
          RESTORE
          PRIMAL
          SAVE
          SOLUTION
          MOVE(XRHS,'B3')
          RESTORE
          PRIMAL
          SAVE
          SOLUTION
          MOVE(XRHS,'B4')
          RESTORE
          PRIMAL
          SAVE
```

```
SOLUTION
MOVE(XRHS,'B5')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B6')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B')
MOVE(XOBJ,'C2')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B2')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B3')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B4')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B5')
RESTORE
PRIMAL
SAVE
SOLUTION
```

```
MOVE(XRHS,'B6')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B')
MOVE(XOBJ,'C3')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B2')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B3')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B4')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B5')
RESTORE
PRIMAL
SAVE
SOLUTION
MOVE(XRHS,'B6')
RESTORE
PRIMAL
SAVE
SOLUTION
CHECK
```

```
       EXIT
NCF    TRACE
UNB    EXIT
       FEND
/*
//MPSEXEC.SYSIN DD *
/*
```

F. Other Commands

In order to find out that the proposed model is defined and coded correctly, the command PICTURE can be used. This command can appear anywhere after the CONVERT statement. PICTURE creates a picture of the magnitude of the nonzero coefficients which are indicated by alphabetic code. This command is useful in finding errors before a problem is executed.

If one wants to solve one problem and then solve a similar problem without starting from step one of the simplex algorithm, the only instructions needed are SAVE and RESTORE. The SAVE procedure will save the optimal basis and is usually placed in the control program after the PRIMAL command. The RESTORE instruction will bring back into the solution the vectors saved using the SAVE command. The RESTORE statement is placed after the second problem is specified and before PRIMAL is called.

G. Interpretation of Computer Output

Out main interest centers on sections 1 and 2 of the computer output. Section 1 gives the value of the program in the C row of the column labeled ACTIVITY. The remaining entries in this column indicate how much of the original B column value is used in the production process.

The shadow prices for the disposal or slack activities are printed in the column labeled DUAL ACTIVITY. The C row value which is shown in this column should be ignored. The remaining values specify the change in the value of the program which would result from one less unit of restraint (or resource) in the original B column entry.

Section 2 provides information on the real activities in the solution.

Activity levels are printed out under a column labeled ACTIVITY.

The column INPUT COST only repeats the net prices assigned in the original model. Hence they have no significance in interpreting the output report except as a means of checking to see that they correspond to the values originally intended.

The lower and upper limit columns will contain meaningful entries only when the original model includes provisions for bounding the activities. In the latter case any bounds imposed are printed out as a reminder.

For the purpose of illustration, a computer output report of the company 4 (ISP) is presented in the following pages. In this output report, the level of activities appears in MWh in order to construct the model more easily.

```
             EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

CONVERT MODISP   TO PBFILE

TIME =   0.00

1- ROWS SECTION.


   0 MINOR ERROR(S) -   0 MAJOR ERROR(S).

2- COLUMNS SECTION.


   0 MINOR ERROR(S) -   0 MAJOR ERROR(S).

3- RHS'S SECTION.

  B

   0 MINOR ERROR(S) -   0 MAJOR ERROR(S).

5- BOUNDS SECTION.

  BND1

   0 MINOR ERROR(S) -   0 MAJOR ERROR(S).

 PROBLEM STATISTICS

    23 LP ROWS,     243 VARIABLES,     681 LP ELEMENTS, DENSITY =  12.18

 THESE STATISTICS CONTAIN ONE SLACK VARIABLE FOR EACH ROW

     0 MINOR ERRORS,     0 MAJOR ERRORS.
```

This page of the computer output gives a summary of the MPSX data to indicate whether there is an error in rows, columns, right hand sides or bounds sections, and, if there is, in which section the errors are. It also gives information about the statistics of the problem, e.g., the number of LP rows, variables, and LP elements.

```
                 EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

SETUP  PBFILE

TIME =   0.03

    MIN
    BOUNDS    = BND1
    SCALE


 MATRIX1   ASSIGNED TO MATRIX1

 ETA1      ASSIGNED TO ETA1

 SCRATCH1 ASSIGNED TO SCRATCH1
 SCRATCH2 ASSIGNED TO SCRATCH2

 MAXIMUM PRICING NOT REQUIRED - MAXIMUM POSSIBLE    7

 NO CYCLING

     POOLS          NUMBER    SIZE     CORE
 H.REG-BITS MAP                         136
 BOUND   VECTOR                         208
 WORK    REGIONS      9        208     1872
 MATRIX  BUFFERS      3       7152    21456
 ETA     BUFFERS      3       3216     9648

                               TOTAL  NORMAL   .FREE.    FIXED BOUNDED
 ROWS     (LOG.VAR.)             23      11       1       11       0
 COLUMNS  (STR.VAR.)            220       0       0        0     220

      681 ELEMENTS - DENSITY =  12.18 -      3 MATRIX RECORDS (WITHOUT RHS'S)
```

Basically the commands on this page are just internal commands. They are not necessarily meaningful to the user. They only give information about how the space in the computer memory should be allocated.

```
PRIMAL        OBJ = C           RHS = B

TIME =     0.04  MINS.        PRICING    7
 SCALE =     .

  ITER     NUMBER   VECTOR    VECTOR   REDUCED       SUM
 NUMBER    INFEAS    OUT        IN       COST        INFEAS
M    1       15       18       141    2.00000     .44E+07
     2                20       181    2.00000     .44E+07
     3                21       201    2.00000     .44E+07
     4                13        30    2.00000     .44E+07
     5                19       161    2.00000     .44E+07
M    6       10        7        18    1.00000-    .38E+07
     7                 8        19    1.00000-    .33E+07
     8                 9        20    1.00000-    .30E+07
     9                10        21    1.00000-    .29E+07
    10                81        81    1.00000     .20E+07
    11                49        49    1.00000     .19E+07
    12                30        13    1.00000-    .18E+07
M   13        6        5       101    1.00000     942169.
```

The optimization iteration logs of the program are given on this page for the program which has the (C) objective function, and the (B) right hand side.

```
                  EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

    ITER    NUMBER  VECTOR  VECTOR  REDUCED     SUM
   NUMBER   INFEAS    OUT      IN     COST     INFEAS

      14                6     121  1.00000   212634.
      15                2      28  1.00000   76896.3
      16               11     221  1.00000   71912.0
      17               12     241  1.00000   68896.6
 M    18       1        3      51  1.00000   31050.0
      19               76      76  1.00000   12310.3
 M    20       0        4      75  1.00000     .
  FEASIBLE SOLUTION

 PRIMAL        OBJ = C              RHS = B

 TIME =      0.05  MINS.         PRICING    7
  SCALE =     1.00000

    ITER    NUMBER  VECTOR  VECTOR  REDUCED   FUNCTION
   NUMBER   NONOPT    OUT      IN     COST     VALUE
 M    21     193      183     183   .84733    .13E+10
      22              123     123   .84736    .13E+10
      23              103     103   .84861    .13E+10
      24               83      83   .85025    .13E+10
      25              221     242   .86370    .13E+10
      26              241     243   .86374    .13E+10
 M    27     149      197     197   .84015    .13E+10
      28              177     177   .84012    .13E+10
      29              137     137   .84019    .13E+10
      30              117     117   .84017    .13E+10
      31               97      97   .84192    .13E+10
      32              163     163   .84729    .13E+10
      33              143     143   .84726    .13E+10
 M    34     142      157     157   .84008    .13E+10
      35              184     184   .78823    .13E+10
      36              124     124   .78826    .13E+10
      37              104     104   .78829    .13E+10
      38               84      84   .79059    .13E+10
      39               75      63   .81090    .13E+10
```

Basically this page of the computer output shows whether the solution is a feasible solution. This and the following pages continue to show the optimization iteration logs.

```
M     40     124     164     164     .78821     .13E+10
      41             144     144     .78817     .13E+10
      42              98      98     .78350     .13E+10
      43              44      44     .78405     .13E+10
      44             201     198     .78108     .13E+10
      45              63      81    1.55101-    .13E+10
M     46     119      77      77     .84204     .13E+10
      47             178     178     .78102     .13E+10
      48             158     158     .78101     .13E+10
      49             138     138     .78114     .13E+10
      50             118     118     .78113     .13E+10
      51              78      78     .78453     .13E+10
      52              64      64     .79158     .13E+10
M     53     112     180     180     .76542     .13E+10
      54             120     120     .76550     .13E+10
```

```
                  EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

     ITER    NUMBER   VECTOR    VECTOR    REDUCED     FUNCTION
    NUMBER   NONOPT     OUT       IN        COST        VALUE

      55                 99        99      .76805      .13E+10
      56                100       100      .76805      .13E+10
      57                 79        79      .76909      .13E+10
      58                 80        80      .76909      .12E+10
      59                 51        58      .77203      .12E+10
 M    60       94       179       179      .76542      .12E+10
      61                159       159      .76536      .12E+10
      62                160       160      .76536      .12E+10
      63                139       139      .76547      .12E+10
      64                140       140      .76547      .12E+10
      65                119       119      .76550      .12E+10
      66                 58        49     1.38885-     .12E+10
 M    67      103        60        60      .75612      .12E+10
      68                 93        93      .75587      .12E+10
      69                 73        73      .75696      .12E+10
      70                 49        45      .77985      .12E+10
      71                181       173      .75308      .12E+10
 M    72       73       112       112      .73118      .12E+10
      73                 92        92      .73410      .12E+10
      74                 72        72      .73427      .12E+10
      75                153       153      .75305      .12E+10
      76                133       133      .75314      .12E+10
      77                113       113      .75315      .12E+10
      78                141       132      .73123      .12E+10
 M    79       55        89        89      .72934      .11E+10
      80                 69        69      .73068      .11E+10
      81                161       152      .73102      .11E+10
      82                121       109      .72644      .11E+10
 M    83       30        30        30      .54308-     .11E+10
```

```
       84           39      39     .49651    .11E+10
       85           25      25     .52315    .11E+10
       86           26      26     .33569    .11E+10
       87           40      40     .31333    .11E+10
       88           81      66     .61212    .11E+10
       89          101      86     .62914    .11E+10
M      90      7    41      41     .26429    .11E+10
       91           76      76     .44171-   .11E+10
       92           28      42     .26429    .11E+10
       93           45      60     .10779-   .11E+10
M      94      1    59      59     .06677    .11E+10
 OPTIMAL  SOLUTION
```

It is shown on this page whether or not there is an optimum solution. The last iteration number, which is number 94 in this example, is the number of Gauss-Jordan elimination tables that it took to get the optimum solution.

```
                EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

SOLUTION   (OPTIMAL)

TIME =    0.06 MINS. ITERATION NUMBER =    94

          ...NAME...     ...ACTIVITY...         DEFINED AS

          FUNCTIONAL    1120593495.63           C
          RESTRAINTS                            B
          BOUNDS....                            BND1
```

Shown on this page are the optimum solution, the value of the (C) objective function, the (B) right hand side, the (BNDl) bounds, the iteration number and the time that it took to solve the problem.

Basically, this page gives a summary of the input data of the program.

```
                EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL  5

SECTION 1 - ROWS

NUMBER  ...ROW..   AT  ...ACTIVITY...   SLACK ACTIVITY  ..LOWER LIMIT.  ..UPPER LIMIT.  .DUAL ACTIVITY

     1  C          BS  1120593495.63    1120593495.63-           NONE            NONE         1.00000
     2  R1         EQ  3178000.00000          .         3178000.00000   3178000.00000        29.40000-
     3  R2         EQ  3368999.99999          .         3368999.99999   3368999.99999        31.45000-
     4  R3         EQ  3571000.00000          .         3571000.00000   3571000.00000        24.76000-
     5  R4         EQ  3784999.99999          .         3784999.99999   3784999.99999        26.39000-
     6  R5         EQ  4012999.99998          .         4012999.99998   4012999.99998        32.90000-
     7  R6         EQ  4252999.99998          .         4252999.99998   4252999.99998        35.83000-
     8  R7         EQ  4508000.00000          .         4508000.00000   4508000.00000        38.33000-
     9  R8         EQ  4778999.99999          .         4778999.99999   4778999.99999        44.67000-
    10  R9         EQ  5064999.99999          .         5064999.99999   5064999.99999        53.90000-
    11  R10        EQ  5368999.99998          .         5368999.99998   5368999.99998        92.66000-
    12  R11        EQ  5691999.99999          .         5691999.99999   5691999.99999        99.15000-
    13  R12        BS  3178000.00000     450405.79997            NONE   3628405.79996          .
    14  R13        BS  3368999.99999     259405.80000            NONE   3628405.79998          .
    15  R14        BS  3571000.00000    1695227.89998            NONE   5266227.89997          .
    16  R15        BS  3784999.99999    1481227.89999            NONE   5266227.89998          .
    17  R16        BS  4012999.99998    1253227.90001            NONE   5266227.89999          .
    18  R17        BS  4252999.99998    1013227.89999            NONE   5266227.89997          .
    19  R18        BS  4508000.00000     758227.89998            NONE   5266227.89998          .
    20  R19        BS  4778999.99999     487227.89999            NONE   5266227.89997          .
    21  R20        BS  5064999.99999     201227.89998            NONE   5266227.89998          .
    22  R21        BS  5266227.89997          .                  NONE   5266227.89997          .
    23  R22        BS  5265227.89997          .                  NONE   5266227.89997          .
```

A summary of the column section. The optimal solution can be read under the activity column.

```
              EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

SECTION 2 - COLUMNS

 NUMBER  .COLUMN.  AT   ...ACTIVITY...    ..INPUT COST..   ..LOWER LIMIT.   ..UPPER LIMIT.   .REDUCED COST.

     24  F4175     UL    29606.80000        12.32000             .           29606.80000       17.08000-
     25  F4275     LL          .            45.36000             .           37795.90000       15.96000
     26  F4375     LL          .            32.56000             .           52284.30000        3.16000
     27  F4475     UL   116537.30000         7.84000             .          116537.30000       21.56000-
     28  F4575     UL  1385849.50000        21.63000             .         1385849.50000        7.77000-
     29  F4675     UL    94489.70000        12.87000             .           94489.70000       16.53000-
     30  F4775     UL   188979.50000         7.16000             .          188979.50000       22.24000-
     31  F4875     UL   220476.10000        25.20000             .          220476.10000        4.20000-
     32  F4975     UL    75591.80000         9.79000             .           75591.80000       19.61000-
     33  F41075    UL    75591.80000         7.67000             .           75591.80000       21.73000-
     34  F41175    UL   529142.50000        25.54000             .          529142.50000        3.86000-
     35  F41275    UL   110238.00000        27.93000             .          110238.00000        1.47000-
     36  F41375    UL    67402.70000         9.72000             .           67402.70000       19.68000-
     37  F41475    UL   212916.90000         8.58000             .          212916.90000       20.82000-
     38  F41575    UL    34646.20000        10.92000             .           34646.20000       18.48000-
     39  F41675    LL          .            42.96000             .           66142.80000       13.56000
     40  F41775    LL          .            31.50000             .           56693.80000        2.10000
A    41  F41875    LL          .            29.40000             .          139844.80000         .
     42  F41975    BS    36531.20002        29.40000             .          134175.40000         .
     43  F4176     UL    29606.80000        13.18000             .           29606.80000       18.27000-
     44  F4276     LL          .            48.53000             .           37795.90000       17.08000
     45  F4376     LL          .            34.84000             .           52284.30000        3.39000
     46  F4476     UL   116537.30000         8.39000             .          116537.30000       23.06000-
     47  F4576     LL  1385849.50000        23.14000             .         1385849.50000        8.31000-
     48  F4676     UL    94489.70000        13.77000             .           94489.70000       17.68000-
     49  F4776     UL   188979.50000         7.67000             .          188979.50000       23.78000-
     50  F4876     UL   220476.10000        26.96000             .          220476.10000        4.49000-
     51  F4976     UL    75591.80000        10.48000             .           75591.80000       20.97000-
     52  F41076    UL    75591.80000         8.21000             .           75591.80000       23.24000-
     53  F41176    UL   529142.50000        27.33000             .          529142.50000        4.12000-
     54  F41276    UL   110238.00000        29.88000             .          110238.00000        1.57000-
     55  F41376    UL    67402.70000        10.40000             .           67402.70000       21.05000-
     56  F41476    UL   212916.90000         9.18000             .          212916.90000       22.27000-
     57  F41576    UL    34646.20000        11.68000             .           34646.20000       19.77000-
```

```
     58  F41676   LL         .             45.97000        .        66142.80000     14.52000
     59  F41776   LL         .             33.70000        .        56693.80000      2.25000
     60  F41876   BS     93355.80001       31.45000        .       139844.80000       .
A    61  F41976   UL    134175.40000       31.45000        .       134175.40000       .
     62  F4177    UL     29606.80000       14.10000        .        29606.80000     10.66000-
     63  F4277    LL         .             51.93000        .        37795.90000     27.17000
     64  F4377    LL         .             37.28000        .        52284.30000     12.52000
     65  F4477    UL    116537.30000        8.97000        .       116537.30000     15.79000-
     66  F4577    BS   1037415.20003       24.76000        .      1385849.50000       .
     67  F4677    UL     94489.70000       14.73000        .        94489.70000     10.03000-
     68  F4777    UL    188979.50000        8.20000        .       188979.50000     16.56000-
     69  F4877    LL         .             28.85000        .       220476.10000      4.09000
     70  F4977    UL     75591.80000       11.21000        .        75591.80000     13.55000-
     71  F41077   UL     75591.80000        8.78000        .        75591.80000     15.98000-
     72  F41177   LL         .             29.24000        .       529142.50000      4.48000
```

```
                 EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

    73  F41277    LL          .           31.97000          .         110238.00000        7.21000
    74  F41377    UL    67402.70000       11.13000          .          67402.70000       13.63000-
    75  F41477    UL   212916.90000        9.82000          .         212916.90000       14.94000-
    76  F41577    UL    34646.20000       12.50000          .          34646.20000       12.26000-
    77  F41677    LL          .           49.19000          .          66142.80000       24.43000
    78  F41777    LL          .           36.06000          .          56693.80000       11.30000
    79  F41877    LL          .           33.65000          .         139844.80000        8.89000
    80  F41977    LL          .           33.65000          .         134175.40000        8.89000
    81  F42077    UL  1637822.10000        7.77000          .        1637822.10000       16.99000-
    82  F4178     UL    29606.80000       15.09000          .          29606.80000       11.30000-
    83  F4278     LL          .           55.56000          .          37795.90000       29.17000
    84  F4378     LL          .           39.73000          .          52284.30000       13.34000
    85  F4478     UL   116537.30000        9.60000          .         116537.30000       16.79000-
    86  F4578     BS  1251415.20001       26.39000          .        1385849.50000            .
    87  F4678     UL    94489.70000       15.76000          .          94489.70000       10.63000-
    88  F4778     UL   188979.50000        8.78000          .         188979.50000       17.61000-
    89  F4878     LL          .           30.74000          .         220476.10000        4.35000
    90  F4978     UL    75591.80000       12.00000          .          75591.80000       14.39000-
    91  F41078    UL    75591.80000        9.40000          .          75591.80000       16.99000-
    92  F41178    LL          .           31.29000          .         529142.50000        4.90000
    93  F41278    LL          .           34.08000          .         110238.00000        7.69000
    94  F41378    UL    67402.70000       11.91000          .          67402.70000       14.48000-
    95  F41478    UL   212916.90000       10.51000          .         212916.90000       15.88000-
    96  F41578    UL    34646.20000       13.37000          .          34646.20000       13.02000-
    97  F41678    LL          .           52.63000          .          66142.80000       26.24000
    98  F41778    LL          .           38.43000          .          56693.80000       12.04000
    99  F41878    LL          .           35.87000          .         139844.80000        9.48000
   100  F41978    LL          .           35.87000          .         134175.40000        9.48000
   101  F42078    UL  1637822.10000        8.32000          .        1637822.10000       18.07000-
   102  F4179     UL    29606.80000       16.15000          .          29606.80000       16.75000-
   103  F4279     LL          .           59.45000          .          37795.90000       26.55000
   104  F4379     LL          .           42.51000          .          52284.30000        9.61000
   105  F4479     LL   116537.30000       10.27000          .         116537.30000       22.63000-
   106  F4579     UL  1385849.50000       28.24000          .        1385849.50000        4.66000-
   107  F4679     UL    94489.70000       17.06000          .          94489.70000       15.84000-
   108  F4779     UL   188979.50000        9.39000          .         188979.50000       23.51000-
   109  F4879     BS    93565.70000       32.90000          .         220476.10000            .
```

```
110  F4979    UL     75591.80000     12.98000    .     75591.80000   19.92000-
111  F41079   UL     75591.80000     10.05000    .     75591.80000   22.85000-
112  F41179   LL         .           33.48000    .    529142.50000     .58000
113  F41279   LL         .           36.46000    .    110238.00000    3.56000
114  F41379   UL     67402.70000     12.89000    .     67402.70000   20.01000-
115  F41479   UL    212916.90000     11.37000    .    212916.90000   21.53000-
116  F41579   UL     34646.20000     14.31000    .     34646.20000   18.59000-
117  F41679   LL         .           56.31000    .     66142.80000   23.41000
118  F41779   LL         .           41.12000    .     56693.80000    8.22000
119  F41879   LL         .           38.38000    .    139844.80000    5.48000
120  F41979   LL         .           38.38000    .    134175.40000    5.48000
121  F42079   UL   1637822.10000      9.00000    .   1637822.10000   23.90000-
122  F4180    UL     29606.80000     17.28000    .     29606.80000   18.55000-
123  F4280    LL         .           63.09000    .     37795.90000   27.26000
```

```
                    EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT   ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   124  F4380     LL          .            45.48000           .          52284.30000        9.65000
   125  F4480     UL    116537.30000       10.99000           .         116537.30000       24.84000-
   126  F4580     UL   1385849.50000       30.22000           .        1385849.50000        5.61000-
   127  F4680     LL     94489.70000       18.25000           .          94489.70000       17.58000-
   128  F4780     UL    188979.50000       10.05000           .         188979.50000       25.78000-
   129  F4880     LL    220476.10000       35.02000           .         220476.10000         .81000-
   130  F4980     UL     75591.80000       13.89000           .          75591.80000       21.94000-
   131  F41080    UL     75591.80000       10.76000           .          75591.80000       25.07000-
   132  F41180    BS    113089.59999       35.83000           .         529142.50000          .
   133  F41280    LL          .            39.01000           .         110238.00000        3.18000
   134  F41380    UL     67402.70000       13.79000           .          67402.70000       22.04000-
   135  F41480    UL    212916.90000       12.17000           .         212916.90000       23.66000-
   136  F41580    LL     34646.20000       15.31000           .          34646.20000       20.52000-
   137  F41680    LL          .            60.26000           .          66142.80000       24.43000
   138  F41780    LL          .            44.00000           .          56693.80000        8.17000
   139  F41880    LL          .            41.06000           .         139844.80000        5.23000
   140  F41980    LL          .            41.06000           .         134175.40000        5.23000
   141  F42080    LL   1637822.10000        9.63000           .        1637822.10000       26.20000-
   142  F4181     UL     29606.80000       18.49000           .          29606.80000       19.84000-
   143  F4281     LL          .            67.50000           .          37795.90000       29.17000
   144  F4381     LL          .            48.67000           .          52284.30000       10.34000
   145  F4481     UL    116537.30000       11.77000           .         116537.30000       26.56000-
   146  F4581     UL   1385849.50000       32.33000           .        1385849.50000        6.00000-
   147  F4681     UL     94489.70000       19.53000           .          94489.70000       18.80000-
   148  F4781     UL    188979.50000       10.75000           .         188979.50000       27.58000-
   149  F4881     UL    220476.10000       37.67000           .         220476.10000         .66000-
   150  F4981     UL     75591.80000       14.87000           .          75591.80000       23.46000-
   151  F41081    LL     75591.80000       11.51000           .          75591.80000       26.82000-
   152  F41181    BS    368089.60002       38.33000           .         529142.50000          .
   153  F41281    LL          .            41.75000           .         110238.00000        3.42000
   154  F41381    UL     67402.70000       14.76000           .          67402.70000       23.57000-
   155  F41481    UL    212916.90000       13.02000           .         212916.90000       25.31000-
   156  F41581    UL     34646.20000       16.38000           .          34646.20000       21.95000-
   157  F41681    LL          .            64.47000           .          66142.80000       26.14000
   158  F41781    LL          .            47.08000           .          56693.80000        8.75000
   159  F41881    LL          .            43.94000           .         139844.80000        5.61000
   160  F41981    LL          .            43.94000           .         134175.40000        5.61000
   161  F42081    UL   1637822.10000       10.31000           .        1637822.10000       28.02000-
```

```
162  F4182    UL     29606.80000        19.78000         .        29606.80000      24.89000-
163  F4282    LL         .              72.23000         .        37795.90000      27.56000
164  F4382    LL         .              52.08000         .        52284.30000       7.41000
165  F4482    UL    116537.30000        12.59000         .       116537.30000      32.08000-
166  F4582    UL   1385849.50000        34.60000         .      1385849.50000      10.07000-
167  F4682    UL     94489.70000        20.90000         .        94489.70000      23.77000-
168  F4782    UL    188979.50000        11.51000         .       188979.50000      33.16000-
169  F4882    UL    220476.10000        40.30000         .       220476.10000       4.37000-
170  F4982    UL     75591.80000        15.91000         .        75591.80000      28.76000-
171  F41082   UL     75591.80000        12.32000         .        75591.80000      32.35000-
172  F41182   UL    529142.50000        41.02000         .       529142.50000       3.65000-
173  F41282   BS    109947.10000        44.67000         .       110238.00000        .
174  F41382   UL     67402.70000        15.79000         .        67402.70000      28.88000-
```

```
                EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.  AT  ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  175   F41482    UL   212916.90000      13.93000          .         212916.90000       30.74000-
  176   F41582    UL    34646.20000      17.53000          .          34646.20000       27.14000-
  177   F41682    LL         .           68.99000          .          66142.80000       24.32000
  178   F41782    LL         .           50.37000          .          56693.80000        5.70000
  179   F41882    LL         .           47.02000          .         139844.80000        2.35000
  180   F41982    LL         .           47.02000          .         134175.40000        2.35000
  181   F42082    UL  1637822.10000      11.03000          .        1637822.10000       33.64000-
  182   F4183     UL    29606.80000      21.17000          .          29606.80000       32.73000-
  183   F4283     LL         .           77.29000          .          37795.90000       23.39000
  184   F4383     LL         .           55.72000          .          52284.30000        1.82000
  185   F4483     UL   116537.30000      13.47000          .         116537.30000       40.43000-
  186   F4583     UL  1385849.50000      37.02000          .        1385849.50000       16.88000-
  187   F4683     LL    94489.70000      22.36000          .          94489.70000       31.54000-
  188   F4783     UL   188979.50000      12.31000          .         188979.50000       41.59000-
  189   F4883     LL   220476.10000      43.12000          .         220476.10000       10.78000-
  190   F4983     UL    75591.80000      17.02000          .          75591.80000       36.88000-
  191   F41083    UL    75591.80000      13.18000          .          75591.80000       40.72000-
  192   F41183    UL   529142.50000      43.89000          .         529142.50000       10.01000-
  193   F41283    UL   110238.00000      47.79000          .         110238.00000        6.11000-
  194   F41383    UL    67402.70000      16.90000          .          67402.70000       37.00000-
  195   F41483    UL   212916.90000      14.91000          .         212916.90000       38.99000-
  196   F41583    UL    34646.20000      18.76000          .          34646.20000       35.14000-
  197   F41683    LL         .           73.82000          .          66142.80000       19.92000
  198   F41783    BS    11688.90001      53.90000          .          56693.80000         .
  199   F41883    UL   139844.80000      50.31000          .         139844.80000        3.59000-
  200   F41983    UL   134175.40000      50.31000          .         134175.40000        3.59000-
  201   F42083    UL  1637822.10000      11.80000          .        1637822.10000       42.10000-
  202   F4184     LL    29606.80000      22.65000          .          29606.80000       70.01000-
  203   F4284     UL    37795.90000      82.70000          .          37795.90000        9.96000-
  204   F4384     UL    52284.30000      60.78000          .          52284.30000       31.88000-
  205   F4484     UL   116537.30000      14.41000          .         116537.30000       78.25000-
  206   F4584     UL  1385849.50000      40.38000          .        1385849.50000       52.28000-
  207   F4684     UL    94489.70000      23.93000          .          94489.70000       68.73000-
  208   F4784     UL   188979.50000      13.17000          .         188979.50000       79.49000-
  209   F4884     UL   220476.10000      47.04000          .         220476.10000       45.62000-
  210   F4984     UL    75591.80000      18.21000          .          75591.80000       74.45000-
  211   F41084    LL    75591.80000      14.10000          .          75591.80000       78.56000-
  212   F41184    UL   529142.50000      46.96000          .         529142.50000       45.70000-
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213  F41284    UL    110238.00000      52.13000    .    110238.00000    40.53000-
214  F41384    UL     67402.70000      18.08000    .     67402.70000    74.58000-
215  F41484    UL    212916.90000      15.95000    .    212916.90000    76.71000-
216  F41584    UL     34646.20000      20.07000    .     34646.20000    72.59000-
217  F41684    UL     66142.80000      78.99000    .     66142.80000    13.67000-
218  F41784    UL     56693.80000      58.79000    .     56693.80000    33.87000-
219  F41884    UL    139844.80000      54.87000    .    139844.80000    37.79000-
220  F41984    UL    134175.40000      54.87000    .    134175.40000    37.79000-
221  F42084    UL   1637822.10000      12.63000    .   1637822.10000    80.03000-
222  F4185     UL     29606.80000      24.24000    .     29606.80000    74.91000-
223  F4285     UL     37795.90000      88.49000    .     37795.90000    10.66000-
224  F4385     UL     52284.30000      65.03000    .     52284.30000    34.12000-
225  F4485     UL    116537.30000      15.42000    .    116537.30000    83.73000-
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            EXECUTOR.  MPSX  RELEASE 1  MOD LEVEL 5

NUMBER  .COLUMN.   AT   ...ACTIVITY...   ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   226  F4565      UL  1385849.50000         43.20000          .         1385849.50000       55.95000-
   227  F4685      UL    94489.70000         25.60000          .           94489.70000       73.55000-
   228  F4785      UL   188979.50000         14.10000          .          188979.50000       85.05000-
   229  F4885      UL   220476.10000         50.33000          .          220476.10000       48.82000-
   230  F4985      UL    75591.80000         19.49000          .           75591.80000       79.66000-
   231  F41085     UL    75591.80000         15.09000          .           75591.80000       84.06000-
   232  F41185     UL   529142.50000         50.25000          .          529142.50000       48.90000-
   233  F41285     UL   110238.00000         55.78000          .          110238.00000       43.37000-
   234  F41385     UL    67402.70000         19.34000          .           67402.70000       79.81000-
   235  F41485     UL   212916.90000         17.07000          .          212916.90000       82.08000-
   236  F41585     UL    34646.20000         21.48000          .           34646.20000       77.67000-
   237  F41685     UL    66142.80000         84.52000          .           66142.80000       14.63000-
   238  F41785     UL    56693.80000         62.91000          .           56693.80000       36.24000-
   239  F41885     UL   139844.80000         58.71000          .          139844.80000       40.44000-
   240  F41985     UL   134175.40000         58.71000          .          134175.40000       40.44000-
   241  F42085     UL  1637822.10000         13.51000          .         1637822.10000       85.64000-
   242  F42184     BS   102772.10001         92.66000          .          110000.00000         .
   243  P42185     BS   425772.10002         99.15000          .          430000.00000         .
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XIX. APPENDIX I: GLOSSARY

Some of the terms met most commonly in discussing energy, both in this thesis and in general usage, are defined on the following pages.

ALGAE - Fast-growing unicellular or polycellular plants that live in fresh or salt water. They are distinguished from fungi by the presence of chlorophyll and the ability to perform photosynthesis.

ANTHRACITE - "Hard coal"; coal containing less than 10 percent volatile matter; mined mainly in eastern Pennsylvania.

AUGER MINING - Mining coal by drilling horizontally into the coalbed with a large-diameter auger.

BARREL - A liquid volume measure equal to 42 American gallons. One barrel oil = 42 gal (or 336 lb).

BIOCONVERSION - A general term describing the conversion of one form of energy into another by plants or microorganisms. Synthesis of organic compounds from carbon dioxide by plants is bioconversion of solar energy into stored chemical energy.

BREEDER REACTOR - A nuclear reactor that produces more fuel than it consumes. Breeding is possible because of two facts of nuclear physics: 1) Fission of some atomic nuclei produces more than one neutron for each nucleus undergoing reaction. In simplified terms, then, one neutron can be used to sustain the fission chain reaction and the excess neutrons can be used to create more fuel. 2) Some nonfissionable nuclei can be converted into fissionable nuclei by capture of a neutron of proper energy. Nonfissionable uranium-238, for example, can thus be bred into fissionable plutonium-239 in a nuclear reactor powered by plutonium.

A measure of the efficiency of a breeder reactor is the breeding ratio, defined as the number of new fissionable atoms produced per atom of fusionable species consumed. The practical measure of efficiency, however, is the doubling time, the length of time required for a net doubling of the amount of fissionable material in the reactor core. Most breeders have doubling times of 10 to 15 years.

Breeder reactors are divided into two types, fast breeders, which use high energy neutrons, and thermal breeders, which use neutrons of much lower energy.

BRITISH THERMAL UNIT (Btu) - The amount of energy necessary to raise the temperature of one pound of water by one degree Fahrenheit at or near 39.2°F (4°C). One Btu is equal to 1054 joules. Conversion rates are approximately as follows:

1 (42 gal) barrel of oil = 5.67 MBtu
1 cubic foot of natural gas = 1,031 Btu
1 KWH of electricity = 3,413 Btu
1 ton coal = 25 MBtu

CHAR - The solid, carbonaceous residue that results from incomplete combustion of organic material. Char produced from coal is generally called coke, while that produced from wood or bone is called charcoal.

COAL - A solid, combustible organic material formed by the decomposition of vegetable material without free access to air. Plant debris early in the earth's history accumulated underwater in swamps and gradually decomposed. With the assistance of anaerobic microorganisms, the debris was gradually transformed into peat - partially carbonized vegetable matter. The conversion of peat to coal occurred after most of the water was removed and under conditions of increased pressure and temperature. The conversion, extending over many millions of years, was progressive, leading first to lignite, then to subbituminous, bituminous, and finally to anthracite.

COAL GASIFICATION - The conversion of coal or a gas suitable for use as a fuel.

COMBINED CYCLE POWER PLANT - A power plant in which two or more different types of turbines are used to extract the maximum amount of useful work from combustion of a fuel. The primary units in such a facility are a gas turbine that extracts energy from the combustion gases before they are used to produce steam and a conventional steam turbine. Additional useful work can also be obtained with a turbine operated by a very high-boiling fluid that extracts energy from the combustion gases before they enter the gas turbine (a topping cycle), or with a turbine operated by a low-boiling fluid that extracts additional energy from the spent steam (a bottoming cycle). The overall efficiency of a combined cycle system may reach 50 percent, compared to the 39 percent efficiency of the best steam turbines now available.

CONVERSION TYPE PROCESS - A method to remove potential pollutants from a fuel by converting it to a clean burning fuel, e.g., elimination of sulfur from residual oil by hydrogenation-conversion of coal to a low sulfur fuel oil, etc.

CRUDE OIL - Petroleum liquids as they come from the ground. Also called simply "crude".

DEUTERIUM - An isotope of hydrogen in which the nucleus contains a proton and a neutron. A deuterium is thus about twice as heavy as a hydrogen atom, whose nucleus contains only a proton, but their chemical properties are almost identical. The natural abundance of deuterium, the amount of hydrogen that occurs as deuterium in nature, is about 0.0156 percent. Deuterium is generally obtained by electrolysis of deuterium oxide (heavy water) that has been separated from normal water by fractional distillation or electrolysis. It is expected to be the primary fuel for fusion power plants.

ELECTROSTATIC PRECIPITATION - The use of an electric field to remove solid particles or droplets of liquid from a gas. Electrostatic precipitation is increasingly used by coal-burning power plants to remove fly ash from the combustion gases. Precipitation results from interaction of an electric field maintained within the exhaust system and an electric charge induced on the surface of the particle or droplet.

ENRICHMENT - The process of increasing the concentration of fissionable uranium-235 in uranium from the naturally occurring level of about 0.7 percent to the concentration required to sustain fission in a nuclear reactor, generally more than 3 percent.

ENRICHED URANIUM - Uranium in which the amount of the fissionable isotope, uranium-235, has been increased above the 0.7 percent contained in natural uranium.

FAST BREEDER - A breeder reactor that operates with neutrons in the fast energy range, i.e., with energies greater than 0.1 million electron volts. The principal reaction envisioned for most proposed fast breeders is conversion of nonfissionable uranium-238 to fissionable plutonium-239.

FISSION - The splitting of an atomic nucleus by a subatomic particle (free neutron) to produce a large amount of energy. The energy released in fission is much greater than that released in simple radioactive decay and, since fission produces neutrons, the reaction can be made self-perpetuating. Self-perpetuation, the initiation of fission in adjacent nuclei by neutrons from a nucleus that has undergone fission, is known as a chain reaction. If the chain reaction proceeds slowly, as when some neutrons are prevented from hitting adjacent fissionable nuclei by the presence of a moderator, it produces heat that can be used for production of steam to generate electricity. If the chain reaction proceeds to rapidly, it produces an explosion of tremendous force.

FOSSIL FUEL - Any naturally occurring fuel of an organic nature, such as coal, crude oil, and natural gas.

FUEL CELL - A device for directly converting the energy released in a chemical reaction into electrical energy.

FUEL OIL - Relatively heavy refined oil used as fuel for producing heat or power.

FUSION - The formation of a heavier nucleus from two lighter ones. The loss mass appears as energy in the same manner as in fission. The most important reactions considered for a fusion plant are: 1) The combination of two deuterium nuclei (one proton and one neutron a piece) to produce a helium-3 nucleus (two protons and one neutron), a neutron, and 3.2 million electron volts of energy. 2) The combination of two deuterium nuclei to produce one tritium nucleus (one proton and two neutrons), one proton, and 4.0 Mev of energy. 3) The combination of a deuterium nucleus and a tritium nucleus to produce a helium-4 nucleus (two protons and two neutrons), one neutron, and 17.6 Mev of energy. Because of its high energy release and because it can be initiated at a lower temperature, this reaction is most often proposed as the basis of fusion power plants.

GEOTHERMAL ENERGY - The heat energy available in the earth's surface.

GROSS NATIONAL PRODUCT (GNP) - The total market value of the goods and services produced by the Nation before the deduction of depreciation charges and other allowances for capital consumption; a widely used measure of economic activity.

HEAT PUMP - A device which transfers heat from a colder to a hotter reservoir by the expenditure of mechanical or electrical energy when the primary purpose is heating the hot reservoir rather than refrigerating the cooler one. A heat pump is essentially a reversed refrigeration process. Heat pumps are a far more efficient method of electric residential heating than the resistive heating now commonly used.

HIGH-SULFUR COAL - Generally, coal that contains more than one percent sulfur by weight.

ISOTOPE - Any of two or more kinds of atoms with the same atomic number (the same number of protons in the nucleus), but with different atomic masses because of differing numbers of neutrons in the nucleus. All isotopes of an element have the same number of orbital electrons, and thus very similar chemical properties, but the differing atomic masses produce slightly different physical properties.

KILOWATT-HOUR (KWh) - The amount of energy equal to one kilowatt in one hour; equivalent to 3,413 Btu's.

LIGHT WATER REACTOR (LWR) - A reactor that uses ordinary water as distinguished from one that uses heavy water (deuterium oxide, D_2O).

LIGNITE - A brownish-black coal in which the alteration of vegetal material has proceeded further than in peat but not so far as subbituminous coal. It has less than 8,300 BTU's when it is moist, mineral matter free.

LIQUIFIED NATURAL GAS (LNG) - Natural gas that has been changed into a liquid by cooling to about -160°C for shipment or storage as a liquid. Liquefication greatly reduces the volume of the gas and thus reduces the cost of shipment and storage.

LIQUEFIED PETROLEUM GAS (LPG) - Propane, butane, or mixtures of them; kept in the liquid state by pressure or refrigeration to facilitate handling.

LOW SULFUR COAL AND OIL - Generally, coal or oil that contains one percent or less of sulfur by weight.

MAGNETOHYDRODYNAMIC (MHD) GENERATOR - A technique for generating electricity directly by moving liquids or gases through a magnetic field rather than indirectly by means of turbines and rotating generators.

NATURAL GAS - A gaseous fossil fuel generally found in association with oil and whose composition varies with its origin. Most unprocessed natural gases contain about 60 to 80 percent methane, 5 to 9 percent ethane, 3 to 18 percent propane, and 2 to 14 percent heavier hydrocarbons. The energy content of raw natural gas varies from 900 to 1300 Btu per standard cubic foot.

OIL SHALE - A sedimentary rock containing solid organic matter (kerogen) that yields substantial amounts of oil when heated to high temperatures.

PETROLEUM - A naturally occurring material (gaseous, liquid, or solid) composed mainly of chemical compounds of carbon and hydrogen.

PHOTOVOLTAIC CELL - A type of semiconductor in which the absorption of light energy creates a separation of electrical charges. This separation creates an electrical potential that can be tapped by allowing electrons to flow through an external circuit. The net effect is direct conversion of light, especially solar energy, into electricity. The efficiency of such cells is generally very low, however, and their cost is still quite high.

PROVED RESERVES - Quantities of hydrocarbons which on the basis of geological and technical data can almost certainly be considered recoverable from known drilled reservoirs under present economic and technical conditions.

PROBABLE RESERVES - Quantities of hydrocarbons which is hoped can be recovered from known reservoirs but without the certainty that would enable them to be included in the preceding category.

QUADRILLION BTU - 10^{15} (thousand million million) Btu's; approximately equal to the heat value of 965 billion cubic feet of gas, 175 million barrels of oil, or 38 million tons of coal.

RADIOACTIVITY - The spontaneous disintegration of the nucleus of an atom with the emission of corpuscular or electromagnetic radiation. These emissions are of three principal types, called alpha, beta, and gamma. Gamma radiation is the most dangerous of the three, since its penetrating power is approximately 100 times that of beta radiation and about 10,000 times of alpha radiation.

REACTOR - An assembly of nuclear fuel capable of sustaining a fission chain reaction.

RESERVES - The amount of a mineral expected to be recovered by present day techniques and under present economic conditions.

RESERVOIR - A discrete section of porous rock containing an accumulation of oil or gas, either separately or as a mixture.

RESOURCES - The estimated total quantity of a mineral in the ground; includes prospective undiscovered reserves.

SOLVENT REFINING - A method to convert coal and hydrogen under pressure to a clean (low-sulfur, low ash) fuel by dissolving most of it, then separating the undissolved coal and mineral matter (ash) from the extract.

STANDARD CUBIC FOOT (SCF) - The amount of gas contained in a volume of one cubic foot under standard conditions of temperature and pressure.

STACK GASES - Gaseous substances emitted from power-plant smoke stacks during burning of fuel.

STRIP MINING - The mining of coal by first removing the overburden from the coalbed.

SUBBITUMINOUS COAL - Coal of rank intermediate between lignite and bituminous. It has calorific value in the range of 8,300 and 13,000 BTU, calculated on a moist, mineral matter free basis.

SYNTHETIC FUEL - Gases or liquid hydrocarbon material produced from solid carbonaceous material.

TAR SAND - Any sedimentary rock that contains bitumen or other heavy petroleum material that cannot be recovered by conventional petroleum recovery methods.

THERMAL BREEDER - A breeder reactor that operates with neutrons in the thermal energy range; that is, neutrons with energies less than 1 electron volt. The reaction most often considered for use in thermal breeders is conversion of nonfissionable thorium-232 into fissionable uranium-233.

UNIT TRAIN - A string of locomotives and cars used exclusively for bulk shipment of minerals or coal from the mine to a single point of consumption. Because all the cars go to one destination, the locomotives can be distributed more efficiently throughout the train, there is no expense of assembling the train, and the overall cost of operation is substantially lower than for a conventional train.

WASTE HEAT - The heat released to the environment from a power plant.

WILDCAT - A well drilled in a locality that has not previously produced crude oil or gas.