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in partial fulfillment of the requirements for the

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BY

JAMES CHIAN-TUNG CHEN

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1973

APPLICATION OF MODELING TECHNIQUES TO THE STUDY AND FORECASTING OF ENERGY NEEDS, ENERGY SUPPLY, ENVIRONMENTAL IMPACTS, THE ASSESSMENT OF NEW TECHNOLOGY, AND ALTERNATIVES

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James C. T. Chen

ABSTRACT

The worsening fuel and energy supply situation, e.g. growing dependence on imports, short term problems and long term dependence on a depleting resource base, has been met with grave concern. Sufficient energy is essential to protecting the economic strength of the United States since almost every measure of well-being depends upon the energy available per capita.

Total energy requirements reflect population and life style, and change in life style has accounted for a major share of the increase in energy requirements. Conservation practices must be implemented, at least in the short term, to gain time for practical solutions to re-establish a balance between increasing energy needs and resource development, and to absorb the impact of the National Environmental Policy Act.

There is needed, among other things, a "tool" that looks at large systems, or aggregate systems in the demands for energy, identifies uses for energy in terms of types and locale, and suggests methods of government intervention directed toward the reduction of energy alternatives. A tool that will explore the sources of energy in terms of prices and make a comparison of supply versus demand so that policy indicators, incentives research and rationing plans, etc. may be developed.

It is proposed to apply these modeling techniques to develop an

aggregate level mathematical model (tool) to assist in public decisions relative to the energy situation. This model should provide a means of identifying even better models for forecasting energy requirements, identifying data needs, and providing a coarse look at the effect of current trends and possible alternatives. It is anticipated that forecasting by this model will be able to answer at aggregate levels quantitatively and accurately the following questions: How much energy will we need in the years to come? How can we supply it? What energy policy should we adopt for the future: What environmental impacts would we suffer? What are the costs to abate them? What new technology is likely to be developed? Will we need to change our pattern of living? What are our alternatives?

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CHAPTER I

INTRODUCTION

For the first time in historical experience, factors are evident which clearly suggest the finite nature of the earth as a habitable entity. These factors center around the extraction of fuels and the production and distribution of energy at ever-steepening growth curve rates for the U. S. as well as the world. The U. S. energy system is currently producing something on the order of 70 x 10^{15} BTU's. (Fig. I-1 & 2)

To sustain an annual nine percent growth rate of electricity in the U. S., the Federal Power Commission has projected a need for 300 new generating stations over the next 20 years with an average capacity of 3000M_W each. Studies of total water cooling needs for such a massive power plant outlay have indicated a water requirement of some 5 x 10^{14} gallons per year.

There appears to be a striking agreement on the gravity of the fuel and energy supply situation, growing dependence on imports, short term problems, and long term dependence on a depleting resource base. Sufficient energy is essential to protect our economic strength, in fact almost any measure of well-being increases as does the energy available per capita.

Total energy requirements reflect population and life style, with life style being responsible for a "lion's share" of the increase; and conservation practices must be implemented, in the short term, to gain time for practical solutions, reestablish a balance between use growth and resource development, and absorb impacts of the National Environmental Policy Act.

Until World War II, the United States was a net exporter of energy supplies. Today, the Middle East and Africa are the major suppliers of oil. The economics of this situation has been one of the prime factors in discouraging the United States' development of its oil shale and tar sands, potentially available in very large amounts. However, the rate at which our energy resources are being tapped has reached such proportions, both nationally and worldwide, that there are now serious questions as to their long-term availability. Hydrocarbon resources are becoming scarce, with a 50% dependence on foreign imports by 1980 as a distinct possibility, with no possibility of meeting projected gas demand with domestic production.

Removal of SO_2 from coals is a constraint. Specific proposals include exploration, on and off shore, transfer from Alaska, more R & D gassification of coal and oil shale, breeder reactor, geothermal, solar, desulfurization, etc. Other measures include export of technology to LDN, rationing, and end-use control and economic measures, primarily charging "true costs," distinctions between the demand for particular fuels, and demand for energy-using sources, and perhaps control of use of materials which are Energy intensive.

There are numerous assorted environmental challenges connected with energy resources and production, such as nuclear generating site location, strip mining and associated land damage, off-shore oil and gas wells, air and water pollution control, the politics and economics of oil imports, super-tankers and oil spills, pipeline and wilderness ecology, above-ground transmission facilities, and 1000-year storage periods for radioactive nuclear wastes. Social values of Americans are changing. The growing comsumption of electric power comes into direct conflict with the insistent and increasing public demand for a better environment and more careful attention to other public interests in private decisions. Systems engineers can no longer consider only traditionally technical and economic factors; attention must also be given to public interest factors from the very beginning of the engineering process and the cost caused by these environmental factors will still need to be kept minimal.

We have recognized the fact that the exponential growth curve of energy demand cannot continue indefinitely without specific consequences in terms of environmental damage. Such added "social" costs will make the economic equation of energy resource development quite a different proposition over the remaining years of this century. In recent years scarcity has been thought of more in terms of cost than of physically running out. Resources would mean nothing if the cost of obtaining them (including social cost) exceeds its price. Can the United States over the balance of the twentieth century count on enough natural resource supplies with an optimal cost to support a rate of economic growth sufficient to have a higher level of living than the average of today?

There are two types of energy sources, one is continuous, or renewable; the other is finite, or nonrenewable. The renewable can be divided into two categories: solar and nonsolar; the first comprises fuel wood, farm waste, photosynthesis fuel, hydropower, wind power, direct conversion; the last consists of tidal and geothermal. The non-renewable are coal, petroleum, natural gas, and uranium (nuclear power).

Fuel sources have been shifting steadily during the past century. Fuel wood was the leading energy source in 1850, by 1910 coal accounted about 75 percent. In the 50 years between 1910 and 1960 coal lost its dominant position to natural gas and oil. Today nuclear power is emerging as a national energy source. Thus, roughly 50 years seem to be required for the energy economy to shift substantially to a new fuel. This is determined primarily by the operating lifetime of power machinery and sucondarily by the long lead time for redirecting available manufacturing and supply capabilities.

A century ago our energy resources went mainly to space heating. Less than a quarter of the heat was utilized for metallurgical processes and industrial activities. Today, more than half of all energy consumed in the U. S. goes into useful work. Paralleling this shift in the way energy is used has been a steady improvement in the efficiency with which energy is converted to useful form. The best of our power plants now operates at a thermal efficiency of 40 percent, a figure that may reach 50 percent by the year 2000.

There is no question that nuclear energy is a saving technical development as a future energy prospect for mankind. Promising, but as yet technically unsolved, is the development of a continuous supply of energy from solar sources; it does not appear to be economically feasible for substantial tapping of this continuous energy supply. But only a small percentage of the land area in the U. S. would be required to absorb the necessary solar radiation to effectively meet most of our energy needs in the year 2000. Even a partial achievement of this goal would make a tremendous contribution.

There is needed, among other things, a tool that will 1) explore the demands for energy, decompose uses in terms of types and a real locale, suggesting alternatives, and government intervention directed to reduction of demands, 2) explore the sources of energy, in terms of prices and costs to abate its pollutants, 3) finally the comparison of demands and supply, prividing policy indicators, on incentives research, rationing, etc.

There is, and unfortunately, continues to be a need for a planning and analysis tool applicable to large public systems -- water, wastes, or energy resources systems, multi-county, urban systems. These systmes are of course very complex, and unfortunately, there is rarely adequate data to properly describe the complexities which arise due to the fact that the processes are imperfectly understood. So, that is a complex reality with a great many variables on which there is available very poor measures and which themselves interrelate in ways very inadequately understood -- must be meaningful and appropriately related to be very useful. Certainly one recognizes the superiority of an explicit quantifiable data and models over intuitive models and hunches. The alternatives to such a model, based on partial knowledge, is a mental model based on the mixture of incomplete information and intuition similar to those controlling most political decisions. A mathematical model deals with the same incomplete information available to an intuitive model, but through organization of information from many different sources into a closed loop at least analysis is permitted and data needs studied.

To arrive at an energy project design, the number of variables is enormous and they are mostly nonlinear. The structure of the system is more hierarchial than functional, and many of the parameters and variables are unquantified at present, especially those associated with ecology. Nontheless, to some degree, a merging of disciplines and the increased use of the system approach has been taking place in the study of public systems, and it is not just a matter of collecting data and figuring out what one has.

If one looks at the type of models being postulated for the design of public systems today, it will be seen that they fall within a spectrum ranging from erudite mathematical models at one end of the spectrum to scenarios at the other. In the first case, the mathematical models may be rigorously developed in a mathematical sense, but all too often are of little use in describing a real complex system in inadequate data. On the other hand, the scenario model -- little data, numerous ideas -- may adequately depict the significant elements of the real system, but it is of little use to the planner because he cannot manipulate it or quantify it.

The target one should try to hit is a reasonable and useable balance between the poles of intuition and selecting hard data. One would like to be able to use the mathematical rigor of the physical scientist and, at the same time, give equal weight to the heuristic insight of the social scientist. The result would be a useable model for a system design. So, perhaps, or certainly for planning purposes, one is dealing with the lowest level of quantification that allows good estimates and the lowest level of complexity which gives a reasonable picture of the real world system with the hope of expounding in both directions.

The application of mathematical modeling techniques can significantly aid the decision-makers to arrive at better decisions. Thus, modeling provides relevant facts and alternatives; the decision-maker chooses the strategy. Operational models are still primitive, primarily because of the probabilistic or random nature of the physical processes involved in waste diffusion. One is sometimes inclined to be skeptical of the value of increasing model sophistication which often seems to have progressed much further than our understanding of the complex real world situation; all models currently proposed in the literature have enormous data requirements which far exceed the data usually available, and which, for the most part, must be derived from actual measurement. Many parameters in the more sophisticated models are simply not known in actual situations.

It is the intent of this project to bring to bear an experienced expertise in aggregate systems; this is an area largely overlooked, an area wherein the engineering discipline and methodology -- the systems approach -- is rationally applied along with the overt needs of large public or aggregate systems; to demonstrate a valuable tool for the decision-maker on a national or regional scale over time in the allocation of energy resources.

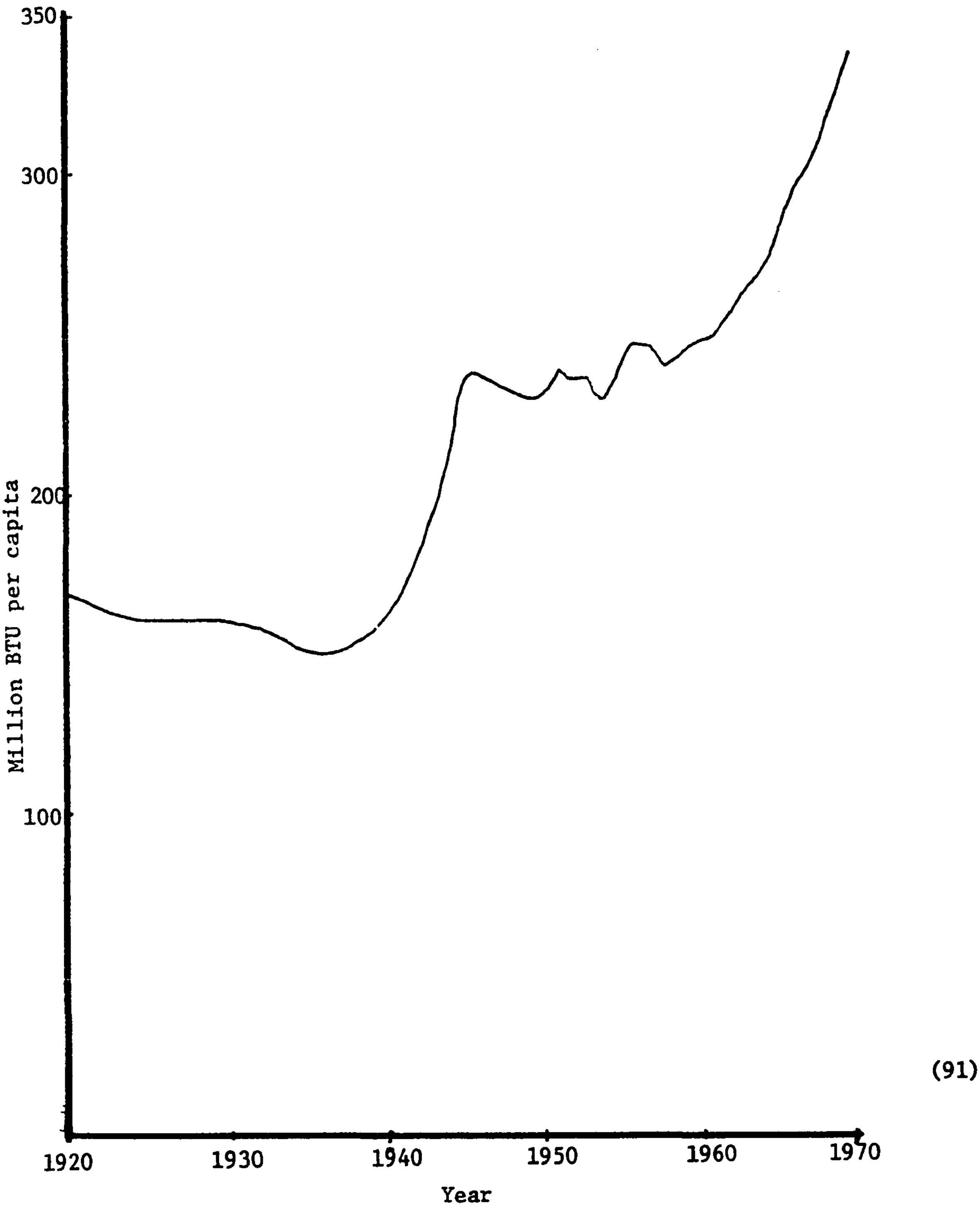
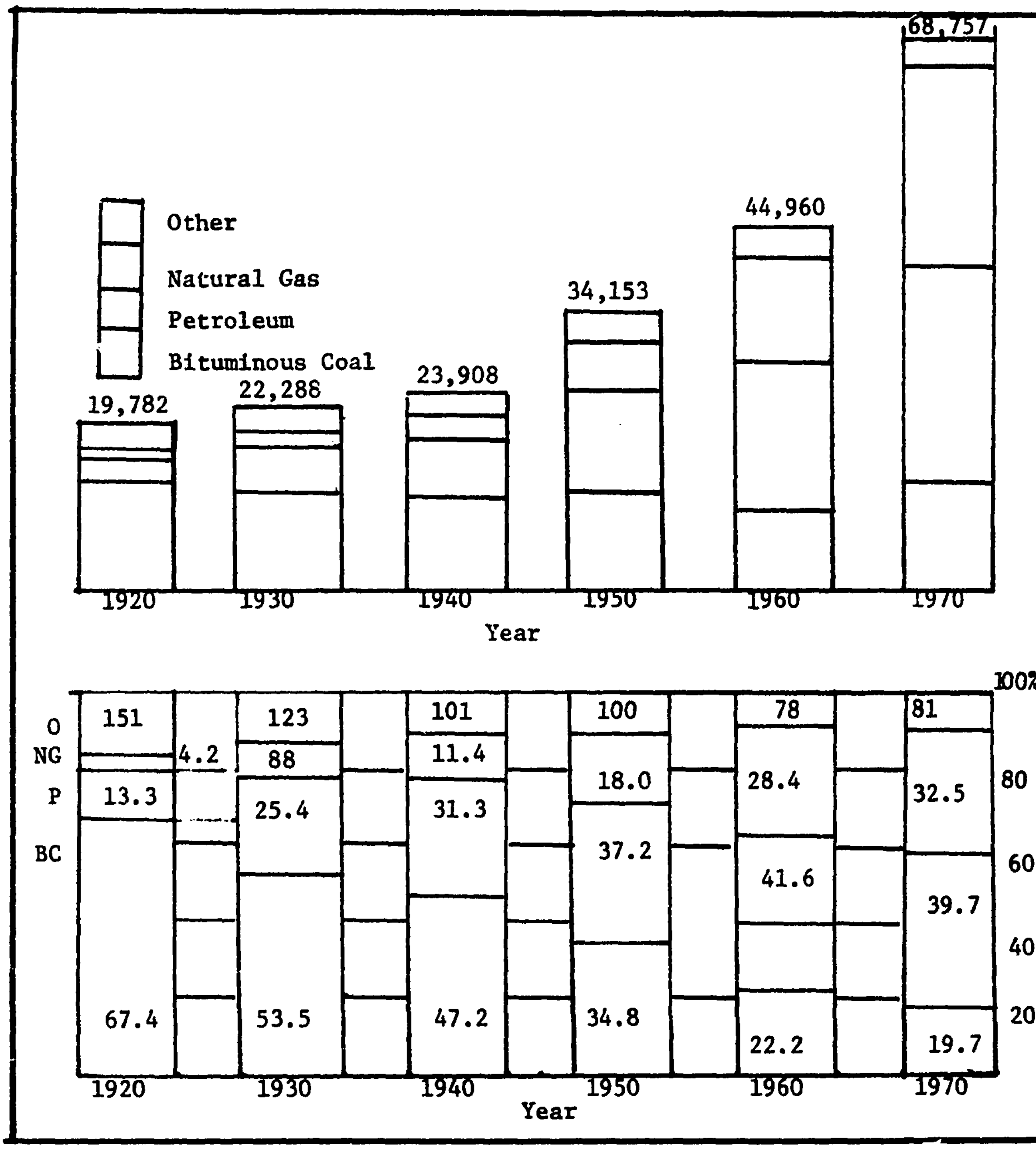


Figure I-1 Historical Total Energy Consumption Per Capita



Year

(91)

Figure I-2 United States Energy Consumption
(Consumption - Trillion BTU)

CHAPTER II

LITERATURE REVIEW

The artful manipulation of energy has been an essential component of man's ability to survive and to develop socially. The use of energy has been a key to the supply of food, to physical comfort and to improving the qulaity of life beyond the rudimentary activities necessary for survival. To know the future demand of energy and how to supply it with a reasonable price have been so important for government or private investors that various forecasts have been made. As early as 1948, Eugene Ayres presented a very long paper, "Major Sources of Energy," to the Program Committee of the American Petroleum Institute. It included critical analyses of resources, description of many of the energy conversion processes, enumeration of the chief sources of waste of energy, and the substitution of the latest statistical and interpretative data. But it did not give us any future energy demand, not even to mention its cost.

Since America was no longer an oil exporter, but instead imported oil, various energy forecasts had been timely made during the 1960's.

RAF[17] was published in 1962. Basically this study, using a building block approach, started with a 1960 base for the end-use and forward projection of the base. These projects figures were then subdivided into different sources of energy categories based on historical trends and some judgements.

There was substantial reliable data collected and disseminated by the trade organizations such as the American Gas Association, Edison Electric Institute, etc. These data were checked against and reconciled with government compiled data, where possible.

In general, the end uses were not broken down by geographic regions except for electricity generation. Low, medium and high forecast values were projected. The medium value represented a "best" estimate and the low to high range is a reflection of uncertainity to be associated with the forecast values. Yet, no statement concerning the confidence to be placed on these limits was given.

The work is a major extension of Energy in the American Economy,1850 to 1975, by Schurr, Netschart, et al. The work is well documented.

These values were not called "forecasts" or "predictions" since they have not been developed with consideration of the cost involved in supplying the required amounts.

It is, of course, very difficult to consider price and resource availability in energy resource forecasts, but it appears to be increasingly necessary to do so, since higher price of one fuel may encourage one to look for (shift to) other fuel. It does not provide the information of non-energy uses and this is very important since more and more chemical products (synthetics) are produced.

"Energy Resources"[4] published in September, 1962, analyzes historical data to obtain objective estimates of ultimate potential reserves for the various fossil fuels in both the United States and the world. U. S. ultimate potential hydroelectric power capacity was included in the projection. The mathematical approach used, showed considerable deep thought and imagination. Throughout, considerable care was taken not only to write down the model (logistic or growth curve) and appropriate ground and development to justify its use.

The author is attempting to point out that the United States does not have available an infinite supply of fossil fules. New sources of supply such as nuclear and solar energy provide some hope. However, associated with them are some rather serious problems -- nuclear waste disposal and efficient harnessing of solar energy.

"NF and ES"[12] published September, 1962 compiles and assesses an existing body of information -- adequacy of fuel to meet projected requirements to 1980. It assumes the ability of continued technological progress to hold costs within limits.

Consumption of fossil fuels is a funciton of end-use energy needs, a form in which needs are supplied and fuel consumed for non-energy purposes. The study analyzes needs and then meausres them against the supply of energy available.

"PEC"[16] published in 1962, presents two aspects of the energy economy:

1. Energy resource consumption by source and by sector;
2. by function and by sector.

It assumes no major changes in our international relations, stability of the real cost of primary energy sources relative to each other and general level of commodity cost, adequate supplies, either foreign or domestic.

Least square trends of historical data and correlation between these data and other indicators were employed. An initial estimate was made of the rate of growth of total energy consumption by sector by correlating the various sectors with general economic indicators. The indicators were: GNP, for total energy and transportation; population, for household and commercial; composite of new construction, producer, durable and personal expenditures, for industrial; and Advisory Committee Report (no. 21) National Power Survey, for electric utilities.

From this analysis, estimates of total consumption and of consumption by consuming sector were derived. Markets were then allocated to energy sources by subjecting the least squares of each source to analysis and judgement based on knowledge of energy industries and markets, consensus of outside experts, and examination of other functional energy forecasts.

"NPS"[13] published in 1964, projected the requirement 2.8 trillion KWH of electricity in 1980 by assembly of data for the 48 power supply area, 16 coordination study area, 8 statistical regions and for sectors. The South Central, West Central and Southwest regions have growth rates of 7.6, 7.2 and 7.2 percent, respectively. East Central region has the slowest annual growth with 5.8 percent per year.

"ERDNP"[5] published in June, 1964, concluded sufficient coal with no significant cost increase, insufficient quantities of natural gas by the year 2000. Uncertainty of nuclear fuels depending on extent of nuclear power installed, efficiency of fuel utilization, and price of uranium ore.

"FGNP"[8] published in December, 1967 adopted the method for forecasting the growth of nuclear power in the United States through 1980 using data on electrical generating capacity, conventional and nuclear, installed during the next seven years, as a basis for extrapolating for a further seven years.

"FNGR"[10] published in June, 1967 estimated the future natural gas requirement by sending a survey questionnaire to all appropriate public and private companies in the United States. Each company was asked to submit data on natural gas requirements in its marketing ares, classified into residential, commercial firm, industrial, interuptible and "other" categories. "Other" included pipeline fuel, company use, unaccounted for, transmission loss, and any other sale or actual use not otherwise specified. Each company was asked to submit "actual" volumes for 1961-1965, "estimated" for 1966-1970 and 1975, "projected" for 1980, 1985 and 1990.

Each company was allowed to use its own operation, policies and local conditions when preparing the forecast. Other factors, such as air pollution, were considered to be clouded with uncertainty; therefore, they are not covered in the guidelines for the study. That present-day relationships of the cost of gas to the competing fuels will remain the same was assumed.

"EUS"[7] published in September, 1967 used a building block approach. Consumption was compiled separately for each type of energy source broken down by each category of consumer within each of the geographical areas used. Ten geographical areas and four consumer categories were used. It was implied that the consumption projections were obtained within each of these 40 (10 x 4) categories and then assumed to give the "all uses" or total consumption values. Mathematical models were not given.

The study is quite complete as far as forecast breakdowns are concerned -- geographical regions, end-use categories, sources of supply, and even different types of petroleum products -- also coal, hydropower vs. nuclear electricity generation.

The source data from 1960 to 1965 were obtained from statistical reports by the federal government and trade associations. Auxillary information concerning fuel prices and other pertinent factors were obtained from the above references or from reports or private communications from other governmental agencies or trade associations.

"CNP"[2] published in February, 1967 concentrated on basic policies. The report relies on data from other sources, such as Edison Electric Institute, Federal Power Commission and Resources in America's Future, as well as other Atomic Energy Commission estimates and the judgement of the authors. It consists of information on international programs. It examines the need for nuclear power, the direction in which the central station nuclear power program should be headed, the rate at which the program should proceed, and the nature and amount of government participation necessary.

"USP"[19] published in July, 1968 forecasts domestic oil and gas over a 15 year period -- 1965 to 1980. It concludes the adequacy of petroleum sources with the question whether they can be located and produced at costs which permit them to compete with other energy sources. The study is primarily concerned with supply factors. It assumes no price change relative to other fuels (questionable). It also assumed that pollution control regulations will have no major impact on consumption of fossil fuels.

It is a fairly straightforward extension of present trend, policies and relationships. No assumtions were made concerning the availability of fuels.

"CGAEM"[1] published in 1968 presents a fairly complete set of projections. Regional aspects of electric power generation and fuel supply were studied. It breaks down by end-use categories, by source of supply categories of total consumption of fuels. End-use energy requirements were projected by summation. The source of supply forecasts were then forced to fit into this framework. Regression analyses were used to forecast the residential requirements using the variables of population, per capita personal income, and further, industrial requiremetns using the variables of industrial production index, non-durables component of GNP, and a mixture of industrial output and the efficiency of energy utilization.

Transportation use was broken down into three categories:

1. passenger cars,
2. industrial related transportation,
3. aviation.

Multiple regression analysis was used with variables:

1. number of auto registrations,
2. average brake horsepower per auto,
3. average miles driven per auto.

For the projection, brake horsepower was assigned the 1964 average. Average miles driven was assigned the value of 9,400 miles. Regression again was used to forecast auto registration with variables of population and economic activity. Multiple regression was used to forecast the industrial transportation. As for aviation, simple correlation with GNP and perhaps some judgements were used.

Sufficiency of all fuels to meet consumption demands without price relationships was assumed. Due to this assumption, alternatives of fuel supply were not discussed. Federal policies were neglected, perhaps due to the difficulty of data collection.

"EMUS"[3] published in July, 1968 presents a complete set of balances of 1947-1965. The main sources of data and information are the Bureau of Mines Energy Series, published in the annual issues of the U. S. Department of the Interior's Minerals Yearbook, Volume II Fuels; supplemented by data for electric utilities obtained from publications and reports of the Federal Power Commission; for the nuclear power industry from reports of USAEC. Regional forecasts are not given. Procedures for the forecasts may be described as opportunistic in that various types, methods and techniques are used. Adequate supplies of energy resources were assumed.

It is also assumed that the real costs of the primary resources relative to each other and to the general level of commodity costs will remain constant or decrease during the forecast period (through the year 2000).

"OEUS"[14] published in October of 1968 gives no references. Forecasts for geographical regionas were used. Total energy was further broken down into end-use categories which were further broken down by source of supply. No statements about regression analysis or the type of mathematical model used could be found anywhere in the study. The projection of total energy use in the study appears to be equivalent to using the model:

$$E = 26{,}000{,}000\ (10)^{(.016519)\ (t - 1965)} \qquad \text{(II-1)}$$

Where "t" is time (1965 is the base year) in year and "E" is energy in barrels of oil equivalent, rather than BTU's. The study assumes that the size of 20-35 year age group is a good indicator of economic activity. No assumption is made regarding the cost of fuels and federal policies.

"PCCP"[15] published in May of 1968 was to provide projections of the consumption of commodities producible on the public lands, which can be used as a basis for evaluating the effects of alternative land policies. The methods and projections were based on the 1963 study by Resources for the Future, Inc. Recent trends in the following are assumed to continue to 1980 and 2000:

1. U. S. consumption needs and preferences
2. Changes in the relative prices of competing commodities
3. Federal policies regarding economic growth, economic stability, regional development, and foreign policy
4. Military committments and mobilization for defense.

"ESDNR"[6] published in 1969 attempts to predict the installation of nuclear reactors versus more conventional fuel for the generation.

"The 1970 National Power Survey"[13] developed load projections for 1980 and 1990. These projections were submitted to the Federal Power Commission's six Regional Advisory Committees (Northwest, East Central, South Central, West Central, Southeast and West) for review and modification. Some of the committees developed their own projections independently. Others adopted the staff-developed projections with revisions. Finally, each Regional Advisory Committee reached a consensus on a projection of the magnitude of the loads which the systems of its region should be proposed to serve during the next two decades. A summation of the regional projections provided the national projection.

In projecting future power requirements to 1990, it was assumed that during the period to 1990 the nation would continue to enjoy a high level of economic activity, technological improvement in the electric utility industry, a somewhat smaller proportion of national resources would be channeled to military purposes than during the late 1960's, no disruptive epidemic or similar catastrophe would occur, and the nation would continue to use electricity as an increasing portion of total energy consumption. As far as energy forecasting is concerned, this report presents a complete set of projections. Included are forecasts for total end-use requirements, a breakdown by end-use categories, a breakdown by source of supply categories, and total consumption of fuels with breakdowns by source of supply.

Efforts are also devoted to regional aspects of electric power generation and fule supply. Federal policy, environmental impact and costs were discussed with some detail.

"U. S. Energy Outlook" by the National Petroleum Council and published in 1971, assumes that current government policies and regulations in respect to oil import controls, natural gas price regulation, leasing of federal lands, environmental controls, tax rates and research funding and the present economic climate for the energy industries would continue without major changes throughout the 1971-1985 period.

projections of total energy have been derived by analysis and synthesis of the component markets, rather than by assuming a fixed relationship between energy demand and GNP, or some other economic index.

Forecasts are given by total energy, by energy consumption, by major markets and by geographical area. Supply developed regionally to fit the demand and possible alternatives were discussed but no trade-off was discussed. Costs were evaluated. Tar sands were discussed.

"The U. S. Energy Problem" by G. C. Saego, published in November of 1971, was to provide a substantive, rational means of evaluating priorities in energy-related research and development offered by government support. The primary thrust of the study is techno-economic. Major outputs of the study are a detailed cost modeling and the resultant determination of the influence coefficients of the technologies on the cost of energy. Energy and power requirements were projected to the year 2040. Costs of basic fuels were studied; environmental constraints were reviewed; alternatives of fuels such as shale oil were discussed.

Managery, by William W. Talley II (1970), developed a computerized model, capable of predicting the energy demand, the resource consumption, the environmental effects, and the balance of payment requirements for available energy resources and demand and technology alternatives. The model provides a systematic procedure for assessing the full implications of energy utilization technology and resource alternatives.

His demand model depends too heavily upon projections made by various authors. It does not ensure us a valid and better projection just by taking the mean of different projections.

GLOSSARY OF TERMS

1. CGAEM - Competition and growth in American Energy Markets, 1947-1985 Texas Eastern Transmission Corporation, 1968.

2. CNP - Civilian Nuclear Power - A report to the President, U.S. Atomic Energy Commission, 1962 (and 1967 Supplement)

3. EMUS - An Energy Model for the United States, featuring Energy Balances for the year 1947 to 1965 and Projections and Forecasts to the years 1980 and 2000 Bureau of Mines, IC 8384, July 1968. U. S. Department of Interior.

4. ER - Energy Resources, A report to the Committee on Natural Resources, M.K. Hubbert, National Academy of Science, Publication 1000-D, National Research Council, 1962.

5. ERDNP - Energy R and D and National Progress Interdepartmental Energy Study Energy Study Group, Ali Bulent Cambel, June 1964 (U.S. Government Printing Office)

6. ESDNR - Economic Strategy for Developing Nuclear Reactors, Paul W. MacAvoy, M.I.T. Press, 1969.

7. EUS - Energy in the United States, 1960-1985, Michael C. Cook, Sartorius and Co., Sep. 1967.

8. FGNP - Forecast of Growth of Nuclear Power, Wash., 1984, United States Atomic Energy Commission, Division of Operations Analysis and Forecasting 1967.

9. FFF - Fossil Fuels in the Future, Office of Operations Analysis and Forecasting, United States Atomic Energy Commission, Milton F. Searl, 1960.

10. FNGR - Future National Gas Requirement of United States. Future Requirements Agency, Denver Research Institute, University of Denver, Vol. 2, June 1967, (under the auspices of the Gas Industry Committee).

11. GUPIP - Gas Utility and Pipeline Industry Projections, 1968-1972, 1975, 1980 and 1985, Dept. of Statistics, American Gas Association.

12. NF&ES - Report of National Fuels and Energy Study Group on Assessment of Available Information on Energy in the United States, Committee on Interior and United States Senate, Sept. 1962.

13. NPS - National Power Survey, Federal Power Commission, 1964 and 1970.

14. OEUS - Outlook for Energy in the United States Energy Division, The Chase Manhattan Bank, N.A., October 1968.

15. PCCP - Projections of the Consumption of Commodities Producible on the Public Lands of the United States, 1980-2000, Prepared for the Public Land Law Review Commission, Robert R. Nathan Associates, Inc, Washington, D.C., May 1968.

16. PEC - Patterns of Energy Consumption in the U.S., William A. Vogely, Division of Economic Analysis.

17. RAF - Resources in America's Future Landsberg, Fischman, and Fisher Resources for the Future, Inc., John Hopkins Press, 1963.

18. TCUSEC - Technological Change and United States Energy Consumption, 1939 - 1954, Alan M. Strout, (unpublished thesis)(energy projection portion of the thesis, University of Chicago).

19. USP - United States Petroleum through 1980, United States Department of Interior, Office of Oil and Gas, July 1968.

CHAPTER III

METHOD OF APPROACH

On Assumptions

In projecting future energy needs and supplies in the Continental United States, it is necessary first of all to have a working idea of what the nation's economy and society at large might be like in the year 2000 and along the way. What would the broad picture be if currents, as modified by already discernible patterns of change, remain in operation? The following assumptions, built in from the start, are:

1) continuing gains in technology,
2) reasonable free flow of world trade,
3) stricter laws on pollution,
4) no "major war" and "cold war" will continue,
5) no major depression or inflation, and
6) population and personal income projection will be from Prof. Reid's Population Model.

On Technology

The total energy consumption can be disaggregated into the following: coal, petroleum, natural gas, nuclear, hydro-electric power, tidal wave, geothermal, wind and solar energy. The major end-use for energy can be classified as industrial, commercial, transportation, residential and miscellaneous.

On Methodology

Demand Model

A demand model has been developed as the following:

$$ED_{t,n} = POP_{t,n} \times UU_{t,n} \qquad \text{(III-a-1)}$$

where: $ED_{t,n}$ = the energy demand for the nation at time, "t",

$POP_{t,n}$ = population of the nation at the time, "t",

$UU_{t,n}$ = the unit use of energy for the nation at the time, "t".

Based upon multiple regression techniques, an evaluation for the energy requirements/10^3 people ($UU_{t,n}$) as a function of population in thousands, income per capita, and mean annual temperature is developed for the nation. This equation takes the following form:

$$UU_{t,n} = b_0 + b_1 p_{t,n} + b_2 I_{t.n} + b_3 T_{t,n} \qquad \text{(III-a-2)}$$

where: $UU_{t,n}$ = as previously defined;

b_i = regression coefficient, $i = 0,1,2,3$;

$p_{t,n}$ = population of the nation at time, "t";

$I_{t,n}$ = personal income per capita of the nation at time, "t";

$T_{t,n}$ = mean annual temperature of the nation at time, "t".

This is essentially saying that the unit requirement in the energy demand is not constant but changes as a function of the population (scale) income (life style), temperature. The demand matrices for the nation at time "t" will be developed as the following:

Source/End-use	Ind.	Tran.	Comm.	Res.	Misc.
Coal (10^6 BTU)	D = Direct I = Indirect				
Petroleum		200			
Natural Gas			50		
Hydropower				10	
Nuclear					3
Geothermal					
Wind					
Solar Energy					

$UU^{ij}_{t,n}$ will be defined as the unit use of i source for j end-use for the nation at time t, i = 1,2,...,8; and j = 1,2,...5. Thus, we have

$$UU^{ij}_{t,n} = b^{ij}_0 + b^{ij}_1 P_{t,n} + b^{ij}_2 + b^{ij}_3 T_{t,n} \qquad \text{(III-a-3)}$$

From historical data, we can obtain the past year's $UU^{ij}_{t,n}$ so that b^{ij}_m, m = 0,...,4, may be obtained to forecast the future $UU^{ij}_{t,n}$.

Therefore, equation:

$$UU_{t,n} = \sum_{i=1}^{8} \sum_{j=1}^{5} UU^{ij}_{t,n} \qquad \text{(III-a-4)}$$

Equation III-g-1 and equation III-a-4 may be combined as the following:

$$ED_{t,n} = P_{t,n} \left(\sum_{i=1}^{8} \sum_{j=1}^{5} UU^{ij}_{t,n} \right) \qquad \text{(III-a-5)}$$

The Supply

The resource supply is balanced with projected net domestic production. The shortage is divided among alternative supplies either from traditional sources such as liquified natural gas, coal, petroleum, and gas imports or resource conversions such as syngas and syncrude from coal and syngas from petroleum in the light of future prices.

The Cost

The future cost of fuels will be roughly estimated. These include wellhead cost of petroleum and natural gas, mine-month cost of coal and nuclear fuel, and actual cost of energy to the consumers.

The Environmental Impacts

The impact of end-use energy consumption will be determined. These include air pollution: HC, CO, SO_2, NO_x; and particulates; solid waste including radioactive materials and land use requirements; thermal pollution and cooling water needs. The cost to abate these pollutants to satisfy the National Environmental Standards will also be estimated.

The conservation practices and Alternatives suggestions on reducing energy consumption are given, and its effects of saving are to be determined. Public decisions relative to the energy situation are to be advised accordingly.

Energy Demand

The energy demand is a function of the population (scale), income (life style), and annual mean temperature. Projected population and income per capita are adopted. Annual mean temperature will be assumed to be 55.12.

The direct energy demands are separated into end-use demand; residential, commercial, transportation, industrial and miscellaneous, and into sources: coal petroleum, and natural gas.

Direct energy demand share will be reduced to approximately 50 percent in the year 2000. Petroleum will still be the leading fuel due to the commanding lead in the transportation market. Natural gas will not be too far behind. Coal will eventually lose its residential and commercial markets.

U. S. Population

The United States population has been projected to the year 2000 by the Bureau of the Census for various assumed birth rates (85). Based on birth rates of two children per family and three children per family, the President's Commission on Population Growth and the American Future has also projected the U. S. population to the year 2070. G.W. Reid also has projected the U. S. population to the year 2050, and his projection is used as the most probable U. S. population (Figure III-b-1).

U. S. Income per Capita

G.W. Reid's Population Model also projected U. S. income per capita. His projected values are used in this model for consistency (Figure III-b-2).

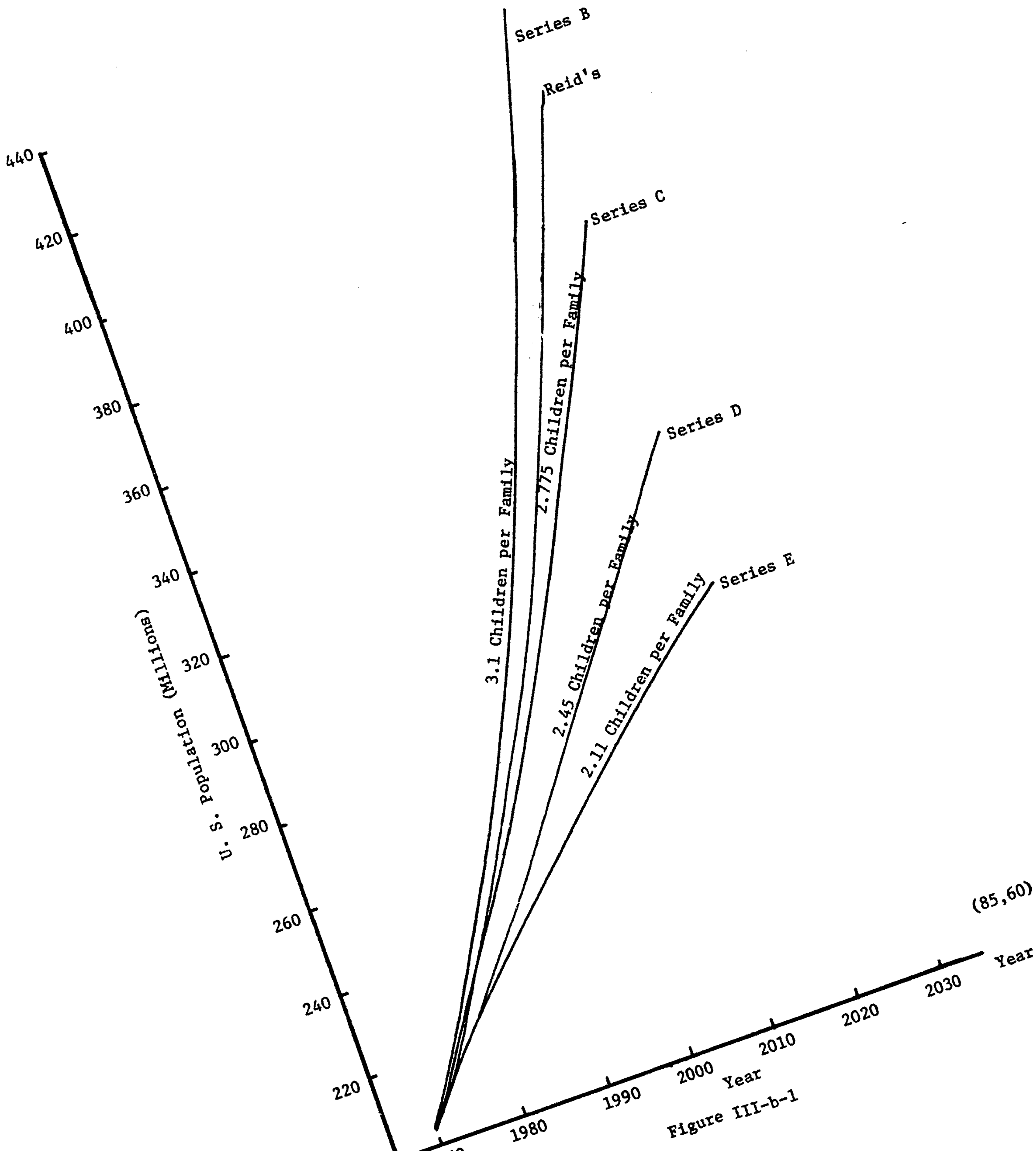


Figure III-b-1

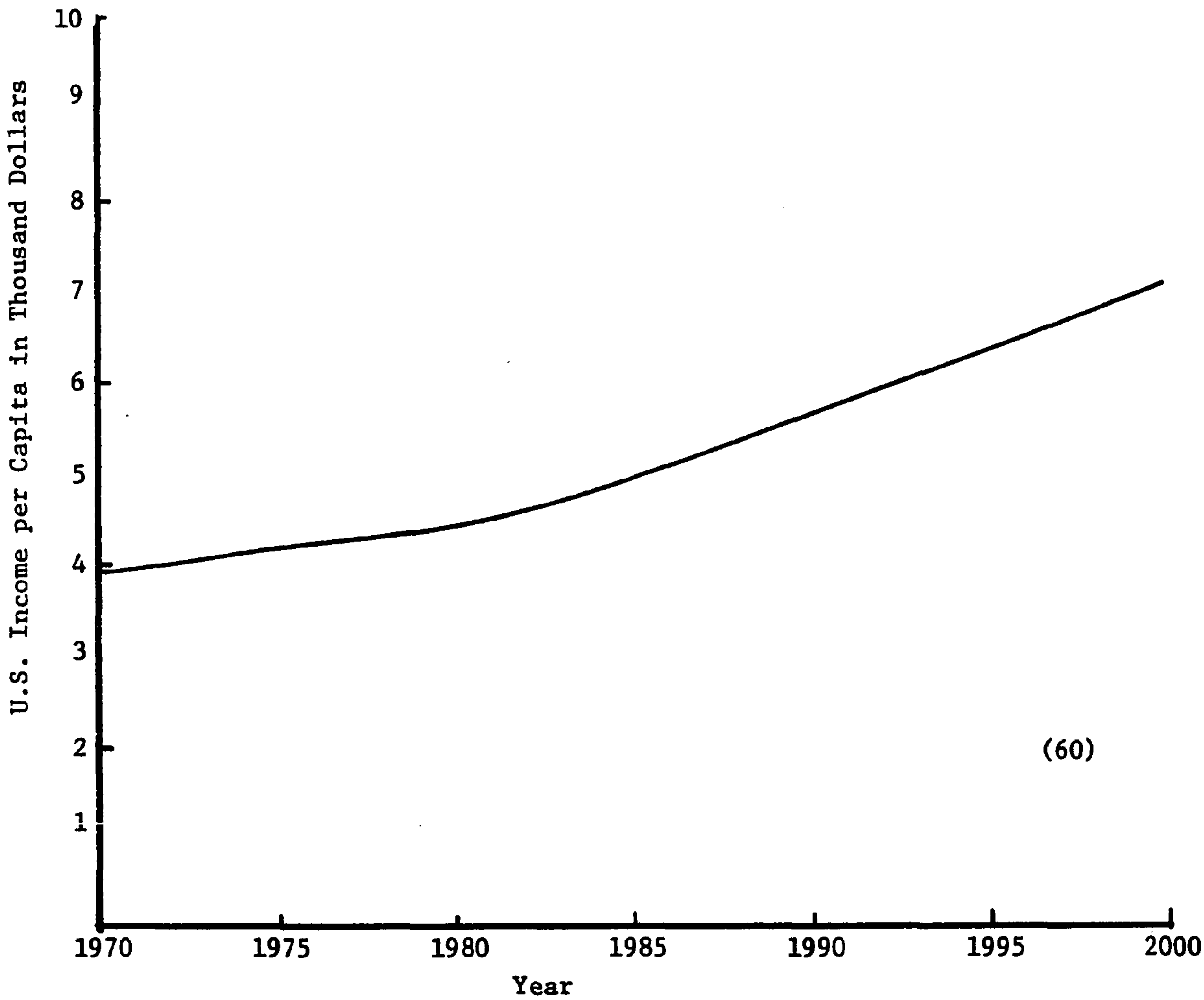


Figure III-b-2 Projected U. S. Income per Capita

Commercial and Residential Projection

The unit energy consumption of coal for commercial and residential use is given by the equation obtained by multiple regression analysis.

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-1)}$$

where: $POP_{t,n}$ = the U.S. population in year "t"

$INC_{t,n}$ = the U.S. income per capita in year "t"

$TEM_{t,n}$ = the U.S. annual mean temperature.

a = -16094	d = +1063
b = -0.22382	R^2 = 0.96
c = +1.51742	F = 58.3

The coal consumption for this use will eventually vanish by the year 1985. due to public awareness of environmental impacts and higher cost. The unit consumption of energy by commercial and residential is given by:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-2)}$$

Petroleum will continue to dominate the market.

The unit use of natural gas for commercial and residential is generated by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-3)}$$

where:

a = 59.6	d = -240.55
b = 0.14847	R^2 = 0.90
c = 4.76783	F = 34.3

The petroleum and natural gas will continue to grow, but its percentage of the total energy consumption will decrease from 19.7 in the year 1970 to 15.7 in the year 2000 (Figure III-b-3).

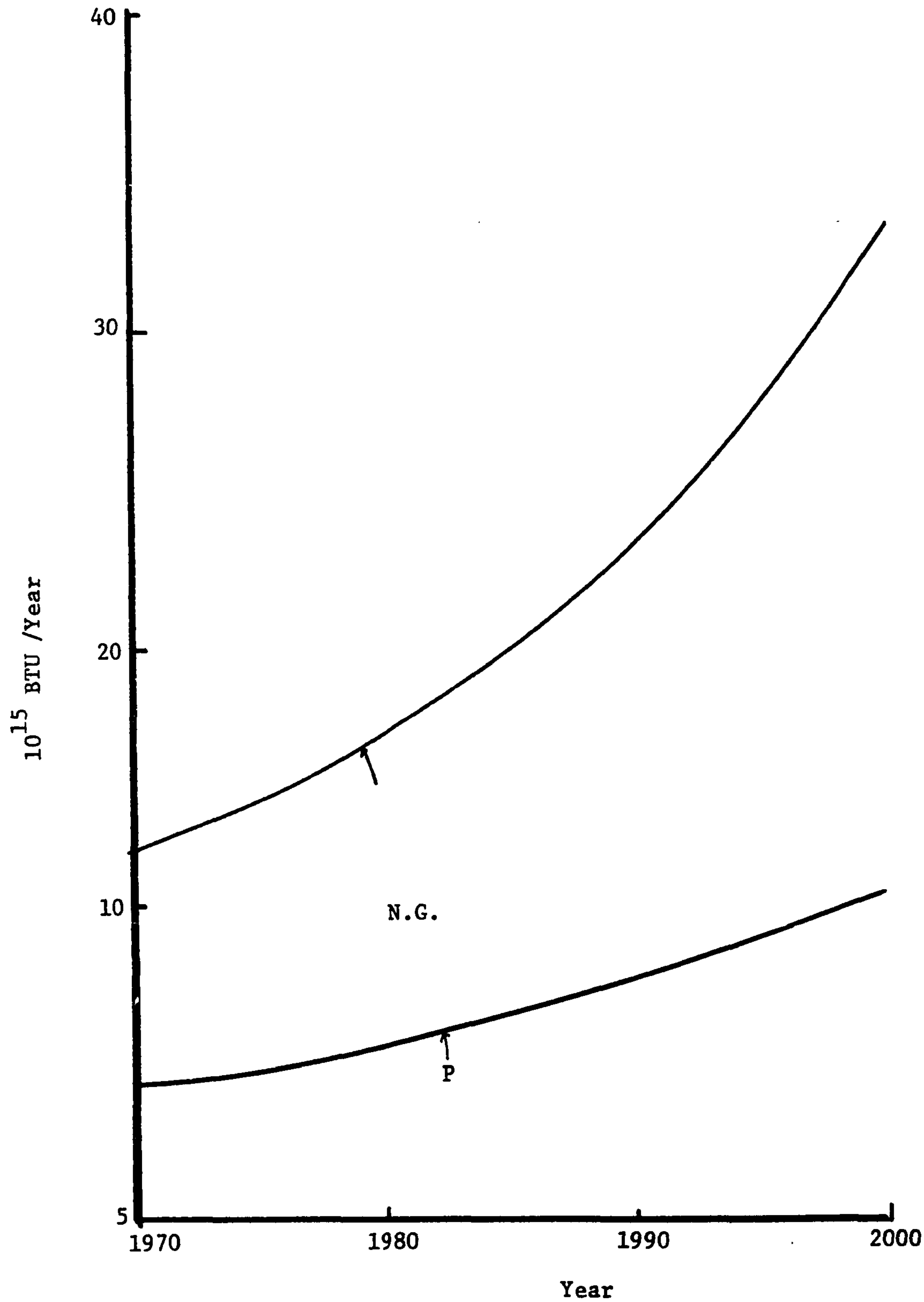


Figure III-b-3 Projected Res. and Com. Energy Demand by Sources

Transportation Projection

The unit energy consumption so coal for transportation is obtained by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-4)}$$

where:

$a = 110.4$ $d = 2.36$

$b = 0.00013$ $R^2 = 0.96$

$c = 0.04431$ $F = 59.3$

The unit energy consumption of petroleum for transportation is given by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-5)}$$

where:

$a = 5824$ $d = 1139.95$

$b = 0.1815$ $R^2 = 0.99$

$c = 15.07399$ $F = 249.3$

The unit energy consumption of natural gas for transportation is generated by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-6)}$$

where:

$a = 3969$ $d = 33.6$

$b = 0.03959$ $R^2 = 0.98$

$c = 33.6$ $F = 119.3$

Transportation demand acounts for 23.9 percent of the total energy consumption in 1970; however, it will decrease gradually to less than 18 percent in the year 2000. Coal (rail) fuel will be replaced completely by oil. Petroleum will still be the only dominating fuel. Natural gas needed for pipeline is going to increase, but it is not significant (Figure III-b-4).

Industrial Projection

The unit energy consumption of coal for industrial use is generated by the equation:

$$UU_{t,n} = a + -(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-7)}$$

where:

a = 77245	d = 1015.84
b = 0.15419	R^2 = 0.99
c = 1.73416	F = 199.7

The unit energy consumption of petroleum for industry is given by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-8)}$$

where:

a = 7411	d = 285.74
b = 0.06095	R^2 = 0.92
c = 285.74	F = 25.4

The unit energy consumption of natural gas for industry is obtained by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-9)}$$

where:

a = 127779	d = 2604.37
b = -0.06605	R^2 = 0.99
c = 13.05959	F = 220.9

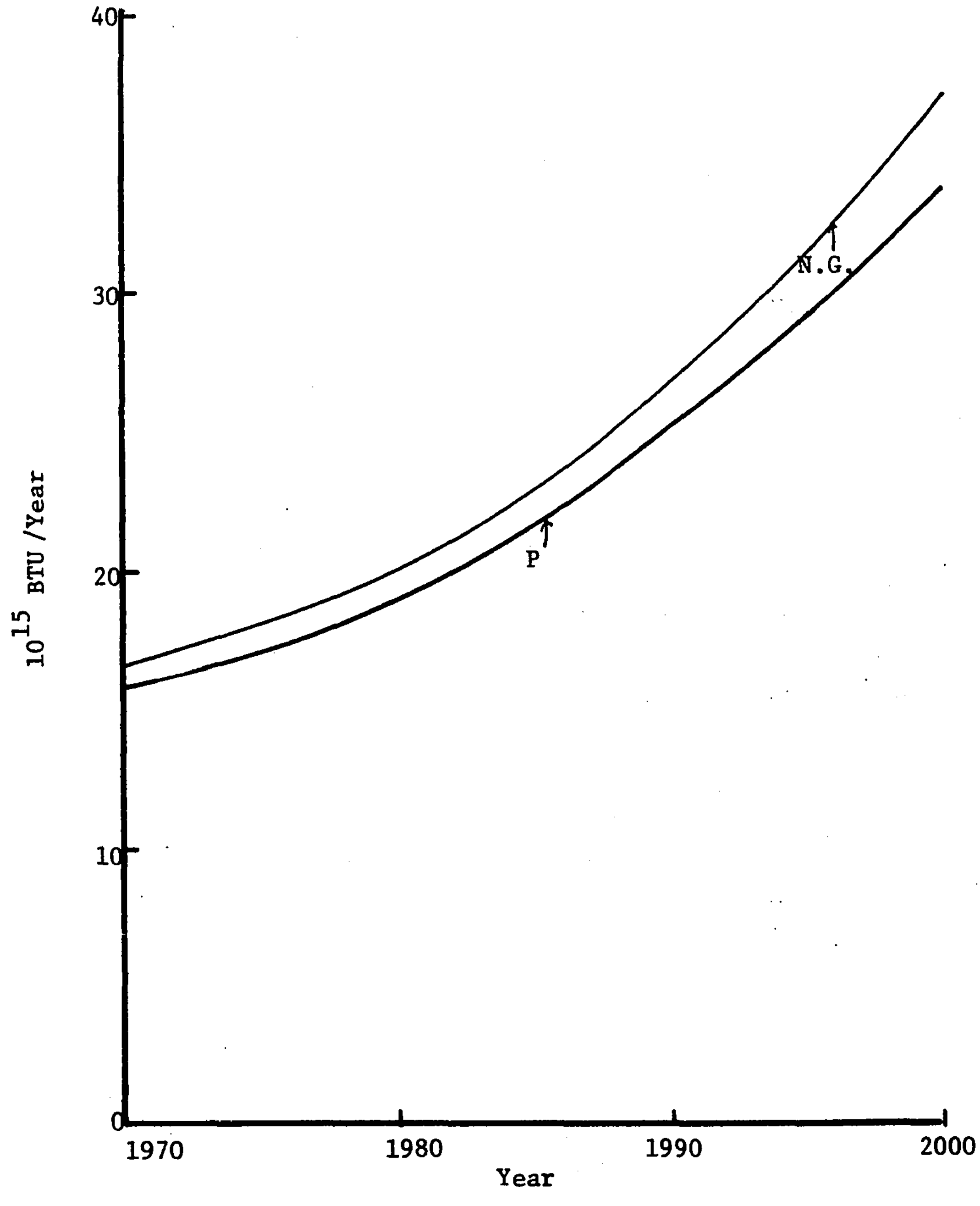


Figure III-b-4 Projected Transportation Energy Demand by Sources

Industrial demand will greatly decrease from 31.7 percent of the total energy requirements in 1970 to only 18.5 percent in the year 2000. This may be due to a larger share of electricity in the future (Figure III-b-5). Coal can no longer compete with the other two fuels. Transportation cost and environmental awareness of the people may be the reasons.

Indirect Energy Demand

The indirect energy demands are divided into again, end-use: residential, commercial, transportation, industrial and miscellaneous: into resources: coal, petroleum, natural gas, hydroelectric power, nuclear, geothermal, tidal and solar. This energy is supplied in the forms of electricity. Electrical energy only accounts for 24.1 percent of the total consumption in 1970, yet it will be doubled by the year 2000. Nuclear power alone will contribute half of that impressive growth. Coal will be the second leading fuel in this market. Oil and natural gas will slowly increase and they are becoming less important. Hydroelectric power will grow; its share however, will be reduced to about 2-3 percent of the total energy consumption. Geothermal power will supply some energy, especialy in the west. Industrial consumption will continue to lead and comes behind the residential use with slight drop in its share absorbed by the industrial consumption. Commercial use will maintain approximately 25 percent throughout. Industrial consumption will increase from 40.8 percent in 1970 to more than 42 percent of the total in the year 2000.

Technology improvement and environmental effect of the electrical generation are also considered. Figure III-b-6 shows the projected electrical generation plant efficiency, and Table III-b-1, the degradation

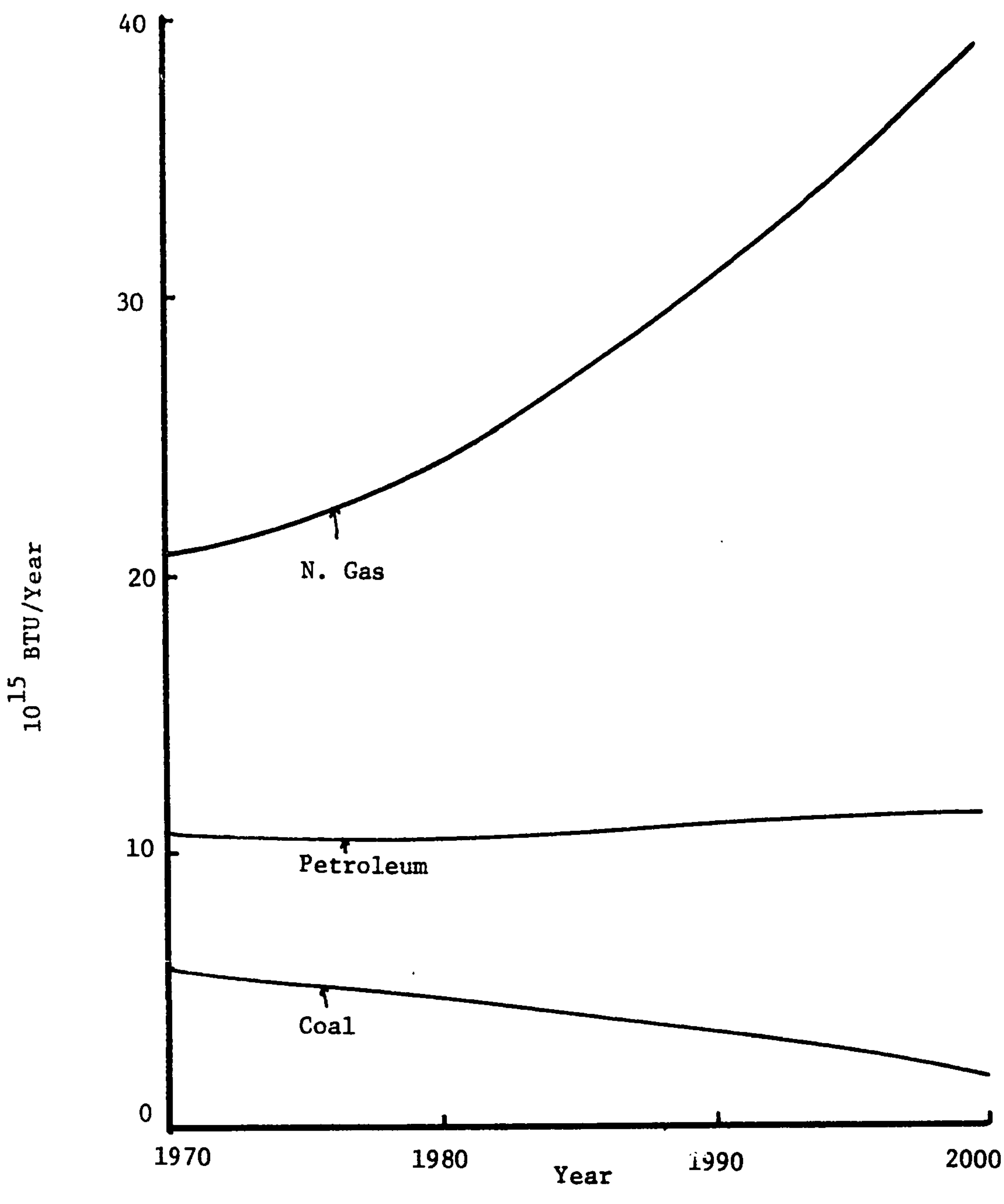


Figure III-b-5 Projected Industry Energy Demands by Sources

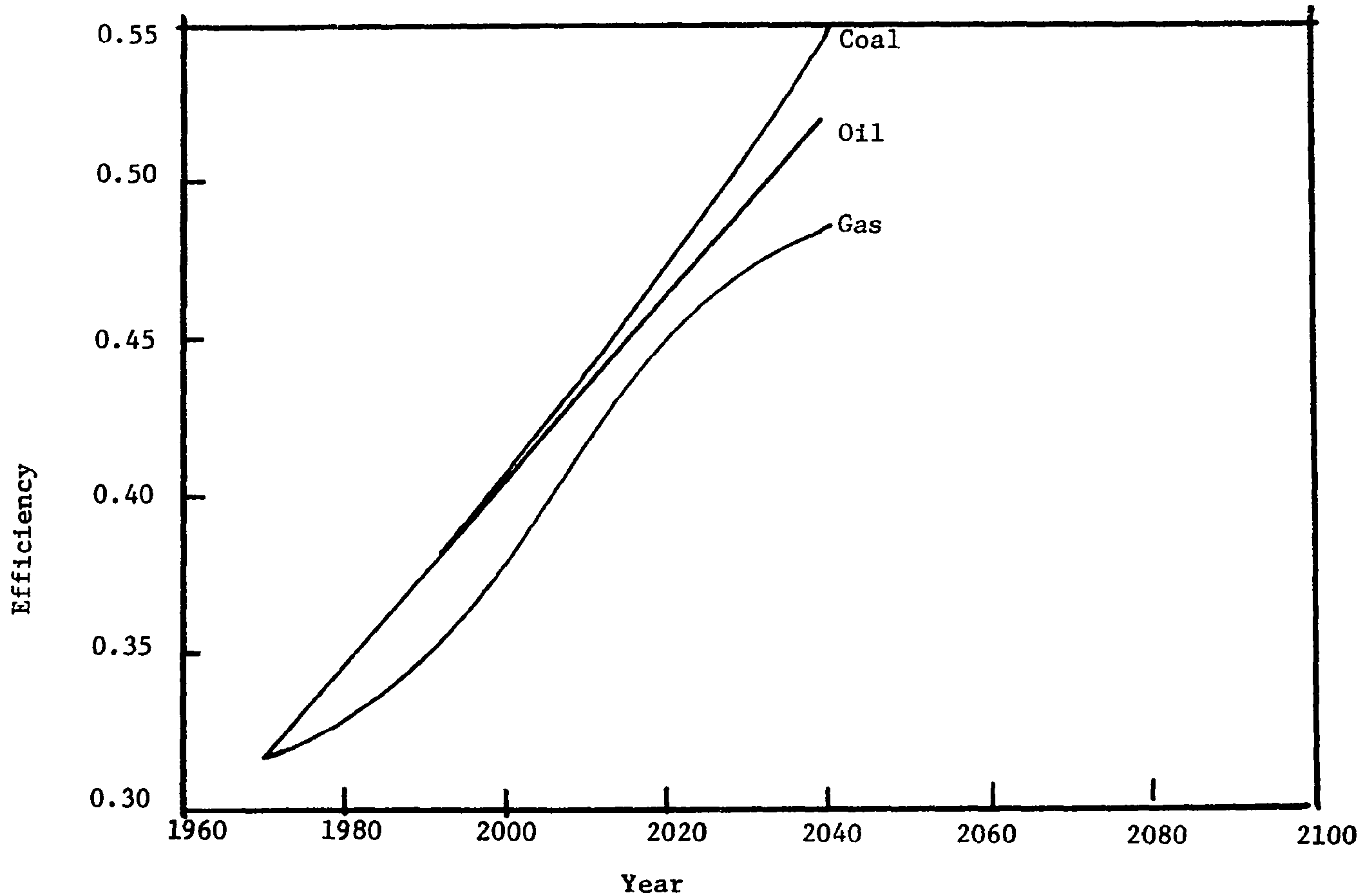


Figure III-b-6 The Projected Electrical Generation Efficiency for Fossil Fuels

(22,49,51,52)

Table III-b-1

Nuclear Power Plant Characteristics

Reactor Design		Year Introduced	Theraml Effic. %	Fuel Cycle	Net* U_3O_8	Net** ThO_2
GCFR	(87)+	2000	0.395	Pu in Th	--	--
GCFR	(87)	2020	0.398	Pu in Th	--	--
HTGR	(84)	1978	0.407	UC-ThC, U-233 recycle	1.63	0.351
LFR	(75)	2020	0.50	D-T pellets	--	--
LMFBR	(85)	1990	0.40	Pu oxide	--	--
LMFNR	(85)	2000	0.42	Pu oxide	--	--
LMFBR	(85)	2010	0.371	Pu carbide	--	--
LMFBR	(85)	2020	0.392	Pu carbide	--	--
LWR	(87)	1970	0.325	Enriched U	2.85	--
LWR	(87)	1980	0.325	Pu in nat. U	2.25	--
LWR	(87)	1990	0.325	Pu in nat. U	1.54	--
MCFR	(75)	2020	0.50	D-T	--	--
MSBR	(59)	2000	0.44	Pu in Th	--	0.417

*Units: 10^{-6} tonnes/10^6 Btu theraml at 0.25 percent tails.

**Units: tonnes/10^6 Btu theraml.

+Numbers refer to references in Bibliography.

factor for electrical power generation cooling water used to obatin the fuel demand for electrical generation for fuel I in yeat t.

$$CED(I,t) = ED(I,t) * EF(I,70) / EF(I,t) \times (FROT(t) + 1.045 \times FRNC(t) + 1.0175 \times (FRFC(t) + FRSP(t) + 1.075 \times FRDC(t) + FRCP(t) \quad \text{(III-b-10)}$$

where:

CED(I,t) = corrected electrical energy demand for fuel I in year t

ED (I,t) = electrical energy demand for fuel I in year t (Figure III-b-8)

EF(I,70) = actual efficiency for fuel in year 1970 (Figure III-b-6)

EF(I,t) = projected efficiency for fuel in year t (Figure III-b-6)

FROT(t) = fraction of electrical generation plants using once through cooling in year t (Figure III-b-7)

FRNC(t) = fraction of electrical generation plants using natural convection cooling towers (Figure III-b-7)

FRFC(t) = fraction of electrical generation plants using forced convection cooling towers (Figure III-b-7)

FRSP(t) = fraction of electrical generation plants using spray ponds (Figure III-b-7)

FRDC(t) = fraction of electrical generation plants using dry cooling (Figure III-b-7)

FRCP(t) = fraction of electrical generation platns using cooling ponds (Figure III-b-7)

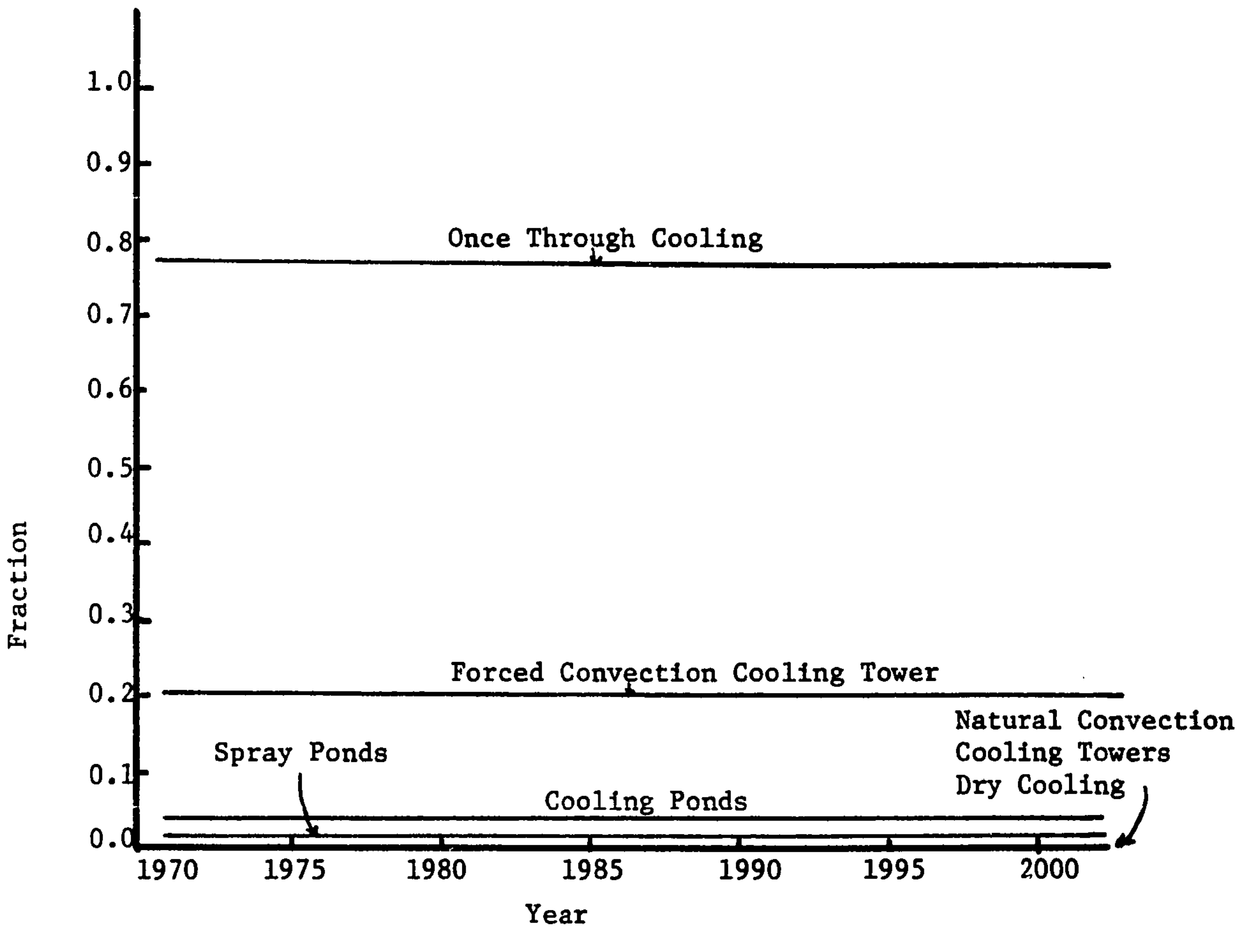


Figure III-b-7 Fraction of Cooling Devices

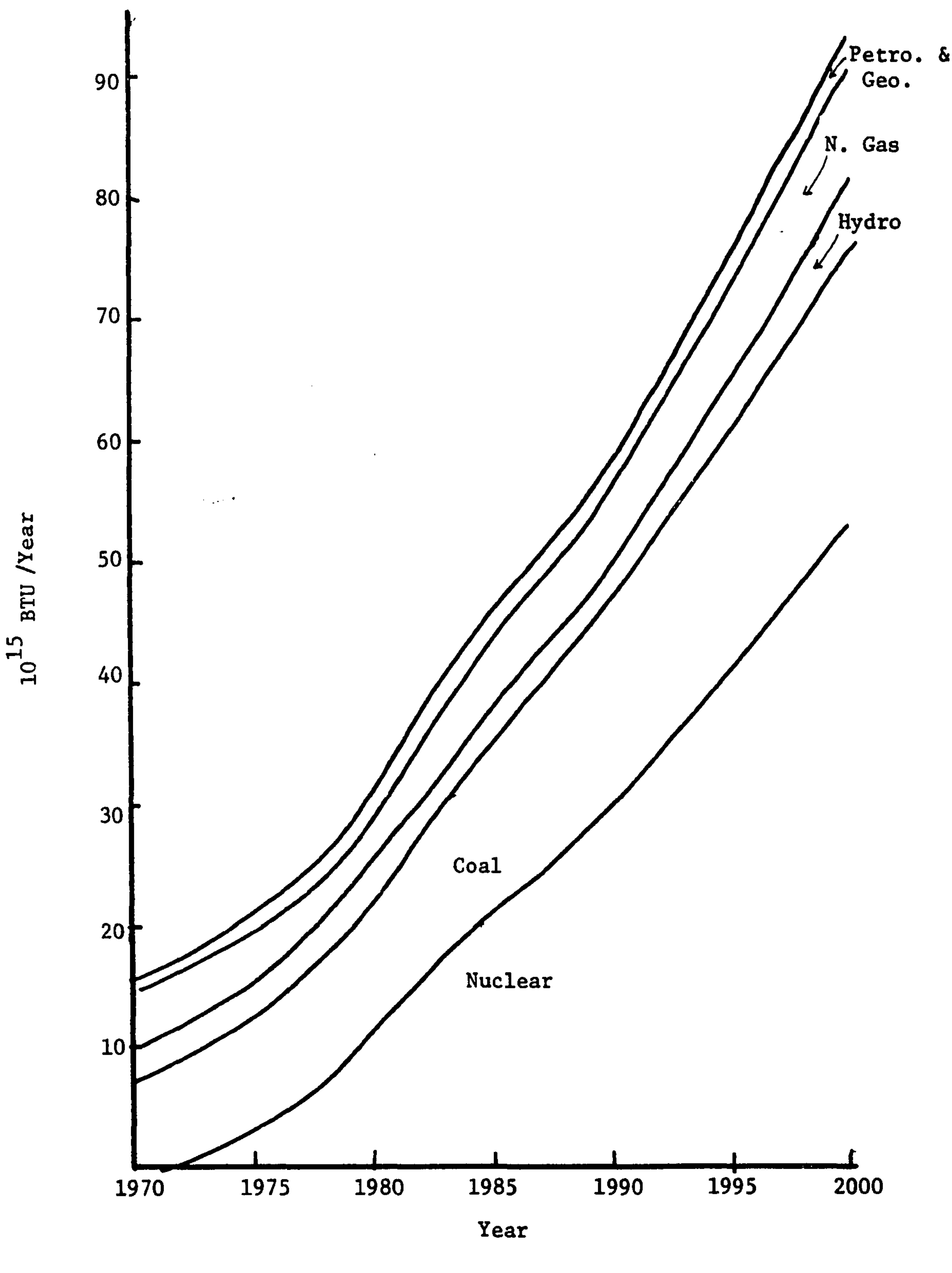


Figure III-b-8 Projected Electrical Power Consumption by Sources

Residential Projection

The unit energy consumption of coal for residential use is given by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-11)}$$

where:

$a = -22169$	$d = 183.2$
$b = 0.07171$	$R^2 = 0.99$
$c = 2.65918$	$F = 837.9$

The unit energy consumption of petroleum for residential use is obtained by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-12)}$$

where:

$a = 45560$	$d = -730.92$
$b = -0.04632$	$R^2 = 0.89$
$c = 1.7576$	$F = 13.6$

The unit energy consumption of natural gas for residential use is generated by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-13)}$$

where:

$a = 20879$	$d = -335.1$
$b = -0.02098$	$R^2 = 0.98$
$c = 2.03136$	$F = 101.2$

Residential consumption will increase from 5673.8 trillion BTU in 1970 to 27925 trillion BTU in the year 2000. This is an increase of almost 5 times.

The unit energy consumption of hydroelectric power for commercial and and residential use, is given by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c\ (INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-14)}$$

where:

$a = 26099$ $\quad d = -406.7$

$b = -0.01407$ $\quad R^2 = 0.97$

$c = 0.84058$ $\quad F = 82$

Commercial Projection

The unit energy consumption of coal for commercial use is obtained by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-15)}$$

where:

$a = 32787$ $\quad d = 320.12$

$b = 0.09085$ $\quad R^2 = 0.99$

$c = 1.36499$ $\quad F = 565.5$

The unit energy consumption of petroleum for commercial use is generated by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-16)}$$

where:

$a = 27247$ $\quad d = -425.64$

$b = 0.03225$ $\quad R^2 = 0.87$

$c = 1.17866$ $\quad F = 12.99$

The unit energy consumption of natural gas for commercial use is given by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-17)}$$

where:

$a = 5675$ $\qquad d = -129.43$

$b = 0.00458$ $\qquad R^2 = 0.98$

$c = 1.17957$ $\qquad F = 131.7$

The unit energy consumption of hydroelectric power for commercial use is obtained by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-18)}$$

where:

$a = 11313$ $\qquad d = -207.21$

$b = 0.0062$ $\qquad R^2 = 0.98$

$c = 0.41071$ $\qquad F = 100$

The commercial requirements of energy will increase from 3727.7×10^{12} BTU in 1970 to 26495 trillion BTU in the year 2000.

Industrial Projection

The unit energy consumption of coal for industry is given by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-19)}$$

where:

$a = -77245$ $\qquad d = 1015.84$

$b = 0.1549$ $\qquad R^2 = 0.99$

$c = 1.73416$ $\qquad F = 199.9$

The unit consumption of natural gas for industry is obtained by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-20)}$$

where :

$a = 48022$ $\quad d = -801.93$

$b = -0.03729$ $\quad R^2 = 0.88$

$c = 1.86471$ $\quad F = 18$

The unit energy consumption of natural gas for industry is obtained by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-21)}$$

where:

$a = 5534$ $\quad d = -278.33$

$b = 0.00188$ $\quad R^2 = 0.98$

$c = 1.84794$ $\quad F = 136.3$

The unit energy consumption of hydorelectric power for industry is derived from the following equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-22)}$$

where:

$a = 22736$ $\quad d = -316.18$

$b = -0.01048$ $\quad R^2 = 0.81$

$c = 0.55676$ $\quad F = 10.2$

The industry consumption will increase more than ten times from 6975.2 trillion BTU in 1970 to 43358 trillion BTU in the year 2000.

Miscellaneous Projection

The unit energy consumption of coal for this use is given by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-23)}$$

where :

$a = 2617$	$d = -3.92$
$b = -0.01106$	$R^2 = 0.93$
$c = 0.30402$	$F = 30.2$

The energy consumption of petroleum for this use is generated by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-24)}$$

where :

$a = 4798$	$d = 54.97$
$b = -0.00175$	$R^2 = 0.94$
$c = 0.23562$	$F = 39.6$

The unit energy consumption of natural gas for this use is derived by the equation:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-25)}$$

where:

$a = 4607$	$d = -51.03$
$b = -0.00993$	$R^2 = 0.96$
$c = 0.21799$	$F = 51.5$

The unit energy consumption of hydroelectric power for this use is obtained by:

$$UU_{t,n} = a + b(POP_{t,n}) + c(INC_{t,n}) + d(TEM_{t,n}) \qquad \text{(III-b-26)}$$

where:

$a = 5361$	$d = -59.48$
$b = -0.01029$	$R^2 = 0.84$
$c = 0.1105$	$F = 12$

Figure III-b-8 shows projected electrical power consumption by sources.

Summary

Total Projected Energy Consumption (Figure III-b-9); Energy Consumption per Capita (Figure III-b-10); Electrical Consumption per Capita (Figure III-b-11); Energy Consumption by Sources (Figures III-b-12 --III-b-15). Nuclear and Geothermal Consumption Projections (Figures III-b-16 and III-b-17) are from references 46, 47 and 39, due to the inadequate data available. Total Energy Consumption by Users (Figure III-b-18) are all shown in the next pages.

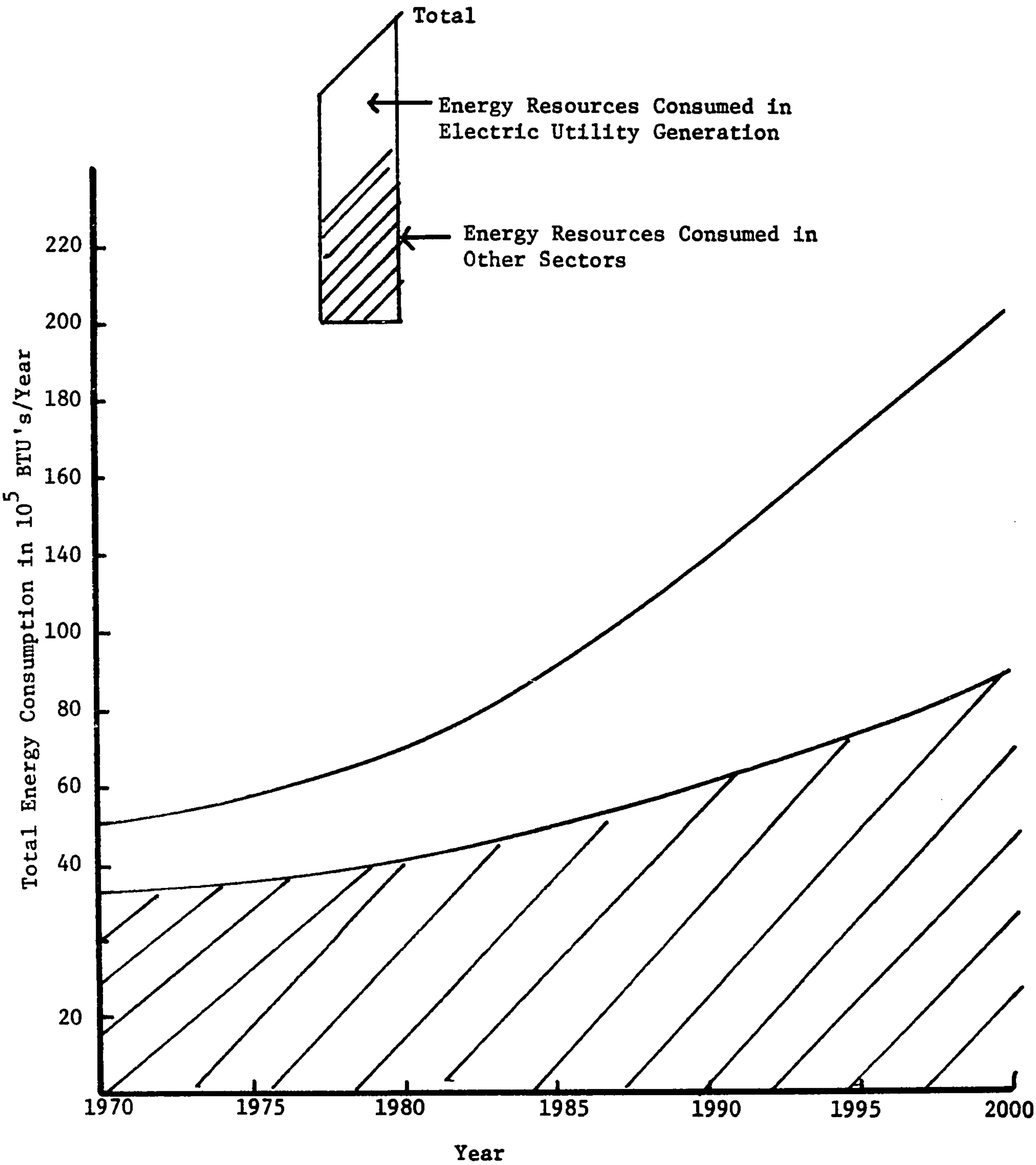


Figure III-b-9 Projected Total Energy Demand

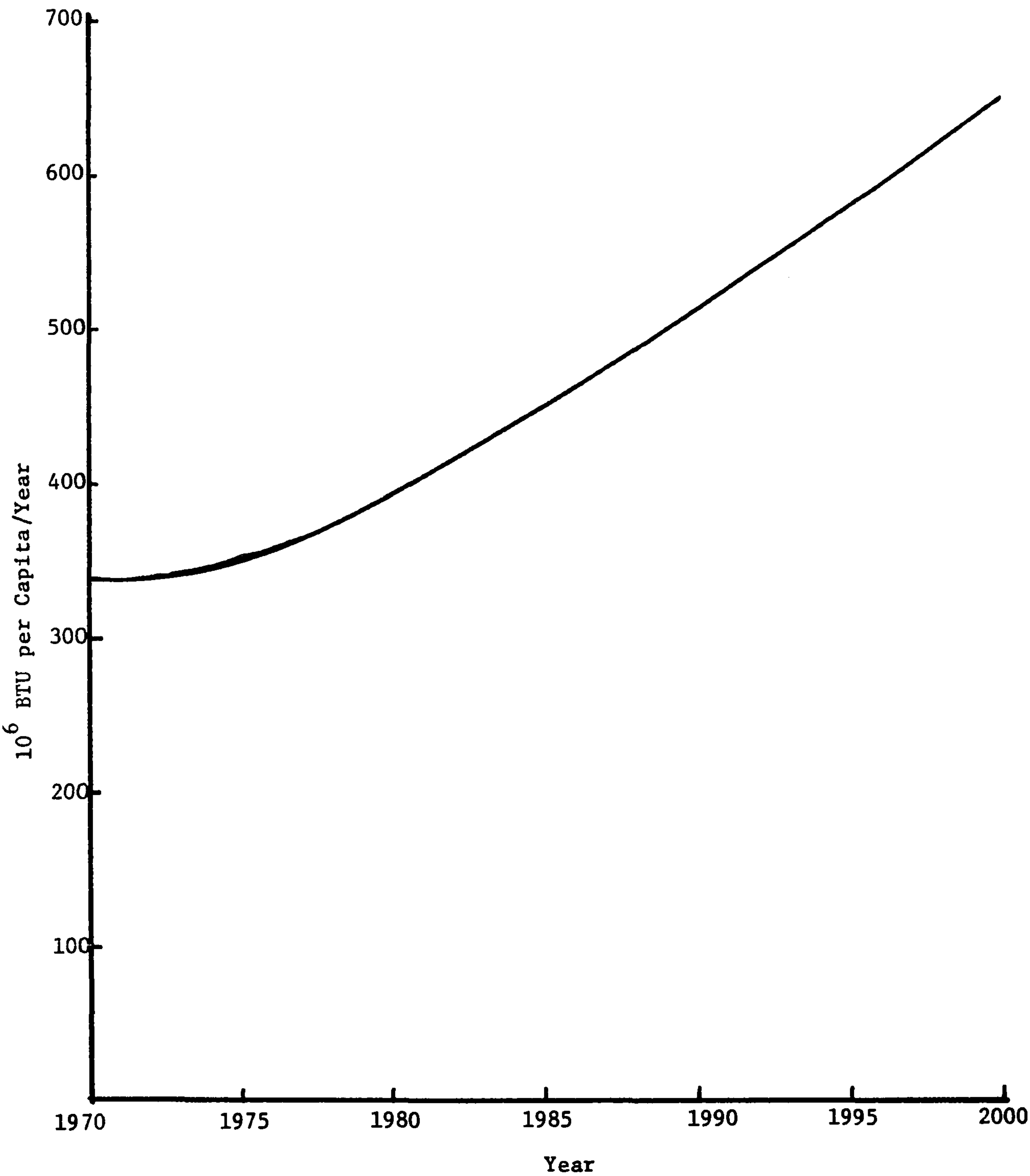


Figure III-b-10 Projected Total Energy Demand per Capita

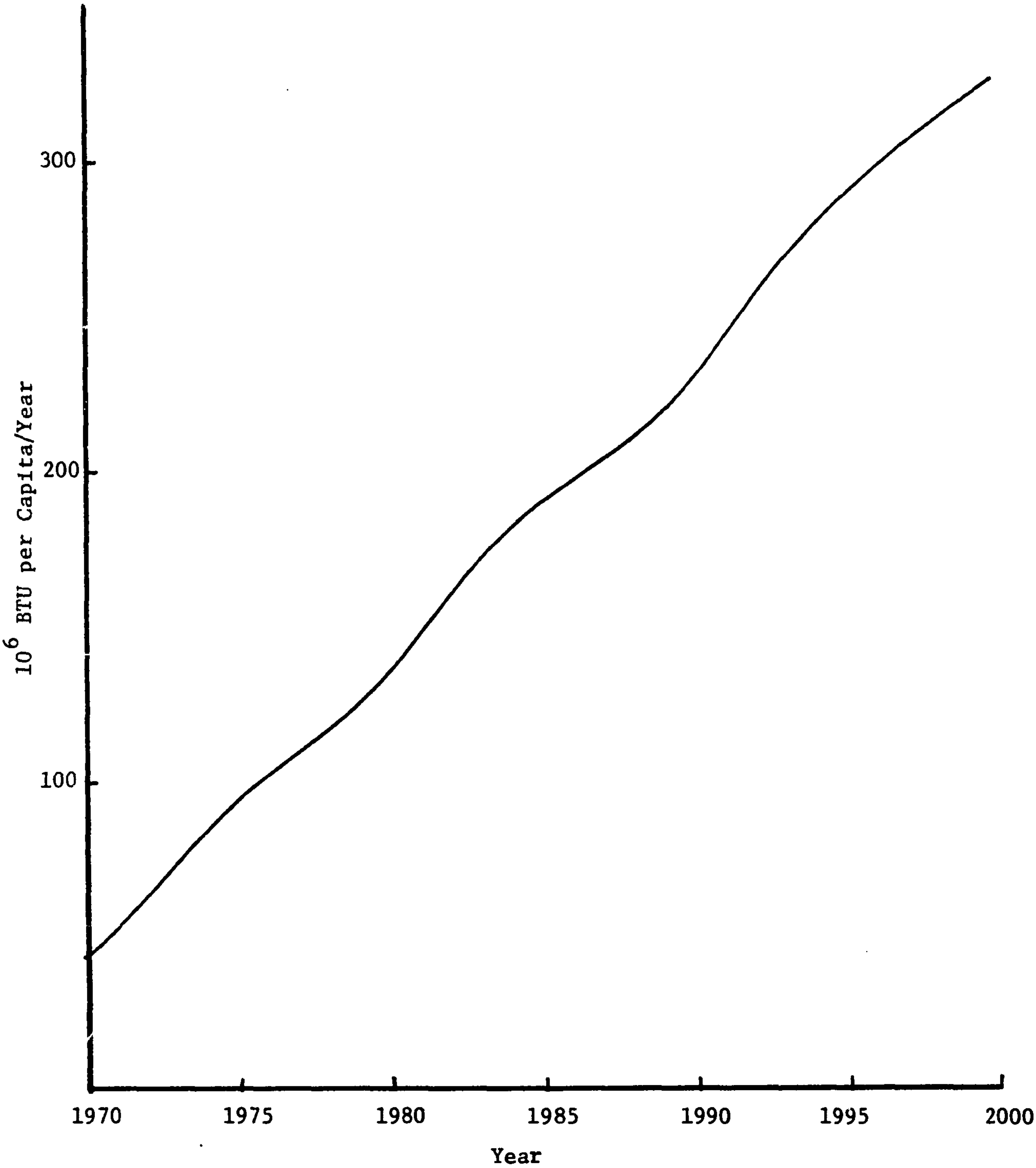


Figure III-b-11 Projected Electrical Consumption per Capita

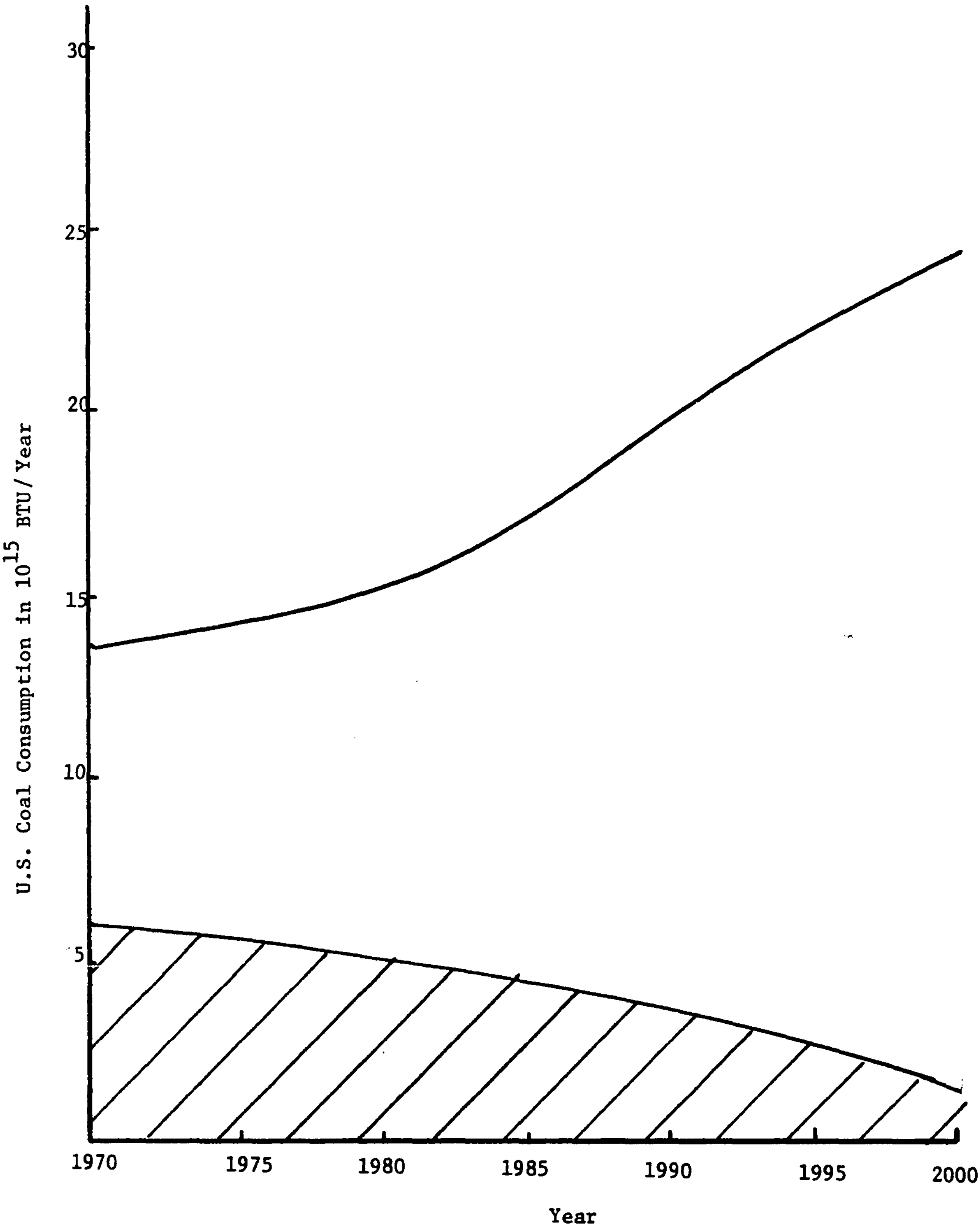


Figure III-b-12 U. S. Coal Demand

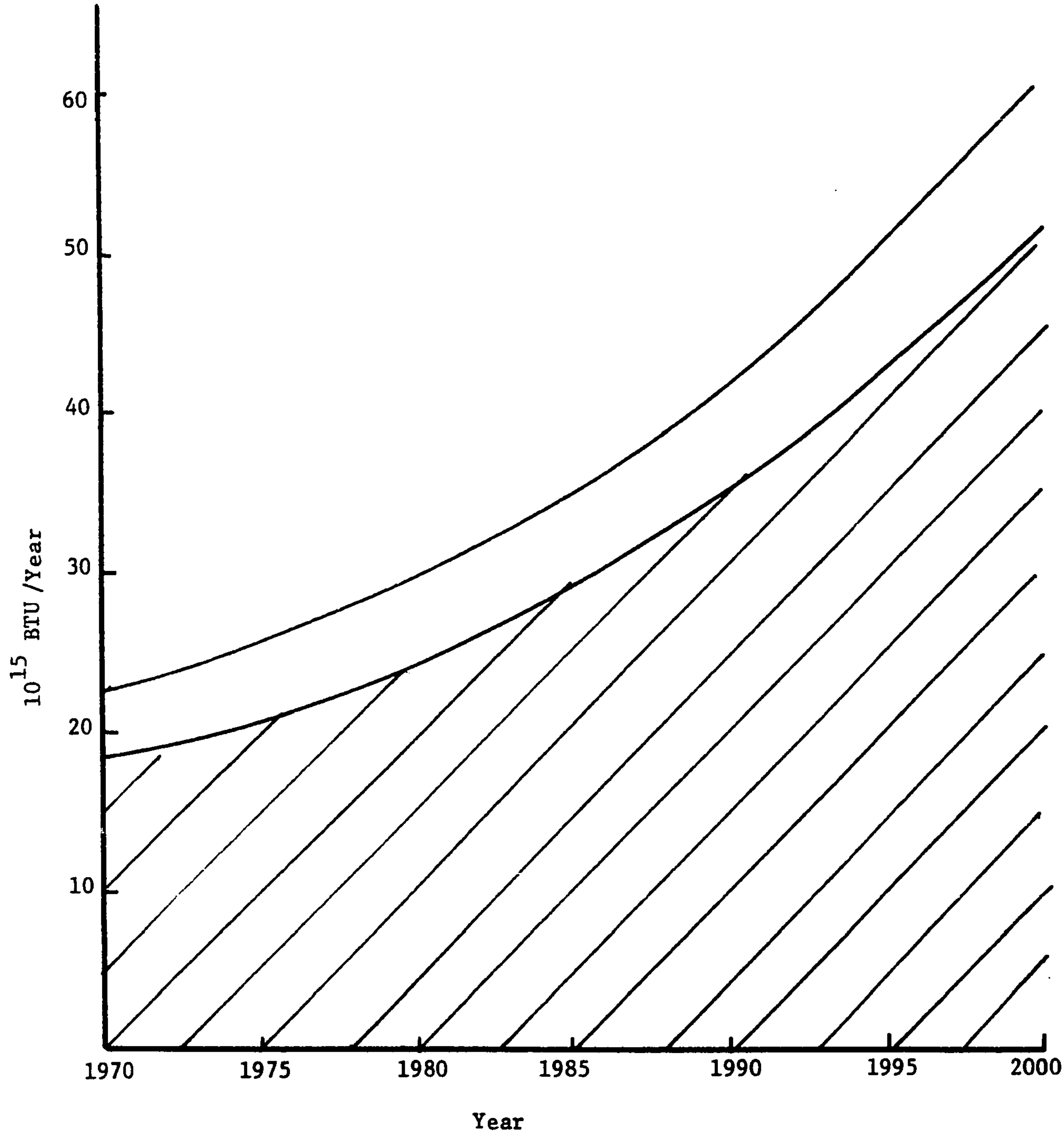


Figure III-b-13 Projected Natural Gas Demand

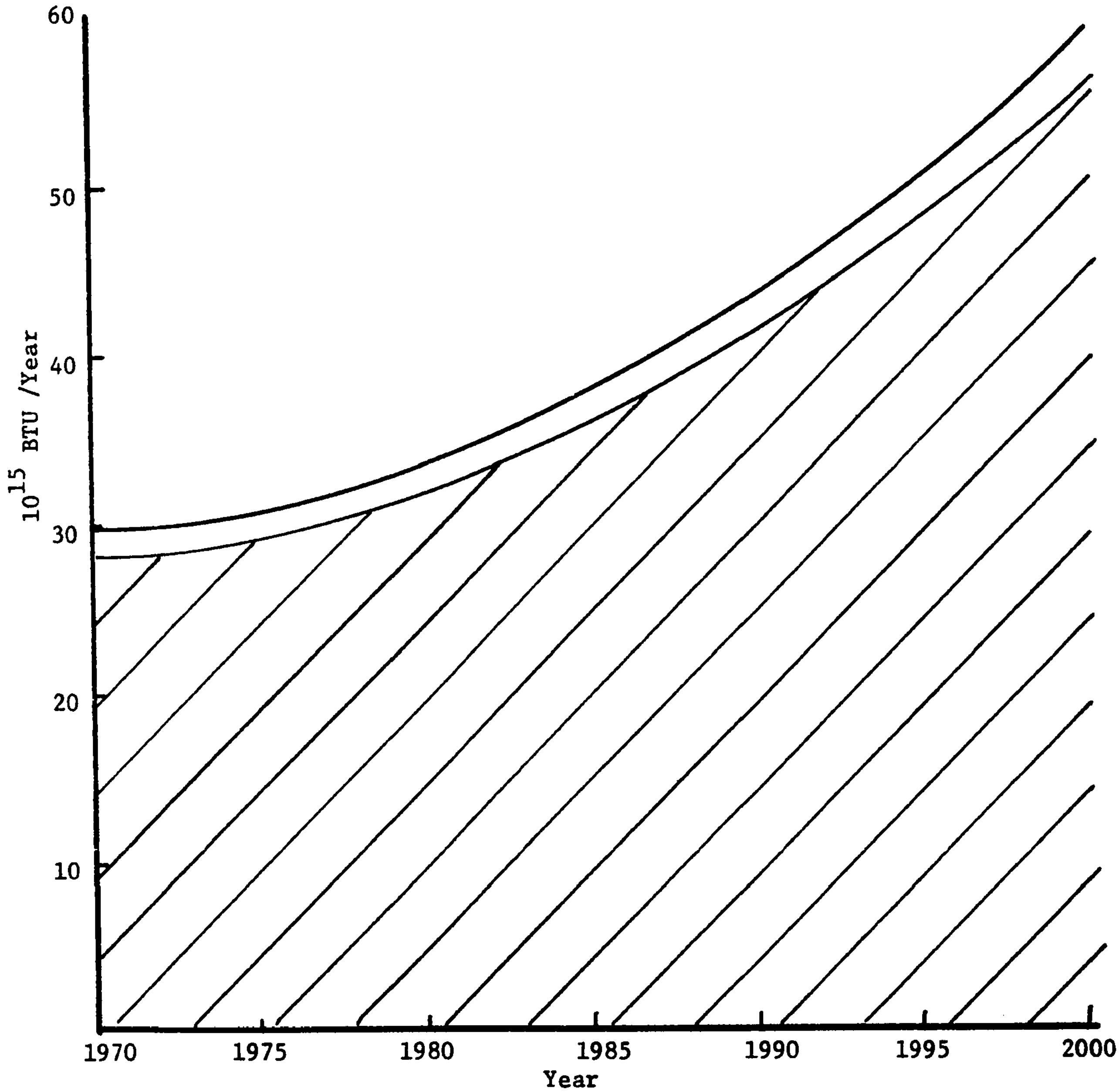


Figure III-b-14 U. S. Petroleum Demand

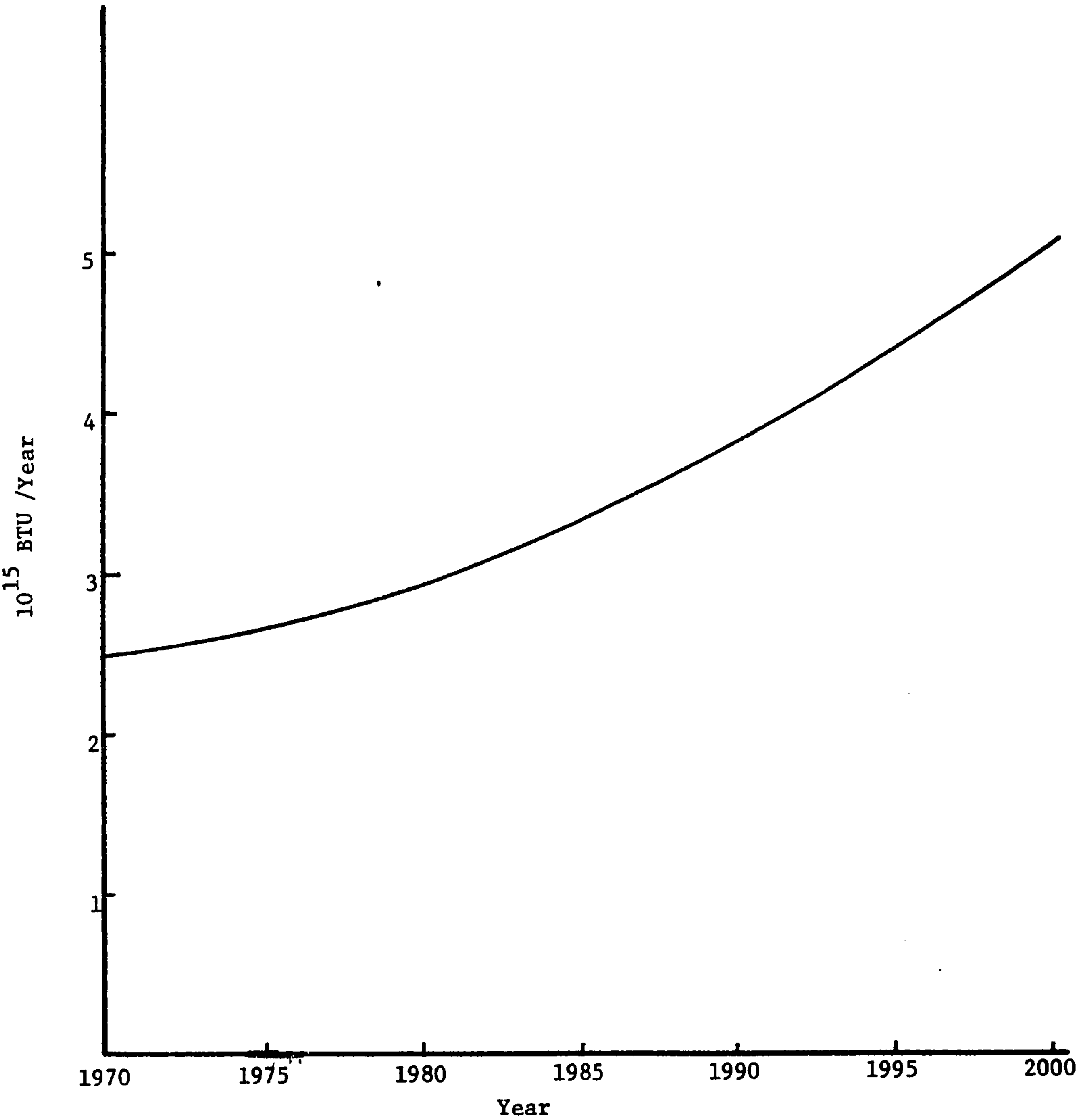


Figure III-b-15 Hydroelectric Demand

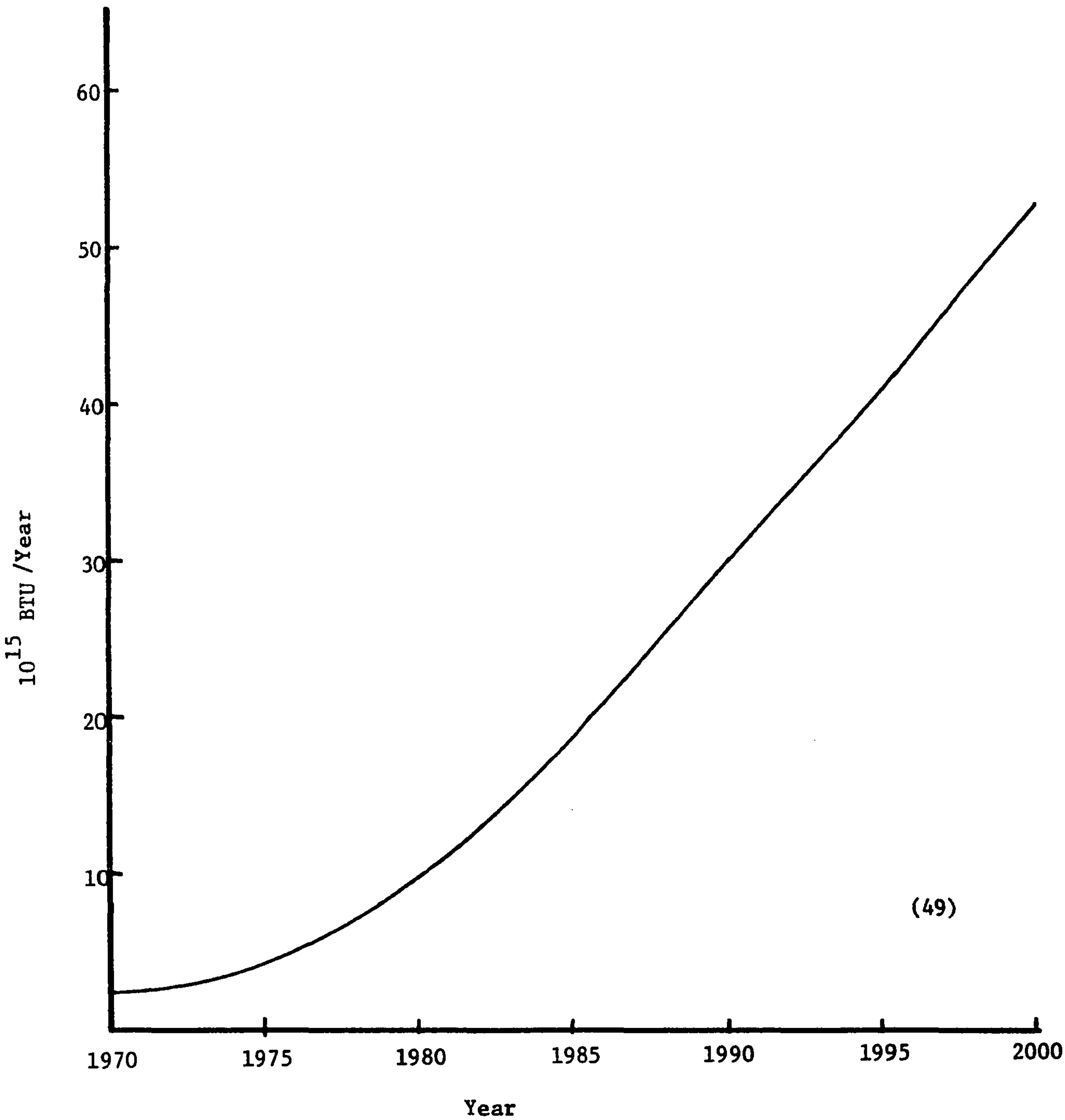


Figure III-b-16 Nuclear Energy Demand

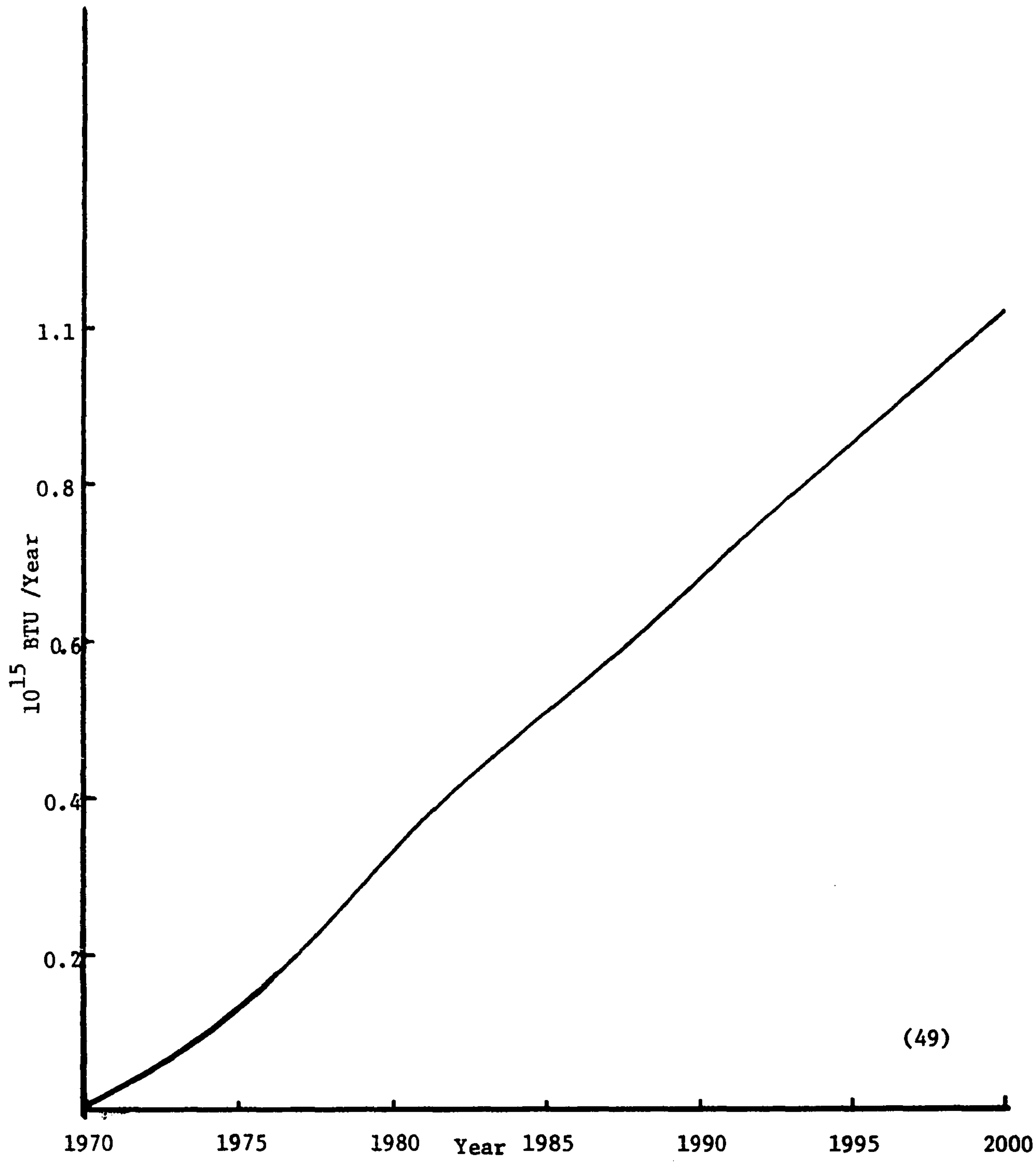


Figure III-b-17 Geothermal Energy Demand

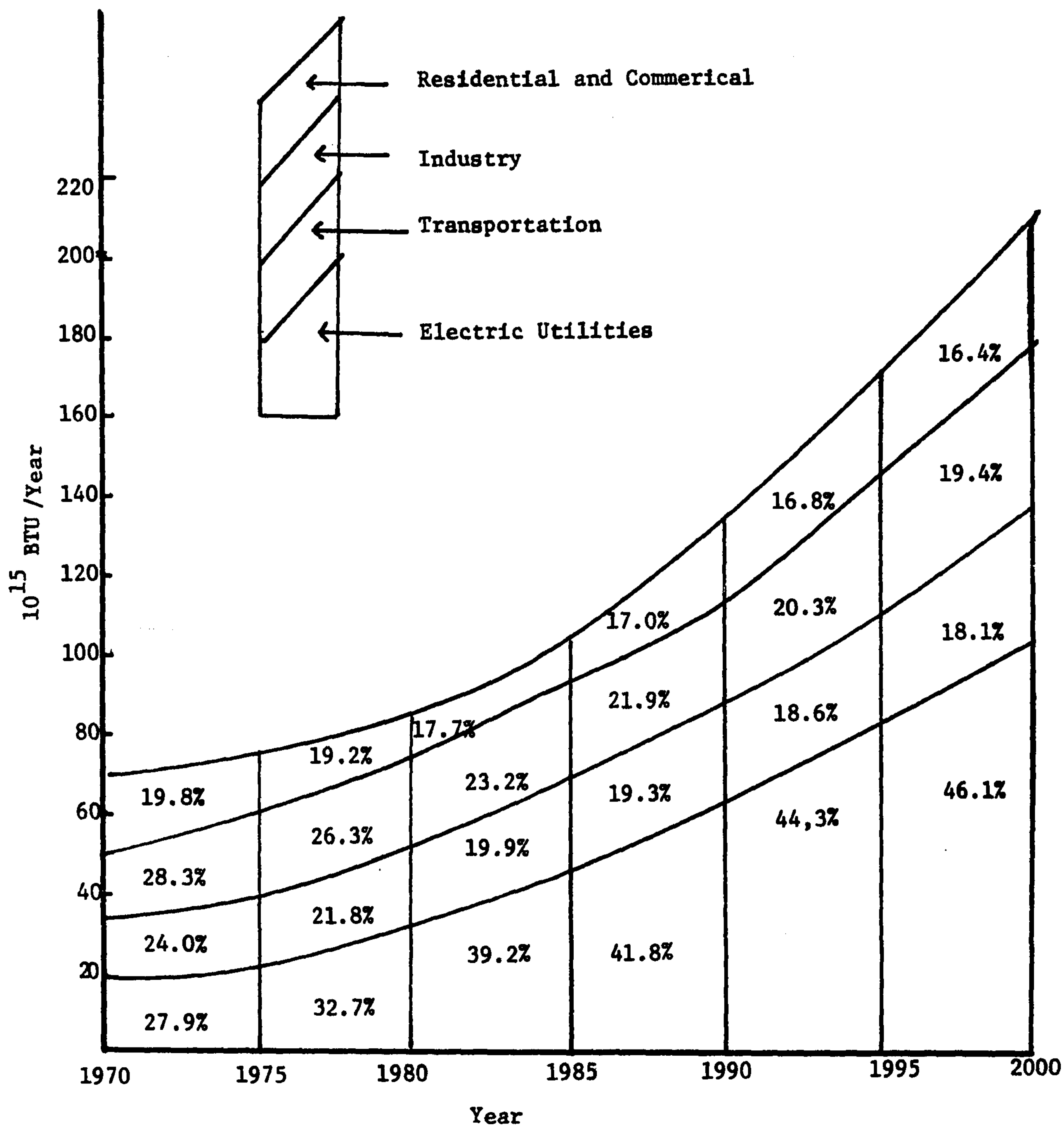


Figure III-b-18 Total Energy Demand by Users

Economics of Energy

Indeveloping policies to choose between alternatives, emphasis must be placed upon the costs of alternatives (fuels), thus justifying the search for the supply prices of natural resources. Policy decisions would then be made in the light of equilibrium levels among different resources. Therefore, those who would seek to coordinate energy policy must be concerned with the prices of the energy, and thence policy determination should be made upon the alternative uses so that a competitive and stable price would be maintained. A more accurate and reliable projection on future prices of fuels would be helpful to the decision-making. It is difficult to make meaningful economic analyses since the type and quantity of data required are not provided by the industry.[1] As recently indicated (103), neither gas nor oil prices lend themselves to statistical analysis, but both nuclear fuel anc coal costs can be examined in some detail. Figure III-d-1 gives the projected fuel cost of coal and nuclear fuel.

"The 1970 National Power Survey" projected that fossil fuel costs for 1990 will increase approximately 50 percent for coal and oil, and 100 percent for gas based on 1968 price.

This same assumption will be applied to this study. Thus, we will assume the fossil fuel cost at the point of production in 1990 will be

[1]"Developing an Operating Cost in Four Important Areas: U.S., Venezuela, North Africa, Middle East," Adelman, Morris A. Proceedings of the Council of Economics, American Institute of Mining, Metallurgical and Petroleum Engineers, 1966.

as the following:

1. The cost of coal and oil will increase as much as 50 percent since 1970.
2. The cost of natural gas will increase 100 percent since 1970.
3. This trend will be extended to the year 2000.

The cost of fuels at the point of consumption will also be estimated by multiplying the factors observed throughout 1955-1970. These factors are given in Tables III-c-1 - III-c-4.

It was estimated that syncrude from oil shale in Colorado will cost from $4.35 to $5.30 per barrel (50).

The cost of syncrude and syngas fron coal are estimated to be from $3.25 to %5.14 per barrel and $.35/mcf to $.60/mcf, respectively (18).

It appears that syncrude from oil shale and coal is almost economically feasible now, yet, coal gasification is not; but it is just a matter of time. In the next chapters, supply and alternatives will be suggested in light of synthetic fuels.

Results

Natural gas will continue to be the cheapest fuel. Coal will give some competition in some areas. Petroleum still will be the most expensive one (Figure III-c-1). Electricity may remain cheap due to more power generated from nuclear power and improved efficiency (Figures III-c-5 and III-c-6).

Table III-c-1

Comparative Prices of Fuels at the Point of Production

	at well 10^3 cf (N. Gas)	at well barrel (oil)	at mine mouth ton (coal)	at well BTU(Million) (N. Gas)	at well BTU(Million) (oil)	at mine mouth BTU(Million) (Coal)
1946	¢ 5.3	$1.41	$3.44	¢ 4.9	¢ 24.3	¢ 13.1
1947	6.0	1.93	4.16	5.6	33.3	15.9
1948	6.5	2.60	4.99	6.0	44.8	19.0
1949	6.3	2.54	4.88	5.9	43.8	18.6
1950	6.5	2.51	4.84	6.0	43.8	18.5
1951	7.3	2.53	4.92	6.8	43.6	18.3
1952	7.8	2.53	4.90	7.3	43.6	18.7
1953	9.2	2.63	4.92	8.6	45.2	18.8
1954	10.1	2.73	4.52	9.4	47.9	17.3
1955	10.4	2.77	4.50	9.7	47.8	17.2
1956	10.8	2.79	4.82	10.0	48.1	18.4
1957	11.3	3.03	5.03	10.5	53.3	19.4
1958	11.9	3.01	4.85	11.1	51.9	18.5
1959	12.9	2.90	4.77	12.0	50.0	18.2
1960	14.0	2.83	4.69	13.0	49.7	17.9
1961	15.1	2.89	4.55	14.0	49.8	17.5
1962	15.5	2.90	4.48	14.4	50.0	17.1
1963	15.8	2.99	4.39	14.7	49.8	16.8
1964	15.4	2.83	4.33	14.3	49.7	16.7
1965	15.6	2.88	4.44	14.5	49.3	16.9
1966	15.7	2.88	4.54	14.6	49.7	17.3
1967	16.0	2.92	4.62	14.9	50.3	17.6
1968	16.4	2.93	4.67	15.2	50.5	17.8
1969	16.7	3.09	4.99	15.5	53.3	19.1
1970	17.1	3.18	6.26	15.9	54.8	23.9
1971	18.2	3.39	7.07	16.9	58.5	27.0

Table III-c-2

Natural Gas Cost

Cents/Million BTU

	at well	electrical	average	ratio 1/2	ratio 1/3
1955	9.7	18.0	40.0	0.539	0.234
1956	10.0	18.5	41.5	0.556	0.241
1957	10.5	19.5	43.1	0.538	0.244
1958	11.1	19.5	46.2	0.569	0.240
1959	12.0	22.3	47.7	0.538	0.252
1960	13.0	23.8	50.1	0.546	0.259
1961	14.0	25.1	51.0	0.558	0.275
1962	14.4	26.4	51.4	0.545	0.280
1963	14.7	25.9	51.2	0.568	0.287
1964	14.3	25.0	51.6	0.572	0.277
1965	14.5	25.0	52.2	0.580	0.278
1966	14.6	25.0	52.2	0.584	0.279
1967	14.9	24.7	51.9	0.603	0.287
1968	15.2	25.1	50.4	0.606	0.302
1969	15.5	25.4	51.5	0.610	0.301
1970	15.9	27.0	53.6	0.589	0.297
			Factor	0.60	0.30

Table III-c-3

Comparative Prices of Coal

Cents/Million BTU

	at mine	electric	coke oven	ratio 1/2(%)	ratio 1/3(%)
1955	17.2	25.2	35.0	68.3	49.1
1956	18.4	26.2	37.6	70.2	48.9
1957	19.4	27.5	41.1	70.5	47.2
1958	18.5	27.4	41.0	67.5	45.1
1959	18.2	26.5	40.1	68.7	45.5
1960	17.9	26.0	40.2	68.8	44.5
1961	17.5	25.8	40.2	67.8	43.5
1962	17.1	25.6	37.5	68.0	45.6
1963	16.8	25.0	35.9	67.2	46.8
1964	16.7	24.4	37.6	68.4	44.4
1965	16.9	24.4	36.8	69.3	45.9
1966	17.3	24.7	37.4	70.0	46.3
1967	17.6	25.2	39.5	69.8	44.6
1968	17.8	25.5	36.4	69.8	48.9
1969	19.1	26.6	41.0	71.8	46.6
1970	23.9	31.1	46.9	76.8	51.0
1971	27.0		58.5		46.1
			Factors	0.70	0.45

Table III-c-4

Comparative Prices of Fuels at the Point of Consumption

Cents/Million BTU

	Crude Oil	Gasoline	Ratio 1/2
1950	43.8	214.2	0.204
1951	43.6	217.3	0.201
1952	43.6	220.6	0.198
1953	45.2	229.6	0.197
1954	47.9	232.4	0.206
1955	47.8	232.6	0.206
1956	48.1	239.5	0.201
1957	53.3	247.8	0.215
1958	51.9	243.1	0.213
1959	50.0	244.0	0.205
1960	49.7	249.1	0.200
1961	49.8	246.2	0.202
1962	50.0	245.2	0.204
1963	49.8	243.5	0.205
1964	49.7	242.9	0.205
1965	49.3	249.3	0.198
1966	49.7	256.7	0.194
1967	50.3	265.4	0.190
1968	50.5	269.8	0.187
1969	53.3	281.0	0.190
1970	54.8		
		Factor	0.20

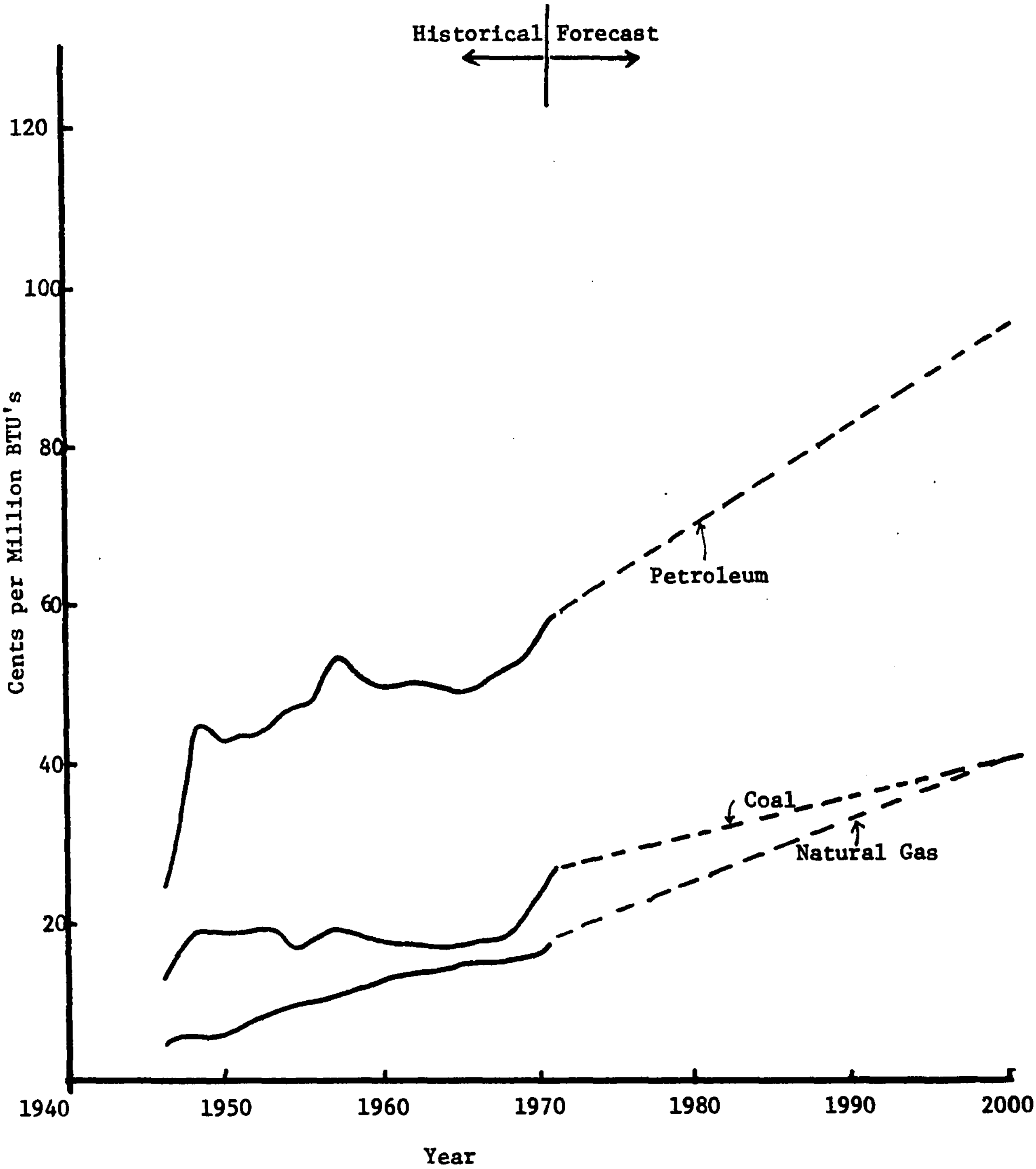


Figure III-c-1 Comparative Average Prices of Mineral Fuels at Point of Production

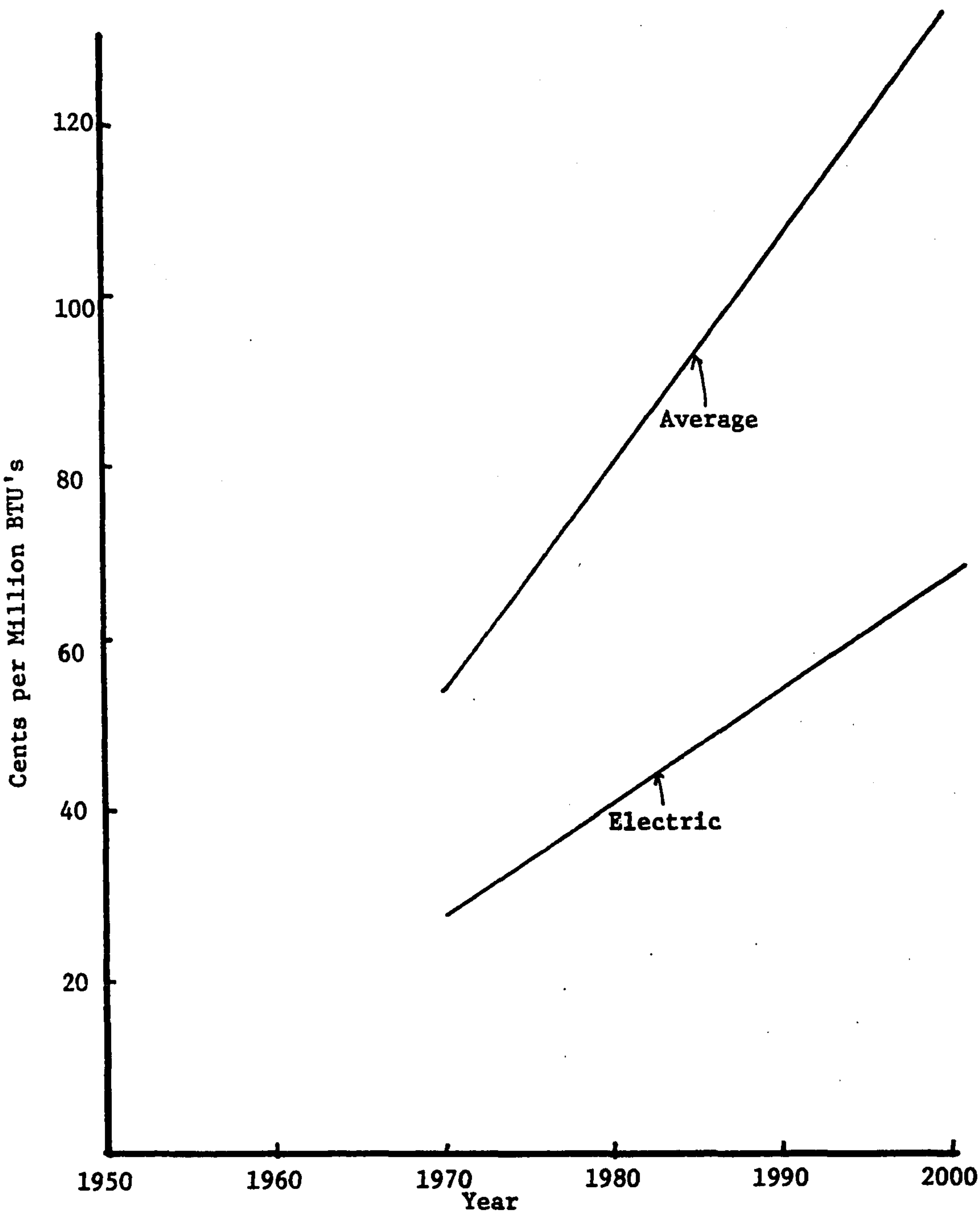


Figure III-c-2 Projected Price of Natural Gas at Point of Consumption

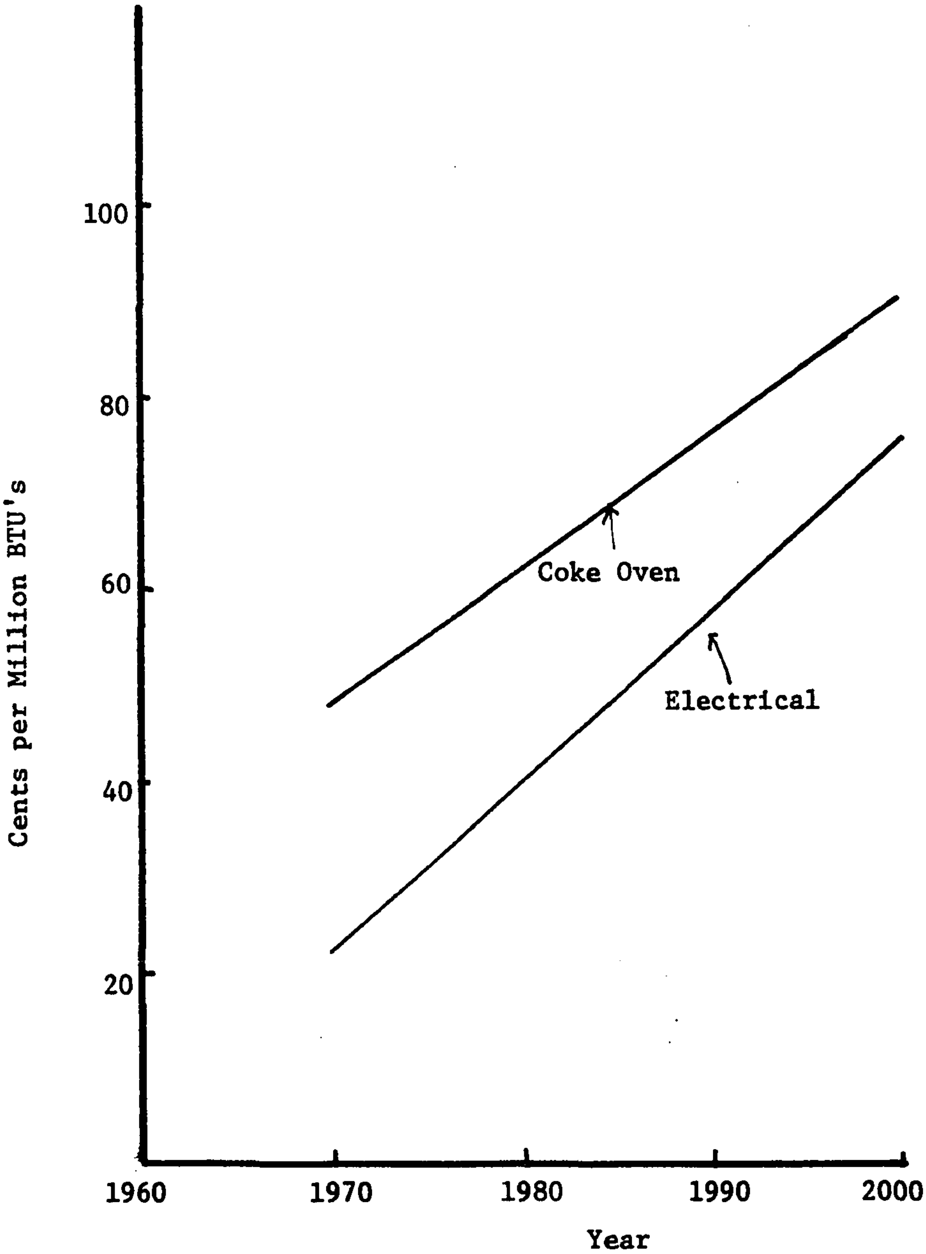


Figure III-c-3 Projected Price of Coal at Point of Consumption

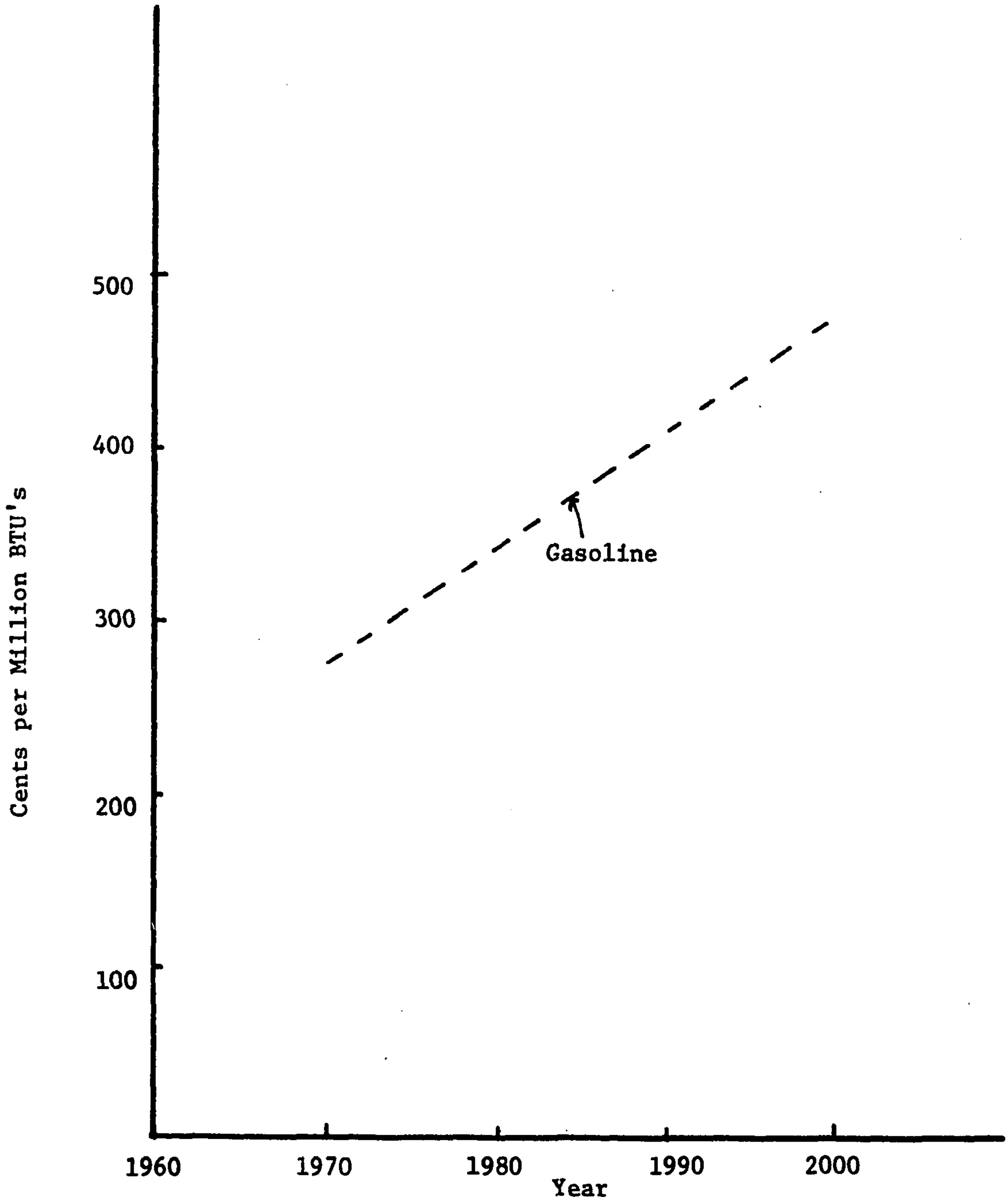


Figure III-c-4 Projected Price of Gasoline at Point of Consumption

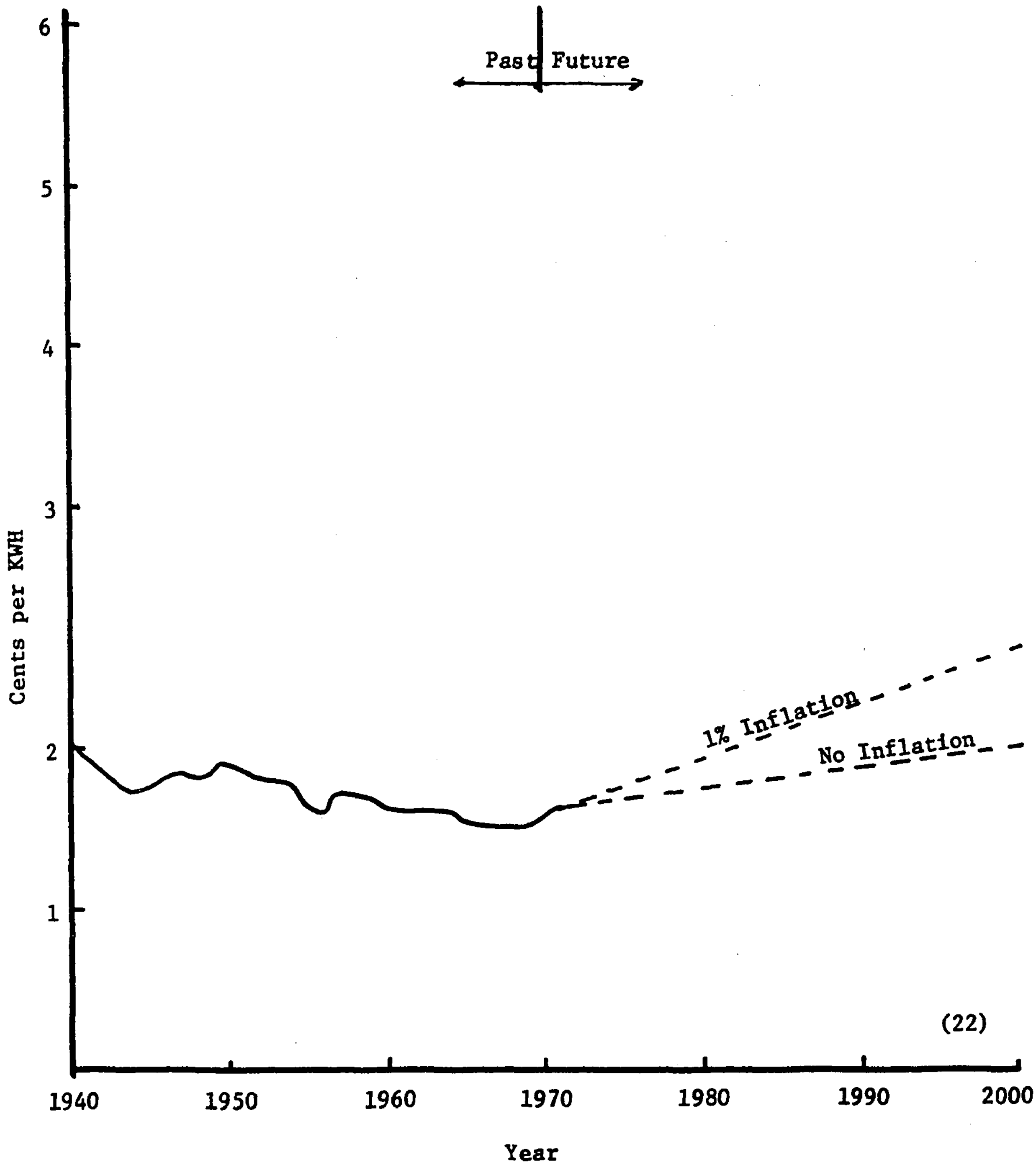


Figure III-c-5 Price of Electricity to Ultimate Consumers

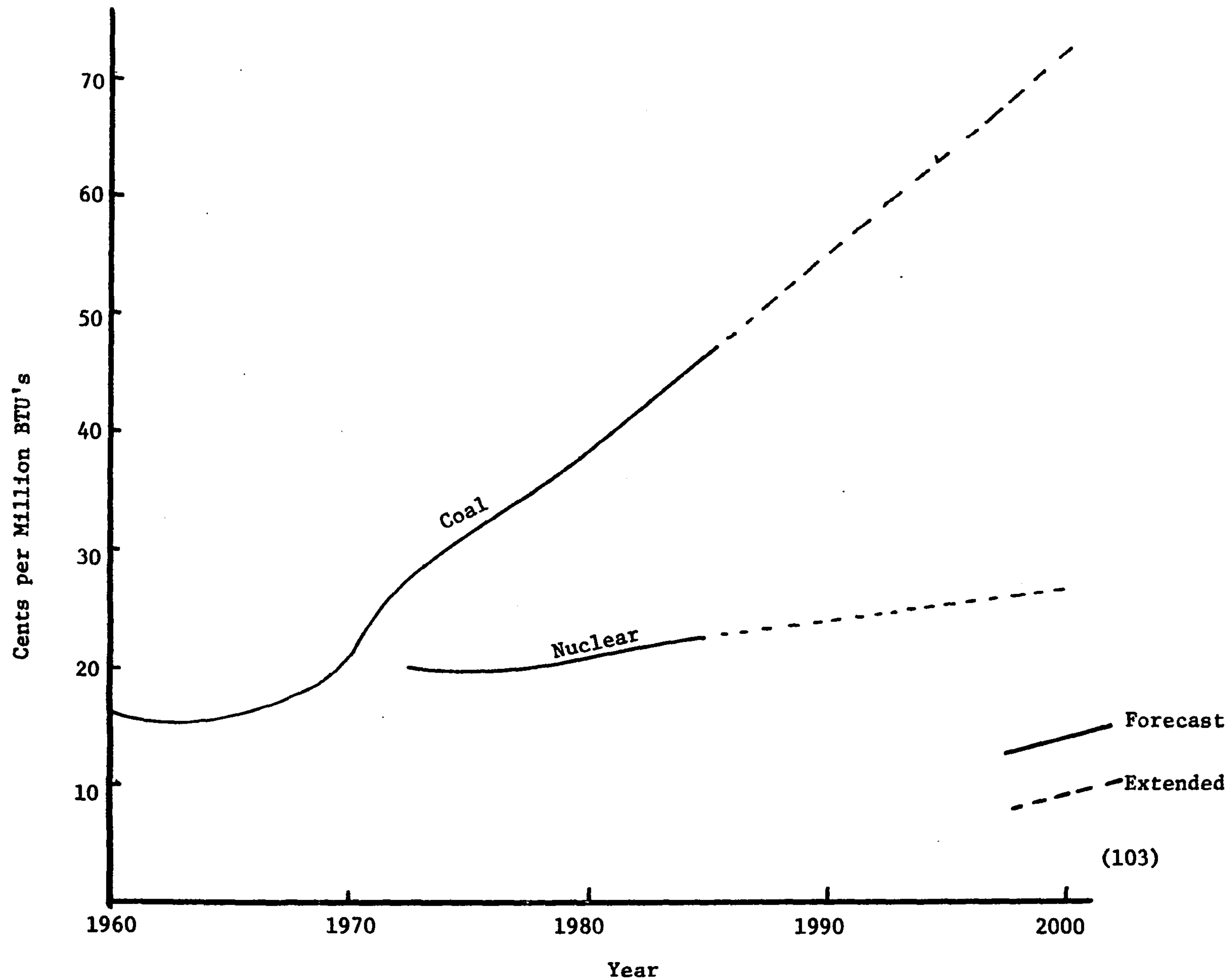


Figure III-c-6 Projection of Fuels' Costs

The Production of Energy and Its Availability

The projected energy requirements on each of the energy sources; coal, petroleum, naturag gas, nuclear, geothermal, tidal, wind and solar must be balaanced with its projected production. It a shortage occurs, then an alternative resource must be used. Estimated ultimate U. S. energy resources (Table III-d-1) are based on the fuel heating values used in references 6 and 97.

Hydroelectric Power

Table III-d-2 shows the developed and estimated undeveloped hydro-electric power. The potential of hydroelectric power is about 180,000 megawatts of capacity capable of producing an average of 715 million megawatt hours of electric energy annually, or equivalent to 7.0 quadrillion BTU. Since hydroelectric power is the cheapest energy (Table III-d-3), we expect that its demand will be met (Figure III-d-1).

Hydroelectric power will not contribute a whole lot in the future, but it does have some regional significance, especially in the regions such as the Pacific, Mountain and Atlantic.

Geothermal

Table III-d-1 shows the potential of geothermal power is between 70 and 130 quadrillion BTU. Table III-d-3 shows that geothermal power is the cheapest cource next only to hydroelectric power. It is assumed that its potential will be fully utilized to meet the demand.

The geothermal power will also not contribute a great deal to the energy market, but it may be significant in states like California,

Table III-d-1

Ultimate U.S. Energy Recoverable Reserves
(Including Alaska)

Resource	Ultimate Reserve 10^{15} BTU	Reference
Coal (50% recovery)	10,296.	(6)
Crude petroleum	1493.5	(6)
Natural gas liquids	180.6	(6)
Natural gas	1465.	(6)
Oil Shale (@ 6%)	6786.0	(6,80)
Tar sands (@ 35%)	32. - 51.	(6)
Geothermal (34% - 46%)	70. - 130.	(96)

Table III-d-2 Water Power - Developed and Estimated Undeveloped, by Geographic Division; 1945 to 1970

Item & Division	1945	1950	1955	1960	1965	1968	1969	1970
Developed Water Power[1]								
United States	15,892	18,675	25,742	33,180	44,490	48,741	50,248	61,952
New England	1,170	1,239	1,385	1,520	1,495	1,487	1,495	1,473
Middle Atlantic	1,668	1,678	1,789	2,472	4,815	4,243	4,231	4,264
East North Central	813	901	943	929	886	939	933	936
West North Central	617	629	962	1,594	2,982	2,726	2,785	2,728
South Atlantic	2,664	2,767	3,536	3,773	5,170	5,755	5,271	5,265
East South Central	2,229	2,729	3,576	3,750	4,497	5,106	5,111	5,224
West South Central	374	466	948	944	1,661	1,768	1,840	1,946
Mountain	2,007	2,286	3,706	4,621	5,560	6,095	6,097	6,202
Pacific	4,345	5,979	8,898	13,578	17,424	21,122	22,485	23,914
Undeveloped Water Power								
United States	77,140	87,604	85,895	114,200	124,087	129,709	128,900	127,990
New England	3,348	3,250	2,586	2,900	3,240	3,302	3,300	3,330
Middle Atlantic	5,175	6,572	8,023	7,600	4,986	4,545	4,545	4,455
East North Central	2,574	2,344	3,051	3,000	1,351	1,288	1,288	1,576
West North Central	4,735	5,775	6,284	6,400	4,146	4,604	4,604	4,390
South Atlantic	7,462	8,151	7,943	8,400	9,977	9,716	9,708	9,556
East South Central	4,552	4,736	3,707	4,600	4,287	3,660	3,660	3,810
West South Central	2,894	3,568	3,506	3,900	3,056	3,403	3,394	3,279
Mountain	17,755	23,440	20,668	23,600	26,530	26,923	26,923	26,655
Pacific	28,635	29,768	31,127	53,800	66,514	72,268	71,478	70,939

[1]Capacity of actual installations only. Electric utilities and industrial plants, excluding pumped storage capacity.

Table III-d-3

Comparison of Cost for Geothermal and Other Sources

	Kaufman (Mill/KWH)
Geothermal	$5.28 (in 1970 Dollars)
Thermal	6.14
Nuclear	5.49
Hydro.	4.78

(103)

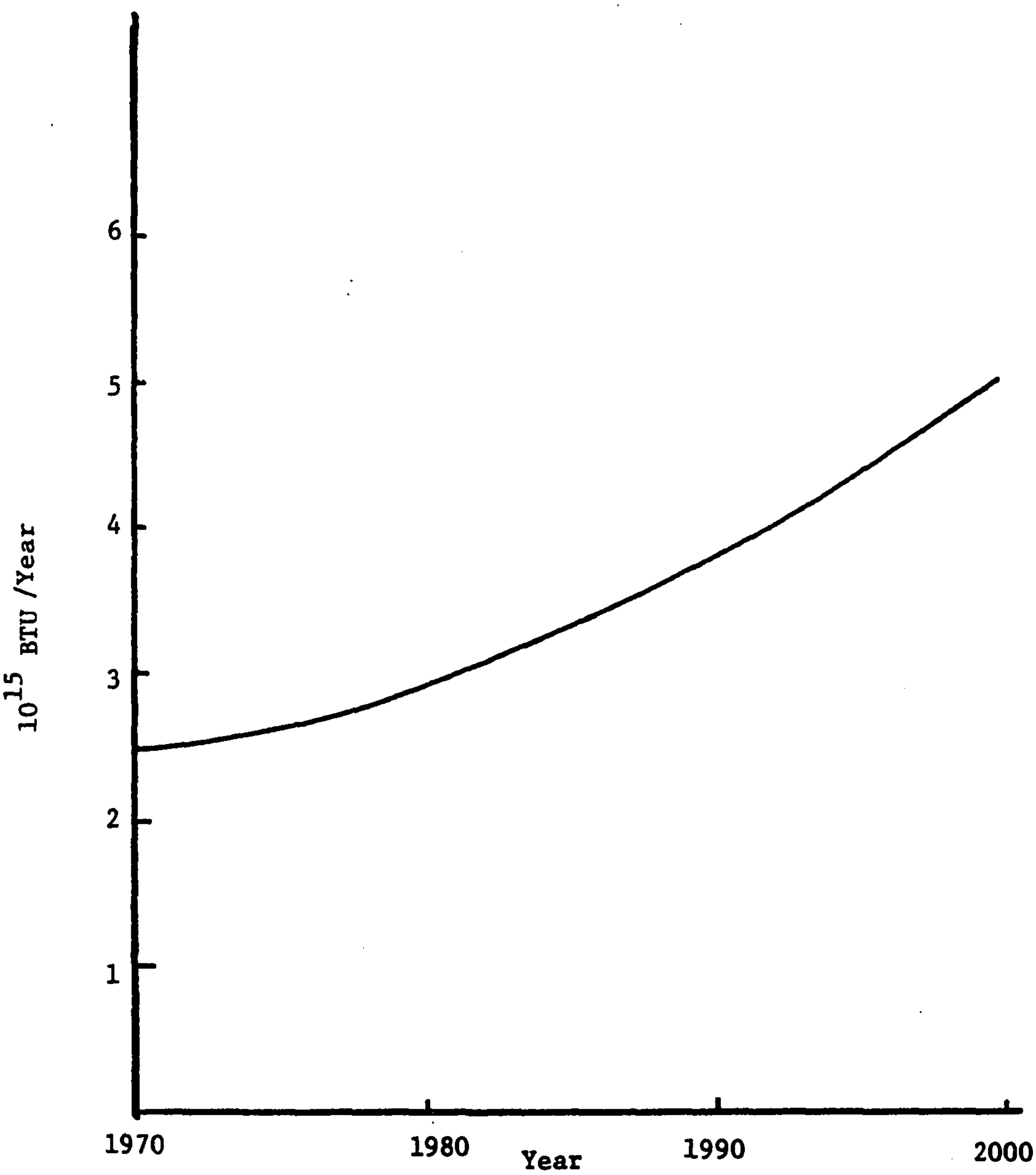


Figure III-d-1 Hydroelectric Energy Production

Nevada, Oregon, and Washington. The potential productive areas of geothermal power with number of hot springs, by states, is given in Table III-d-4. The projected geothermal power production is shown in Figure III-d-2.

Nuclear

An estimate of domestic uranium (as U_3O_8) resources as a function of price is given in Table III-d-4.

The known reserves are mostly located in New Mexico, Wyoming, Texas, Colorado, Utah, Alaska, South Dakota and Washington.

Since a pound of pure nuclear fuel -- say, uranium 235 -- is equivalent to 3 million pounds of coal; this is the reason why the fuel cost shown in Table III-d-4 is so low. Enormous increase absorbed in the cost of extracting uranium ores from the ground and converting them to the uranium concentrate U_3O_8 without having a marked effect on the cost of generating useful energy from the uranium contained. Therefore, we can assume that all the demand on nuclear power will be met.

The projected nuclear production is shown in Figure III-d-3.

Coal

Coal can be used not only directly as end-use fuel, but also to generate electricity and be converted into synthetic gas and synthetic oil. The sum of all these coal demands is the annual coal production requirements.

Table III-d-4

The Potential Geothermal Power

State	Number of Hot Springs
California	181
Oregon	86
Nevada	152
Idaho	196
Washington	16
New Mexico	38
Montana	40
Utah	56
Colorado	44
Wyoming	116
Arizona	21
West Virginia	30
Virginia	20

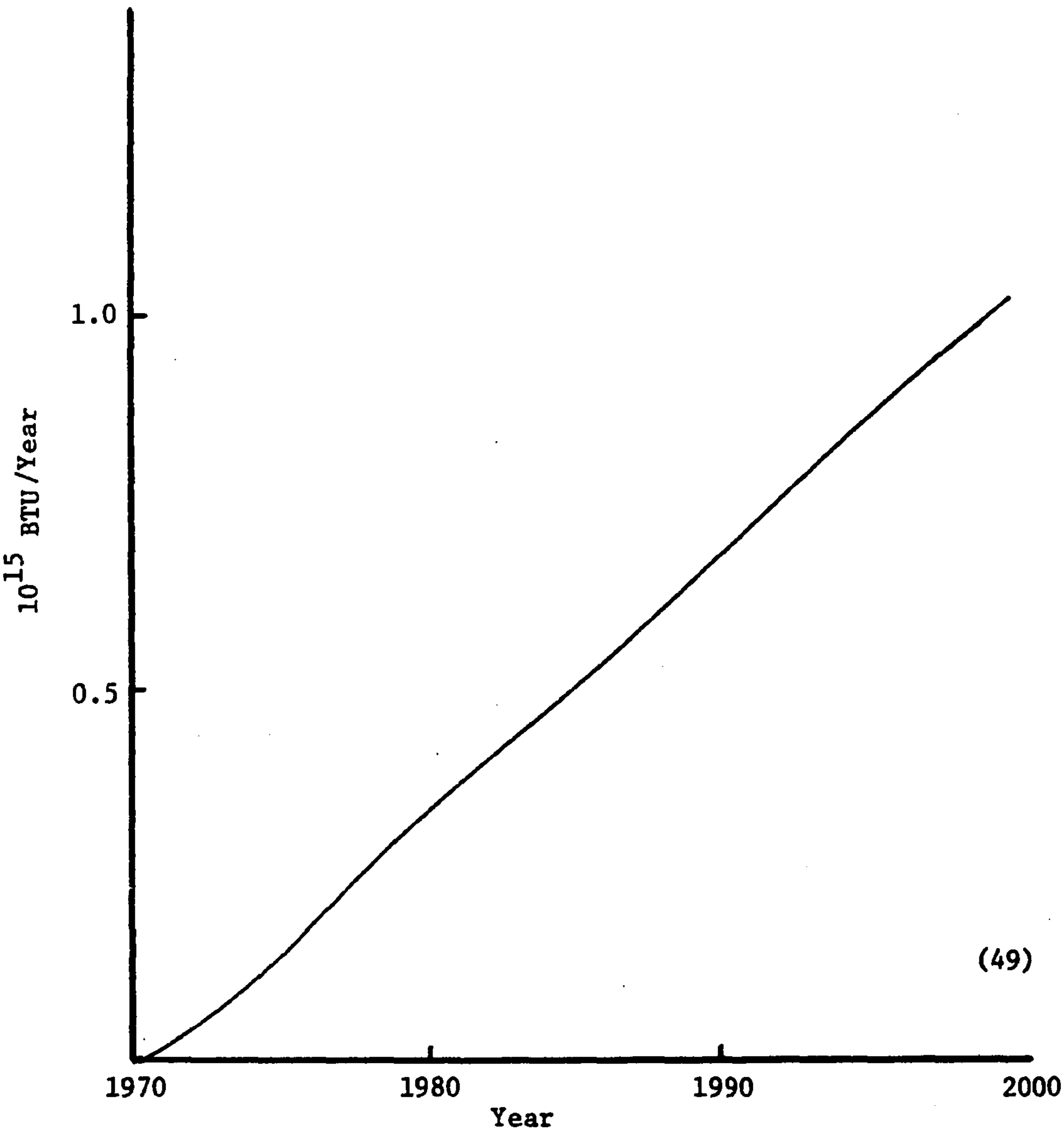


Figure III-d-2 Geothermal Energy Production

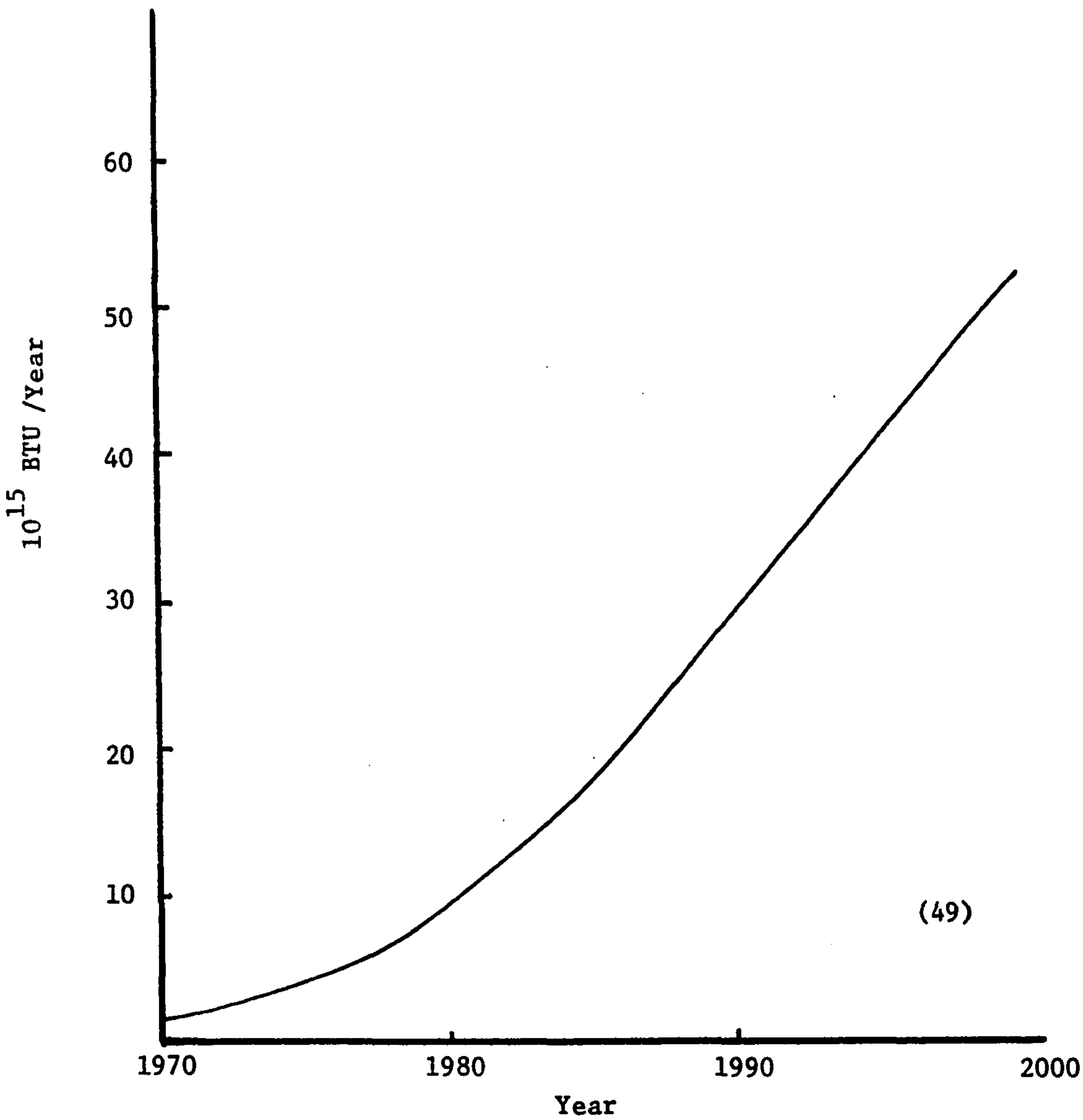


Figure III-d-3 Nuclear Energy Production

Table III-d-5

An Estimate of Domestic Uranium (as U_3O_8) Resources as

a Function of Price

Price Range (up to \$/lb. U_3O_8)	Cumulative (in tons U_3O_8) Reasonably assured	Estimated additional	Total
\$ 10	390,000	680,000	1,070,000
30	750,000	1,660,000	2,410,000
50	4,750,000	3,660,000	8,410.000
100	8,750,000	8,660,000	17,410,000
200	Possibly 2 billion on land an 4 billion in sea water.		

Source: Robert D. Nininger, U.S. Atomic Energy commission, "Nuclear Resources," speech given at Energy Resource Conference, University of Kentucky, Lexington, May 11, 1971. Conversion from BTU in source to tons made for this table.

Table III-d-6 shows the historical production of coal by states. The potential recoverable coal is estimated to be approximately 390 billion short tons, equivalent to $10,296 \times 10^{15}$ BTU. This figure is arrived at based on a recovery factor of 50 percent and using an economic cut-off on bed thickness of 28 inches for bituminous coal and 5 feet for sub-bituminous coal and lignite.

Solar, Tidal and Wind

Solar energy may be used not only to produce electricity but also heat needed for various end-uses. The time when this ultimate source of energy will have to be used to supplement the dwindling supplies of other sources remains indefinite but could be as soon as the year 2000 (51).

The tidal power will most likely be used to generate electricity with maximum potential capacity of 75 billion KWH/year (51).

Wind may be used directly as in wind driven pumps, mills, etc. or may be used to generate electricity.

These resources may not be utilized in great quantity by the year 2000 (51).

Natural Gas Production

The equation developed by Elliot and Turner (21) is used to project the natural gas production:

$$\mathrm{CDNGP}(t) = \frac{\mathrm{UDNGR}}{1 + \exp(b(1 + c) - \exp(a(1 + k))} \qquad \text{(III-d-1)}$$

Table III-d-6 Coal - Production, by States: 1951 to 1970 (in thousands of short tons)
(Includes coal consumed at mines)

State	1951-1955, Avg.	1956-1960, Avg.	1961-1965, Avg.	1966-1970, Avg.	1960	1965	1967	1968	1968	1970
TOTAL	496,725	469,288	473,559	570,410	434,329	526,954	564,882	556,706	570,978	612,661
Anthracite (Pa.)	33,898	22,975	16,931	11,372	18,817	14,866	12,256	11,461	10,473	9,729
Bit. & Lignite	462,827	446,313	456.628	559,038	415,512	512,088	552,626	545,245	560,505	602,932
Alabama	12,176	12,413	13,484	16,832	13,011	14,832	15,486	16.440	17,456	20,560
Colorado	3,544	3,394	3,978	5,555	3,607	4,790	5,439	5,588	5,530	6,025
Illinois	46,781	46,090	51,795	64,197	45,977	58,483	65,133	62,441	64,722	65,119
Indiana	16,232	15,659	15,311	19,387	15,538	15,565	18,772	18,486	20,086	22,263
Kentucky	66,426	69,038	75,621	105,792	66,847	85,766	100,294	101,156	109,050	125,305
Missouri	2,873	2,898	3,165	3,646	2,890	3,564	3,696	3,205	3,301	4,447
Ohio	35,847	35,379	35,968	48,854	33,957	39,390	46,014	48,323	51,242	55,351
Pennsylvania	89,680	74,839	71,261	79,235	65,425	80,308	79,412	76,200	78,631	80,491
Tennessee	5,923	7,086	6,010	7,522	5,931	5,865	6,832	8,148	8,082	8,237
Utah	6,025	5,642	4,706	4,503	4,955	4,992	4,175	4,316	4,657	4,733
Virginia	20,399	28,400	31,209	35,865	27,838	34,053	36,721	36,966	35,555	35,018
W. Virginia	138,858	134,167	130,948	146,887	118,944	149,191	153,749	145,921	141,011	144,072
Wyoming	4,704	2,060	2,917	4,582	2,024	3,260	3,588	3,829	4,602	7,222
Other States	13,349	9,247	10,255	16,080	8,568	12,029	13,315	14,254	16,580	24,091

Source: U.S. Bureau of Mines, Minerals Yearbook.

where :

CDNGP(t) = cummulated domestic natural gas production in year t in trillion BTU.

UDNGR = ultimate recoverable domestic natural gas reserves.

a,b,c, and k = constants determined by regression analysis of cummulative and annual production data.

Using the DeGolyer and NcNaughton (17) ultimate doemstic natural gas reserves, adjusted cummulated production (1,17,42,56) and non-linear regression analysis the constant for equation (III-d-1) are:

$a = -0.07234$

$b = -19841$

$c = -0.006899$

$k = -1540.5$

The annual production of domestic natural gas is given by:

$$ADNGP(t) = CDNGP(t) - CDNGP(t - 1)$$

The historical and projected domestic natural gas production is shown in Table III-d-7 and Figure III-d-4.

Petroleum and Natural Gas Liquids

Domestic natural gas liquids production is given by equation:

$$CDNGLP(t) = \frac{180,600}{1 + \exp(b(1 + c) - \exp(a(1 + k))} \qquad \text{(III-d-2)}$$

where:

CDNGLP(t) = cummulated domestic natural gas liquids production in year t in trillion BTU.

$a = -0.07234$ $\qquad$ $c = -0.006899$

$b = -1984.1$ $\qquad$ $k = -1540.5$

Table III-d-7 Natural Gas - Production, 1950 to 1970, and Reserves, 1960 and 1970, by States
(In billions of cubic feet)

State	Marketed Production[1]								Reserves[2]	
	1950	1955	1960	1965	1967	1968	1969	1970	1960	1970
TOTAL	6,282	9,405	12,771	16,040	18,171	19,322	20,698	21,921	263,759	290,746
Arkansas	48	32	55	83	117	157	169	181	1,460	2,561
California	558	538	518	660	681	715	678	649	8,844	6,300
Colorado	11	49	107	126	117	121	119	106	2,043	1,629
Illinois	13	8	12	7	5	4	4	5	173	415
Kansas	364	471	634	793	872	836	883	900	19,620	13,325
Kentucky	73	73	75	79	89	89	81	78	1,144	978
Louisiana	832	1,680	2,968	4,467	5,717	6,416	7,228	7,788	63,386	82,957
Michigan	11	8	21	35	34	40	36	39	586	940
Mississippi	114	163	172	167	139	135	131	126	2,542	1,334
Montana	39	28	33	28	26	19	41	43	626	1,100
Nebraska	(x)	13	15	11	8	8	7	6	118	58
New Mexico	213	541	799	937	1,068	1,164	1,138	1,139	15,604	13,290
N. Dakota	1	5	19	36	40	41	34	35	1,151	567
Ohio	43	34	36	36	41	43	50	52	766	993
Oklahoma	482	615	824	1,321	1,413	1,391	1,524	1,595	17,311	16,954
Pennsylvania	91	99	114	84	90	88	79	77	1,192	1,378
Texas	3,125	4,731	5,893	6,637	7,189	7,495	7,853	8,358	119,489	106,353
Utah	4	17	51	72	49	46	47	43	1,526	1,065
W. Virginia	190	212	209	207	211	237	232	242	1,831	2,436
Wyoming	62	78	182	236	240	248	304	339	3,935	4,234
Other States[3]	5	9	12	18	25	28	60	120	411	31,850

Z - Less than 500 million cubic feet.

[1]Comprises gas sold or consumed by producers, including loss due to natural gas liquids recovery, losses in transmission, amounts added to storage, & increases in gas in pipelines. Beginning 1965, data on pressure base of 14.73 pounds per square inch absolute; prior years, 14.65.

[2]Estimated recoverable proved reserves. Offshore reserves included for Calif., La., and Texas. Excludes gas loss due to natural gas liquids recovery. Source: Amer. Gas Assoc., Arlington, Va.

[3]Prior to 1960, excludes Alaska.

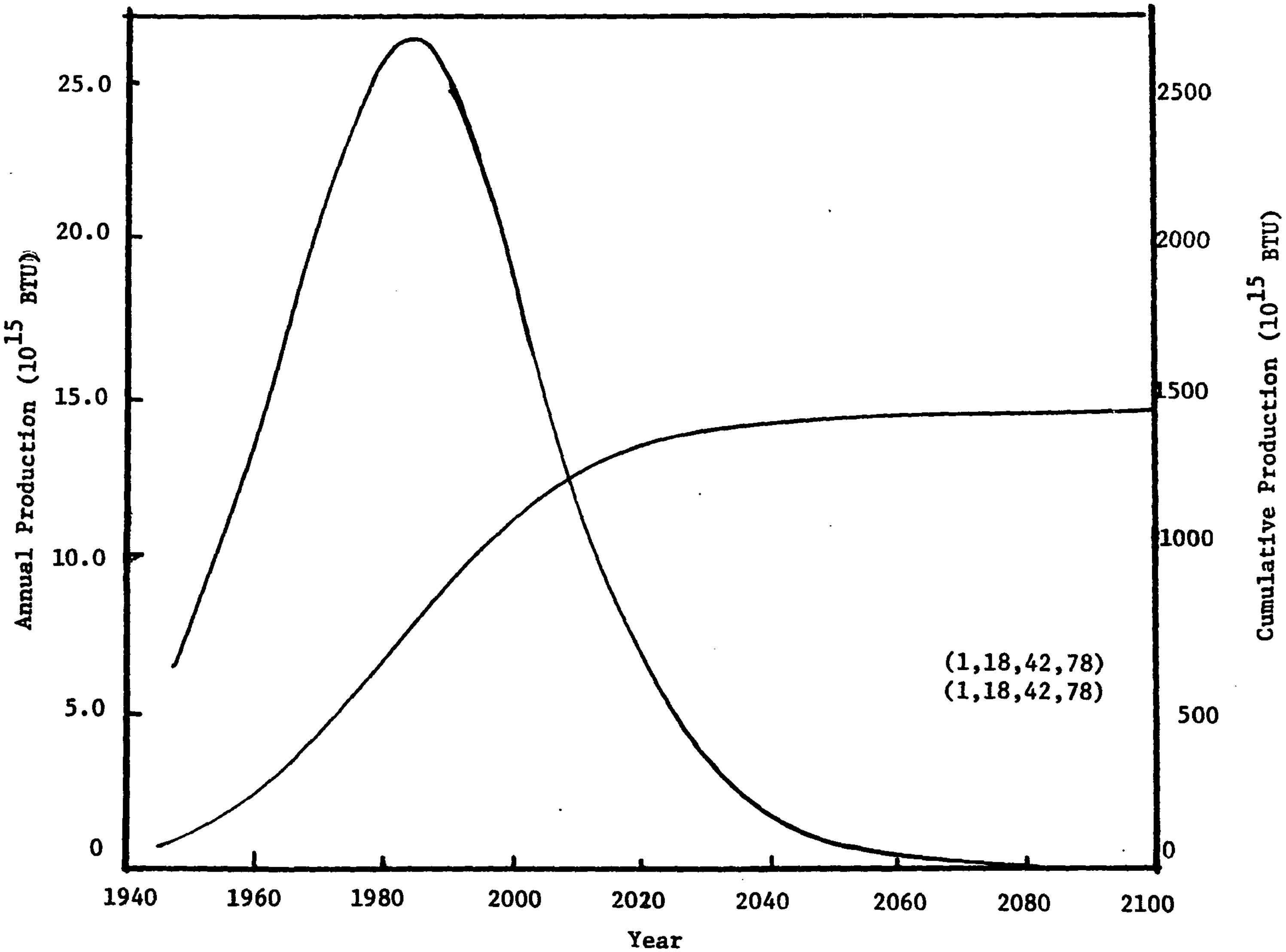


Figure III-d-4 Projected Domestic Natural Gas Production

The annual projection of natural gas liquid is given by:

$$CDCPP(t) = \frac{UDCPP}{1 + \exp(b(1 + c) - \exp(a\ (1 + k))} \qquad \text{(III-d-3)}$$

where:

CDCPP(t) = cumulated domestic crude petroleum production in year t

UDCPP = ultimate domestic crude petroleum reserves (Table III-d-8)

a,b,c, and k = constants determined from regression analysis or cumulated and annual production data.

Based on the ultimate domestic crude petroleum reserves of DeGolyer and McNaughton (17) and Elliot (20), the constants for equation III-d-3 are:

a = -0.054

b = -2005

c = 0.002

d = -1835.2

Thus, the domestic crude petroleum production is given by:

$$ADCPP(t) = CDCPP(t) - CDCPP(t - 1)$$

The cumulated and annual total petroleum energy production is shown in Figure III-d-5.

The historical production of petroleum by states is given in Table III-d-8.

Oil Shale Production

Ultimate U. S. oil shale recoverable reserves is 6786 quadtrillion (Table III-d-1) BTU. The principal oil shale deposits include: (1) Green

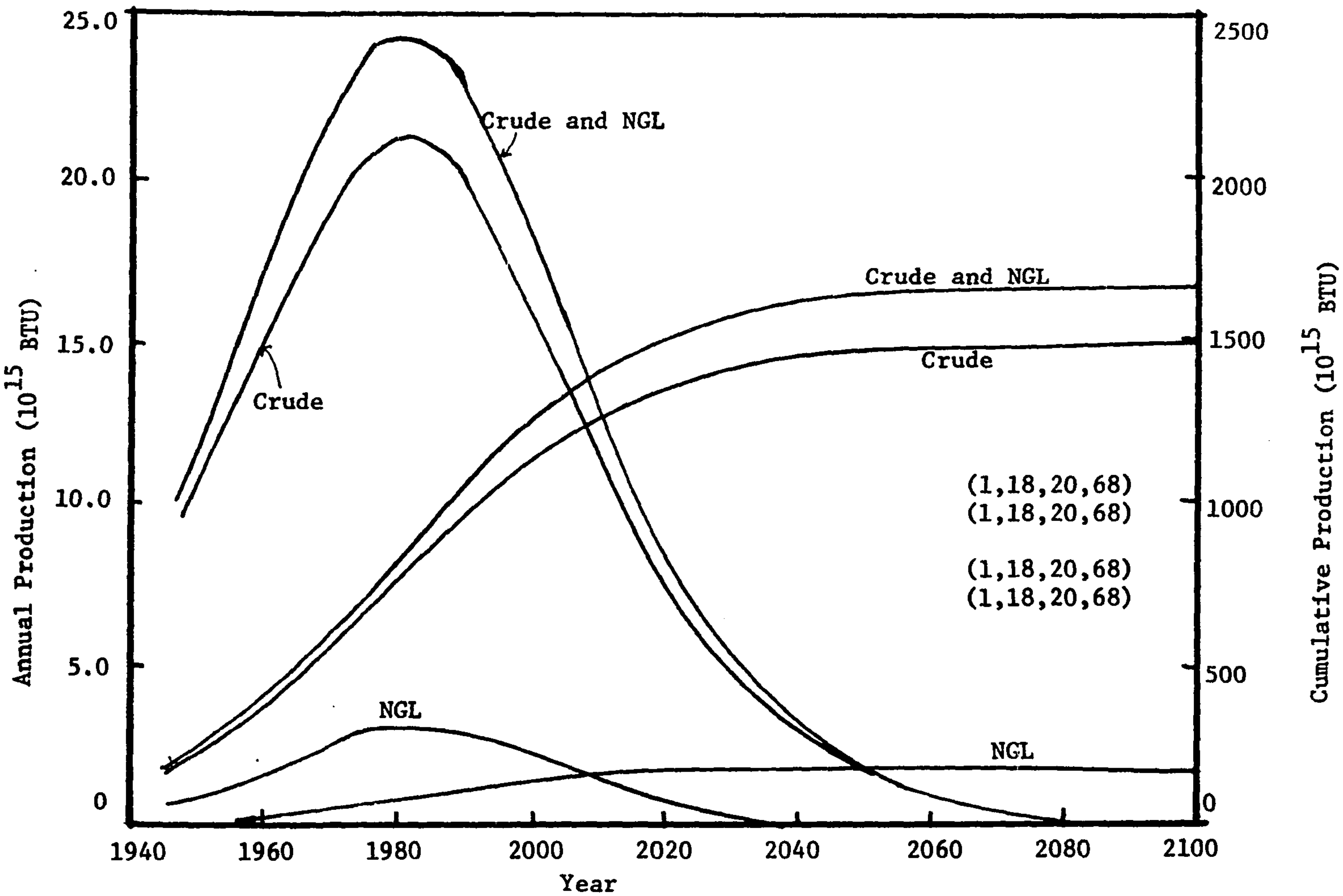


Figure III-d-5 Projected Cumulated and Annual Crude Petroleum and Natural Gas Liquids Production

Table III-d-8 Crude Petroleum - Producing Oil Wells, 1970, Production, 1956 to 1971, and Future and Proved Reserved, 1960, 1970 & 1971, by States (In Million of barrels of 42 Gallons)

State	Producing Oil Wells, 1970		Production						Proved Reserves[1]		
	Approx. No., Dec. 31	Avg. Production per Well per day (barrels)	1956-1960, Avg.	1961-1965, Avg.	1966-1970, Avg.	1969	1970	1971 (prel.)	1960	1970	1971
TOTAL	539,999	18.0	2,567	2,737	3,292	3,372	3,517	3,478	31,612	39,001	38,063
Ala.	562	35.0	5	8	8	8	7	8	(2)	65	61
Alaska	202	1,190.1	-	10	53	74	84	79	(2)	10,149	10,115
Ark.	7,082	7.5	29	27	21	18	18	18	302	130	118
Calif.	40,437	25.0	324	303	365	375	372	359	3,659	3,984	3,706
Colo.	1,770	37.8	51	39	30	28	25	27	364	389	333
Ill.	26,134	4.5	79	73	54	51	44	39	556	229	209
Ind.	4,055	5.0	12	12	9	8	7	7	66	37	31
Kans.	43,490	5.3	120	109	94	89	85	79	884	539	502
Ky.	11,659	2.7	20	19	14	13	12	11	129	61	52
La.	27,934	86.7	341	512	804	845	907	948	4,785	5,710	5,399
Mich.	4,311	7.8	11	17	13	12	12	12	78	46	59
Miss.	3,102	63.2	44	56	60	64	65	64	407	355	342
Mont.	3,243	31.6	27	31	40	44	38	35	267	242	228
Nebr.	1,244	24.6	21	22	13	12	11	10	86	41	36
N. Mex.	17,314	20.4	99	113	127	129	128	118	1,084	761	657
N. Y.	5,861	0.6	2	2	3	1	1	1	32	11	10
N. Dak.	1,457	35.0	16	25	24	23	22	21	431	192	174
Ohio	15,860	1.7	6	9	11	11	10	9	75	128	129
Okla.	78,019	7.7	204	201	225	225	224	218	1,791	1,351	1,405
Pa.	36,801	0.3	7	5	4	4	4	4	108	51	47
Texas	177,221	19.0	1,004	970	1,142	1,152	1,250	1,223	14,758	13,195	13,023
Utah	889	73.9	22	30	24	23	23	24	208	182	166
W. Va.	12,750	0.7	2	3	3	3	3	3	51	53	52
Wyo.	9,280	48.1	118	140	146	155	160	155	1,427	1,017	997
Other Sts.	313	47.5	(3)1	1	5	5	5	6	65	83	211

\- Represents zero

[1] Dec. 31. From reports of Comm. on Petro. Reserves. Amer. Petr. Inst.; Figures for Calif., La., & Texas include offshore reserves. [2] Included in other states. [3] Prior to 1960, excludes Hawaii.

River Formation of Colorado, Utah and Wtoming. (2) Miocene and Pliocene Monterey and Sisquor Formations of California. (3) Middle Tertiary lake basin deposits in Southern Montana. (4) Triassis and Jurassic marine deposits in Northern Alaska, (5) Phosphoric Formation of Montana.

Oil shale production is given by the equation:

$$OSP(t) = OD(t) \times FOS(t)$$

where

$OD(t)$ = oil demand in year t

$FOS(t)$ = fraction of oil demand exceeding domestic supply to be supplied by oil shale reserves.

The Resources Requirements

<u>Assumption</u>

1. Coal will be produced by 50% strip mining and 50% underground mining.
2. Synthetic crude petroleum from coal will be produced 50% in coal liquefaction plants and 50% in combined coal conversion plants.
3. The shortage in natural gas will be supplied with the projected fraction of natural gas exceeding domestic production supplied by alternate sources (Figures III-e-1, III-e-2, III-e-3).
4. The shortage in oil will be supplied with the projected fraction of oil exceeding domestic production supplied by alternate sources (Figure III-e-4 and Figure III-e-5).
5. Two base cases are examined. First, we assume that imports are needed to balance the demand after 1990. Secondly, no imports are allowed after 1990 due to the balance of payments deficit and political implication -- dependence on foreign imports. (Alternatives are also provided in both cases).

<u>Results</u>

Total domestic supply will continue to increase, yet the gap between demand and supply is growing wider (Tables III-e-2a and III-a-2b). Imports are necessary to balance the demand at least before 1990 for both cases. Coal is going to play a more important role in the years to come (Figures III-e-7, III-e-8, III-e-9 and III-e-10) either used directly or as synthetic fuels. Energy sources will gradually shift from petroleum and

Table III-e-1

Characteristics of Coal Gasification and/or Liquefaction Plants

(219,33,43,44,64)

Characteristic	Gasification	Liquefaction	Gasification and Liquefaction
Overall efficiency (BTU product/BTU Coal)	0.633	0.85	0.738
Product Fraction			
refined coal	--	--	0.073
syncrude	--	1.0	0.323
syngas	1.0	--	0.604
Airborne Emissions ($lb/10^6$ BTU-product)			
CO_2	80.5	62.5	72.0
CO	--	--	--
SO_2	--	--	--
NO_x	--	--	--
particulate	--	--	--
hydrocarbon	3.92	--	--
aldehydes	0.65	--	0.142
Sulfur ($lb/10^6$ BTU-prod.)	5.23		3.30
Solid waste ($lb/10^6$ BTU)	7.84		3.82

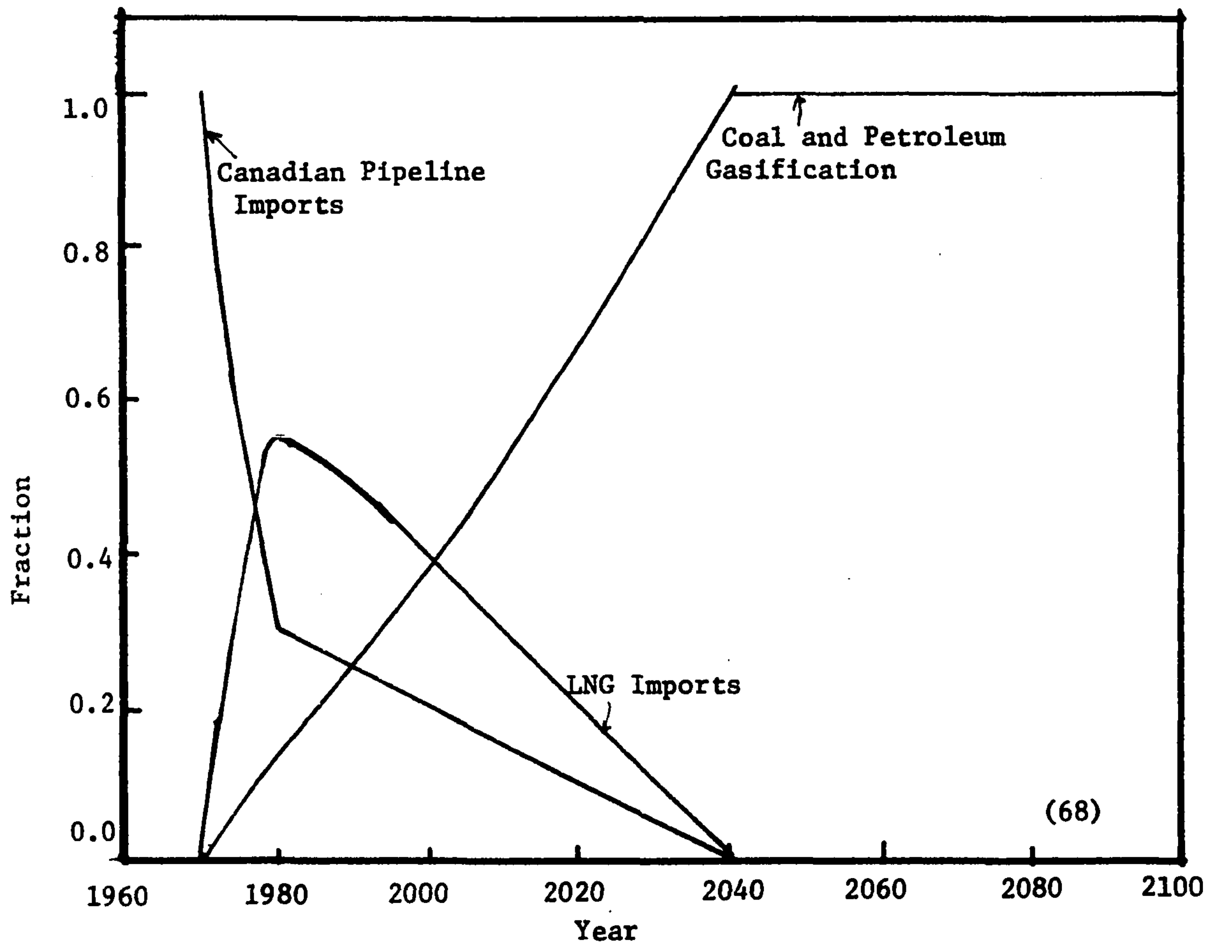


Figure III-e-1 Projected Fraction of Natural Gas Demand Exceeding Domestic Production Supplied by Alternate Sources (with imports after 1990)

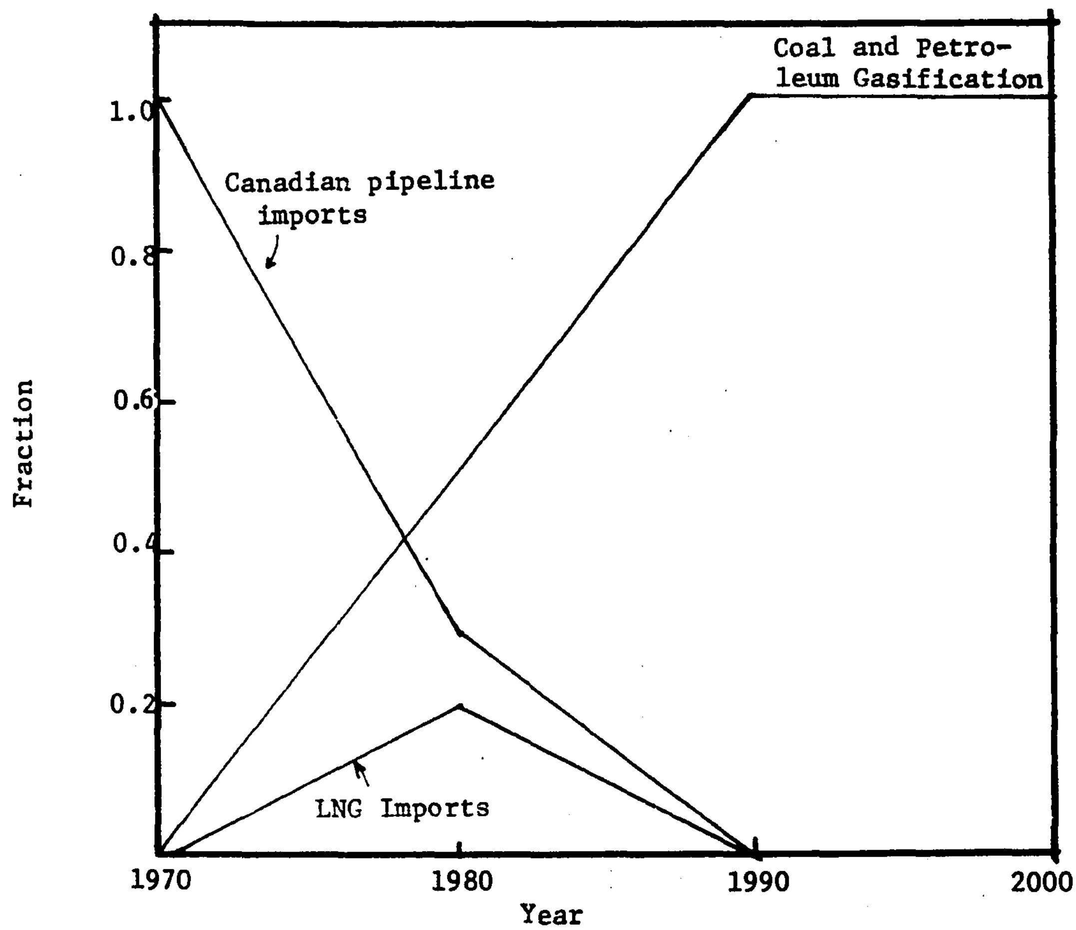


Figure III-e-2 Projected Fraction of Natural Gas Demand Exceeding Domestic Production Supplied by Alternate Sources (No imports after 1990)

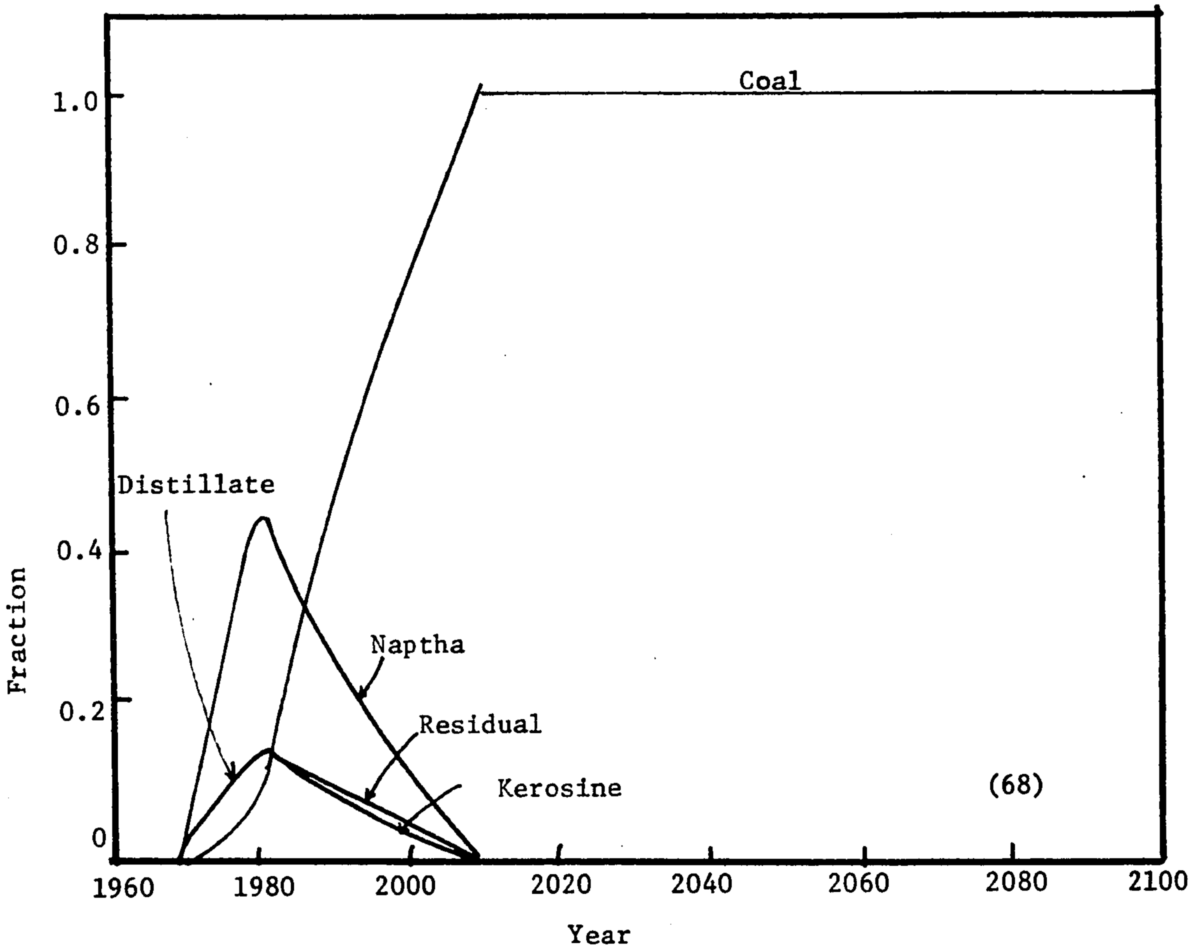


Figure III-e-3 Projected Synthetic Natural Gas Fuel Fractions (With Imports after 1990)

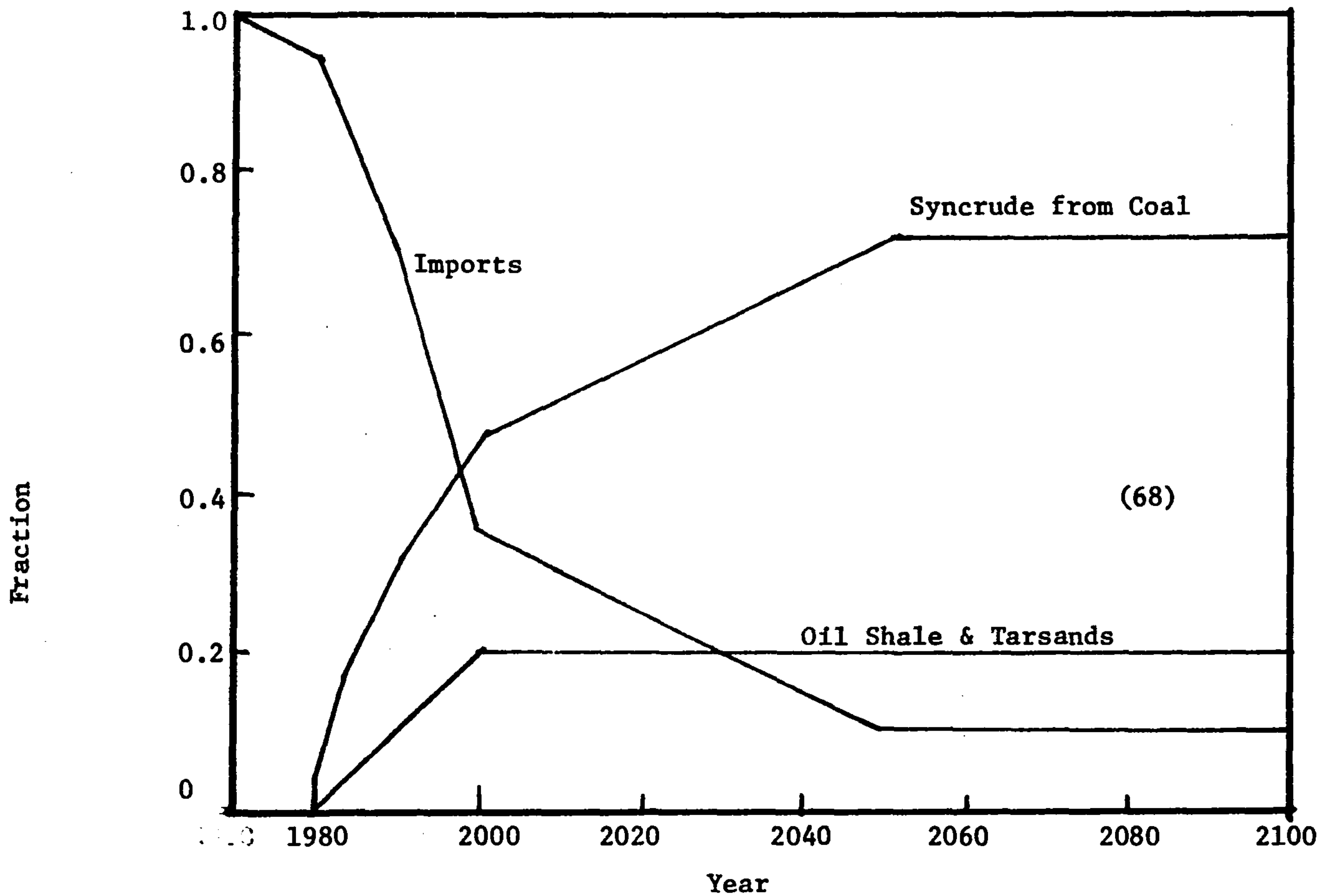


Figure III-e-4 Projected Fraction of Petroleum Demand Exceeding Demestic Production Supplied by Alternate Sources (With imports after 1990)

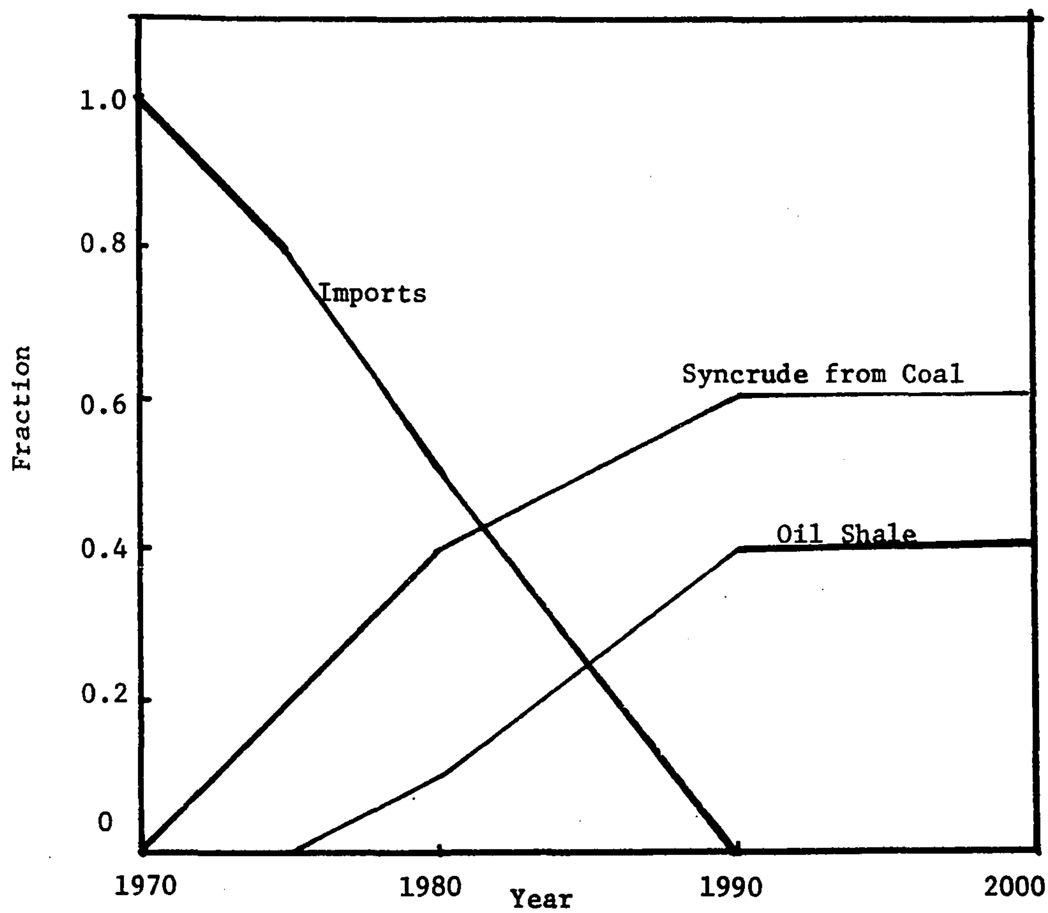
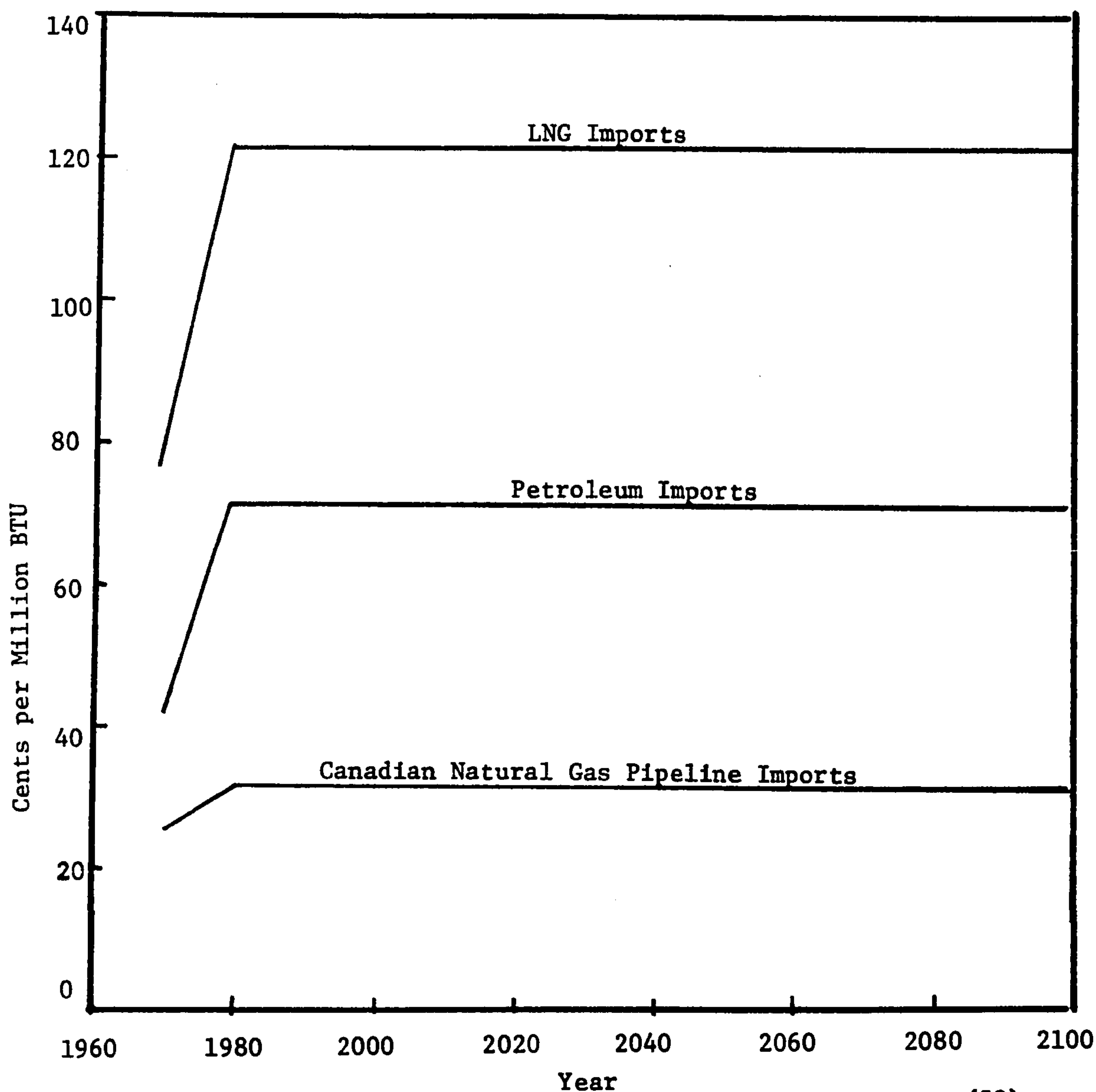


Figure III-e-5 Projected Fraction of Petroleum Demand Exceeding Domestic Production Supplied by Alternate Sources (No imports after 1990)



(52)

Figure III-e-6 Projected Import Energy Unit Costs in 1970 U.S. Dollars

Table III-e-2a

Energy Balance (Trillion BTU)

	1975	1980	1985	1990	1995	2000
U.S. Domestic Energy Consumption	76,380	91,708	116,341	138,531	168,331	202,223
Projected Domestic Supply						
Oil* - Conventional	23,600	24,335	24,000	22,886	20,500	18,316
Synthetic	190	478	2,886	7,182	17,260	27,062
Subtotal	23,790	24,703	26,886	30,068	37,760	45,378
Gas - Conventional	23,500	25,857	26,500	25,143	22,700	19,184
Synthetic	117	497	1,691	4,068	9,642	16,496
Subtotal	23,617	26,344	28,191	29,211	32,342	35,680
Coal**	14,338	15,847	17,595	20,245	21,773	23,262
Hydro	2,677	2,964	3,340	3,808	4,433	5,106
Nuclear(Fission)	3,340	9,490	21,500	28,400	40,500	53,000
Geothermal	120	343	514	680	855	1,020
Total Domestic Supply	67,882	79,801	98,026	112,412	137,663	164,446
(% of U.S. Consumption)	88.9	87.0	84.3	81.2	81.8	81.3
Import Requirement to Balance						
Oil	7,437	9,087	11,547	13,711	12,758	13,030
(% of Oil Supply)	23.8	26.8	29.9	31.2	25.3	22.3
Natural Gas	1,056	2,817	6,765	12,205	17,907	24,744
(% of N. Gas Supply)	4.3	9.7	19.4	29.5	35.6	40.9
Total Imports	8,492	11,904	18,312	25,916	30,665	37,774
(% of Energy Supply)	11.1	13.0	15.7	18.7	18.2	18.7

*Excludes BTU's consumed in conversion of coal to syncrude and syngas.

**Excludes BTU's consumed in conversion of petroleum product to syngas.

Table III-e-2b

Energy Balance (Trillion BTU)

	1975	1980	1985	1990	1995	2000
U.S. Domestic Energy Consumption	76,380	91,708	116,341	138,531	168,331	202,223
Projected Domestic Supply* (Without imports after 1990)						
Oil - Conventional	23,600	24,335	24,000	22,886	20,500	18,316
Synthetic	1,310	4,186	9,678	21,094	30,819	40,094
Subtotal	25,100	28,989	33,678	43,980	50,519	58,410
Gas - Conventional	23,500	25,847	26,500	25,143	22,700	19,184
Synthetic	294	1,332	6,513	16,276	27,451	41,241
Subtotal	23,911	27,676	33,013	45,487	59,793	60,425
Coal**	14,338	15,847	17,595	20,245	21,773	24,262
Hydro	2,677	2,964	3,340	3,808	4,433	5,106
Nuclear (Fission)	3,340	9,490	21,500	28,400	40,500	53,000
Geothermal	120	343	514	680	855	1,020
Total Domestic Supply	69,486	85,309	109,640	138,531	168,331	202,223
(% of U.S. Consumption)	90.9	93.0	94.2	100	100	100
Import Requirement to balance						
Oil	6,120	5,068	4,531	0	0	0
(%of Oil Supply)	24.3	17.4	13.4	0	0	0
Natural Gas	880	1,331	2,170	0	0	0
(% 9f N. Gas Supply)	3.6	4.8	6.5	0	0	0
Total Import	7,000	6,399	6,701	0	0	0
(% of Energy Supply)	9.1	6.9	5.7	0	0	0

*Excludes BTU's consumed in conversion of coal to syncrude and syngas.

**Excludes BTU's consumed in conversion of petroleum product to sungas.

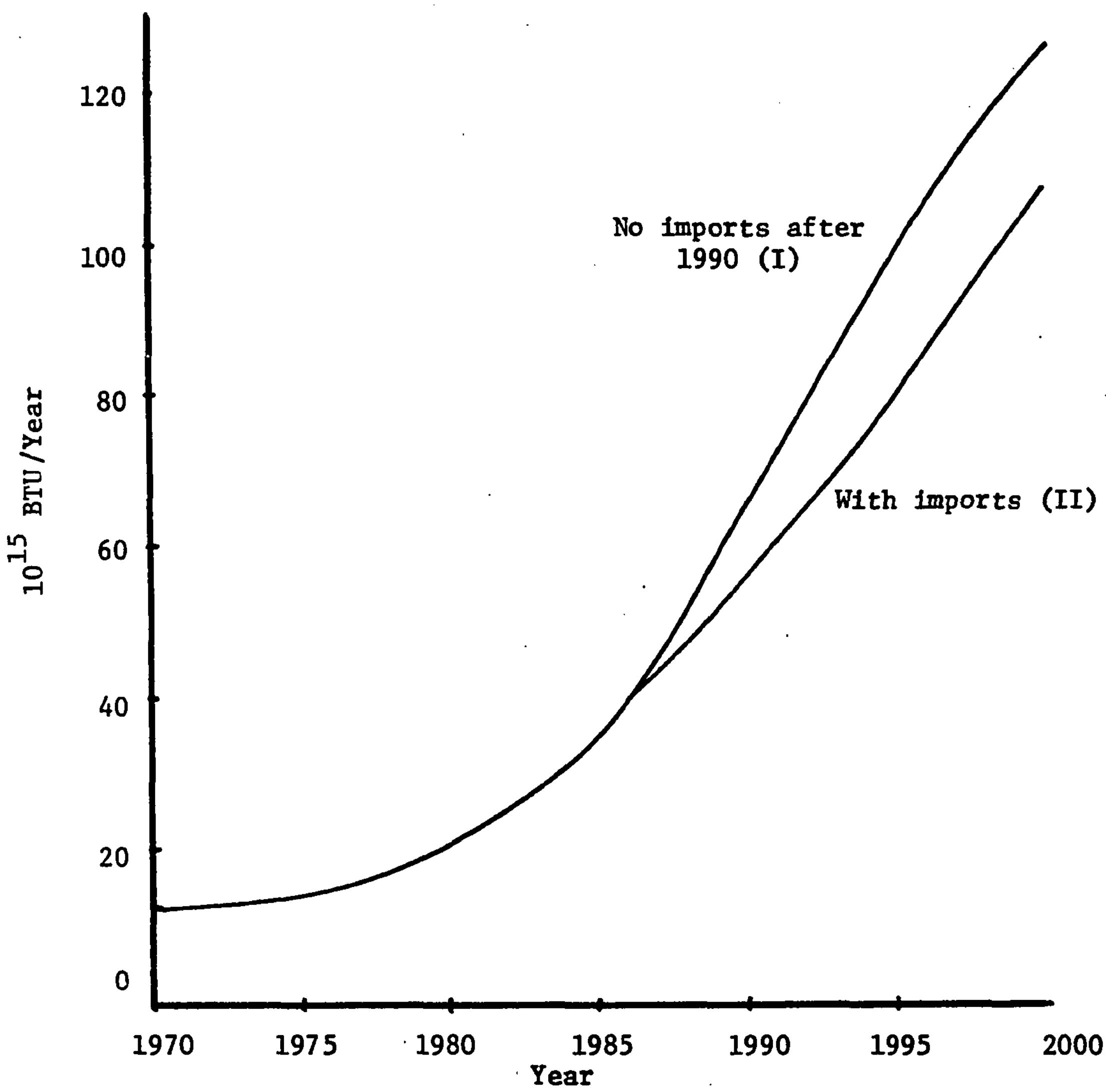


Figure III-e-7 Projected Annual Coal Requirement

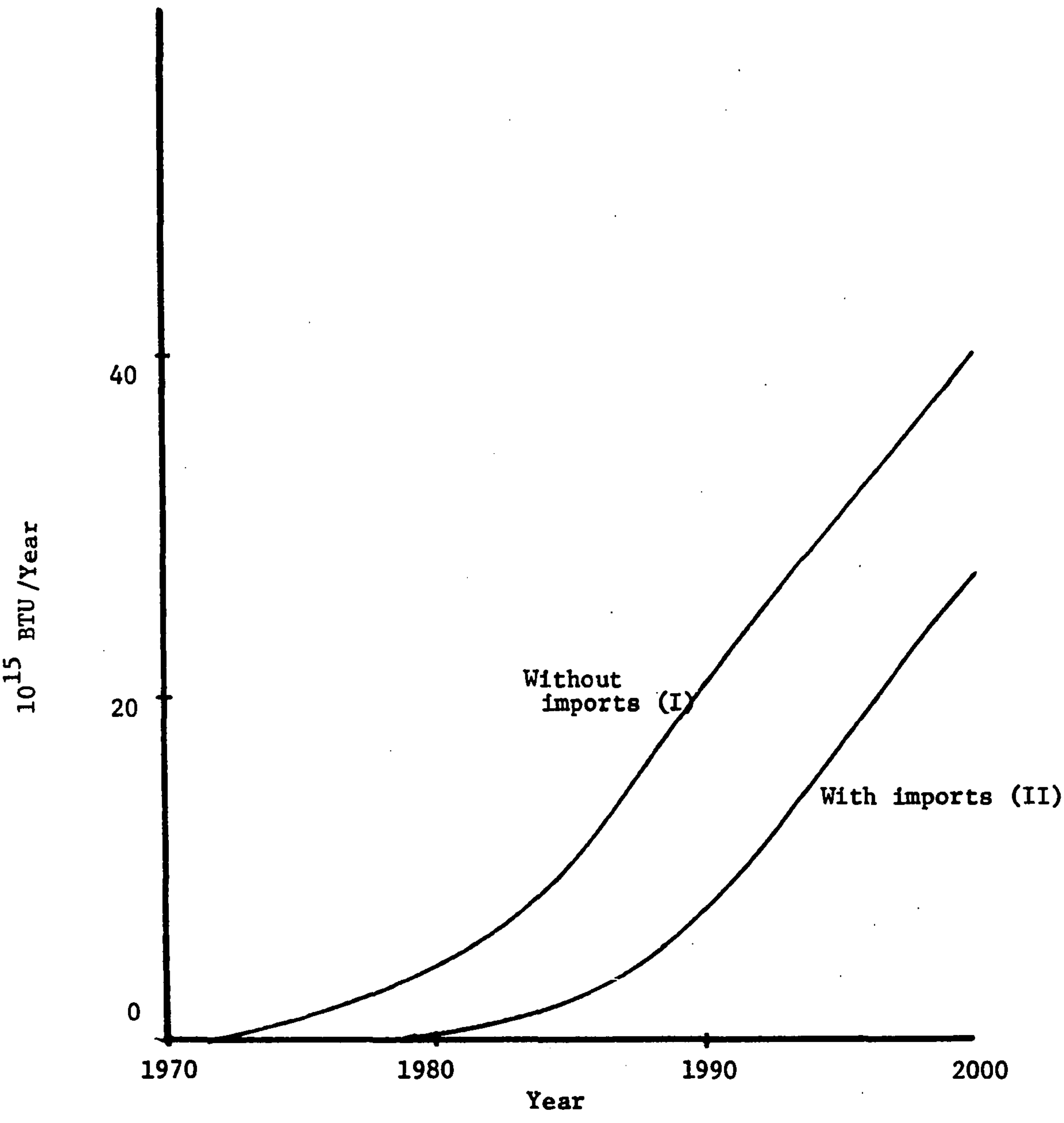


Figure III-e-8 Projected Annual Syncrude Demand Production

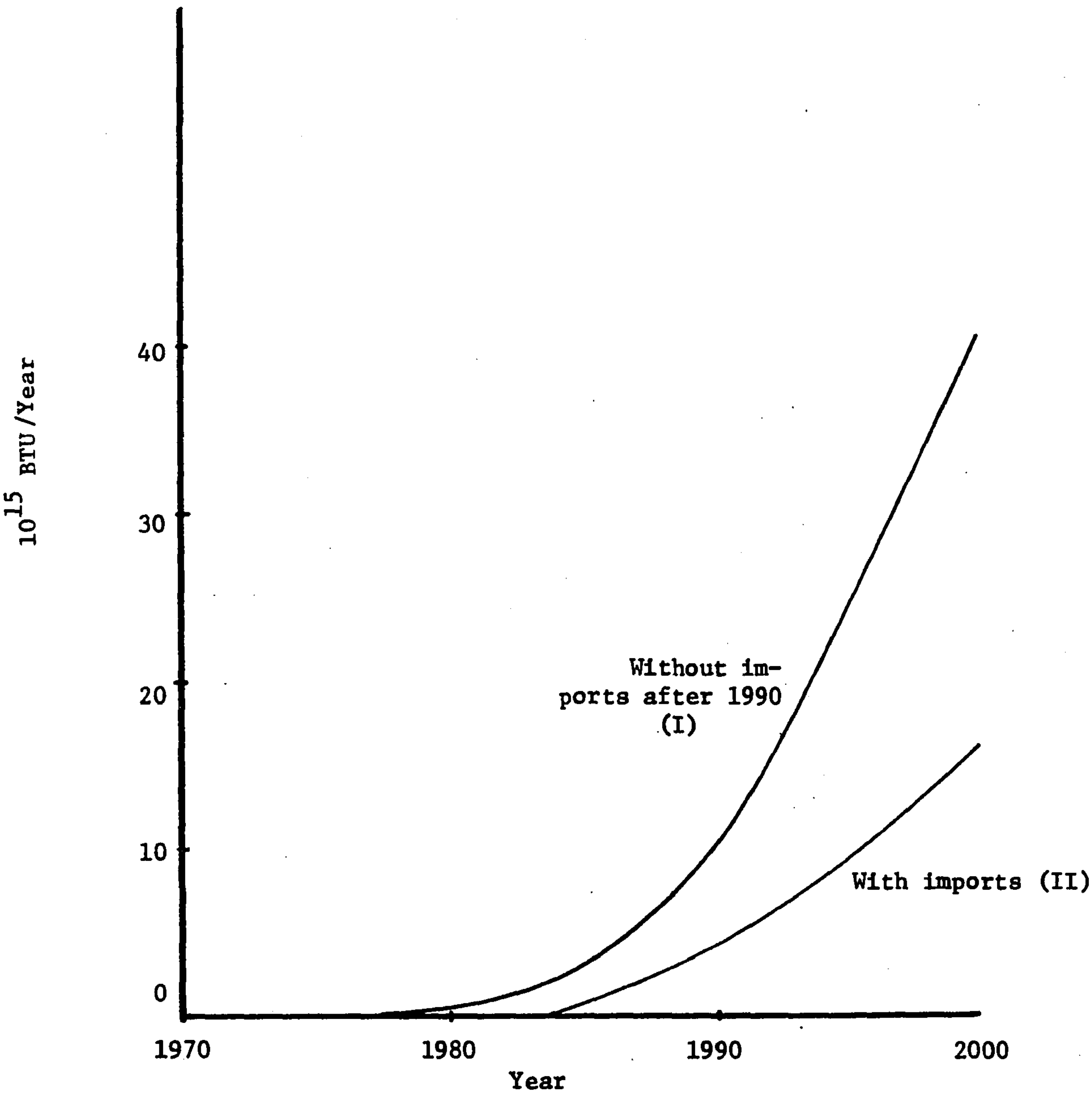


Figure III-e-9 Projected Annual Coal Requirement for Syncrude Production natural gas to both coal nuclear power.

If President Nixon's plan to end the dependency upon imports of all energy sources by 1980 is carried out, then the burden will fall on coal even heavier than before. Alternatives will be discussed in Chapters V and VI. Imports of crude oil, Canadian pipeline gas and LNG and balance of payments deficit are calculated by using the cost of energy from Figure III-e-6, and are shown in Figures III-e-11, III-e-13, III-e-14, III-e-15 and III-e-16. Projected annual oil shale and tar sands production is shown in Figure III-e-12.

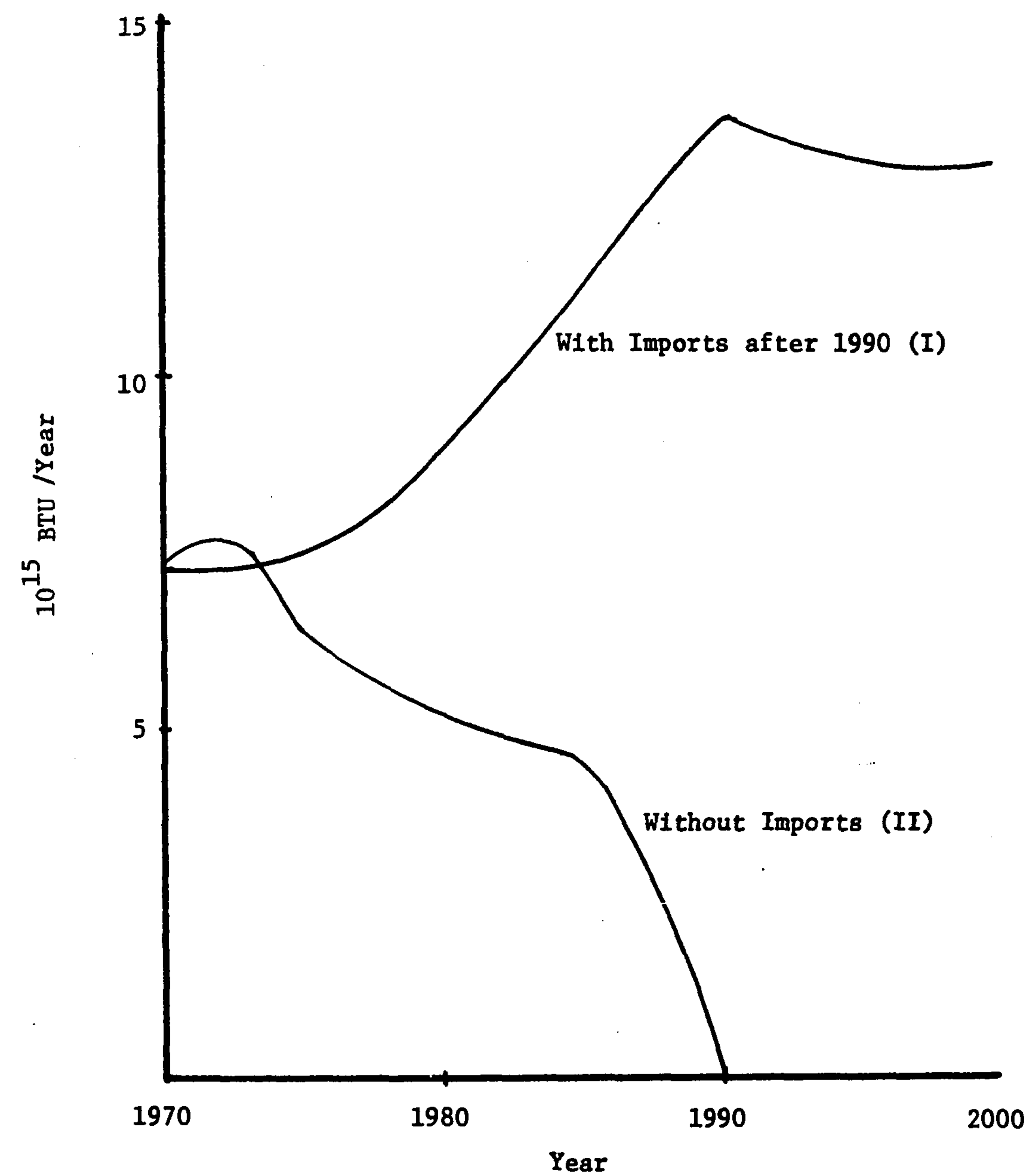


Figure III-e-10 Annual Crude Oil Import Requirement

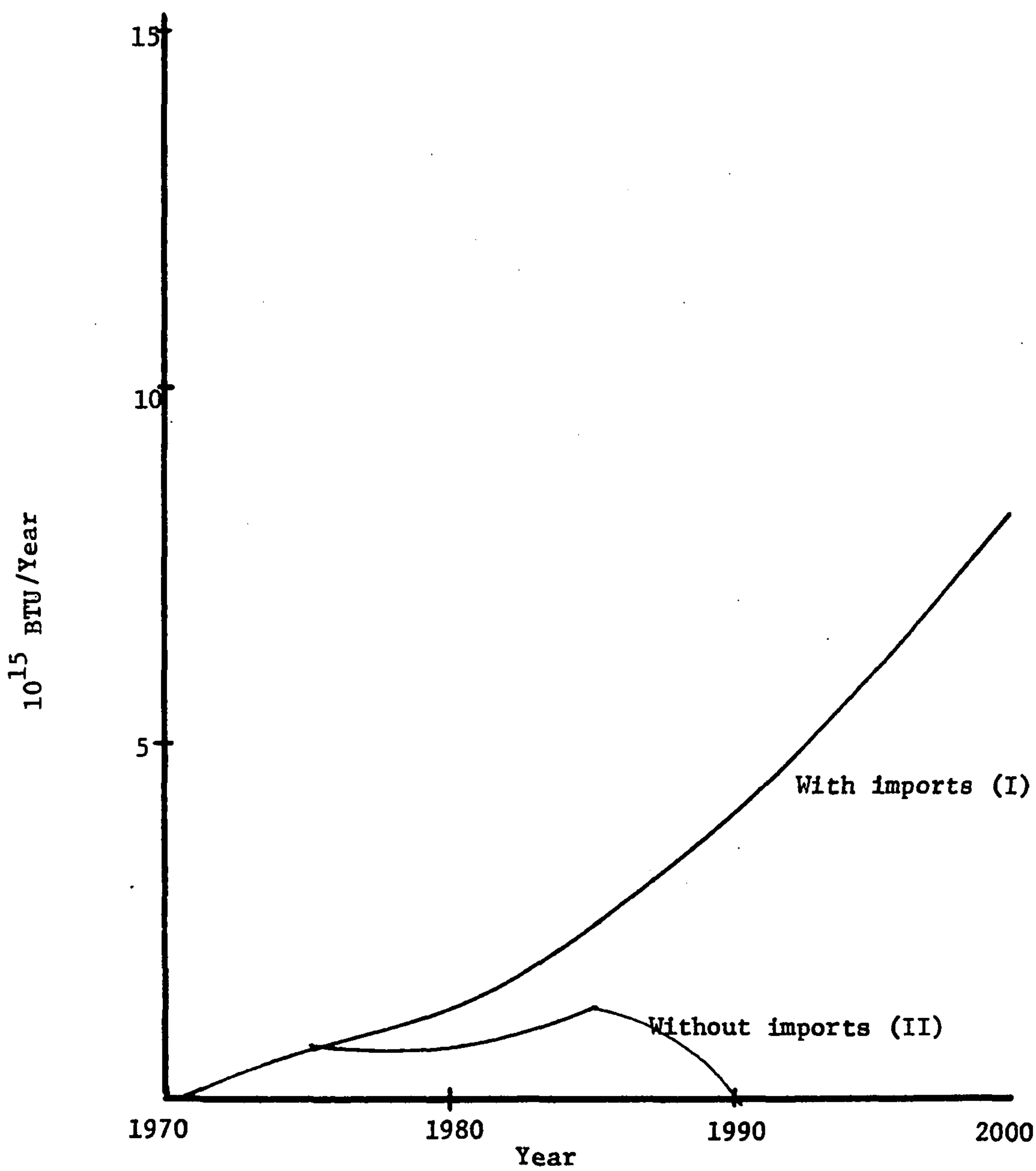


Figure III-e-12 Projected Annual Canadian Gas Imports

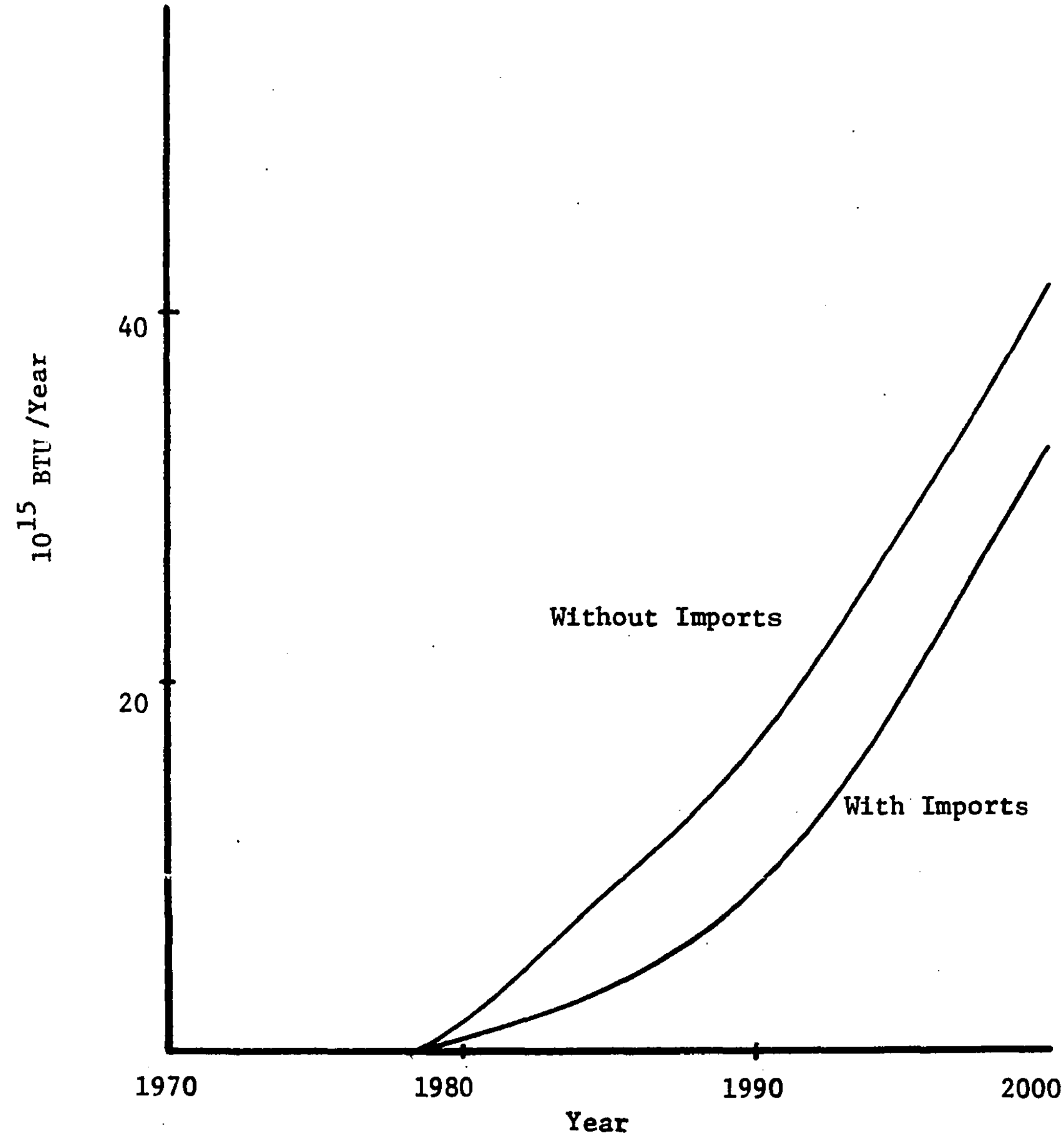


Figure III-e-13 Projected Annual Syngas Demand

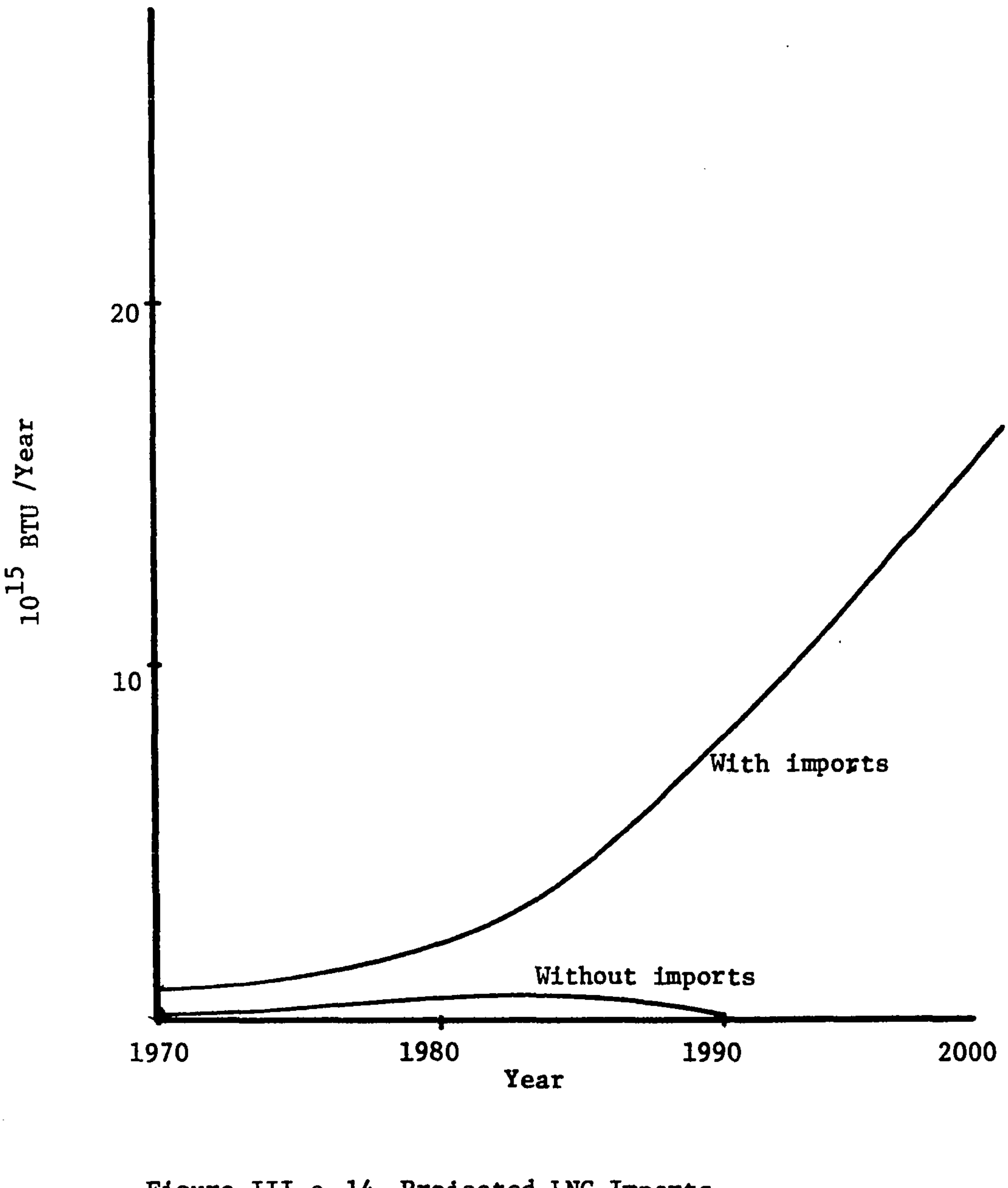


Figure III-e-14 Projected LNG Imports

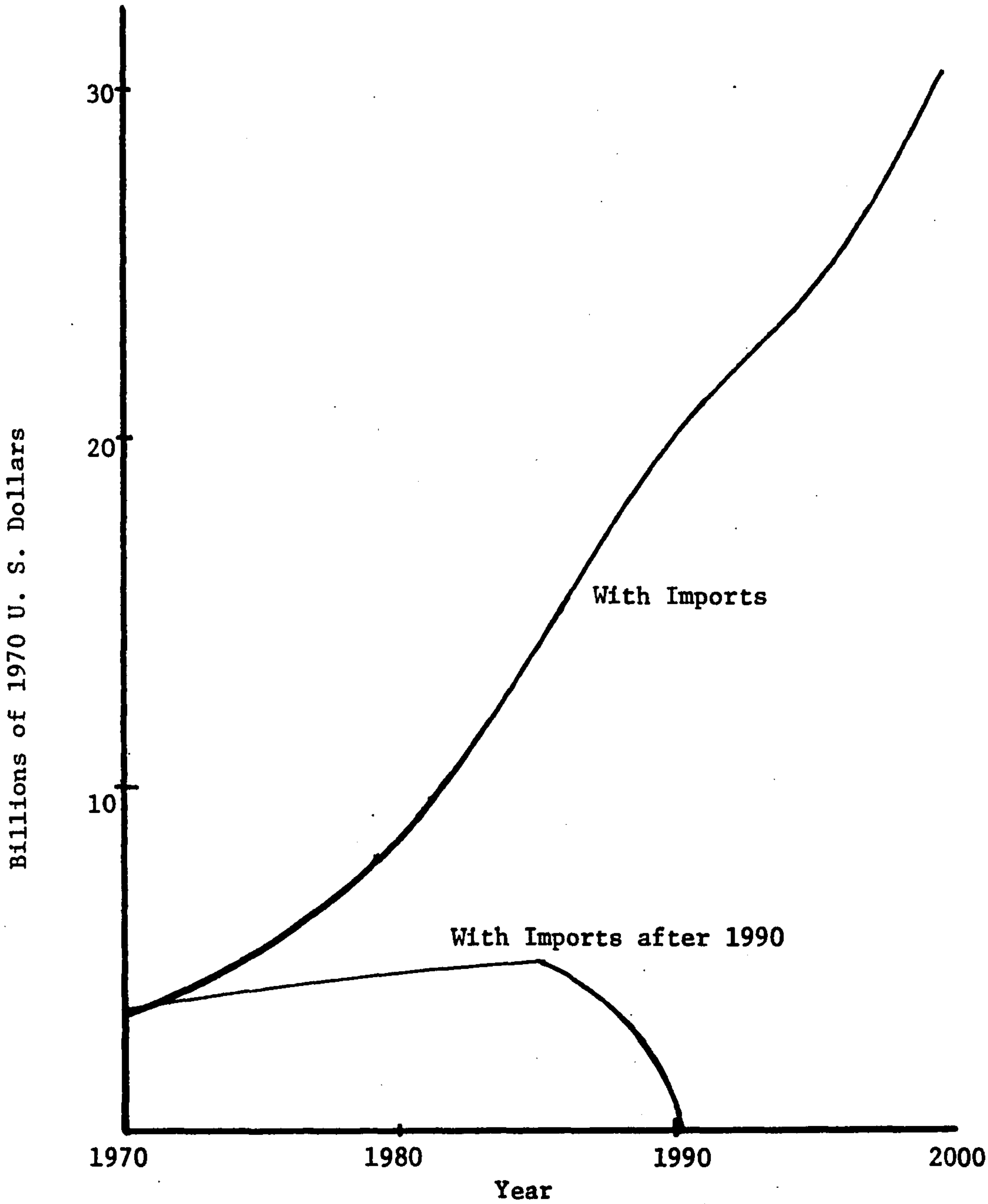


Figure III-e-15 Balance of Payments Deficit

Environmental Impacts

Air Borne Emissions

The air borne emissions in tons/year are determined for end-use energy consumption. It is given by:

$$TAE(t) = 500 \times (\sum_{ijk} (NTED(i,j,k,t) \times AEF(i,j,k,t) \times SCON(i,j,k,t) + TED(i,j,k,t) \times AEF(i,j,k,t) \times TFF(i,k,t))). \qquad \text{(III-f-1)}$$

where

NTED(i,j,k,t) = non-transportation energy demand of fuel i, end-use j and index k in year t (Tables A-1, A-2, A-3, A-4, A-5, and A-6).

TAE(t) = Total airborne emissions in year t

AEF(i,j,k,t) = Airborne emissions factors of fuel i, end-use j, and index k in year t (Tables III-f-1, III-f-2, III-f-3 and III-f-4).

SCON(i,k,t) = sulfur content of fuel i and index k in year t (Table III-f-5).

TED(i,j,k,t) = Transportation energy demand of fuel i, end-use j and index k in year t (Tables A-1, A-2, A-3, A-4, A-5 and A-6).

TFF(i,t) = Transportation fuel fraction of fuel i, in year t (Figures III-f-1, III-f-2 and III-f-3).

500 = Conversion factor

K = 1,   CO

Table III-f-1 Electrical Generation Airborne Emission Factors (99)

Fuel	CO_2	CO	SO_2**	NO_x	Particulate	Hydrocarbon	Aldehyde
Coal, 1970	224	0.0379	1.4394S	0.6818	0.9848	0.0136	0.00189
Coal, 1980+	224	0.0379	1.2S	0.07	0.20	0.0136	0.00189
Natural Gas, 1970	122	0.004	0.0006	0.370	0.0150	0.04	0.003
Natural Gas, 1980+	122	0.004	0.006	0.20	0.015	0.040	0.0030
Distillate oil, 1970	170	0.000267	1.0488S	0.701	0.053	0.0134	0.0067
Distillate oil, 1980+	170	0.000267	0.8S	0.30	0.054	0.0134	0.0067
Residual oil, 1970	170	0.000267	1.0488S	0.701	0.053	0.0134	0.0067
Residual oil, 1980+	170	0.000267	0.80S	0.30	0.054	0.0134	0.0067

*Units: lb/million BTU.

**S = percent sulfur in fuel.

Table III-f-2 Residential Airborne Emission Factors (lb/10^6 BTU) (99)

Fuel Type	CO_2	CO	SO_2*	NO_x	Particulate	Hydrocarbon	Aldehyde
Electricity	--	--	--	--	--	--	--
Natural gas	120	0.02	0.0006	0.05	0.019	0.008	0.01
Distillate oil	170	0.036	1.024S	0.086	0.072	0.0216	0.0144
Residual oil	170	0.036	1.024S	0.086	0.072	0.0216	0.0144

*S = percent sulfur in fuel.

Table III-f-3 Commercial Airborne Emission Factors (99)

Fuel Type	CO_2	CO	SO_2*	NO_x	Particulate	Hydrocarbon	Aldehyde
Coal	224	0.378	1.4394S	0.227	0.1515	0.1136	0.000189
Electricity	--	--	--	--	--	--	--
Natural gas	122	0.020	0.0006	0.10	0.019	0.008	0.01
Distillate oil	170	0.00144	1.024S	0.288	0.108	0.0216	0.0444
Residual oil	170	0.00134	1.049S	0.267	0.1536	0.02	0.00668

*S = percent sulfur in fuel.

Table III-f-4 Industrial Airborne Emission Factors (lb/10^6 BTU) (99)

Fuel Type	CO_2	CO	SO_2*	NO_x	Particulate	Hydrocarbon	Aldehyde
Coal	224	0.0758	1.4394S	0.5682	1.7235	0.0379	0.00189
Natural gas	122	0.0004	0.0006	0.12	0.018	0.04	0.003
Distillate oil	170	0.00144	1.024S	0.288	0.108	0.0216	0.0144
Residual oil	170	0.00134	1.049S	0.267	0.1536	0.02	0.00668

*S = percent sulfur in fuel.

Table III-f-5 Transportation Airborne Emission Factors (lb/million BTU) (4,65,99)

Demand Type	Fuel Type	CO_2	CO	SO_2	NO_x	Particulates	Hydrocarbons	Aldehydes
Airplane	Hydrogen	--	--	--	0.0276	--	--	--
	Gasoline	149	1.070	0.082	0.206	0.324	0.7	0.021
	Jet fuel	149	1.070	0.082	0.206	0.329	0.7	0.021
	Methanol	149	0.135	--	0.0064	--	0.0277	--
Auto (1970)	Gasoline	149	17.08	0.04	1.46	0.071	2.992	0.021
Auto	Hydrogen	--	--	--	0.0276	--	--	--
	Gasoline	149	0.78	0.04	0.092	0.071	0.094	0.021
	Methanol	149	0.135	--	0.0064	--	0.0277	--
	Electricity	--	--	--	--	--	--	--
Bus	Hydrogen	--	--	--	0.0276	--	--	--
	Gasoline	149	0.78	0.04	0.092	0.071	0.094	0.021
	Distil. Oil	170	0.77	0.194	1.32	0.094	0.590	0.022
	Methanol	149	0.135	--	0.0064	--	0.0277	--
Railroad	Hydrogen	--	--	--	0.0276	--	--	--
	Distil. oil	160	0.77	0.194	1.32	0.094	0.590	0.022
	Methanol	149	0.135	--	0.0064	--	0.0277	--
Ships	Hydrogen	--	--	--	0.0276	--	--	--
	Distil. oil	170	0.77	0.194	1.32	0.094	0.590	0.022
	Residual oil	170	0.00134	1.049S*	0.267	0.1536	0.020	0.00668
	Methanol	149	0.135	--	0.0064	--	0.0277	--
Truck	Hydrogen	--	--	--	0.0276	--	--	--
	Gasoline	149	0.78	0.04	0.092	0.071	0.094	0.021
	Distil. oil	170	0.77	0.194	0.32	0.094	0.590	0.022
	Methanol	149	0.135	--	0.0064	--	0.0277	--

*S = percent sulfur in fuel.

Table III-f-6 Sulfur Content of Non-Transportation Fuel (46)

Fuel	Year	% Sulfur
Coal	1970	2.8
	1980+	0.83
Distillate	1970	0.6
	1980+	0.6
Residual	1970	2.253
	1980+	0.75

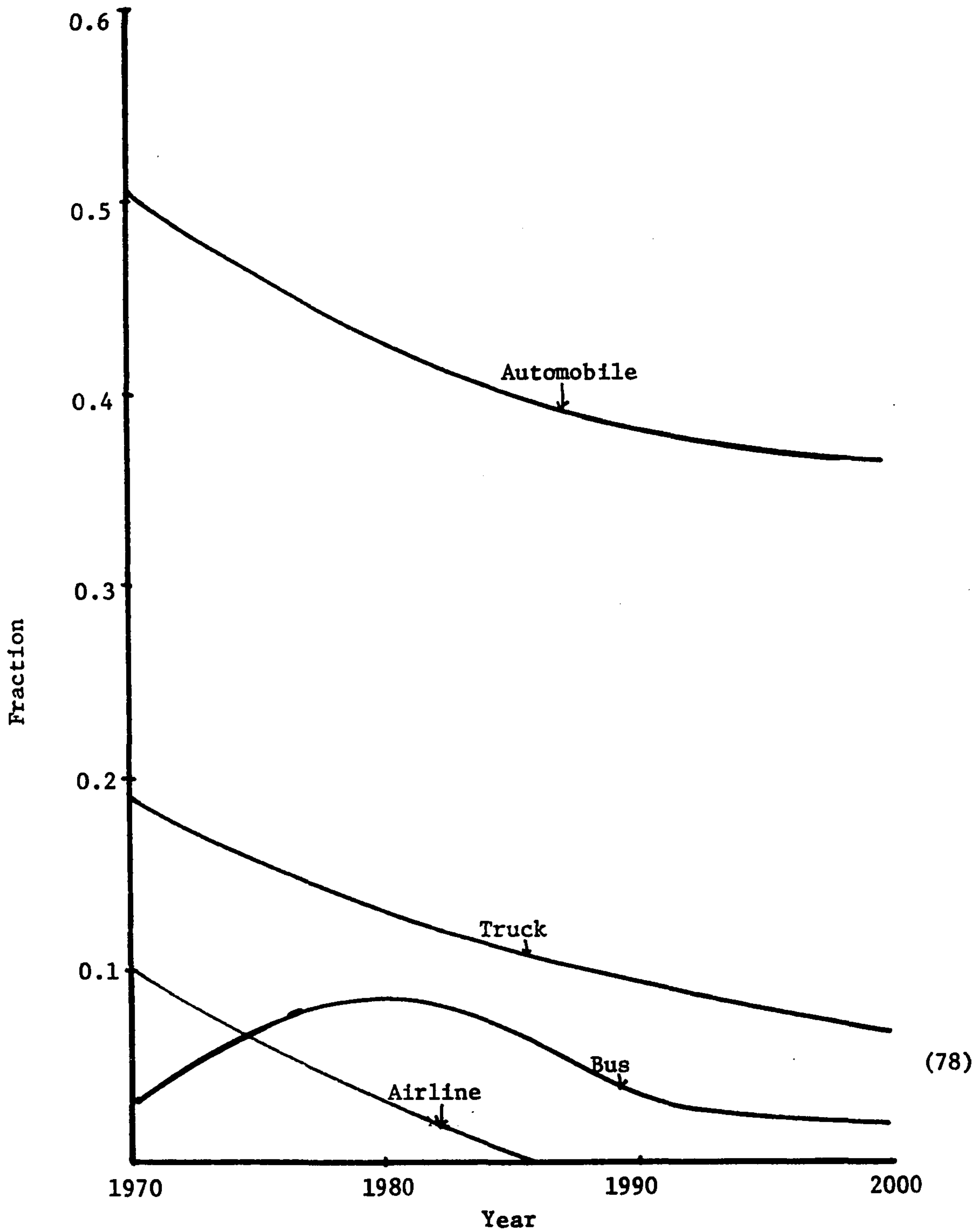


Figure III-f-1 Projected Gasoline Fuel as Percentage of Total Transportation Fuel

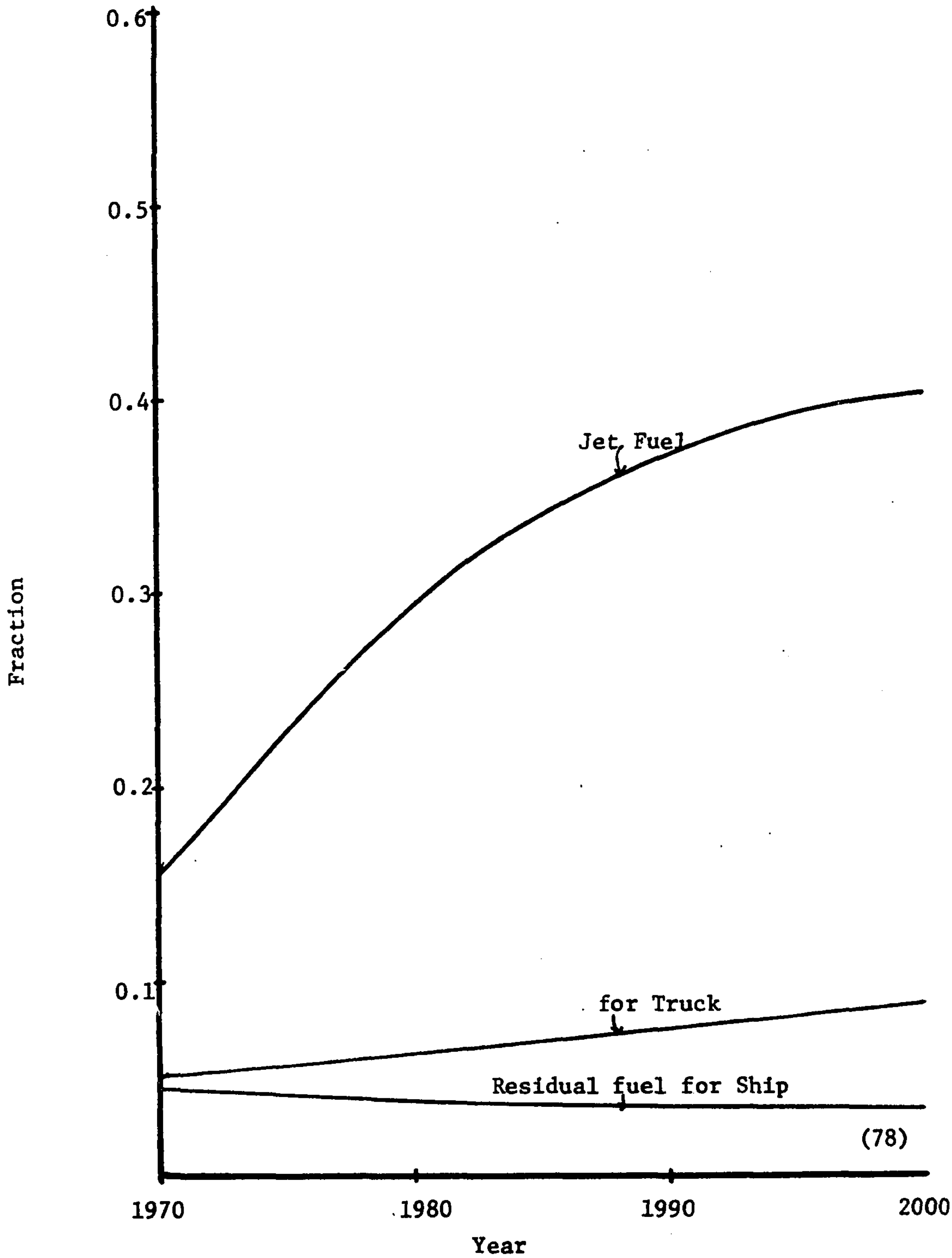


Figure III-f-2 Projected Fraction of Tranpsortation Fuel

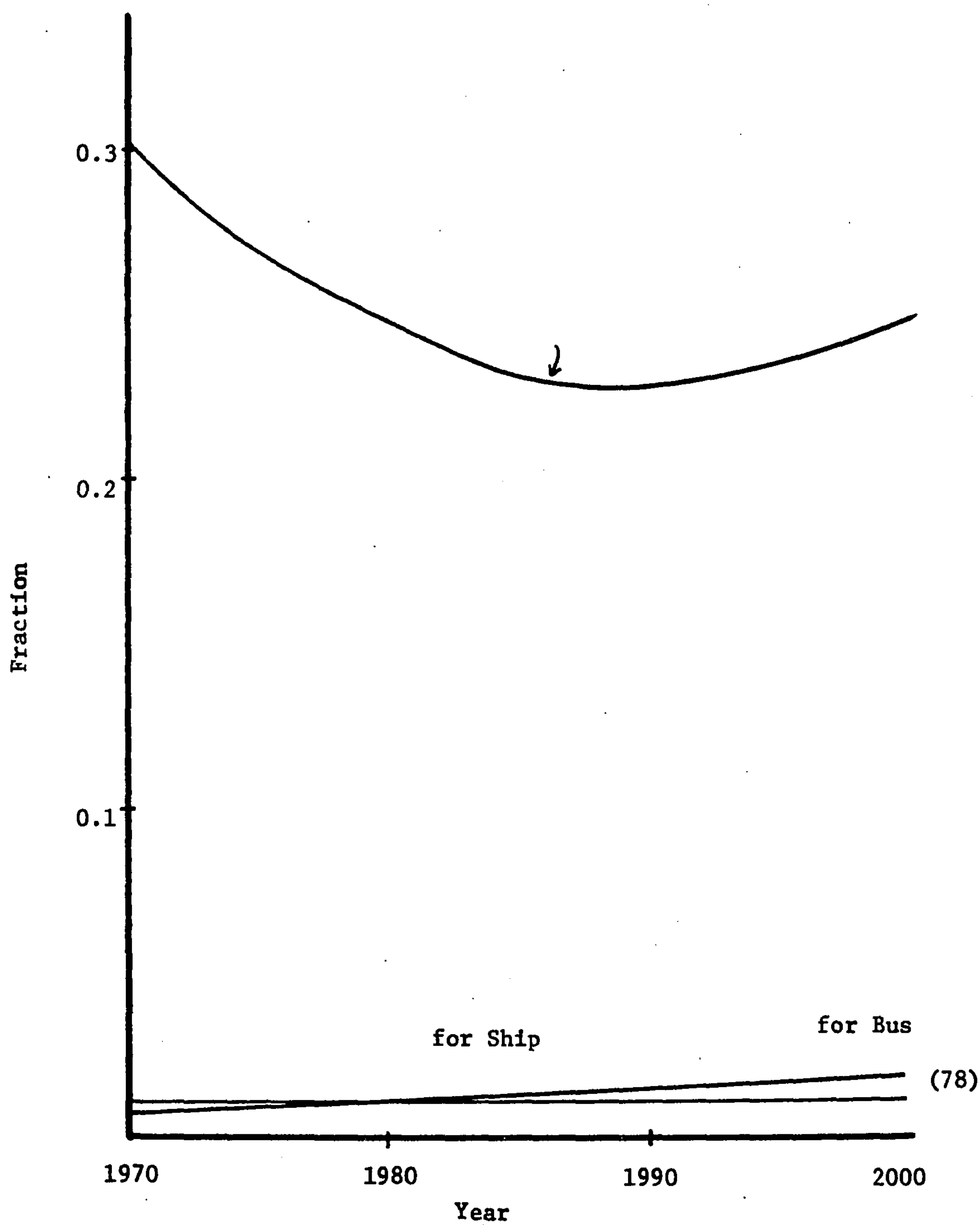


Figure III-f-3 Projected Fraction of Transportation Fuel

$k = 2$, NO_x

$k = 3$, SO_2

$k = 4$, HC and

$k = 5$, particulates.

The annual CO, NO_x, SO_2, HC and particulates are decreasing until 1980. After that the curves will slowly increase (Figures III-f-4, III-f-5, III-f-6, III-f-7 and III-f-8). (See Appendices for detail).

Note that stricter environmental constraints are imposed on emission factors (Tables III-f-1 and III-f-5).

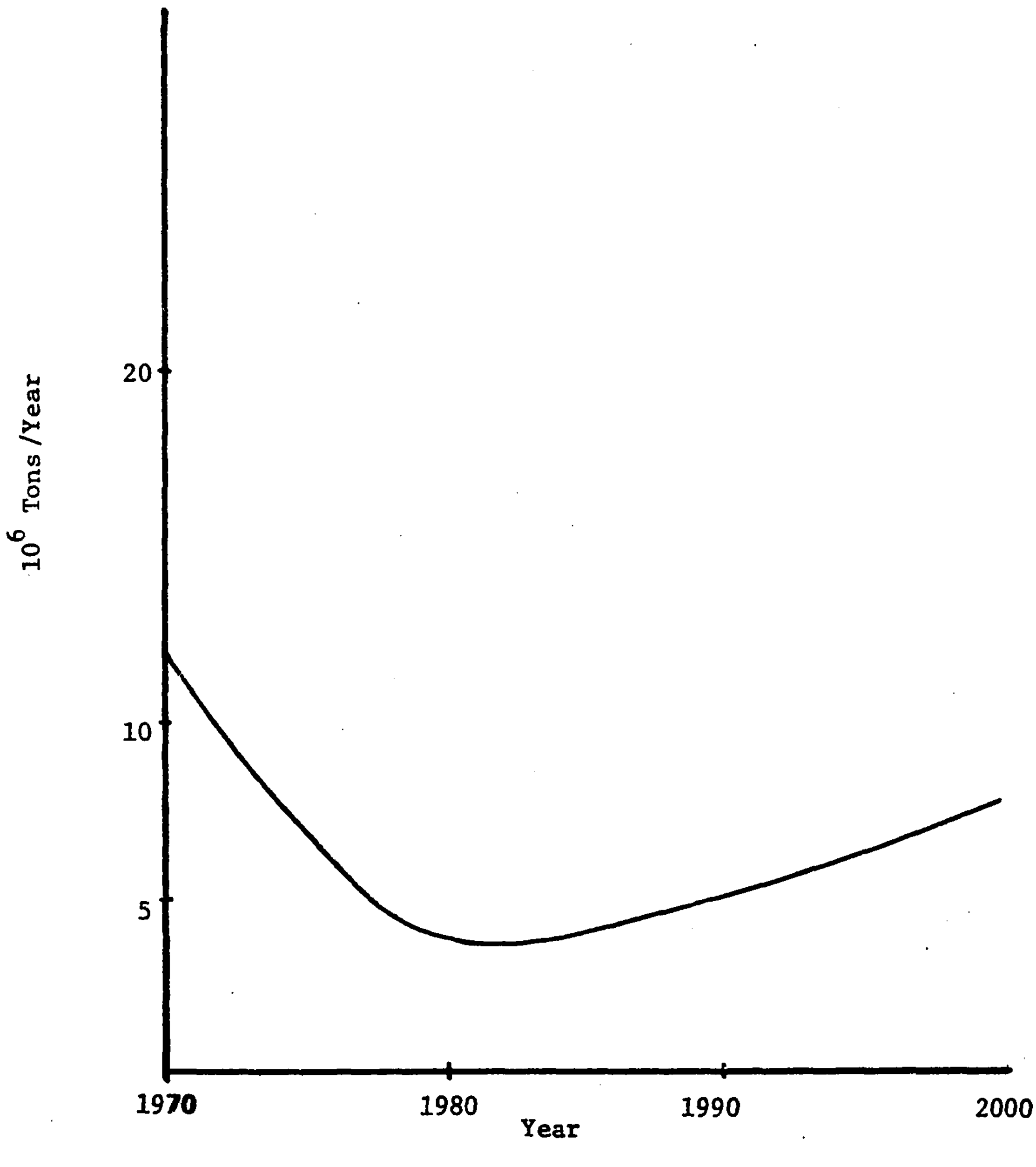


Figure III-f-4 Annual Hydrocarbon Emission

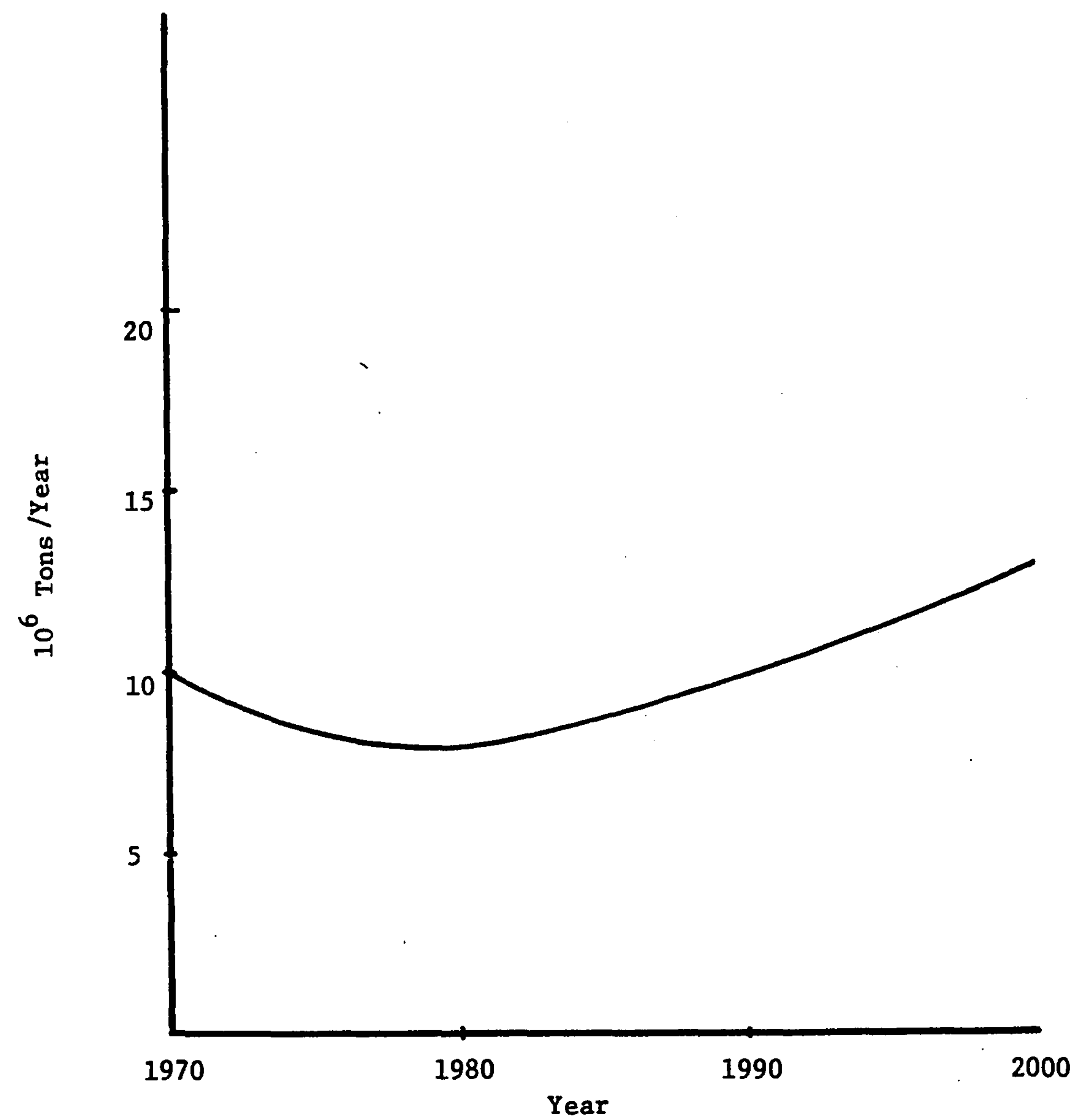


Figure III-f-5 Annual NO_x Emission

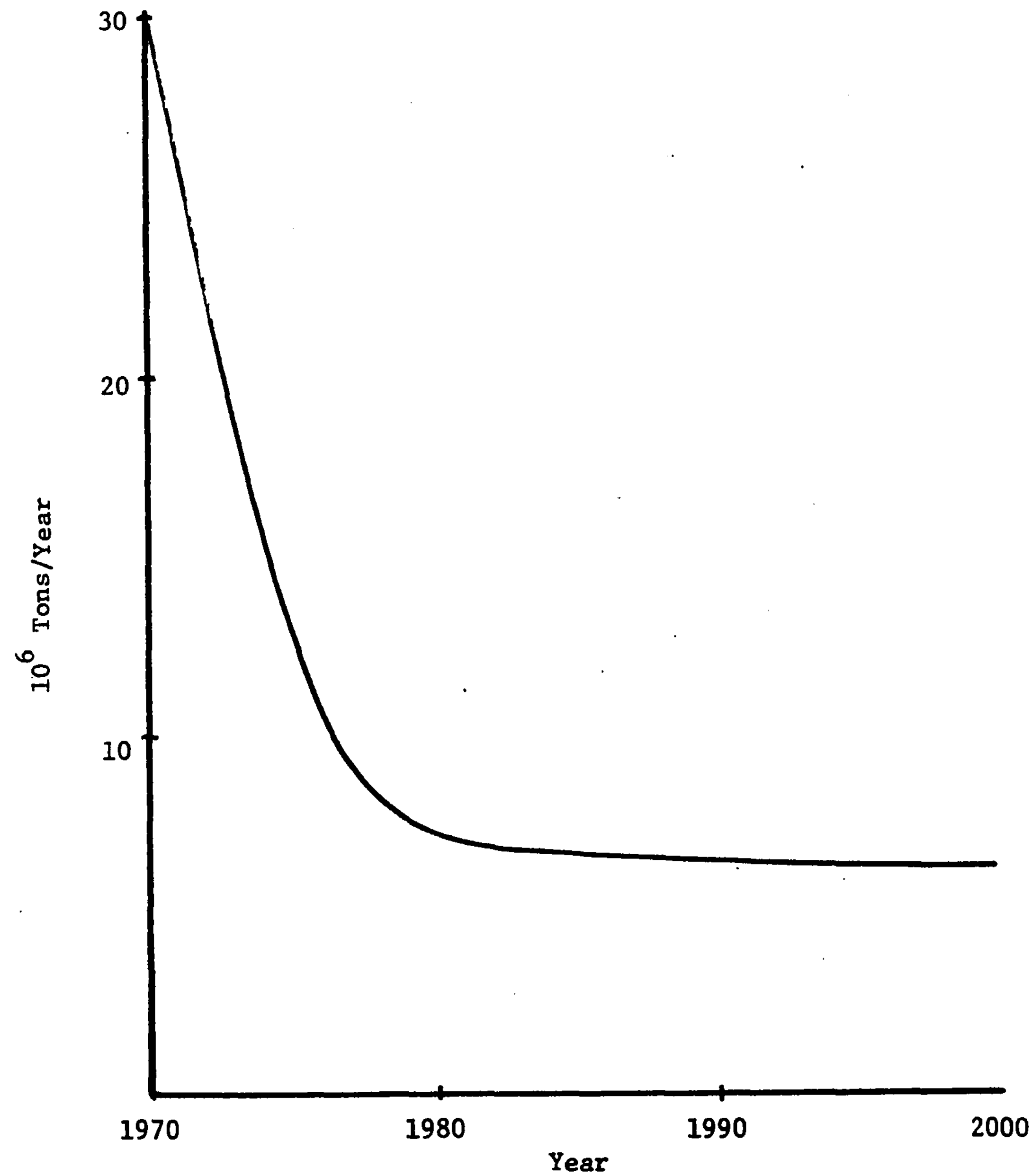


Figure III-f-6 Annual Particulate Emission

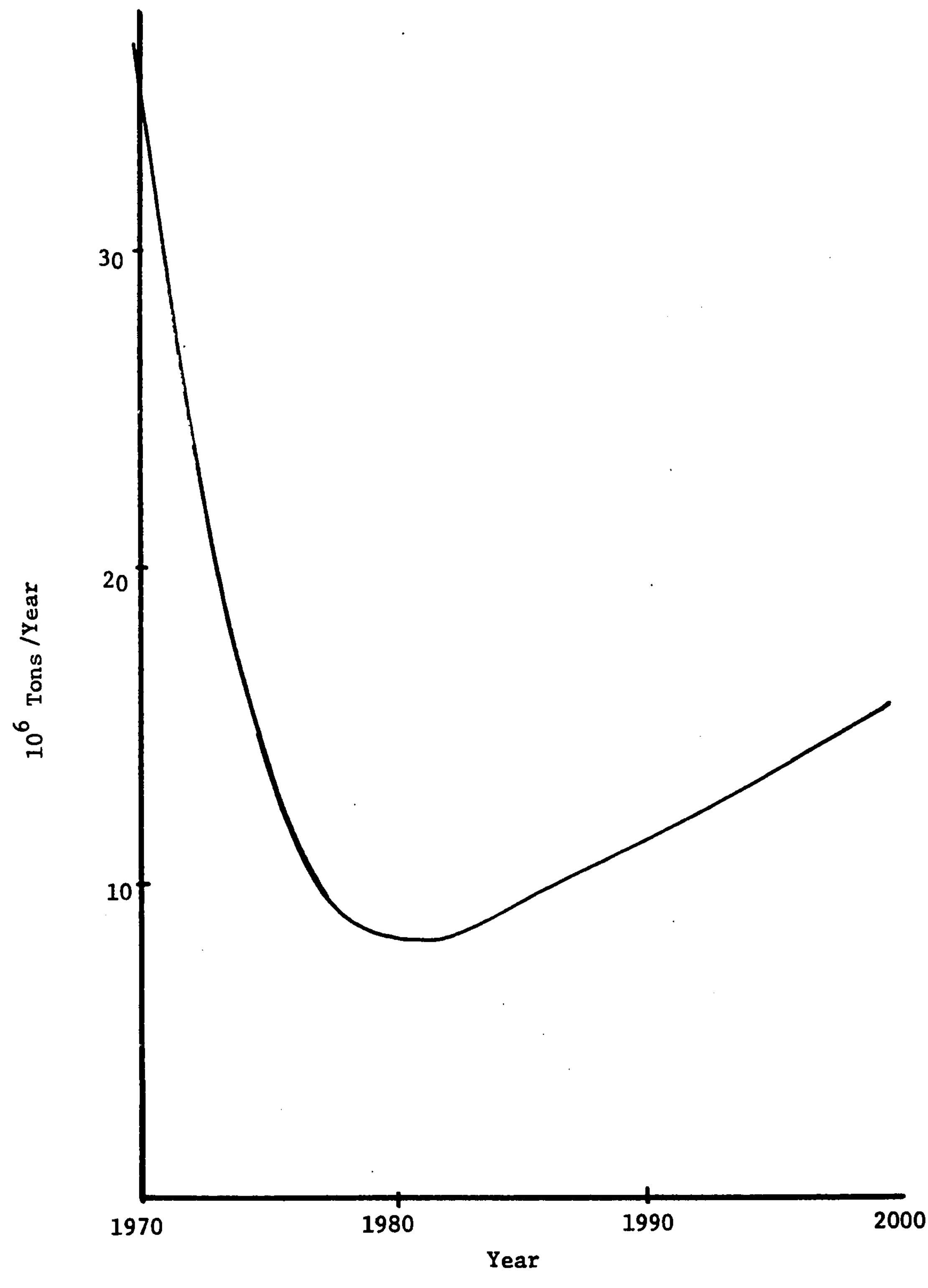


Figure III-f-7 Annual CO Emission

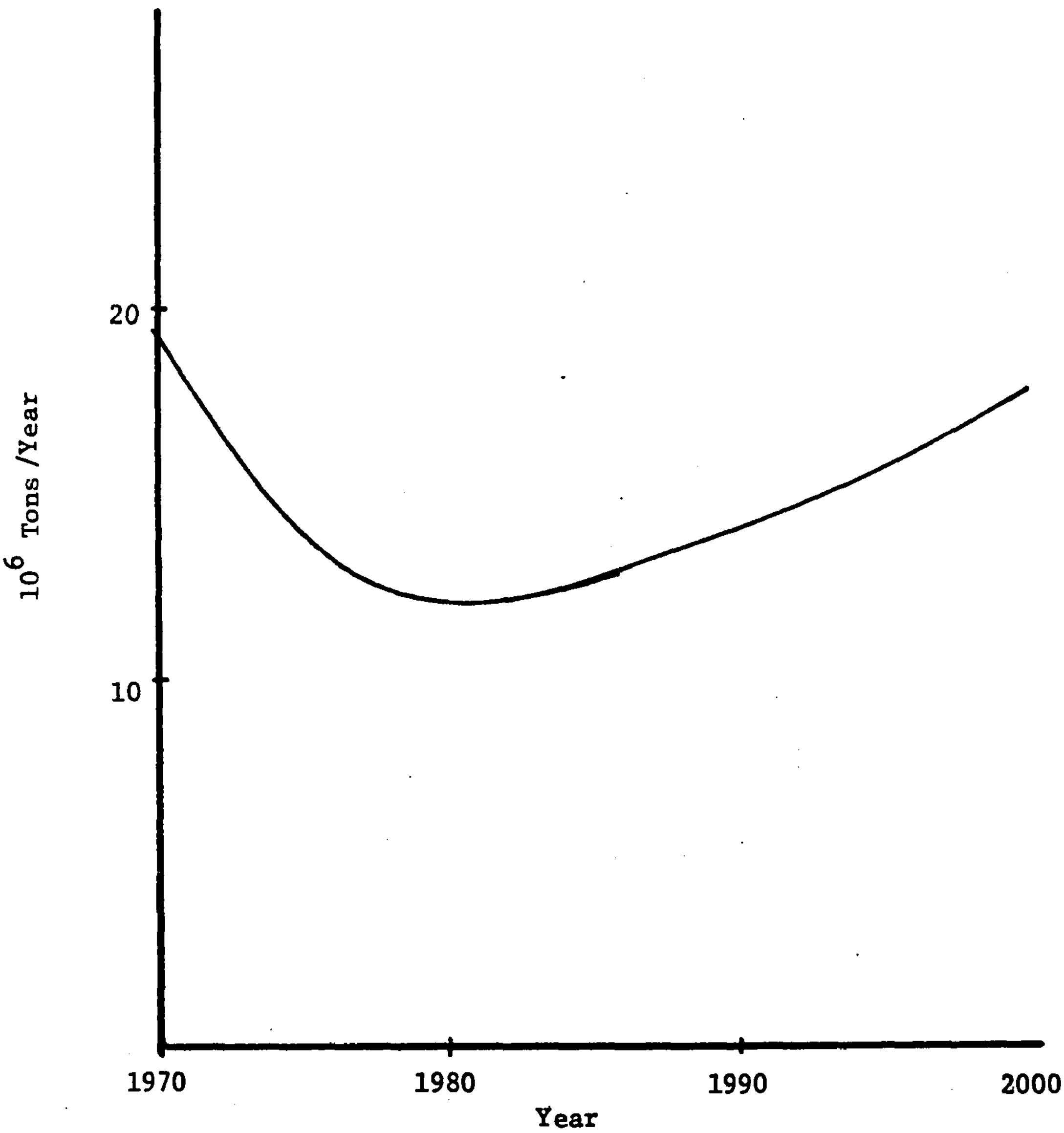


Figure III-f-8 Annual SO_2 Emission

Solid Waste Production

The amount of solid waste produced is determined for oil shale, tar sands and syncrude and syngas from coal.

1. Oil Shale:

   SWOSP(t) = CSWOS x OSP(t) (III-f-2)

   where:

   SWOSP(t) = amount of solid waste created by oil shale production in year t in tons/year.

   CSWOS = the coefficient of solid waste from oil shale (Table III-f-7).

   OSP(t) = amount of oil shale production in year t Figure III-e-10).

2. Tar Sands:

   SWTSP(t) = SWTSC x TSP(t) (III-f-3)

   where:

   SWTSP(t) = amount of solid waste created by tar sands production in year t in tons/year.

   CSWTS = the coefficient of solid waste from tar sands (Table III-f-8).

   TSP(t) = amount of tar sands production in year t (Figure III-e-10).

3. Syncrude:

   SWSCP(t) = SWSCP(t) = CSWSC x SCPC(t) (III-f-4)

   where:

   SWCSP(t) = amount of solid waste created by suncrude production in year t in tons/year.

CSWSC = the coefficient of solid waste from syncrude (Table III-e-1).

SCPC(t) = amount of syncrude production from coal in year t (Figure III-e-6).

4. Syngas:

$$SWSGP(t) = CSWSG \times (SGPC(t) \qquad \text{(III-f-5)}$$

where:

SWSGP(t) = amount of solid waste from syngas by coal in year t in tons/year.

CSWSG = the coefficient of solid waste from syngas.

SGPC(t) = amount of syngas production from coal in year t (Figure III-e-7).

The amount of total solids in year t in tons/year is given by:

$$TSW(t) = SWOSP(t) + SWTSP(t) + SWSGP(t) \qquad \text{(III-f-6)}$$

Water Usage

The water requirements for electrical generation, oil shale production, tar sands production and coal conversion to syngas and syncrude are determined.

1. Electrical generation:

The water requirements for once through cooling of electrical power stations is given by:

$$WROT(t) = \sum_{i} (FROT(t) \times COT(i) \times CED(i,t) \qquad \text{(III-f-7)}$$

Table III-f-7 Solid Waste Production Coefficient

Resource	Coefficient tons/million BTU Product
Oil shale	0.4055 (48,52)
Tar sands	0.5862
Syncrude	0.00191*
Syngas	0.00191*

* From Table III-e-1.

Table III-f-8 Total Solid Waste Production
(10^6 ton/year)

Resource	1980	1990	2000
Tar sand	0.0 (0.000392)*	0.00456 (0.001732)*	0.01499 (0.007358)*
Oil shale	0.0 (0.000062)*	0.00659 (0.000277)*	0.002095 (0.001180)*
Syncrude	1.07342 (45.38924)*	11.08182 (61.53256)*	44.74175 (78.271036)*
Syngas	1.49935 (0.34571	12.27366 (5.05577)*	49.7746 (21.06157)*
Total	2.57277 (45.735404)*	23.356595 (66.590339)*	94.55129 (99.341144)*

*No imports after 1990.

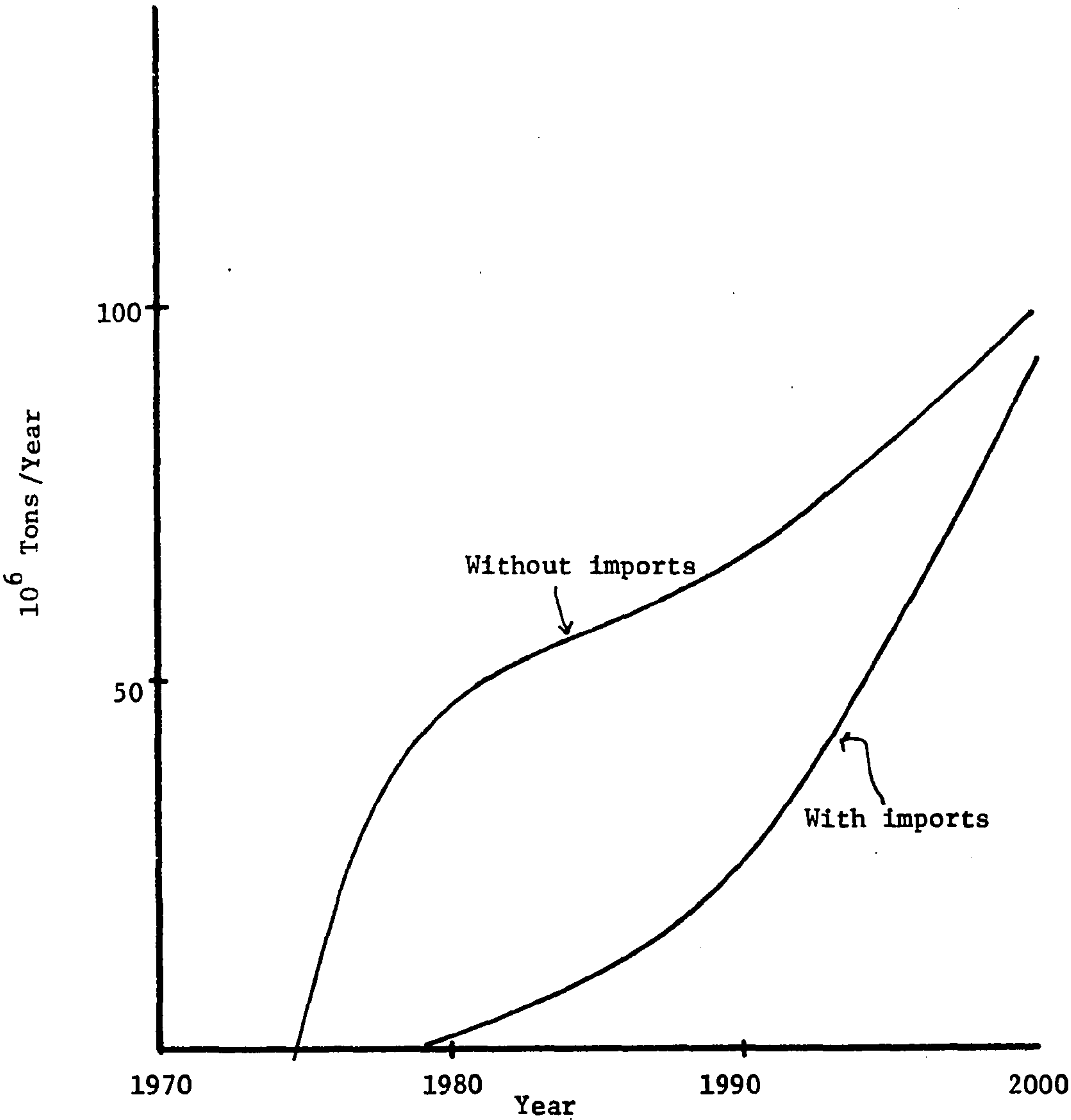


Figure III-f-9 Projected Annual Solid Waste Production where:

FROT(t) = fraction of electrical generation plants using once through cooling in year t (Figure III-b-7)

COT(t) = coefficient of water usage for once through cooling of fuel i (Table III-f-10).

CED)i,t) = corrected electrical energy demand of fuel i year t.

The water consumed in electrical power stations due to evaporation, spray and draft in cooling towers, cooling and spray ponds and once through cooling is given by:

$$
\begin{aligned}
WRESD(t) = {}_{i}\ & (FROT(t) \times COTE(i)) + (FRNC(t) + FRFC(t))) \\
& \times CCT(t) + (FRSP(t) + FRCP(t)) \times CCP(i) \\
& \times CED(i,t)) \qquad \text{(III-f-8)}
\end{aligned}
$$

where:

COTE(i) = coefficient of water usage of once through due to evaporation for fuel i (Table III-f-10).

CCT(t) = coefficient of water usage for cooling towers for fuel i (Table III-f-10).

CCP(i) = coefficient of water usage for cooling and spray ponds for fuel i (Table III-f-10).

2. Oil Shale Recovery:

The water consumption of oil shale recovery is given by:

$$WRTS(t) = 81.8 \times OSP(t) \quad \text{acre/feet per year} \qquad \text{(III-f-9)}$$

3. Tar Sands Recovery

The water consumption of tar sands recovery is given by:

Table III-f-9 Water Usage Coefficients

Use	Coefficient*	Reference
Electrical generation		
fossil--once-thru (thru-condenser)	29520.0 (assume ΔT = 15°F)	22
fossil--once-thru (evaporation)	162.7	22
nuclear--once-thru (thru condenser)	20470.2 (assume ΔT = 18°F)	22
nuclear--once-thru (evaporation)	187.2	22
fossil-cooling pond (evap., spray & drift)	217.9	22
fossil-cooling tower (evap., spray & drift)	380.6	22
nuclear--cooling pond (evap., spray & drift)	257.8	22
nuclear--cooling tower (evap., spray & drift)	466.5	22
Oil shale	81.8**	51
Tar sands	81.8**/***	14
Coal gasification	75.0**	10
Coal liquefaction	10.39**	10
Synthetic fuel--hydrogen		
feed water	58.8**	32
electrolytic cell cooling	73.2**	32

*Units: acre-feet/10^2 BTU waste heat.

**acre-feet/10^{12} BTU product.

***assumed same as oil shale.

$$WRTS(t) = 81.8 \times TSP(t) \qquad \text{(III-f-10)}$$

4. Syngas Conversion:

$$WRSG(t) = 75.0 \times SGP(t) \qquad \text{(III-f-11)}$$

5. Syncrude Conversion:

The water consumption of syncrude conversion is given by:

$$WRSLC(t) = 10.39 \times SLC(t) \qquad \text{(III-f-12)}$$

Total water requirements in year t for energy utilization in year, TWR(t), is given by:

$$TWR(t) = WROT(t) + WRESD(t) + WROS(t) + WRTS(t) + WRSG(t) + WRSLC(t) \quad \text{acre-feet} \qquad \text{(III-f-13)}$$

Table III-f-10 Total Water Requirements
(acre-feet)

	1980	1990	2000
Electrical water			
Thru condenser	0.541317567	1.014879352	1.610654614
Thru evaporation	0.005909956	0.015151471	0.020085537
Tar sand	0.0	0.000092025	0.000292435
	(0.000008752)*	(0.000860863)*	(0.00148342)*
Oil shale	0.0	0.000481950	0.001954500
	(0.000079264)*	(0.000095624)*	(0.000164908)*
Syncrude	0.000005839	0.000060282	0.000243385
	(0.000060615)*	(0.000246907)*	(0.000425778)*
Syngas	0.000058875	0.000481950	0.001954500
	(0.000013575)*	(0.000827025)*	(0.003143290)*
Total	0.547291737	1.027757105	1.633522906
	(0.547291737)*	(1.029051217)*	(1.635954429)*

*No imports after 1990

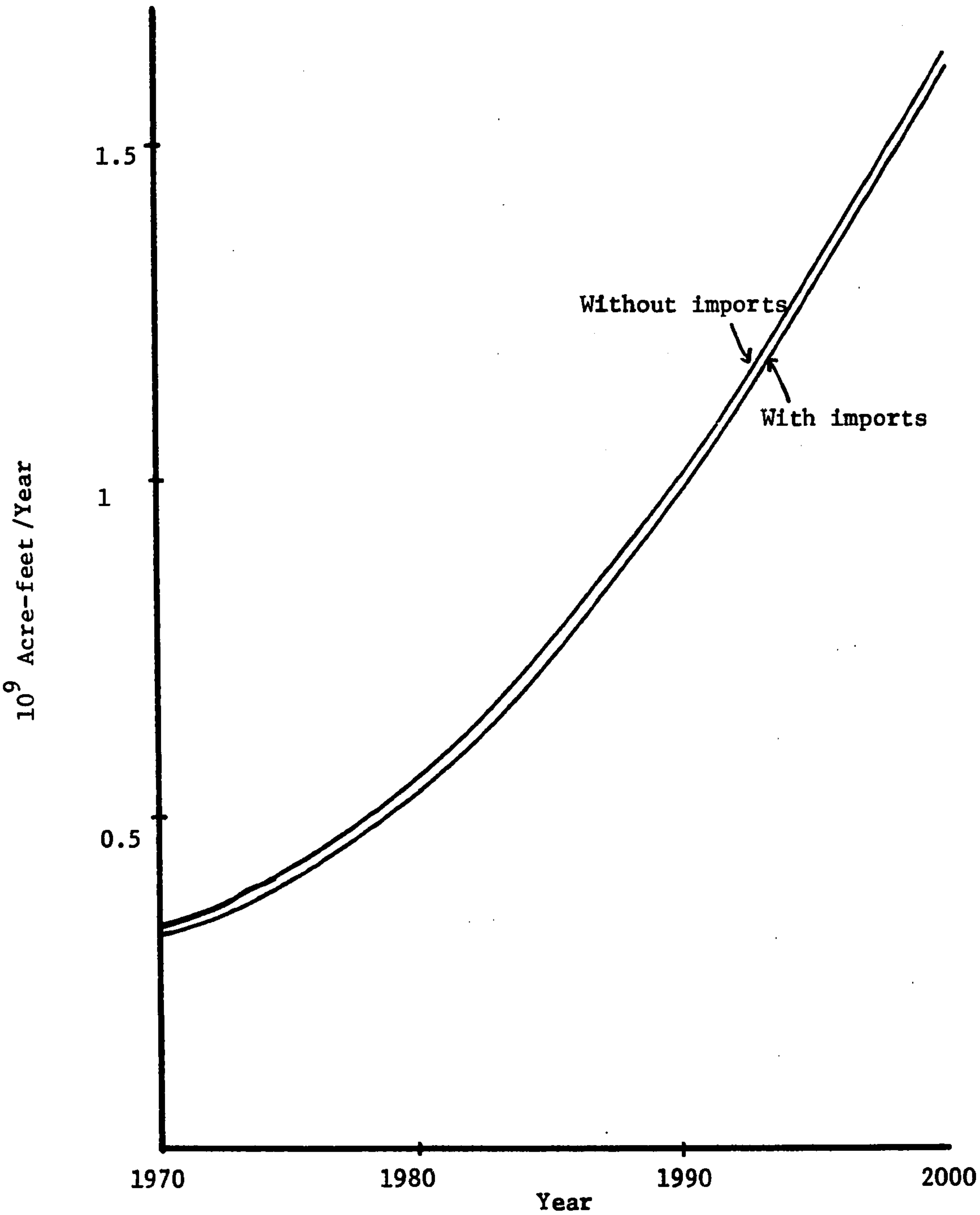


Figure III-f-10 Projected Annual Water Requirement

Land Use

The amount of land requirement for energy supply in acres for year t includes the land requirement for strip-coal mining, oil shale production, tar sands production, electrical power transmission lines, electrical power plant siting and waste heat removal systems.

1. Coal:

Land use for coal mining in year t, LUCM(t), is given by:

$$LUCM(t) = CLUCM \times FCSM(t) \times TDC(t) \qquad \text{(III-f-14)}$$

where:

CLUCM = coefficient of coal mining land use (Table III-f-11).

FCSM(t) = fraction of coal strip mined in year t.

TCD(t) = total coal resource requirement in year t (Figure III-e-5).

2. Oil Shale Recovery:

Land use for oil shale recovery in year t, LUOS(t), is given by:

$$LUOS(t) = CLUOS \times OSP(t) \qquad \text{(III-f-15)}$$

where :

CLUOS = coefficient of land use for oil shale recovery (Table III-f-9).

OSP(t) = oil shale production in year t (Figure III-e-10).

3. Tar Sands Recovery:

Land use for tar sands recovery in year t, LUTS(t), is given by:

$$LUTS(t) = CLUTS \times TSP(t) \qquad \text{(III-f-16)}$$

Table III-f-11 Land Use Coefficient

Energy Utilization	Coefficient (acres/trillion BTU)
Coal mining - strip	13.44 (4)
Oil shale	2.33 (Assume 30' thick deposit) (52)
Tar sands	0.0233 (Assume 1/100 of oil shale)
Electric power - transmission	407. (4)
Electric power plant siting	
Coal	34.2 (4)
Oil	8.56 (4)
Gas	5.13 (4)
Nuclear	10.00 (4)
Solar	636.2 (75)
Geothermal	133.8 (75)
Hydroelectric	39,200.
Cooling towers and spray ponds	0.298 (108)
Cooling ponds	22.0 (108)

where

CLUTS = coefficient of land use for tar sands recovery (Table III-f-11).

TSP(t) = tar sands production in year t (Figure III-e-10).

4. Transmission Lines:

$$LUETL(t) = CLUETL \times TCED(t) \times 0.91 \qquad \text{(III-f-17)}$$

where

CLUETL = coefficient of land use for electrical transmission lines (Table III-f-11).

TCED(t) = total corrected electrical demand in year t (Tables A-1 through A-6).

5. Generating Stations:

Land use for electrical generating stations in year t, LUEGS(t), is given by:

$$LUEGS(t) = \sum_{i}(CLUEGS \times CED(i,t)) \qquad \text{(III-f-18)}$$

where

CLUEGS = coefficient of land use for electrical generating stations (Table III-f-11).

CEDS(t) = corrected energy demand for fuel i in year t (Tables A-1 through A-6).

6. Waste Heat Removal for Electrical Power Stations:

Land use for waste heat removal for electrical power stations in year t, LUWHR(t), is given by:

$$LUWHR(t) = (CLUCT \times FRNC(t) + CLUCP \times FRCP(t) + CLUSP \times FRSP(t) \times TCED(t) \qquad \text{(III-f-19)}$$

where :

CLUCT = coefficient of land use for cooling towers (Table III-f-11).

FRNC(t) = fraction of natural convection cooling towers (Figure III-b-7).

CLUCP = coefficient of land use for cooling ponds (Table III-f-11).

FRCP(t) = fraction of cooling ponds in year t (Figure III-b-7).

CLUSP = coefficient of land use for spray ponds (Table III-f-11).

FRSP(t) = fraction of spray ponds in year t (Figure III-b-7).

Radioactive Material Production and Releases

The environmental impacts of radioactive materials are determined by using the nuclear environmental coefficients from Table III-f-10, and the amount of power supplied by each type of nuclear reactor (Fig. III-f-12)

1. Tritium:

The amount of tritium released by nuclear reactors in year t, TR(t), is given by:

$$TR(t) = 10^6 \times \sum_i (CTR(i) \quad NPD(i,t)) \qquad \text{(III-f-20)}$$

where :

CTR(i) = coefficient of tritium released from reactor type i (Table III-f-12).

NPD(i,t) - nuclear power demand of fuel i in year t (Tables A-1 through A-6)

Table III-f-12 Land Use Requirements (Million acres)

	1980	1990	2000
Cooling water	0.117600	0.239560	0.473760
Oil shale	(0.002257)	0.002621 (0.024520)	0.008329 (0.042280)
Tar sands	0.000002	0.000026 (0.000027)	0.000083 (0.000046)
Transmission line	11.122581	21.423311	34.530706
Power Station			
Coal	0.381911 (0.308286)	0.569806 (0.896837)	0.773569 (1.711100)
Oil	0.012523	0.017008	0.023890
Gas	0.023618	0.032354	0.044615
Nuclear	0.094900	0.280400	0.530000
Geothermal	0.045893	0.090984	0.135476
Hydropower	0.396583	0.509510	0.683182
Subtotal	0.955428	1.500062	2.190732
Cooling towers and spray ponds	0.001789	0.003447	0.005556
Cooling	0.019820	0.038176	0.061533
Subtotal	0.021609	0.041623	0.067089
Total	12.217218 (12.145850)	23.206203 (23.555134)	37.270699 (38.24173)

( ) - No imports after 1990.

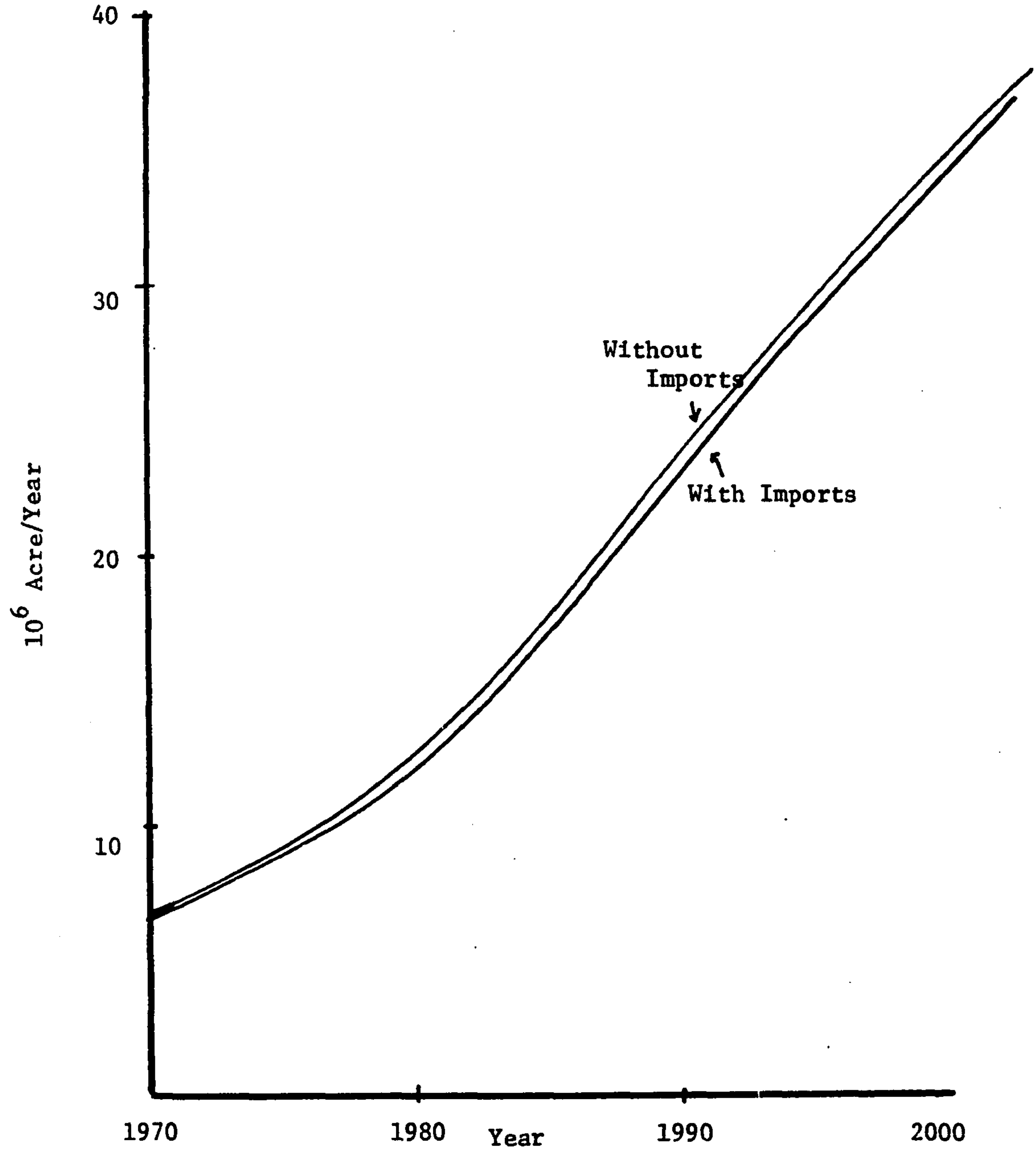


Figure III-f-11 Projected Annual Land Requirement

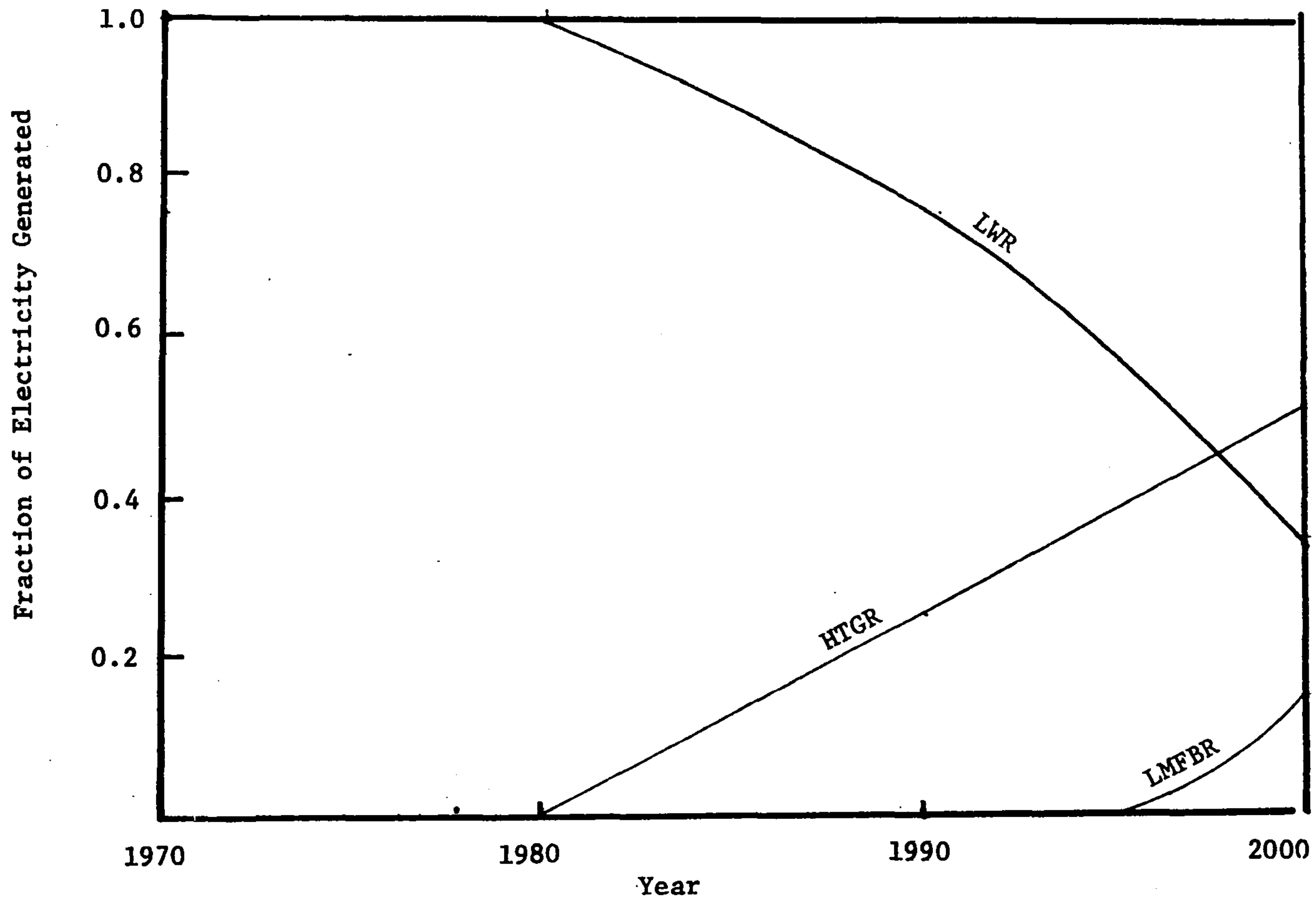


Figure III-f-12 Projected Fraction of Electrical Generation by Type (6,23)

Table III-f-13 Nuclear Environmental Coefficients (4,27,52,55,59)

Reactor Type	Population Exposure (man-rem per 10^6 BTU-th)	Long-lived Radio. Mate* (curries per 10^6 BTU-th)	Long-lived Rad. Waste (curies per 10^6 BTU-th)	Kr-85 (Ci per 10^6 BTU-th)	Tritium (Ci per 10^6 BTU-th
GCFR	4.55×10^{-6}	--	--	0.00167	0.00045
HTGR	4.55×10^{-6}	3.04×10^{-6}	--	0.0082	0.00025
LFR	4.55×10^{-6}	--	--	--	--
LMFBR	4.55×10^{-6}	3.45×10^{-6}	0.16	0 00167	0.00045
LWR	4.55×10^{-6}	5.18×10^{-6}	0.18	0.0073	0.000265
MSBR	4.55×10^{-6}	--	--	0.0082	0.066
MCFR	4.55×10^{-6}	--	--	--	4.69

*Taken 10 years after generation due to reprocessing plant holdup time.

2. Krypton-85:

The amount of K-85 released by nuclear reactors in year t, K-85, is given by:

$$K\text{-}85(t) = \sum_i CK\text{-}85(i) \times NPD(i,t) \qquad \text{(III-f-21)}$$

where

CK-85(i) = coefficient of K-85 released by nuclear reactors type i (Table III-f-12).

3. Long-lived Solid Waste:

The long-lived material and waste released by nuclear reactors in year t, LLRM(t) and LLRW(t), are given by:

$$LLRM(t) = CLLRM(i) \times NPD(i,t) \qquad \text{(III-f-22)}$$

and

$$LLRW(t) = CLLRW(i) \times NPD(i,t) \qquad \text{(III-f-23)}$$

where

CLLRM(i) and CLLRW(i) are coefficients of long-lived material and waste released by nuclear reactors type i.

4. Population Exposure:

The population exposure by man-rem is given by:

$$PE(t) = \sum_i (CPE(t) \text{ c } NPD(i,t)) \qquad \text{(III-f-24)}$$

where

CPE(t) = coefficient of population exposure in year t (Table III-f-12).

Table III-f-14 Radioactive Material Production and Release

	1980	1990	2000
Population exposure (Million man-rem)	0.043179	0.129219	0.241149
LWR	0.043179	0.099111	0.108276
HTGR	0.0	0.030108	0.096218
LMFBR	0.0	0.0	0.036654
Tritium (million Ci)	2.514485	7.426742	15.218155
LWR	2.514485	5.772442	6.306205
HTGR	0.0	1.654300	5.286750
LMBFR	0.0	0.0	3.625200
Kyrpton-85 (Million Ci)	69.277000	213.275480	360.577120
LWR	69.277000	159.104440	173.718100
HTGR	0.0	54.261040	173.405400
LMFBR	0.0	0.0	13.453520
Long-lived radio. mate. (mill. Ci)	0.049158	0.132951	0.215348
LWR	0.049158	0.112834	0.123268
HTGR	0.0	0.020116	0.064286
LMFBR	0.0	0.0	0.027793
Long-lived radio. (mill. cu. ft. waste)	1708.200000	3920.000000	25,085.960000
LWR	1708.200000	3920.000000	23,797.000000
HTGR	0.0	0.0	0.0
LMFBR	0.0	0.0	1,288.960000

Abatement Cost

The pollution cost includes the cost of air pollution from stationary and mobile sources and the cost of thermal pollution abatement.

The cost to abate air pollution by mobile sources in year t is given by:

$$CAPM(t) = 32 \times (APT(t) - APTP(t)) \qquad \text{(III-g-1)}$$

where:

32 = \$32/ton (41)

APT(t) = air pollution from transportation in 1970 trend in year t (Tables C-1, C-2, C-3, C-4 and C-5).

APTP(t) = projected air pollution from transportation in year t (Tables C-1, C-2, C-3, C-4 and C-5).

The cost to abate air pollution by stationary sources in year t is given by:

$$CAPS(t) = 64 \times (APST(t) = APSP(t)) \qquad \text{(III-g-2)}$$

where:

APST(t) = air pollution from stationary sources in year t (Tables B-1, B-2, B-3, B-4 and B-5).

APSP(t) = projected air pollution from stationary sources in year t (Tables B-1, B-2, B-3, B-4 and B-5).

64 = \$64/ton (41)

The cost to abate thermal pollution from electrical power generation plants in year t is given by:

$$CTP(t) = 0.15 \times (CED(t)) \qquad \text{(III-g-3)}$$

where:

0.15 = mill/kwh (23)

CED(t) = Corrected electrical energy demand in kwh per year in year t (Tables A-1, A-2, A-3, A-4, A-5 and A-6).

The solid waste created by synthetic fuel from coal or oil shale and tar sands are not discussed due to the wide range of uncertainty of productivity depending on policies adopted by the government. The cost for disposal of these wastes are, therefore, not estimated.

Figure III-b-7 shows the abatement cost for air pollution and thermal pollution.

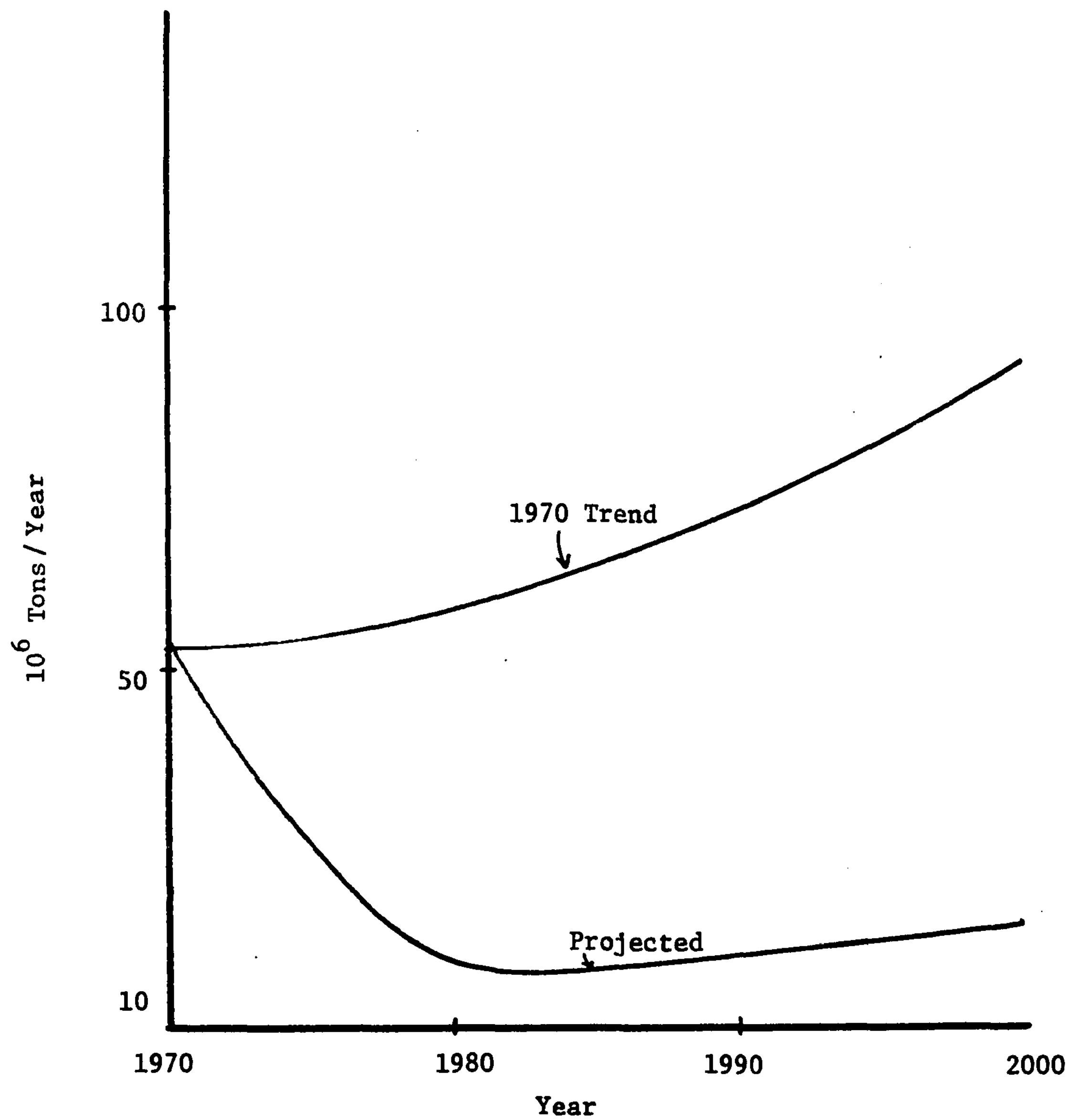


Figure III-g-1 Annual CO Emission

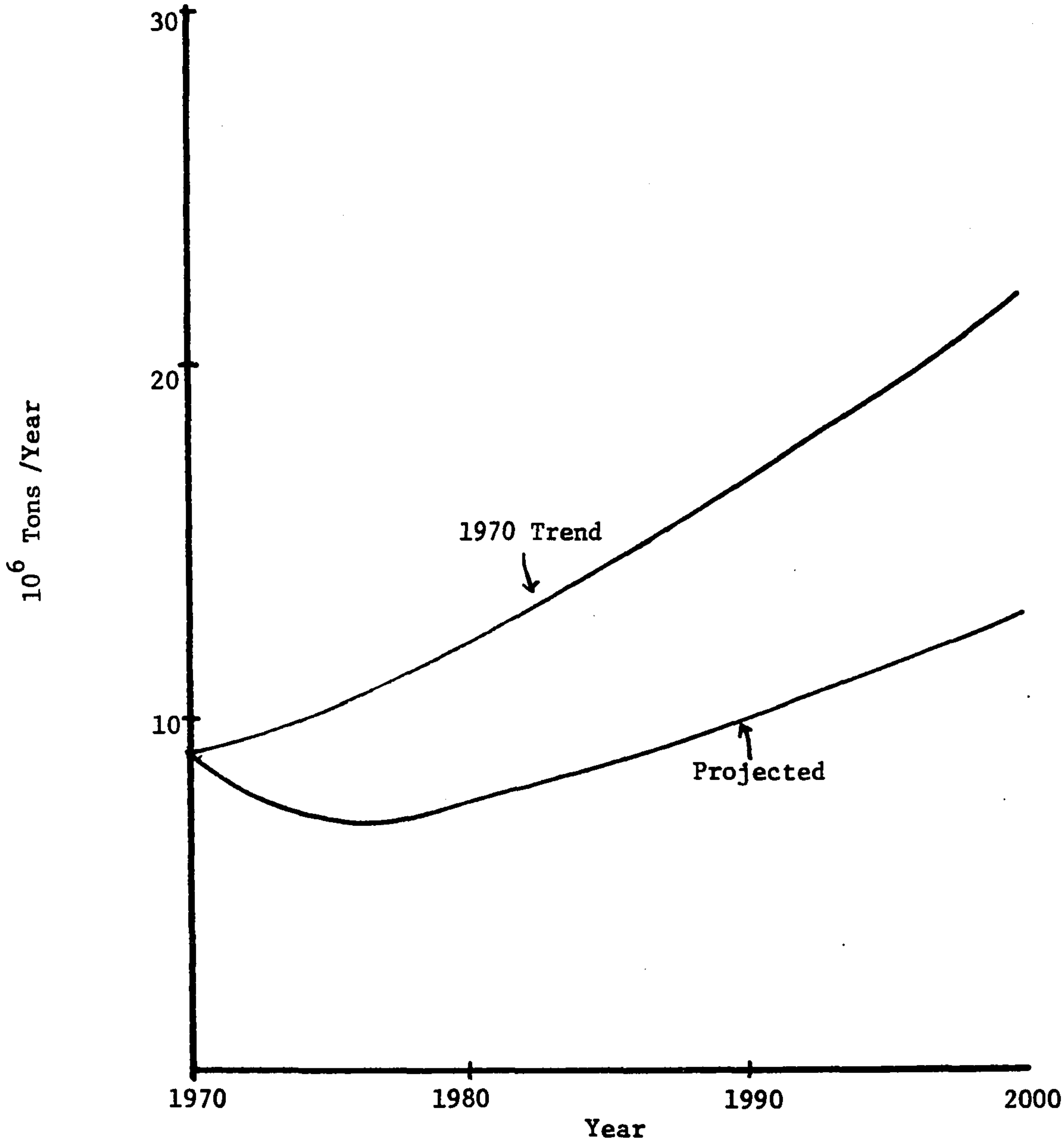


Figure III-g-2 Annual NO_x Emission

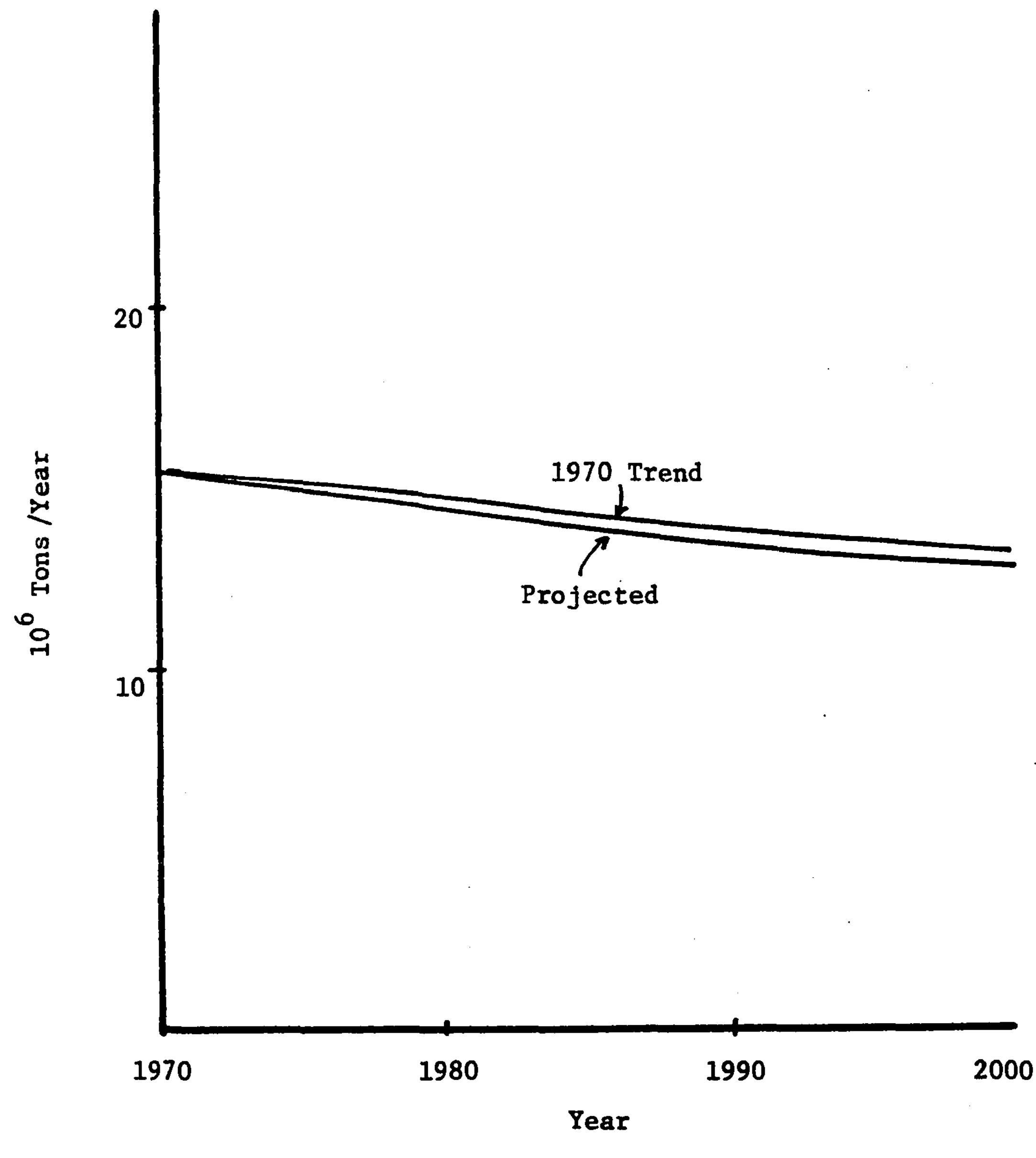


Figure III-g-3 Annual SO_2 Emission

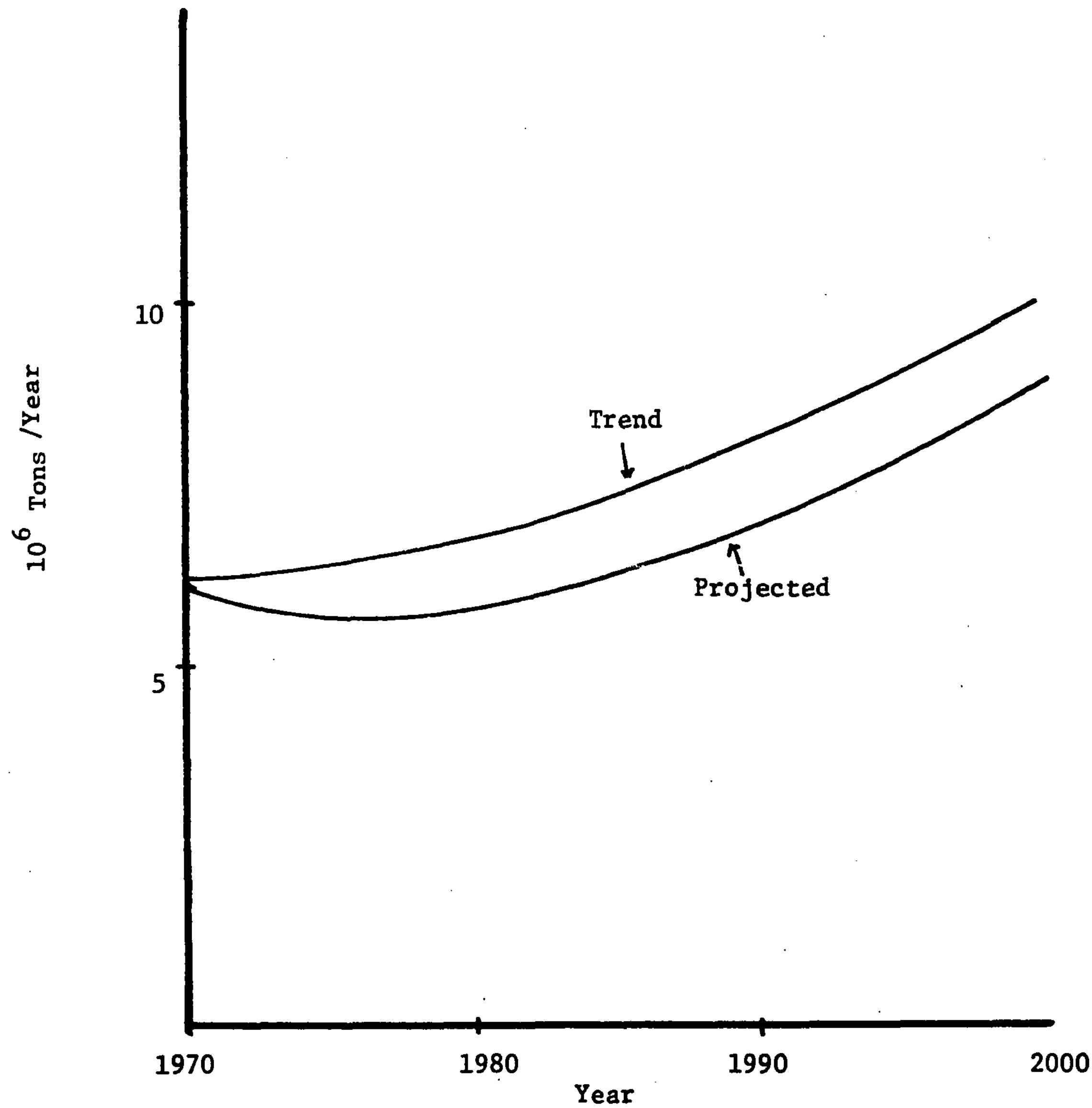


Figure III-g-4 Annual Particulates Emission

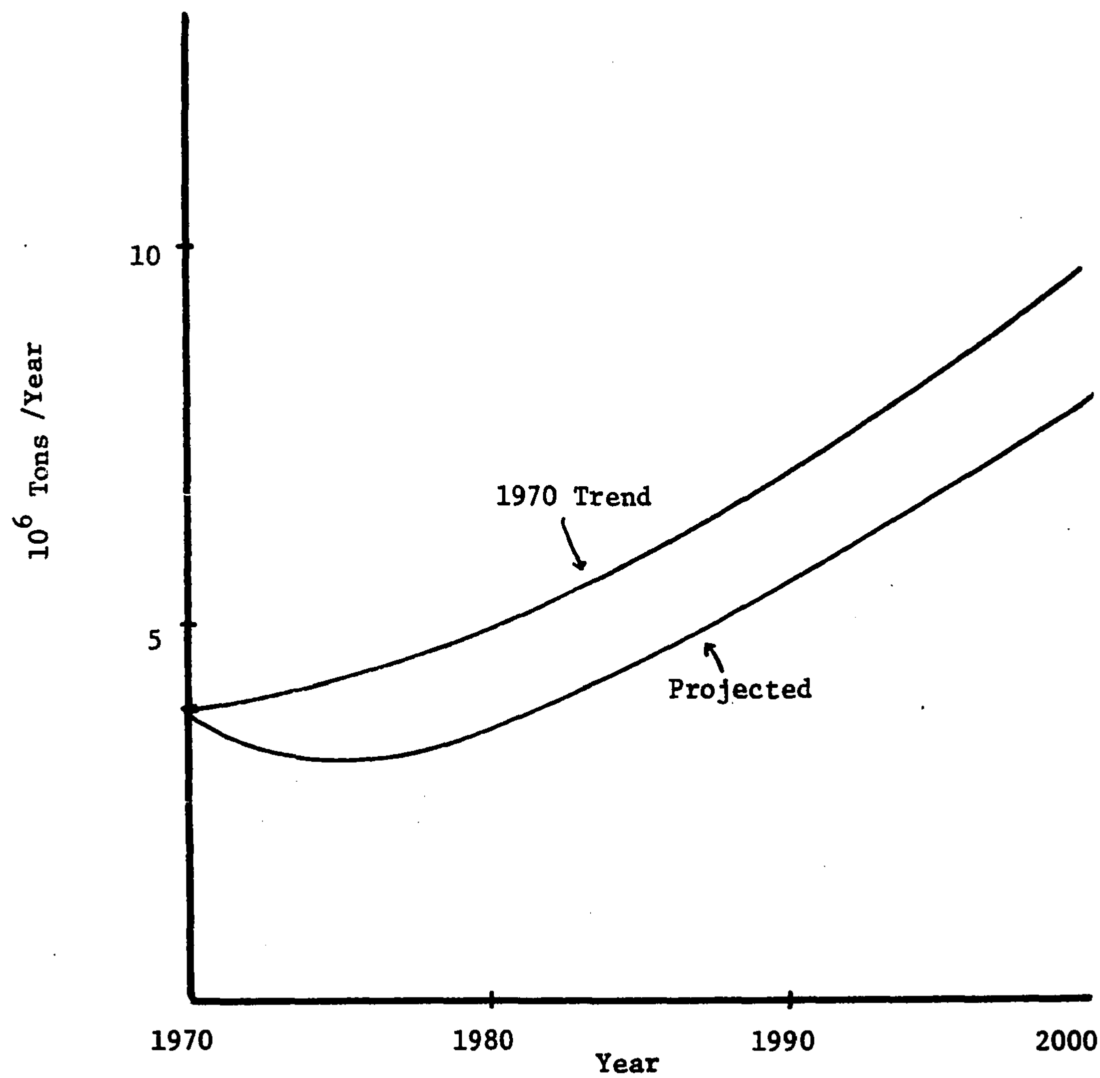


Figure III-g-5 Annual Hydrocarbon Emission*

*Exclude HC from Coal Gasification

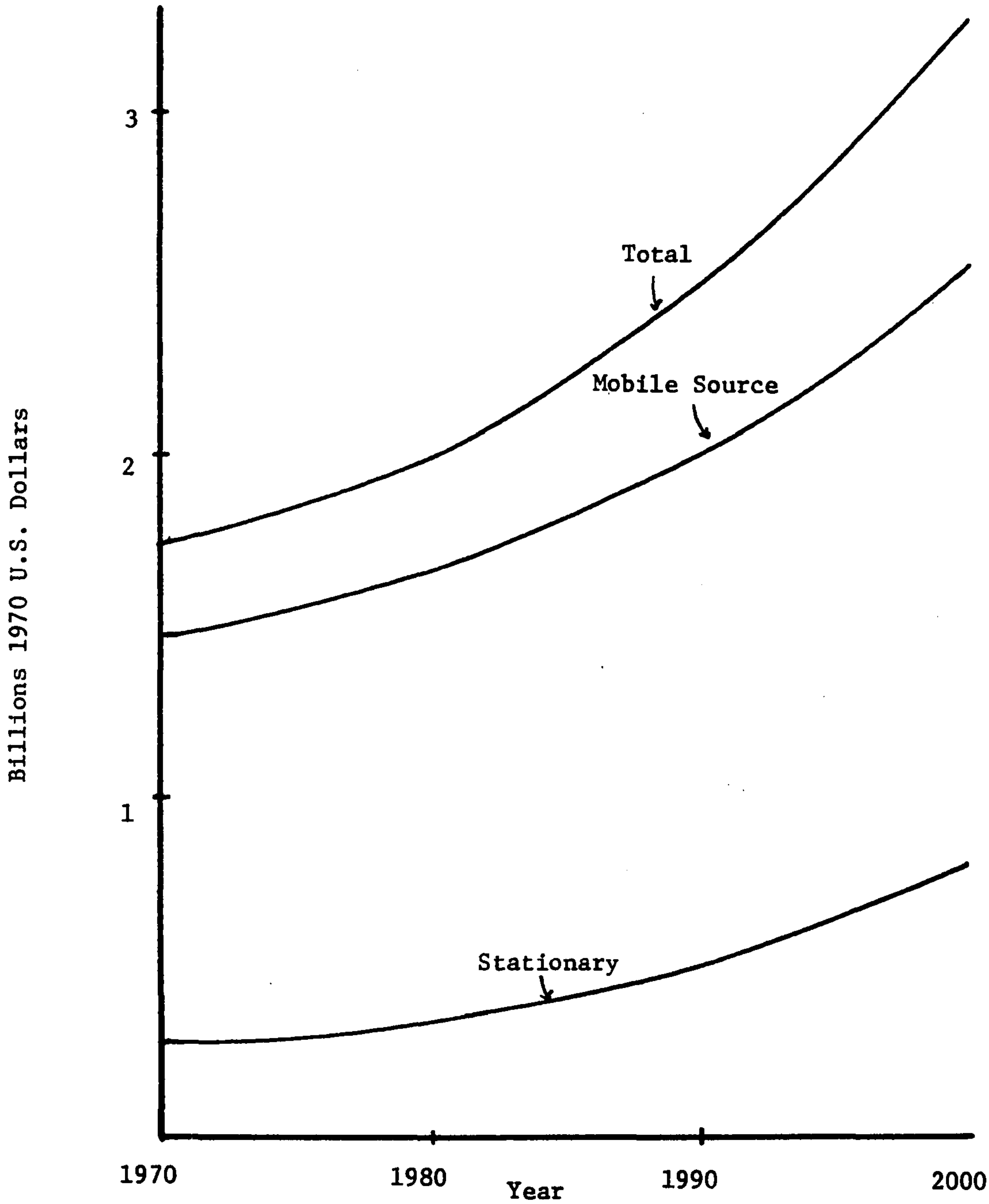


Figure III-g-6 Annual Costs to Abate Air Pollution

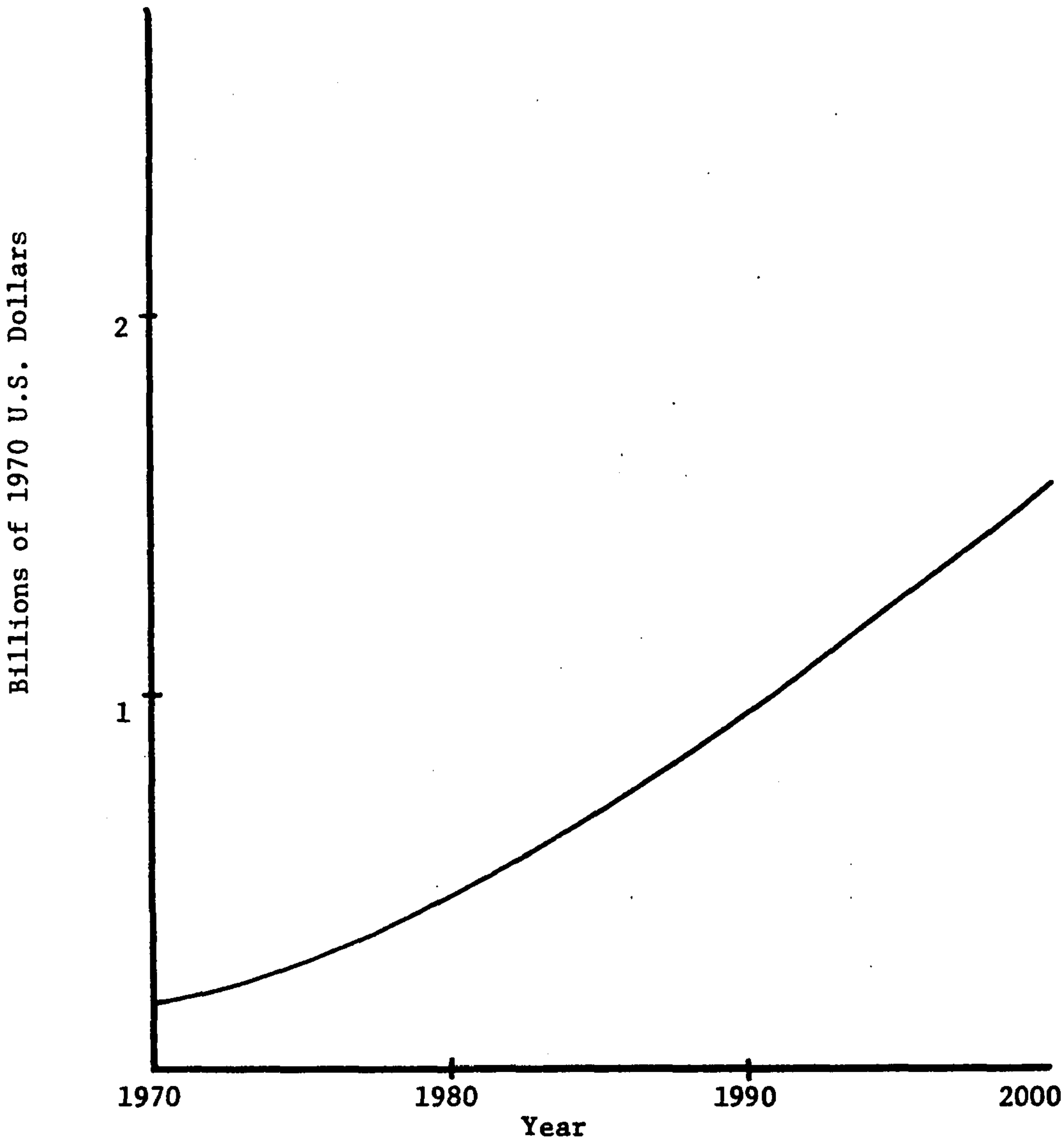


Figure III-g-7 Annual Cost to Abate Thermal Pollution

CHAPTER IV

POPULATION ALTERNATIVE

Assumption

The United States birth rate has been decreasing. If we use the projection with 2.11 children per family (Figure III-b-1), then the effect of this decreased birth rate on the U. S. energy requirements, the balance of payments and on the environment may also be determined.

Result

The total resource requirements and end-use consumption for the population alternative are shown in Figure IV-1.

All resource requirements, environmental impacts and balance of payments may be obtained by multiplying the correction factor (Figure IV-2) -- the ratio of the total energy resource requirements for the population alternative to the base case.

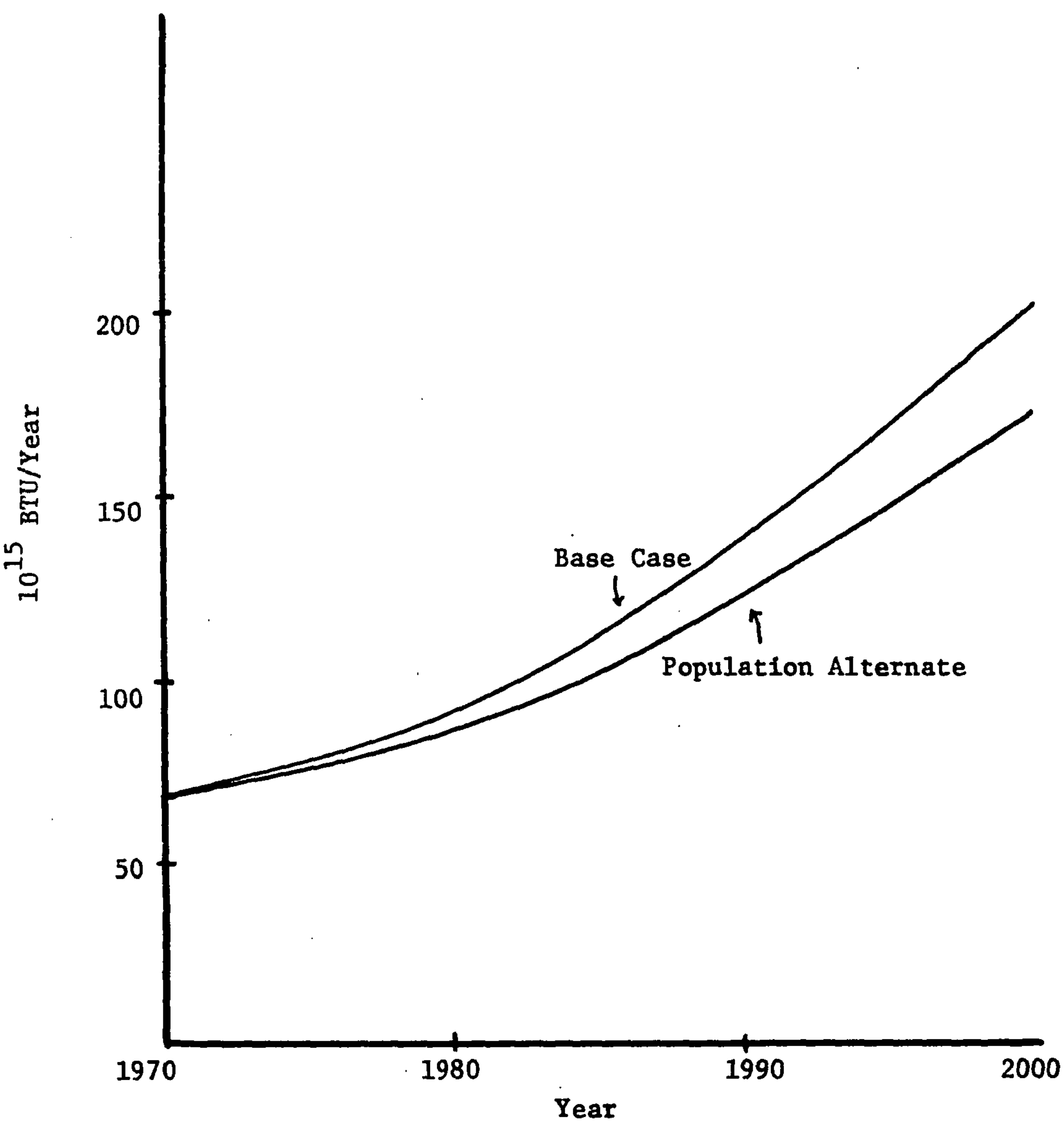


Figure IV-1 Projected Total Energy Consumption -- Population Alternatives

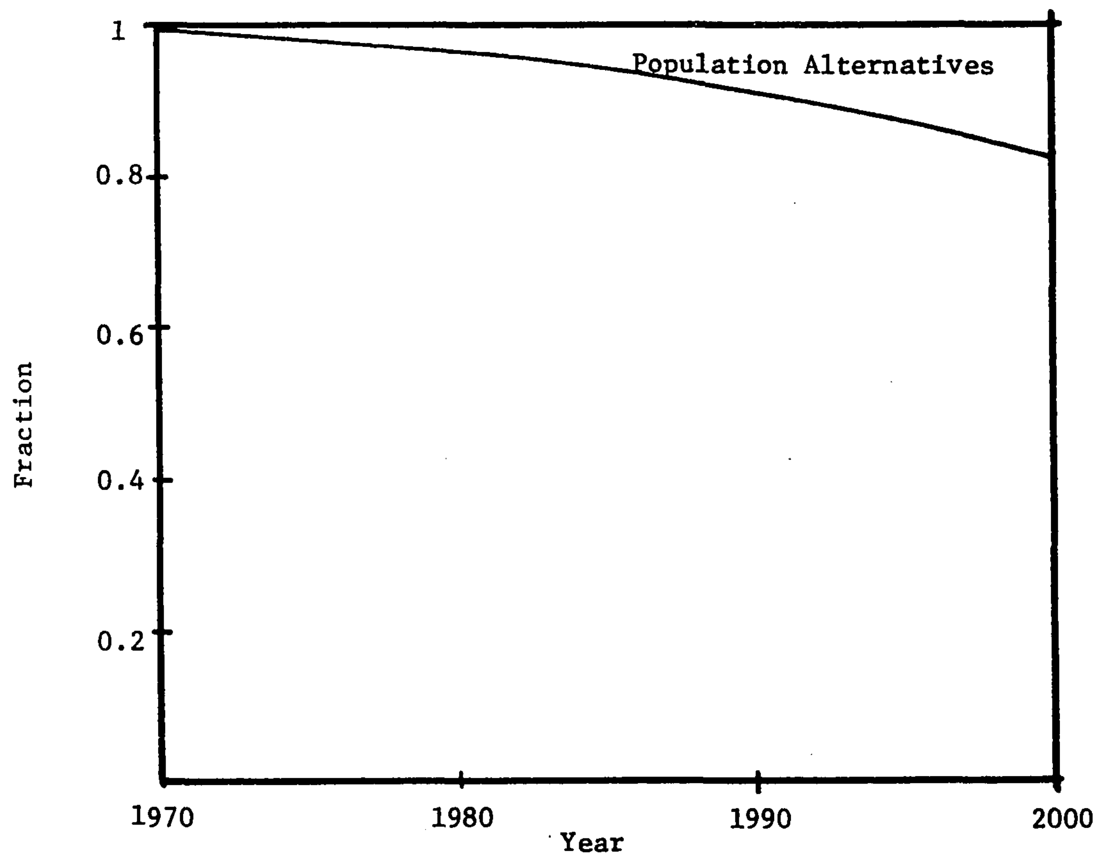


Figure IV-2 Correction Factor for Base Case Resource Requirements and Environmental Impacts -- Population Alternatives

CHAPTER V

CONSERVATION ALTERNATIVE

Assumptions

The Office of Emergency Preparedness has recently estimated the sector-by-sector potential energy savings from various suggested energy conservation measures. The following measures were suggested and the percentage of energy savings was determined:

1. Short-term measures (1972-1975)

   Residential/Commercial -- Establish upgraded construction standards and provide tax incentives and insured loan for improved home insulation; (saving: 10%).

   Industry -- Increase energy price to encourage improvement of processes and replacement of inefficient equipment; provide tax incentive to encourage recycling and reusing of component materials; (saving: 9%).

   Transportation -- Conduct educational programs to stimulate public awareness of energy conservation in the transportation sector; establish government energy efficiency standards; improve airplane load factors; promote development of smaller engines and vehicles; improve traffic flow; improve mass transit and intercity rail and air transport; promote automobile energy-efficiency through low-loss tires and engine tuning; (Saving: 10%).

Electric Utilities -- Restructure rates for heavy uses to smooth out demand cycle; facilitate new construction; (Saving: 4%).

2. Long-term Measures (after 1980)

Residential/Commercial -- Provide tax incentives and regulations to encourage replacement of old buildings by energy-efficient new buildings; research and development funding to develop new energy sources; solar and wind power; (Saving: 30%).

Industry -- Same as that of 1980; (Saving: 18%).

Transportation -- Provide R and D support for hybrid engine, non-petroleum engines, advanced traffic control systems, dual personal rapid transit, high-speed transit, new freight systems, and people movers; decrease demand through rationing and financial support for urban development and reconstruction; (Saving: 25%).

Electric Utilities (1975-1980) -- Smooth out daily demand cycle through government regulation; facilitate new construction; support R and D efforts; (Saving: 3%).

Results

The total resources requirements are calculated and shown in Figure V-1 to6. The environmental impacts may be obtained by multiplying the correction factors from Figure V-7. U. S. energy demand would be met by domestic production.

Electric Utilities -- Smooth out daily demand cycle by means of government facilitating of new construction; decrease electricity demand; (Saving: 4%).

Residential/Commercial (1975-1980) -- Establish upgraded construction standards and tax incentives and regualtions to promote design and construction of energy-efficient dwellings, including the use of the total energy concept for multi-family dwellings; provide tax incentives, R and D funds, and regulations to promote energy-efficient appliances, central air conditioning, water heaters and lighting; (Saving: 14%).

Industry (1975-1980) -- Establish energy-use tax to provide incentive to upgrade processes and replace inefficient equipment; promote research for more efficient technologies; provide tax incentives to encourage recycling and reusing component materials; (Saving: 14%).

Transportation -- Improve freight handling systems; support pilot implementation of most promising alternatives to internal combustion engine; set tax on size and power of autos; support improved truck engines; require energy-efficient operating procedures for airplanes; provide subsidies and matching grants for mass transit; ban autos within the inner city; provide subsidies for intercity rail networks; decrease transportation demand through urban refurbishing projects and long-range land use planning; (Saving: 21%).

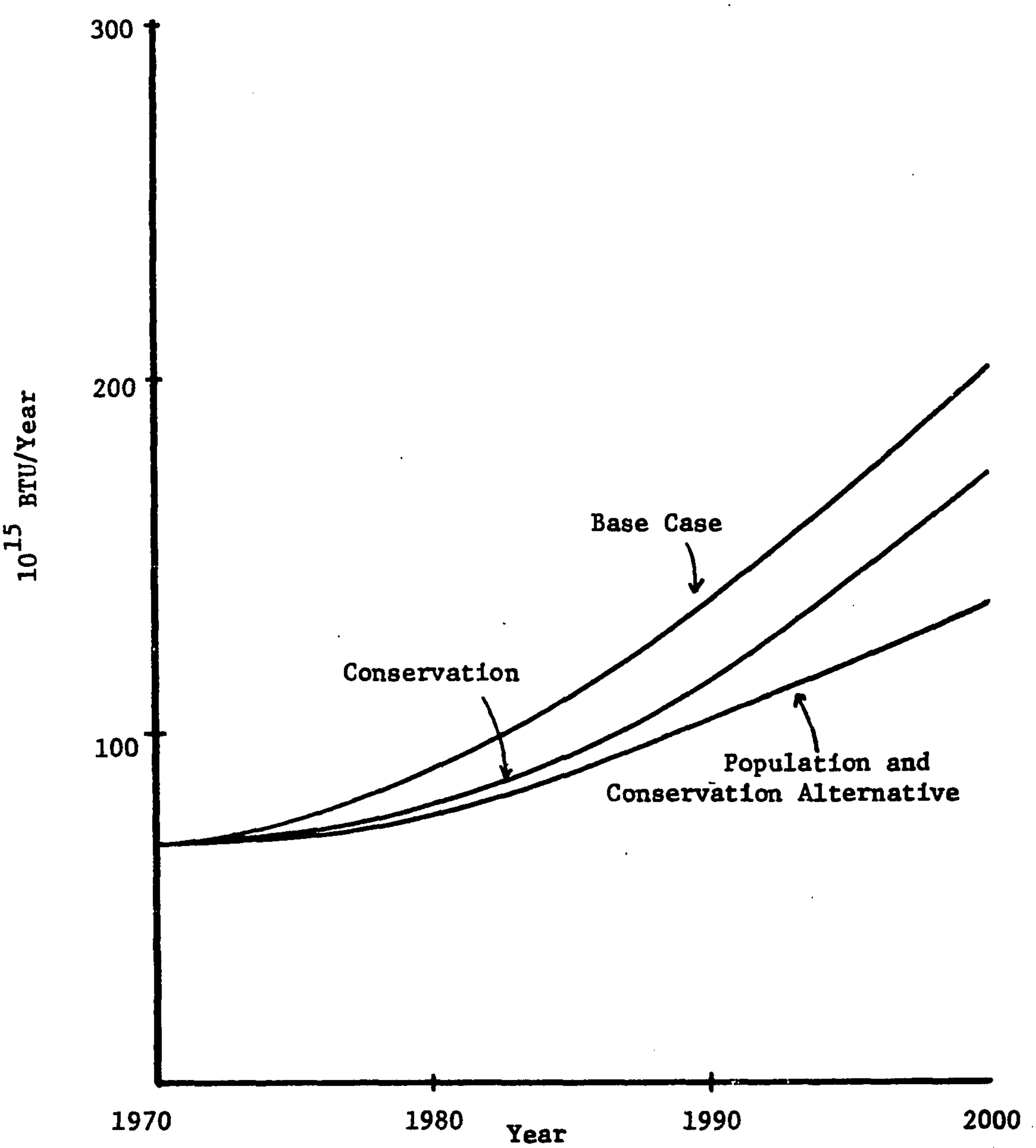


Figure V-1 Projected Annual Energy Consumption -- Conservation Alternative

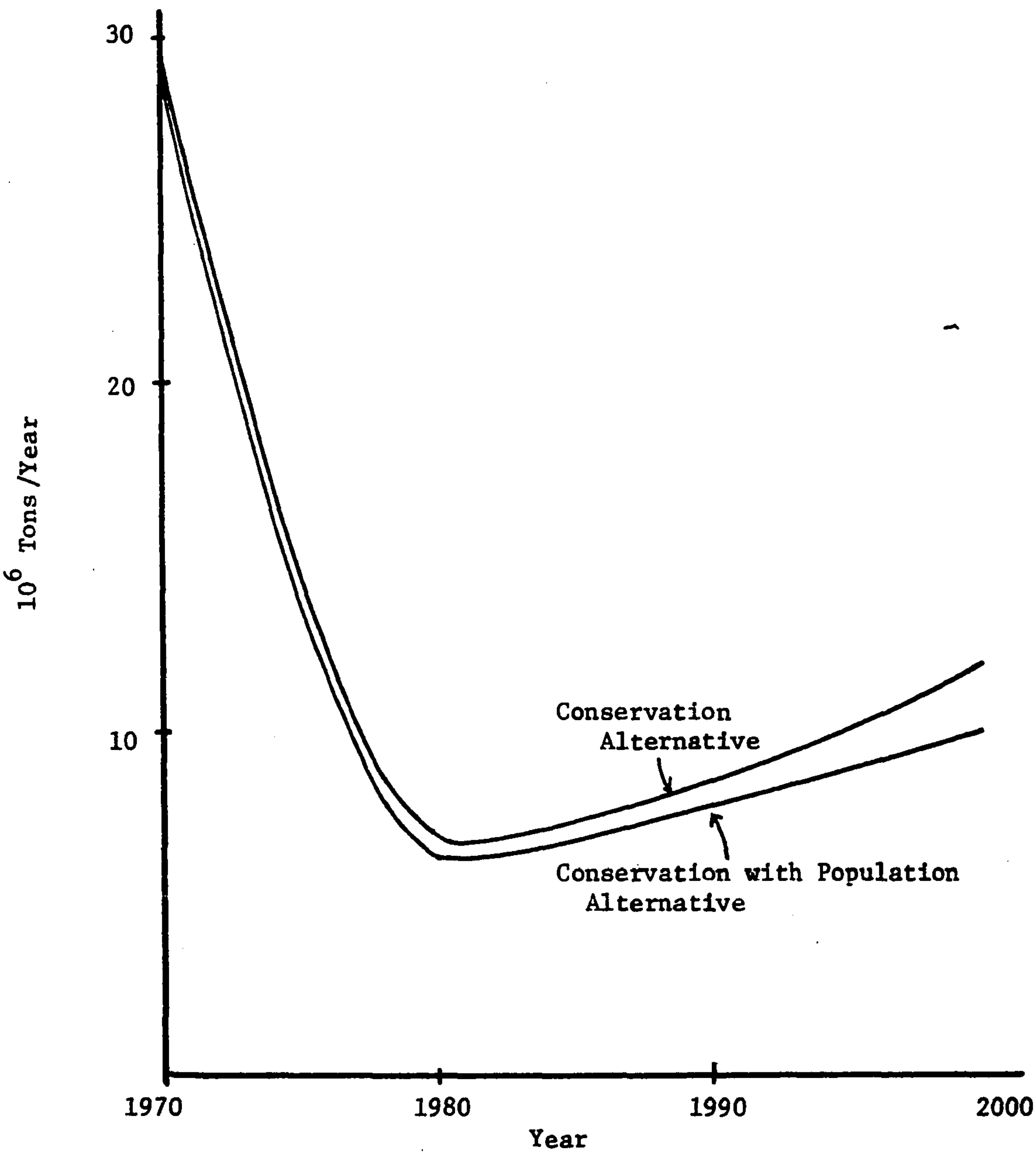


Figure V-2 Annual CO Emission -- Conservation and Population Alternatives

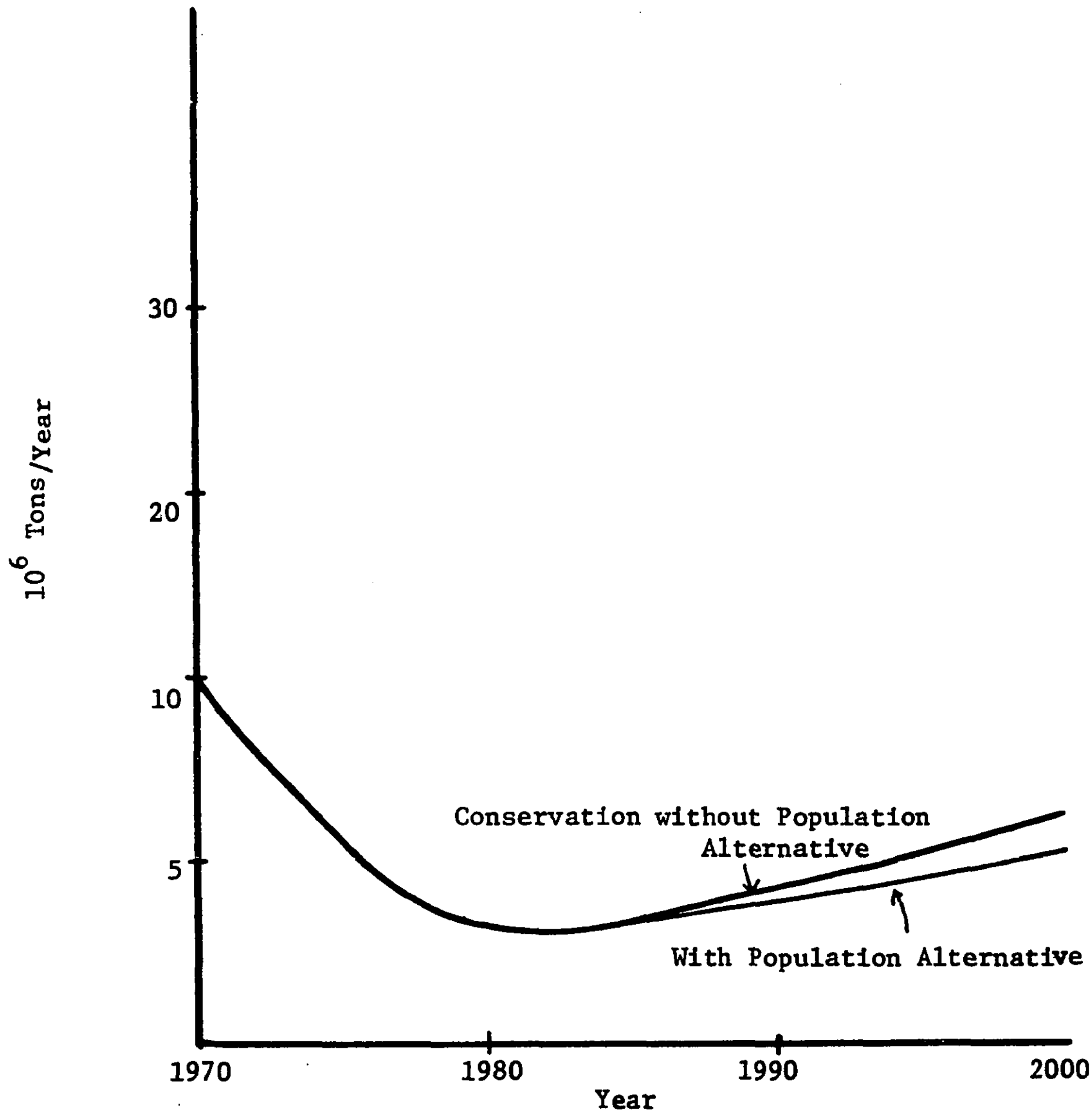


Figure V-3 Annual Hydrocarbon Emission -- Conservation and Population Alternative

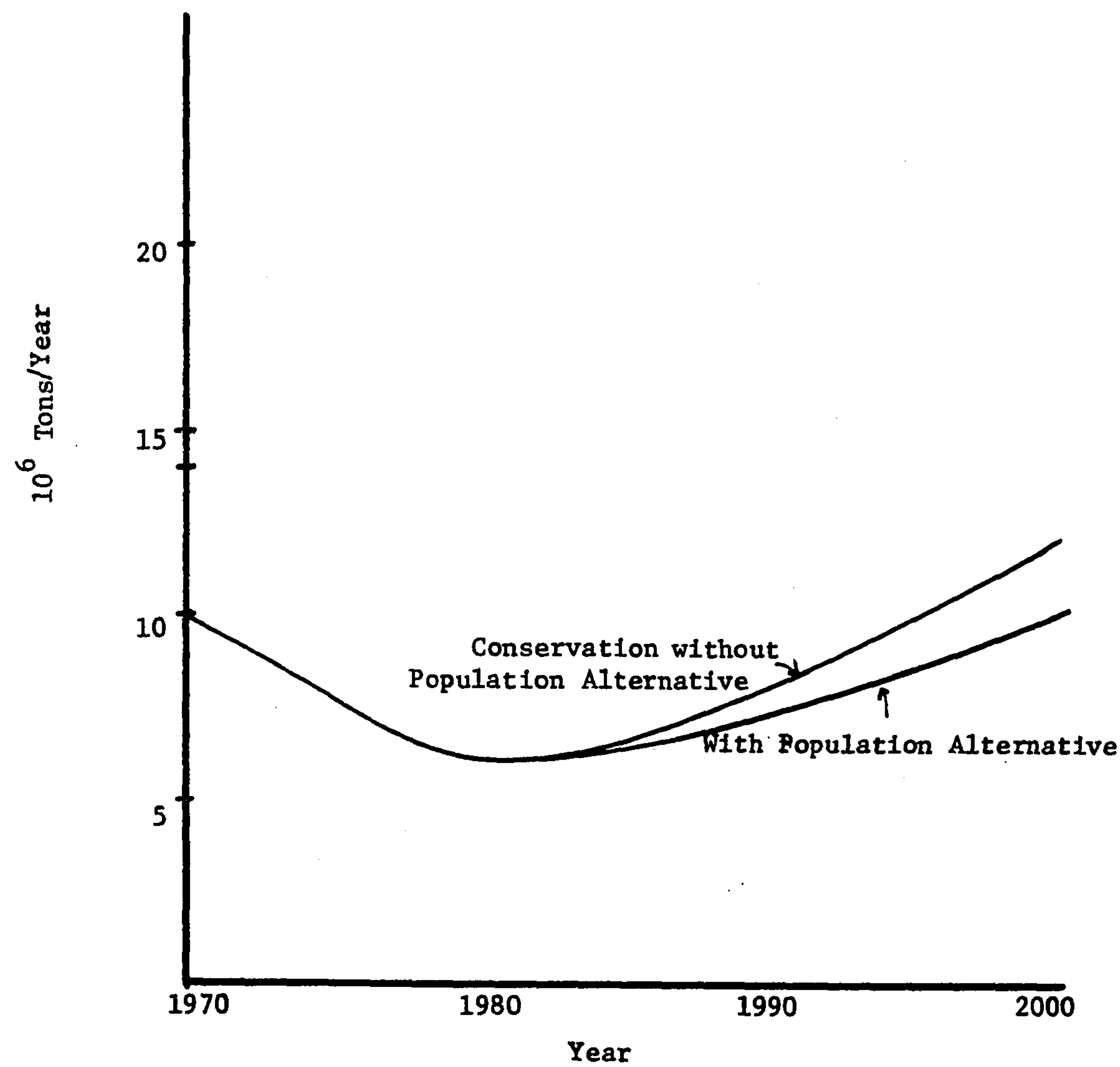


Figure V-4 Annual NO_x Emission -- Conservation with Population Alternatives

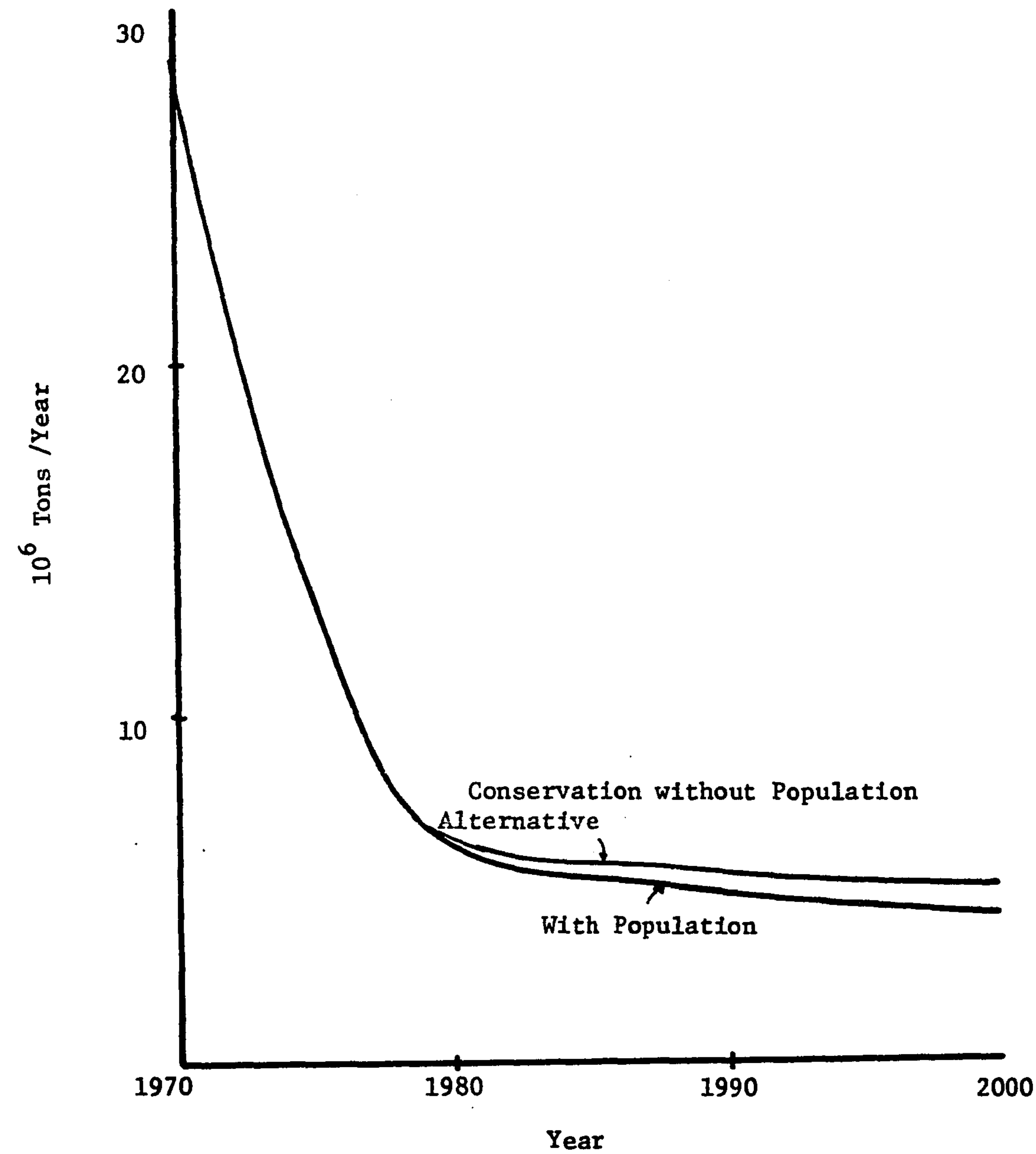


Figure V-5 Annual Particulate Emission -- Conservation and Population Alternatives

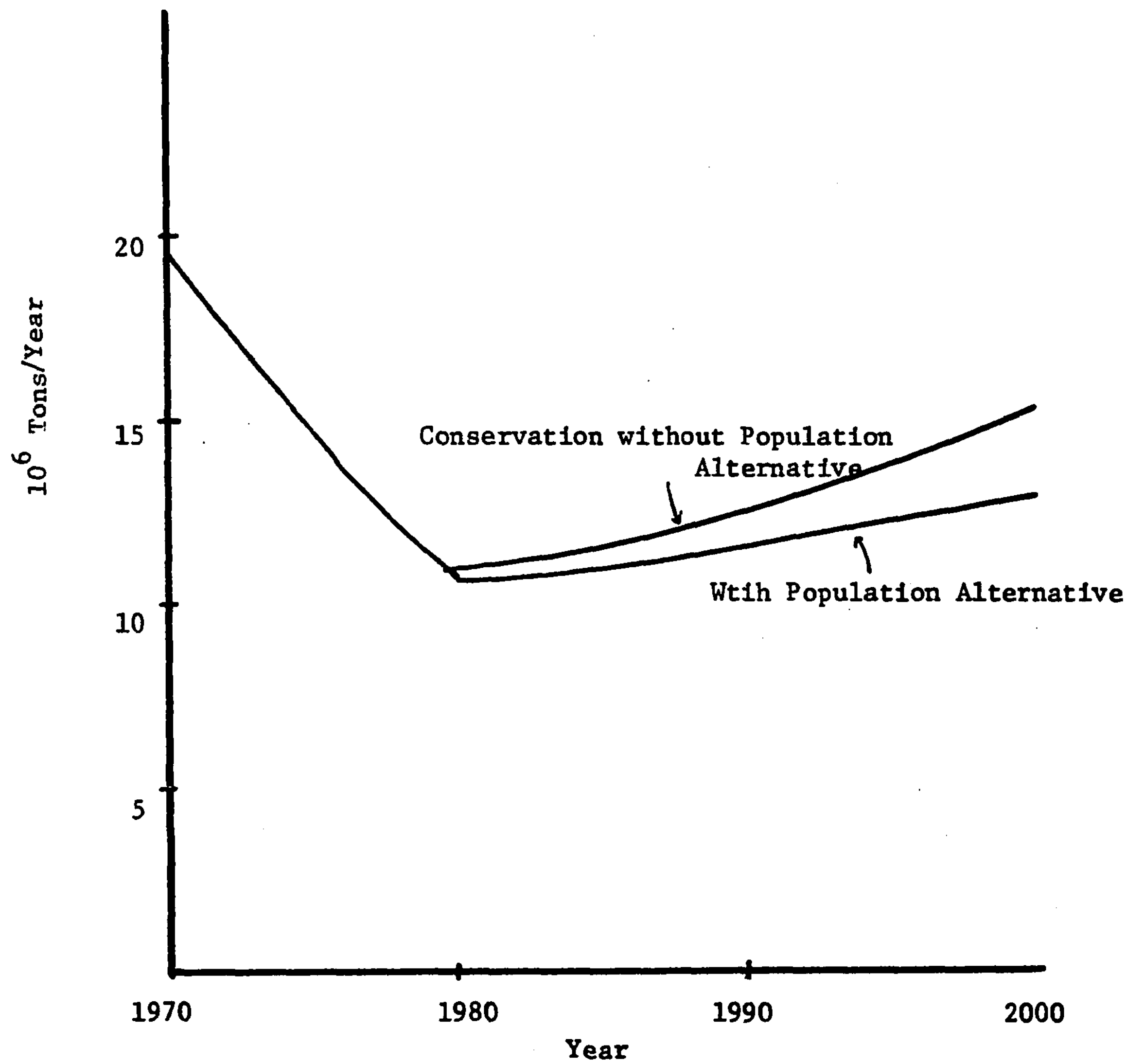


Figure V-6 Annual SO_x Emission -- Conservation and Population Alternatives

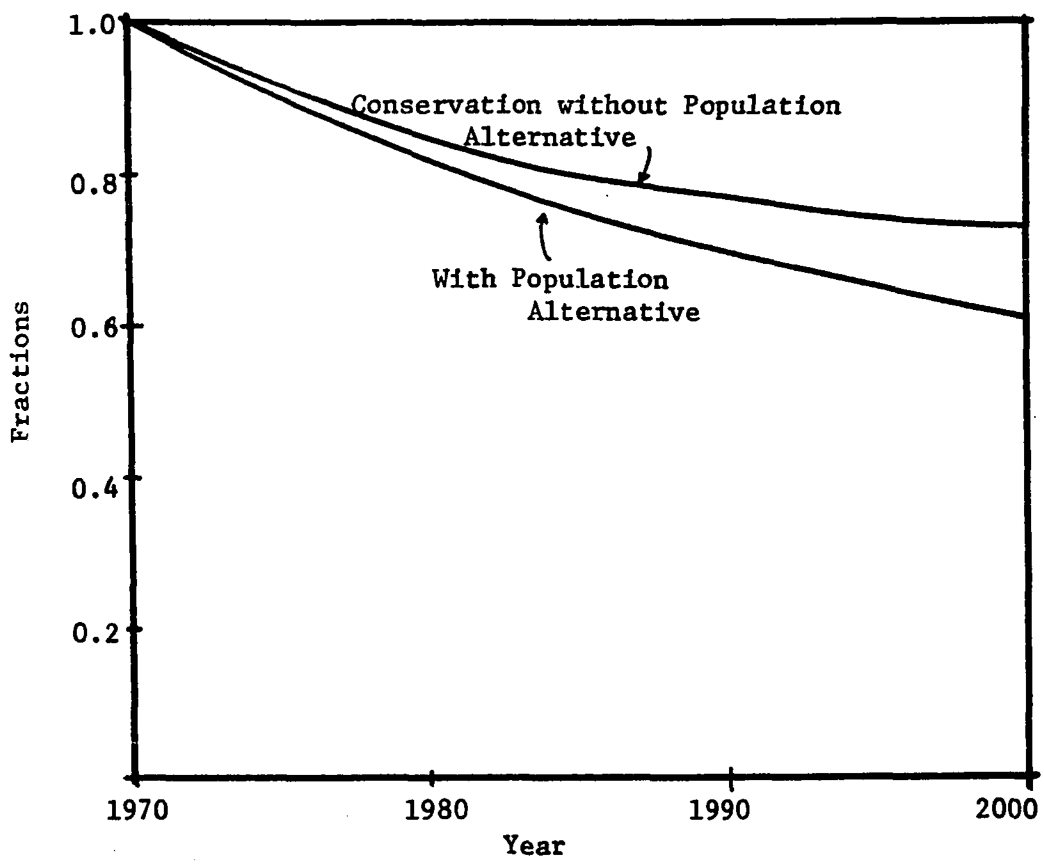


Figure V-7 Correction Factor for Environmental Impacts Other than Air Pollution -- Conservation (with /without Population Alternative)

CHAPTER VI

NATURAL GAS SUPPLY ALTERNATIVES

After the 1985's, projected natural gas production capacity will begin to decrease (Figure III-d-2), while the demand for natural gas increases. Several alternative resources are available to meet the projected demand; coal gasification, crude petroleum and petroleum products gasification, Canadian pipeline imports and liquified natural gas imports.

Factors for the selection of alternative natural gas supplies are:

1. The maximum allowable deficit due to imports of natural gas.
2. National security implication as it was demonstrated by the Mideast war; the embargo of Arabian oil to America.

Assumption

The following assumptions are made for the natural gas supply alternatives for the year 1980 and beyond:

1. No natural gas imports are allowed and syngas are all from coal.
2. No natural gas imports are allowed and syngas are all from coal and from petroleum product accounts for 50% each of natural gas demand exceeding domestic natural gas production.
3. Natural gas imports are allowed for 50% of the natural gas

exceeding domestic production with the remaining half supplied equally by syngas from coal and petroleum products. Natural gas imports are divided by Canadian pipeline and LNG imports.

Results

The annual coal requirements decrease as the amount of LNG imports increase (Figure VI-1 - VI-3).

Since coal conversion to syngas decreases with increasing imports, the annual production of solid waste decreases (Figure VI-4). It is unlikely that the United States could support the 16 billion dollars per year in 2000 and beyond (Figure VI-5).

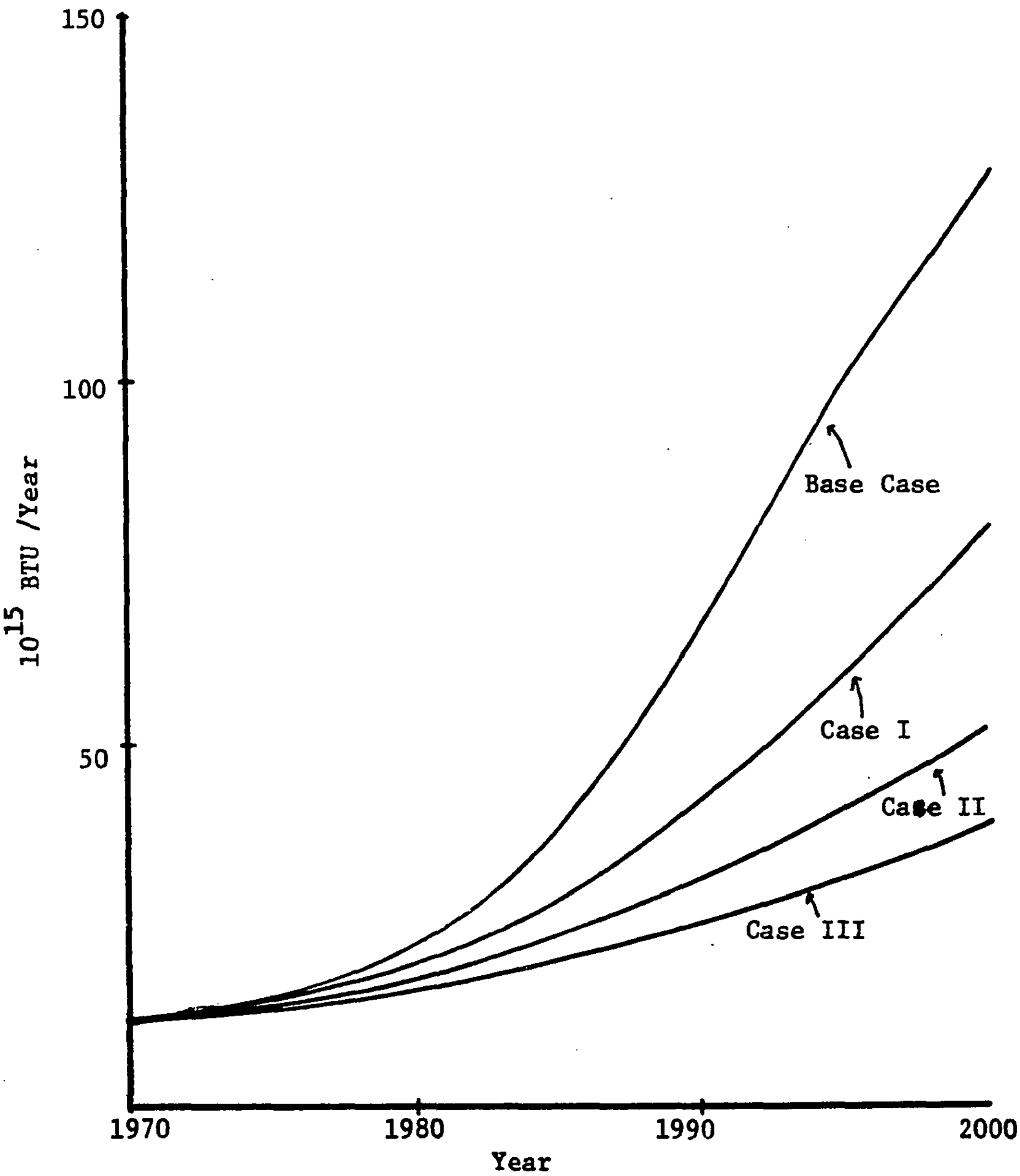


Figure VI-1 Annual Coal Requirement -- Natural Gas Supply Alternative

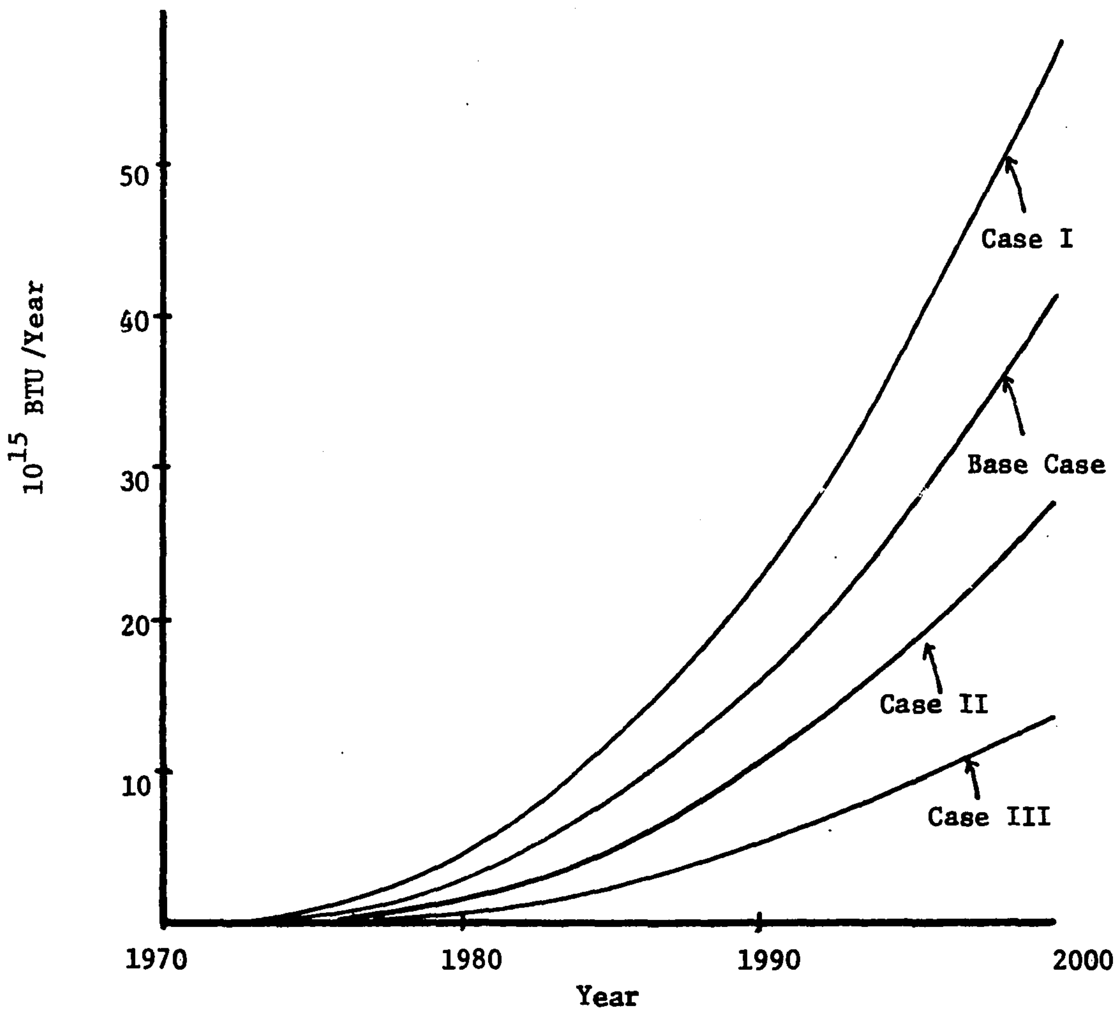


Figure VI-2 Annual Coal Requirement for Syngas

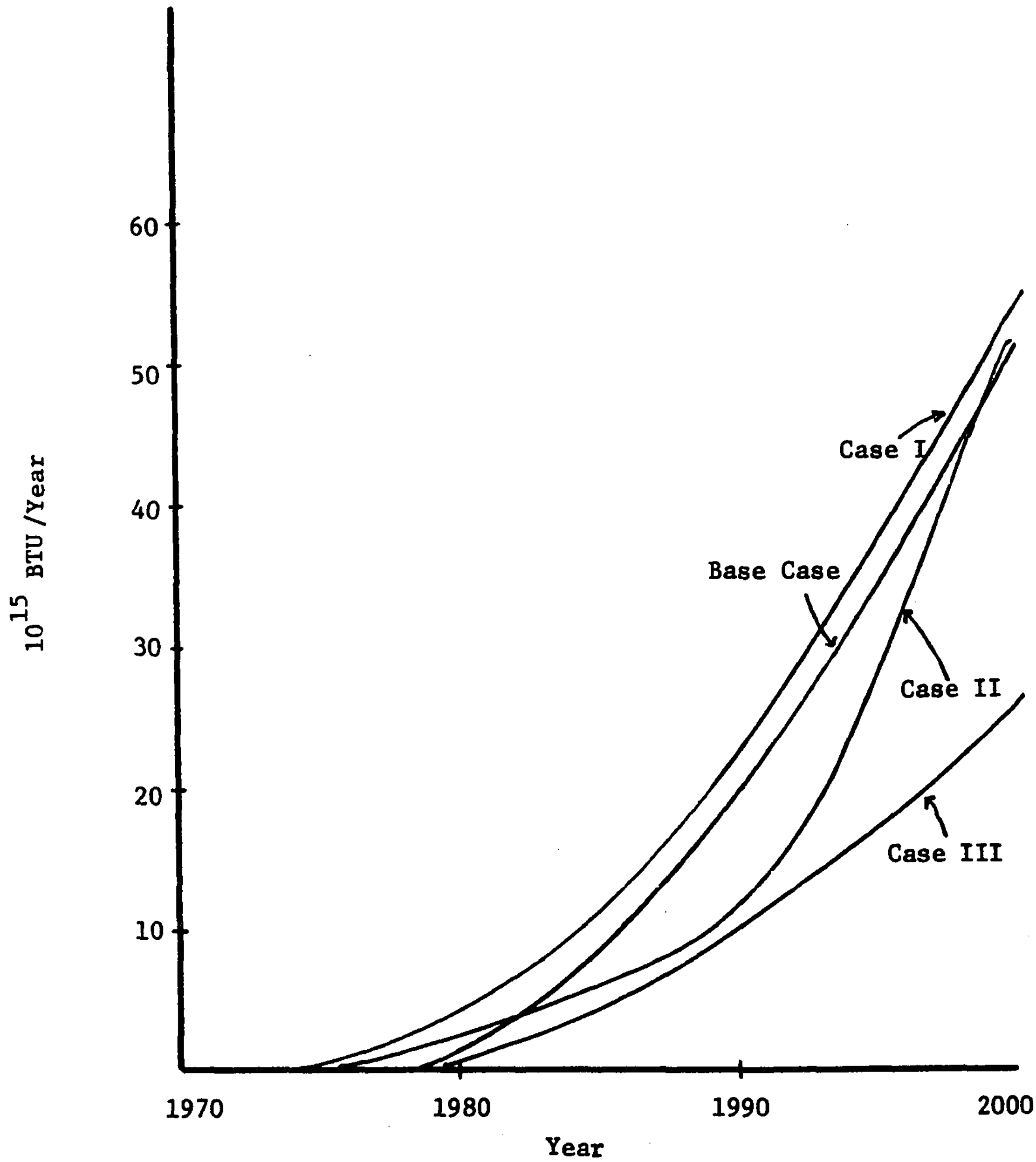


Figure VI-3 Annual Syngas Requirement -- Natural Gas Supply Alternative

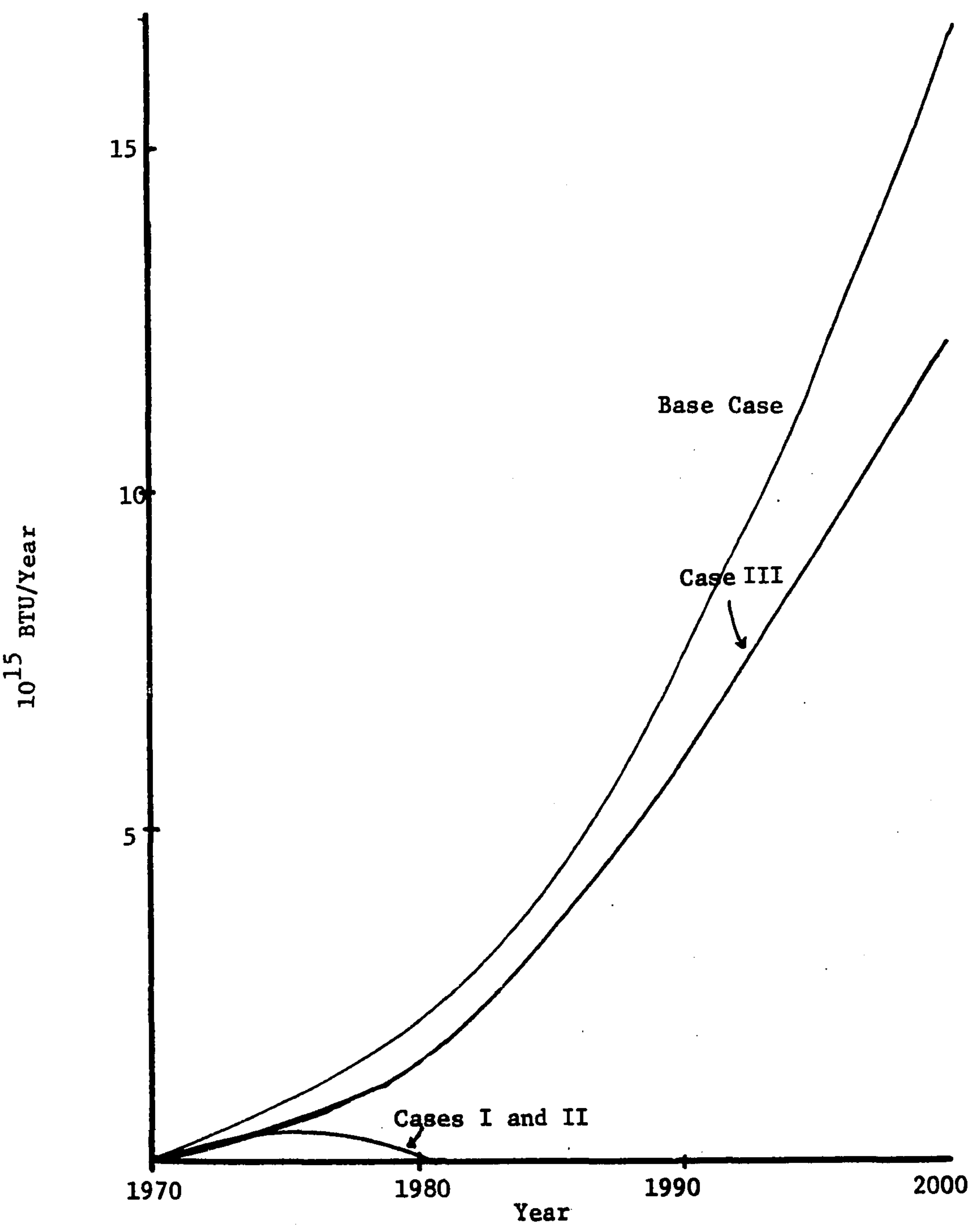


Figure VI-4 Annual LNG Imports -- Natural Gas Supply Alternative

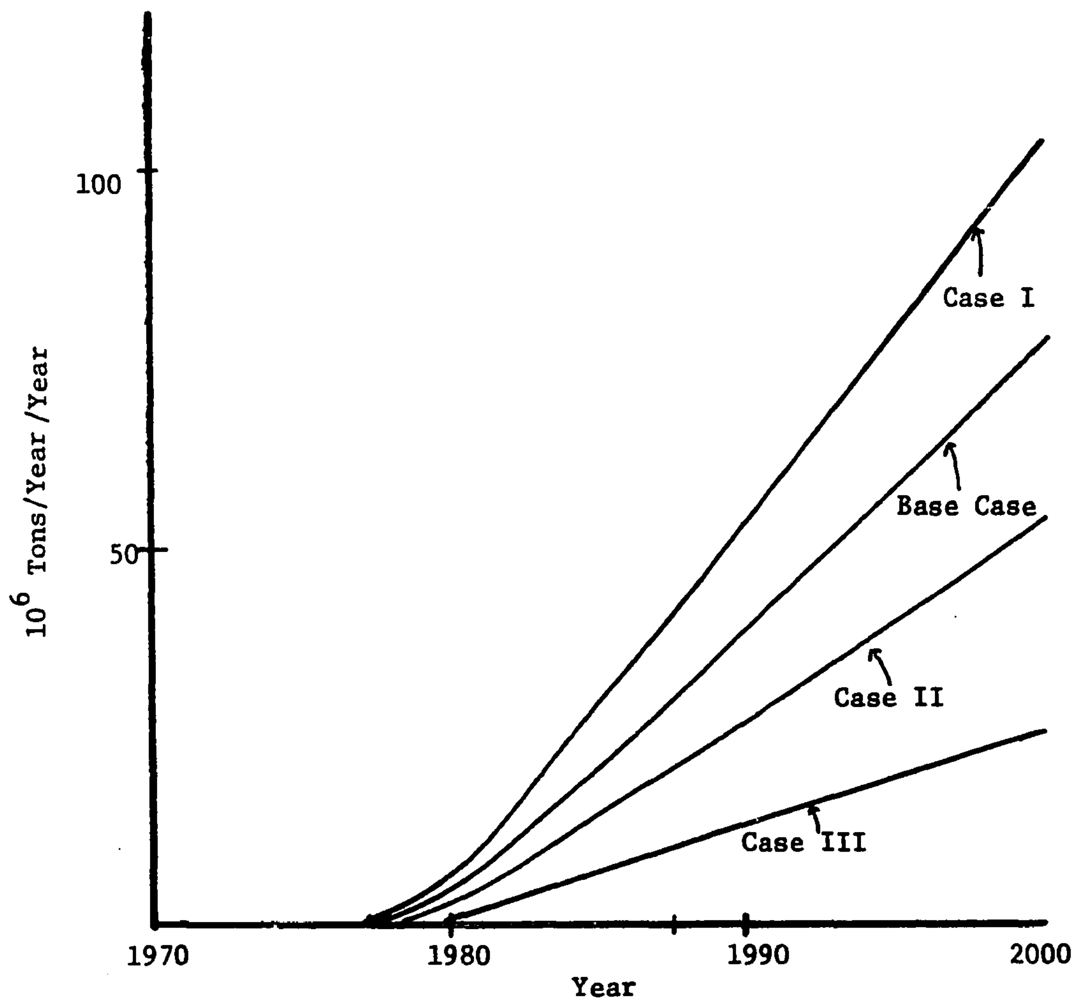


Figure VI-5 Annual Solid Waste Production -- Natural Gas Supply Alternative

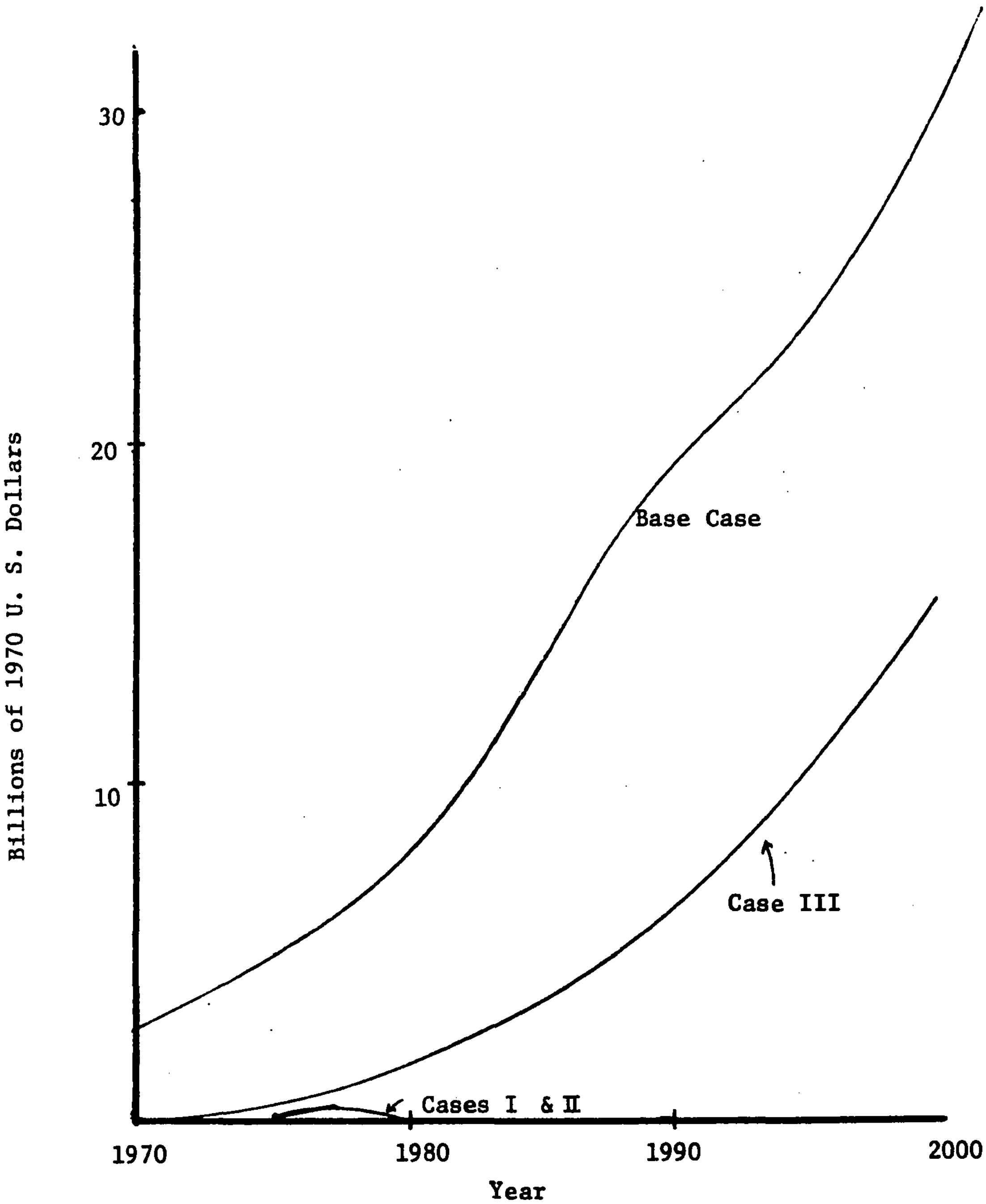


Figure VI-6 Balance of Payment Deficits - Natural Gas Supply Alternative

CHAPTER VII

PETROLEUM ALTERNATIVES

After the 1980's, projected oil domestic production capacity will begin to decline (Figure III-d-3) while the demand for oil grows faster. Several alternative resources are available to meet the projected demand; coal , liquefaction, oil shale and tar sand recovery, and imports.

Factors for the selection of alternative oil supplies are:

1. The maximum allowable deficit due to the oil imports.
2. National security implications.

Assumptions

The following assumptions are made for the oil supply alternatives for the year 1980 and beyond.

1. No oil imports are allowed, syncrude from coal will account for 50% of oil demand exceeding domestic oil supply. Oil shale and tar sand will share the other half.
2. Oil imports account for 50% of the demand exceeding domestic oil supply. Syncrude from coal will split the other half with oil shale and tar sand.

Results

As the imports of crude oil increases, the requirements of coal production decreases (Figures VII-1 and VII-2). The production of oil shale also decreases with the increase of imports of crude oil; thus, the amount of solid waste decreases because less syncrude from coal, and oil shale and tar sands are needed (Figure VII-3).

It is unlikely that the United States could support the huge deficits as shown by Base 1 and Case 2 (Figure VII-4).

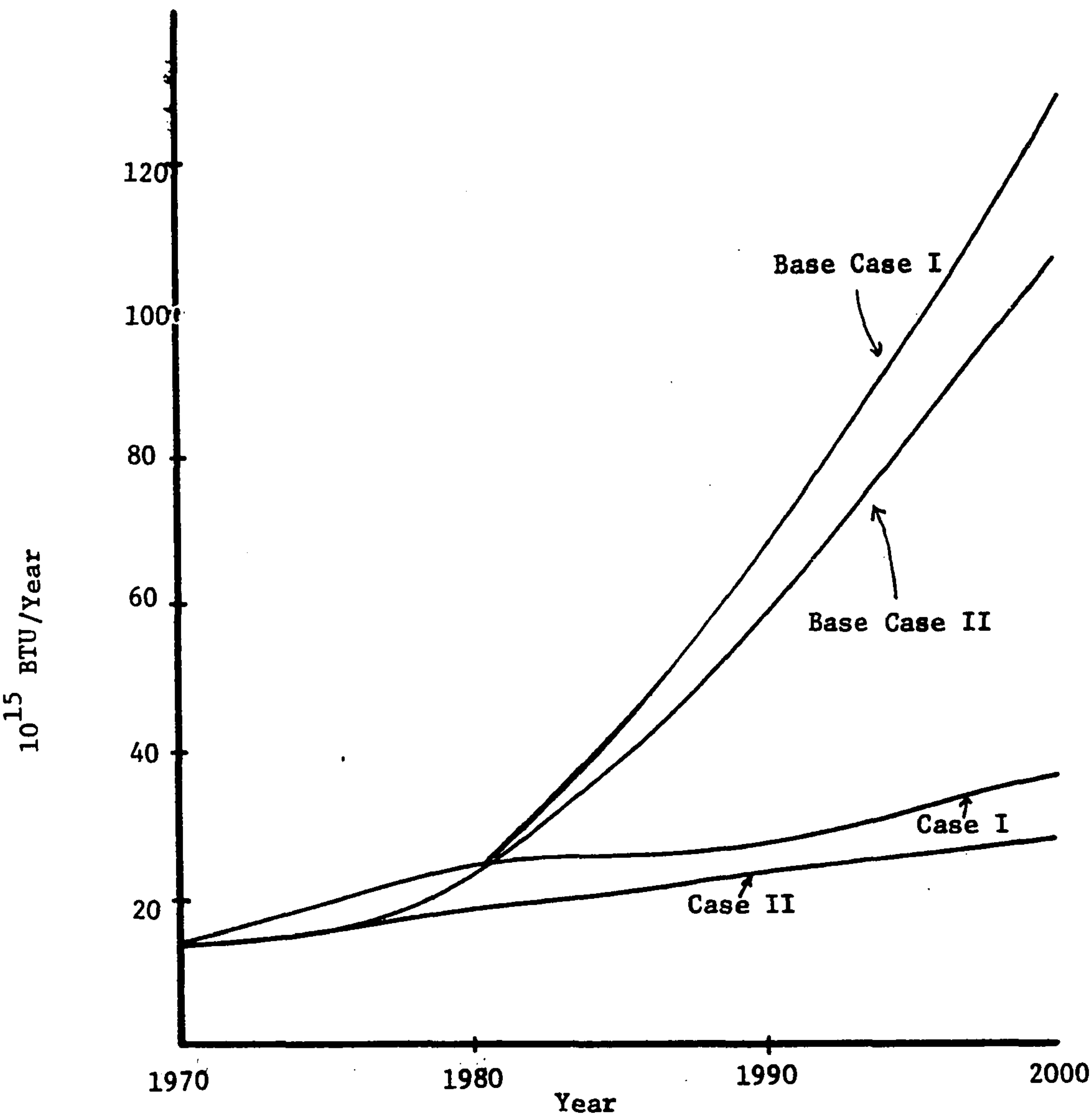


Figure VII-1 Annual Coal Requirements -- Oil Supply Alternative

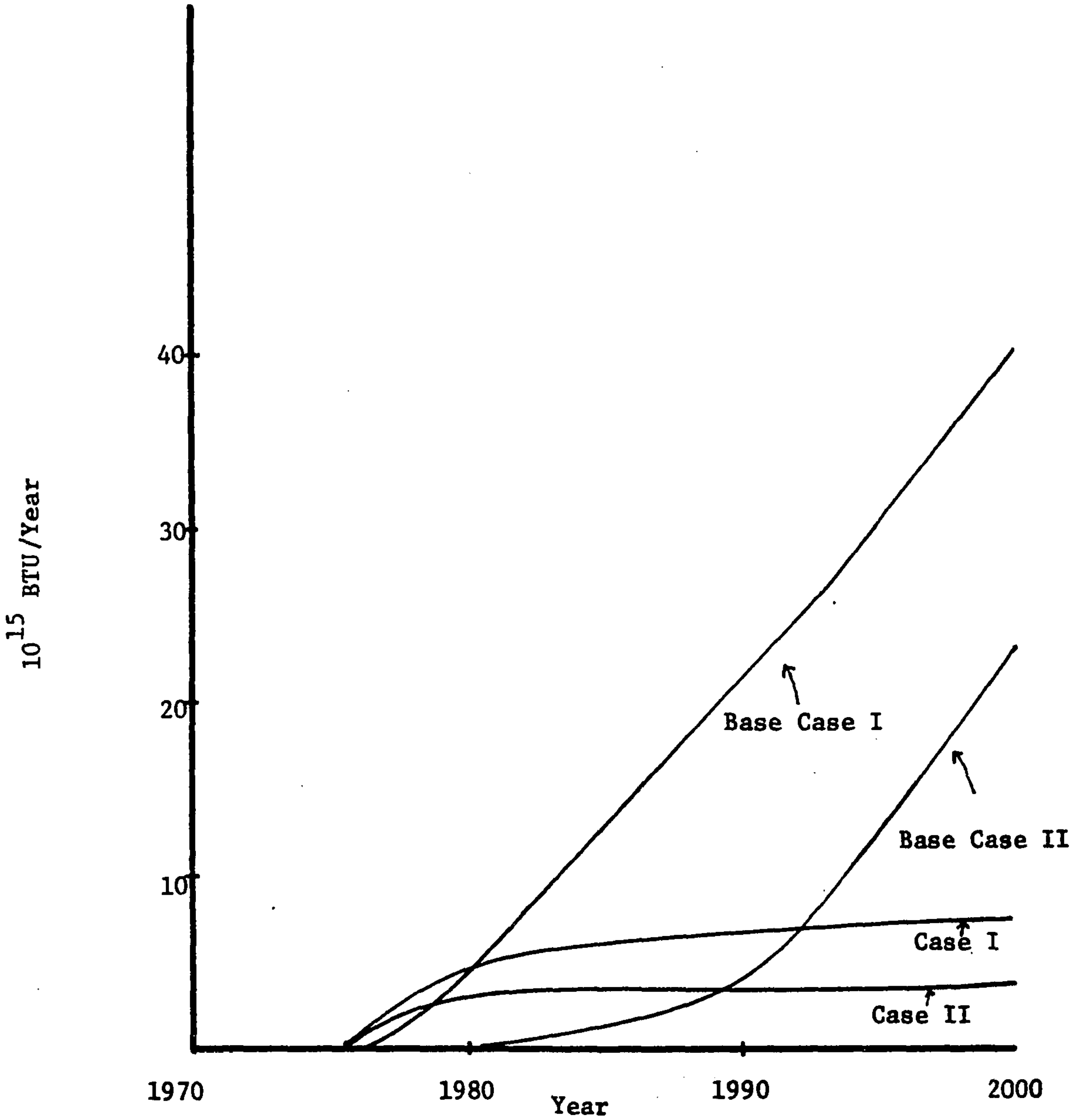


Figure VII-2 Annual Coal Requirement for Syncrude -- Oil Supply Alternative

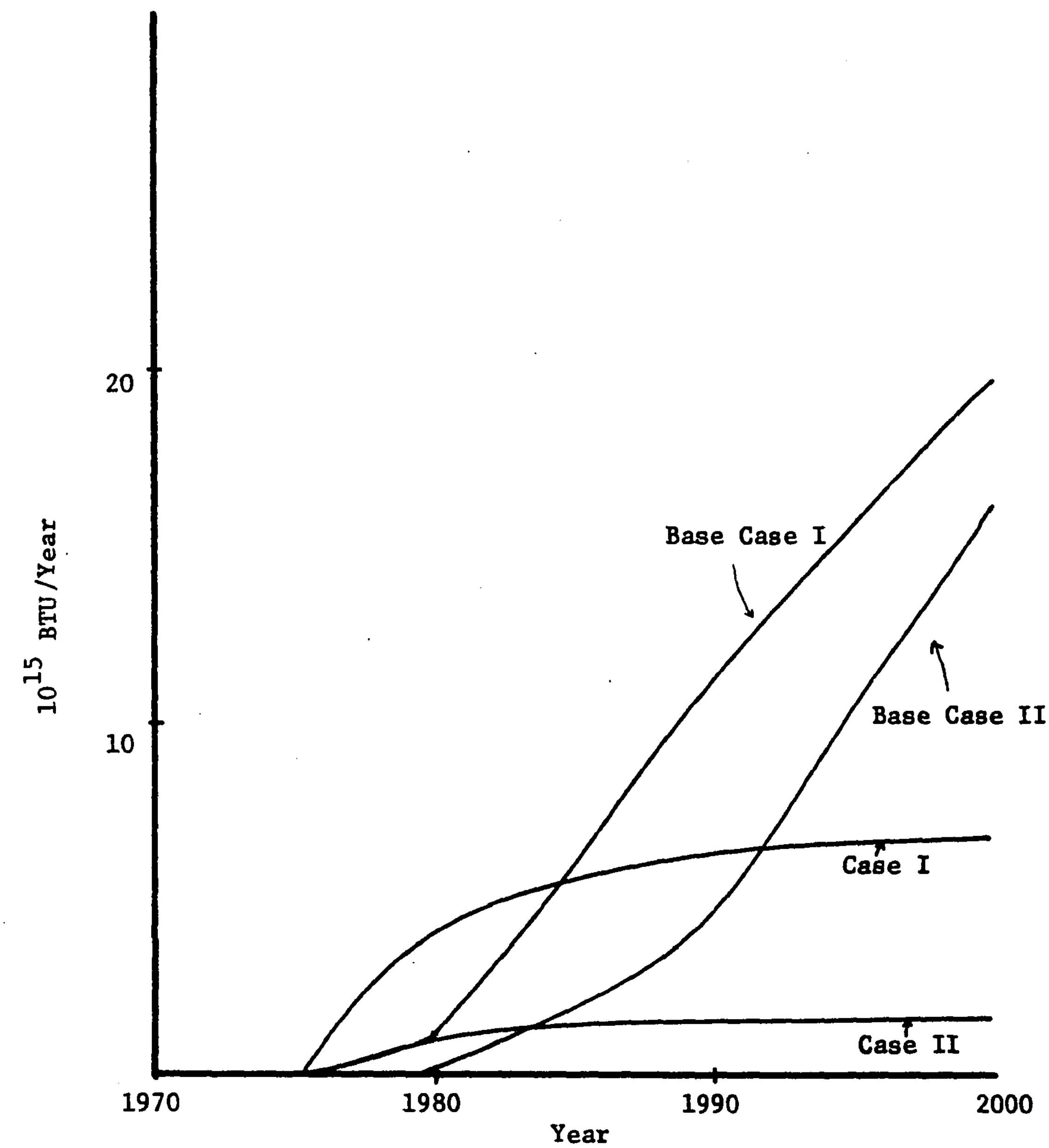


Figure VII-3 Annual Oil Shale and Tar Sand Production

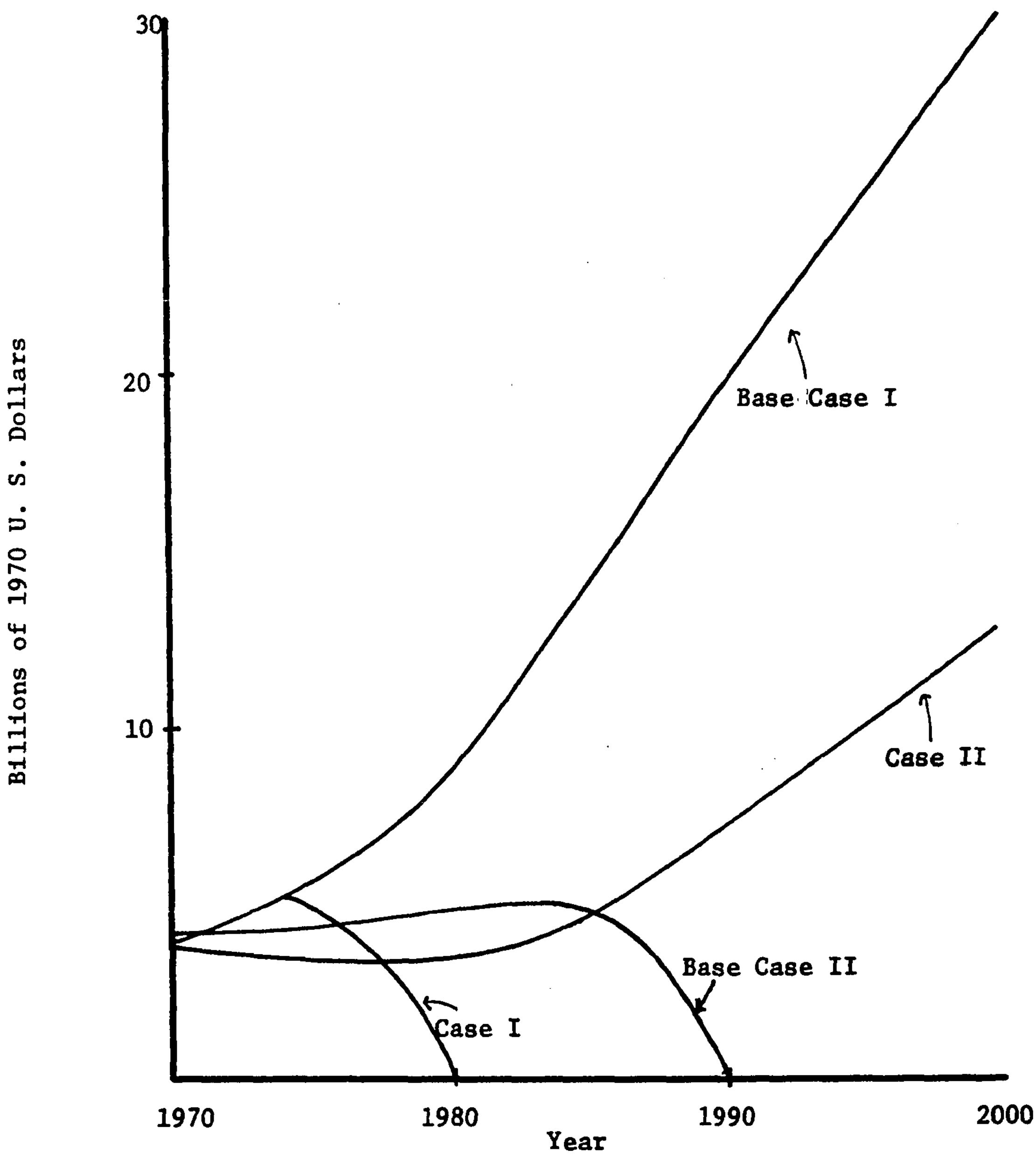


Figure VII-4 Annual Balance of Payment Deficits

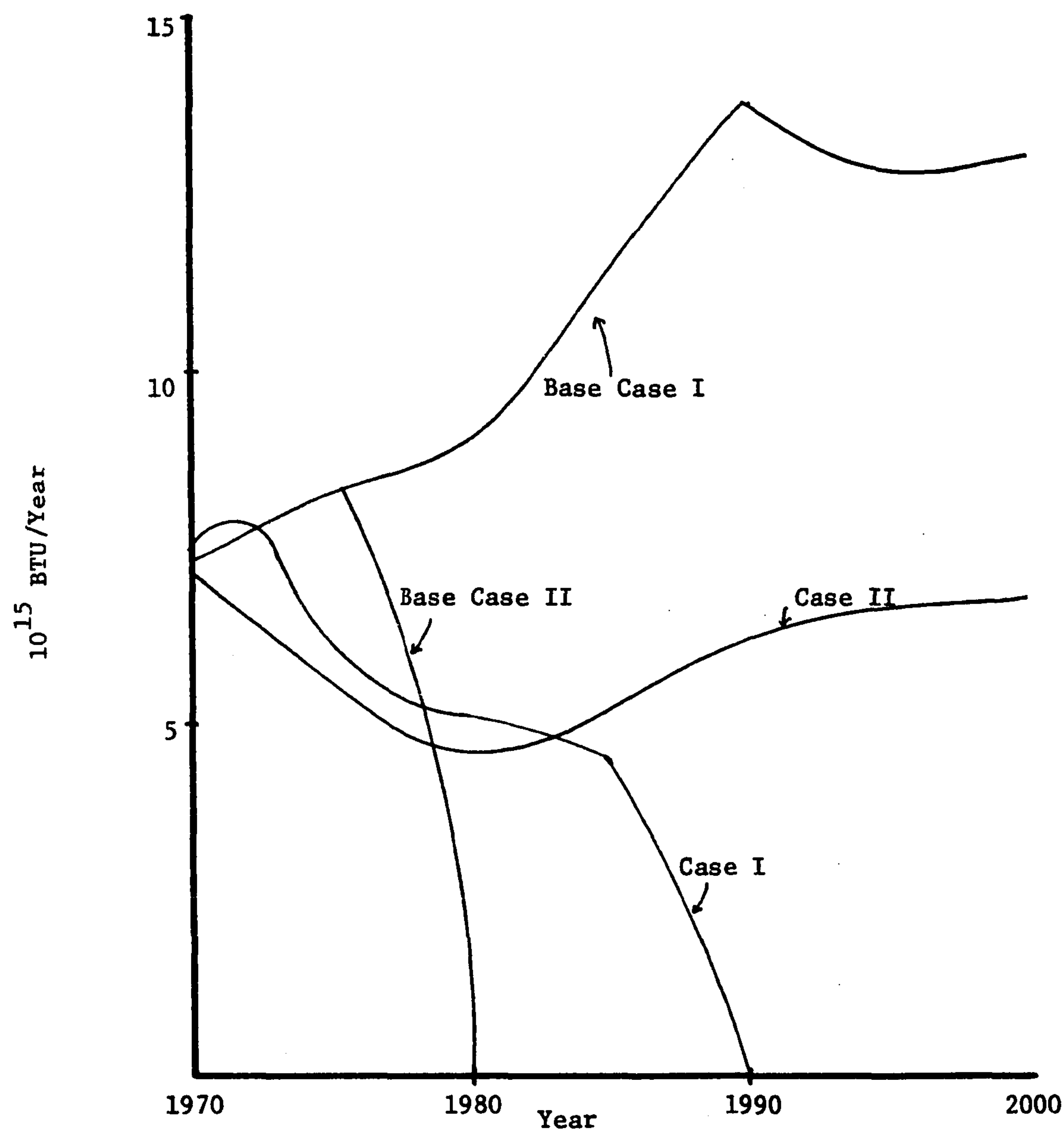


Figure VII-5 Annual Oil Imports -- Oil Supply Alternative

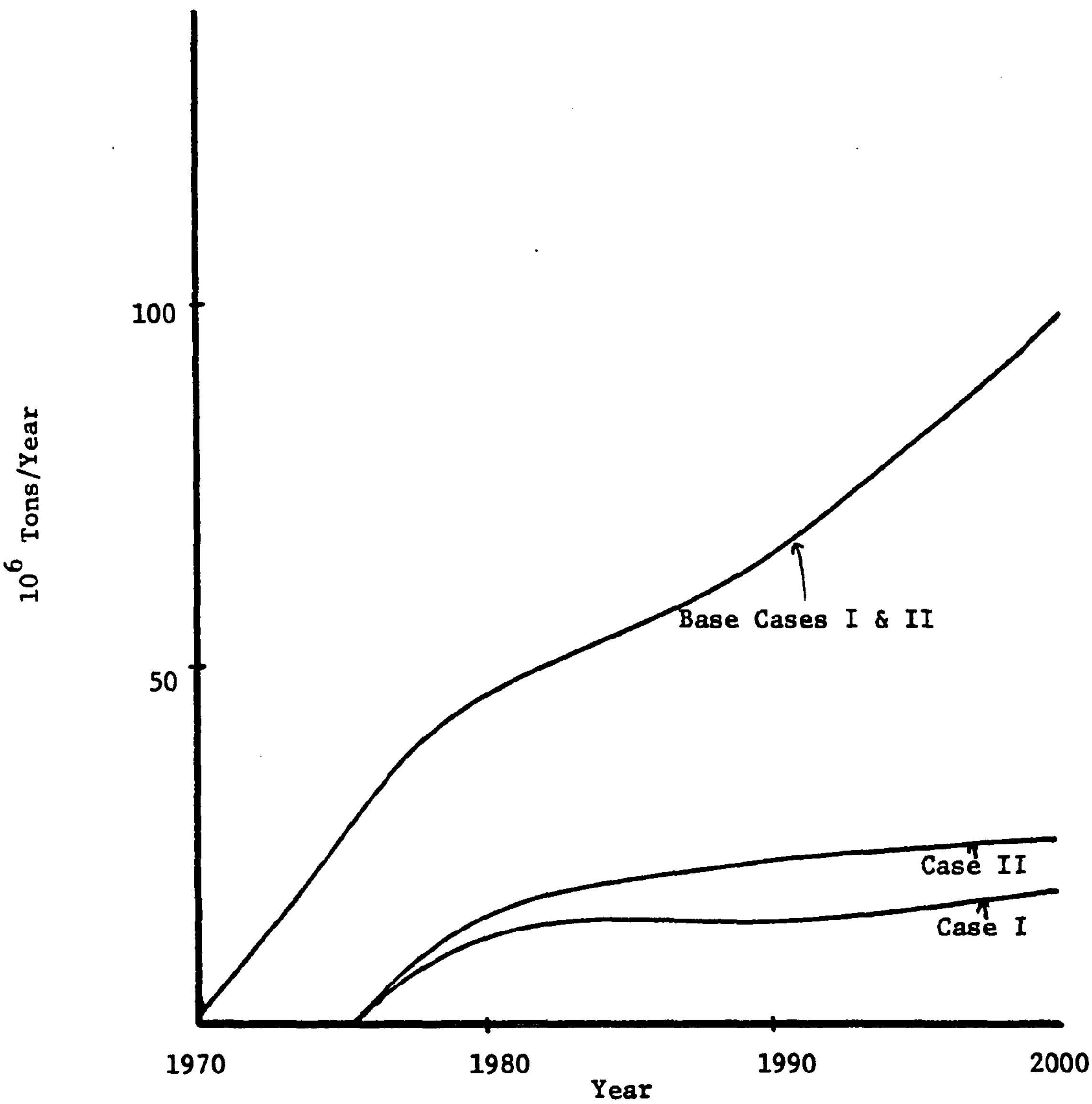


Figure VII-6 Annual Solid Waste Production -- Oil Supply Alternative

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

Summary

The study draws the nation towards a series of goals both probable and possible. It does this by cohorts of life style (income) and population (scale). The model draws the unit-use over time by reference to goals, to demographic, economic, and physical constraints by using mathematical programming techniques. The model thus is deterministic and probabilistic, and, in that it is articulated over time, is stochastic. Both initial conditions and output goals are reset after time, and the process can be repeated.

Coefficient correlation (R^2) and F values are provided for each projection. The first of these, R^2, values range from 0.81 to 0.99. the second, F, values range from 11.4 to 837.9. Overall they are well correlated. The F values of 11.4 and 837.9 with 3 and 7 degrees of freedom are significant at the 0.5% (0.005) and 0.1% (0.001) level, respectively.

Alternatives to meet the demand are closely examined with their possible environmental impacts, advanced technologies and balance of payment deficits so that government policy may be made to reach the set goals, and research and development may be directed accordingly. The alternatives are:

1. Limiting the U. S. population growth rate to 2.1 children per family (see Chapter IV).

2. Employing conservation practices which include: upgrading construction standards for buildings; improving efficient use of energy for industry and transportation; setting tax on size and power of automobiles; providing subsidies and matching grants for mass transits (see Chapter V).
3. Importing Canadian pipeline gas and LPG, or producing synthetic gas from coal and petroleum (see Chapter VI).
4. Importing crude oil, or producing syncrude from oil shale and coal (see Chapter VII).

Analyses of the energy consumption and of various alternatives have reaffirmed that the United States is faced with an "energy crisis." The United States energy consumption is projected to increase from 68 quadrillion BTU's (338 million BTU's per capita) in 1970 to 202 quadrillion BTU's (650 million BTU's per capita) in the year 2000; i.e., to increase by a factor of 3 (Figure III-b-9, Table VIII-1).

Electric utilities will account for more than 46 percent of the total energy consumption; residential and commercial, 16.4 percent; industry, 19.4 percent and transportation, 18.1 percent in the year 2000 (Figure III-b-18).

The gap between demand and supply is widening. The United States domestic supply of conventional petroleum is projected to increase from 23,600 trillion BTU'g in 1970 to 24,335 trillion BTU's in 1980; but it will gradually decrease to 18,316 trillion BTU's in the year 2000 (Table III-e-2a). The U. S. domestic supply of conventional natural gas is projected to increase from 23,500 trillion BTU's in 1970 to

26,500 trillion BTU's in 1980; but it also will decrease to 19,184 trillion BTU's in the year 2000 (Table III-e-2a). Without domestic supply from synthetic fuels, the United States must import as much as 11 percent of the energy consumption in 1970 to almost 60 percent of the energy consumption in the year 2000 (Table III-e-2).

Increasing imports of petroleum and natural gas will most likely shift the "energy crisis" to an economic balance of payment "crisis" and national security problems, as demonstrated in the embargo of crude oil to the United States from Arab nations.

The presence of vast combined resources of coal, oil shale, and nuclear raw materials do not assure an adequate U. S. energy supply for the future in the forms needed, consistent with environmental standards. The limited availability of petroleum and natural gas reserves calls for the development of technology, required for the production of synthetic fuel from coal and oil shale as rapidly as possible.

Syncrude production is projected to increase from 190 or 1,310 trillion BTU's in 1975 to 27,062 to 40,094 trillion BTU's in 2000 (Table III-e-2a and 2b). Syngas production is projected to increase from 117 or 194 trillion BTU's in 1975 to 16,496 or 41,241 trillion BTU's in the year 2000, depending on government policies (Table III-e-2a and 2b).

Nuclear power is projected to increase from 3,340 trillion BTU's in the year 1975 to 53,000 Trillion BTU's in the year 2000; i.e., an increase of production by a factor of almost 16 (Figure III-b-16). Fast breeder reactors must be developed as soon as possible. A successful breeder would multiply the usefulness of raw materials by a factor of 50 or more (94). The technology of fusion nuclear power must also be economically developed soon, since nuclear power will provide more than 50 percent of the electrical energy production by the year 2000 (Figure III-b-8).

Associated with the alternatives to meet the energy demand are the possible environmental impacts and balance of payment deficits. The United States just can not afford $46 billion for importing energy annually! (Figures VI-6 and VII-4) not even to mention its political implications.

The model quantifies the impacts of energy policy decisions into acceptable indices. Environmental impacts in terms of costs to abate air pollution and thermal pollution are estimated.

The costs to abate air pollution from energy utilization ranges from $1.78 billion in 1970 to $3.3 billion in the year 2000 (Figure III-g-1). The cost to abate thermal pollution from electrical generation ranged from $175 million in 1970 to $1.58 billion in the year 2000 (Figure III-g-2).

Based on our model, end-use consumption does not change in spite of different alternatives, therefore, the amount of air pollution and thermal pollution will remain the same with respect to different alternatives.

Solid waste production will increase ranging from 2.5 to 45.7 million tons in 1980 and 94.5 to 99.3 million tons in the year 2000 (Table III-f-8).

Land use requirements will also not change too much with respect to different alternatives, yet they also will require from 12.1 million acres in 1980 to 37.2 or 38.2 million acres in the year 2000 (Table III-f-13).

Long-lived radioactive waste materials will increase from 1,708 million cubic feet in 1980 to 23,797 million cubic feet in the year 2000. How to contain or dispose of this huge volume of waste is a challenging problem.

Environmental costs for the utilization of energy must be internalized. This may lead to a higher price of fuel, yet it may prevent waste or inefficient use of energy and thus reduce energy consumption. Higher prices may in turn give more incentives for developing new energy sources. The price of fuels may be increased gradually over a long period of time, say 20 years.

The most dramatic effects on energy consumption are caused by population growth. The trend to 2.1 children per family would reduce energy consumption by about 25 percent by the year 2000 (Figure IV-1). Together with the conservation practices, energy consumption would be reduced by more than 33 percent of total energy consumption by the year 2000 (Figure V-1).

Research and development on energy must be encouraged. Government policy must be formulated not only towards the reduction of energy consumption in housing, transportation and industry, but also to encourage the development of new fuel sources, such as synthetic fuel from coal and oil shale. Consistency with other government policies is also very important. For example, the cost of gas from coal may well be in the neighborhood of $.60 per thousand cubic feet (18); until recently, the acres in 1980 to 37.2 or 38.2 million acres in the year 2000 (Table III-f-13).

Long-lived radioactive waste materials will increase from 1,708 million cubic feet in 1980 to 23,797 million cubic feet in the year 2000. How to contain or dispose of this huge volume of waste is a challenging problem.

Environmental costs for the utilization of energy must be internalized. This may lead to a higher price of fuel, yet it may prevent waste or inefficient use of energy and thus reduce energy consumption. Higher prices may in turn give more incentives for developing new energy sources. The price of fuels may be increased gradually over a long period of time, say 20 years.

The most dramatic effects on energy consumption are caused by population growth. The trend to 2.1 children per family would reduce energy consumption by about 25 percent of the base case in the year 2000 (Figure IV-1). Together with the conservation practices, energy consumption would be reduced by more than 33 percent of total energy consumption of the base case by the year 2000 (Figure V-1).

Research and development on energy must be encouraged. Government policy must be formulated not only towards the reduction of energy consumption in housing, transportation and industry, but also to encourage the development of new fuel sources, such as synthetic fuel from coal and oil shale. Consistency with other government policies is also very important. For example, the cost of gas from coal may well be in the neighborhood of $.60 per thousand cubic feet (18); until recently, the

the Federal Power Commission regulations have limited natural gas producers to prices of about \$.25 at the wellhead in most areas. This will discourage the gasification of coal. Government can undertake larger, longer-lived, and riskier research and development projects such as solar energy utilization. Multi-nation efforts in this direction may greatly benefit every nation joined in the project.

Solar, Wind, and Tidal power are not considered economically feasible by the year 2000 in this study. If we have a technology break-through and internalize the pollution cost for the utilization of these energy sources, then there are good prospect of earlier utilization of these clear energy sources.

Recommendations for Future Work

1. Environmental costs by sources and by end-use should be estimated so that the increase in price can be justified. Environmental costs should include abatement costs for air pollution, thermal pollution, solid wastes and radioactive wastes.
2. Cost and benefit analysis on energy consumption should be made so that the degree of abatement may be optimally determined.
3. Projection on coal production should be made.
4. World energy consumption and resources should also be projected.
5. Improvement should be made in projecting nuclear and geothermal energy demand.

Table VIII-1

Ratio of Increase of Energy Consumption in Year 2000 Compared to 1970

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	-0	-0	-0	-0.295	-0	-0.295
	I	2.732	3.264	0	2.981	0.997	2.895
*Petro.	D	1.168	2.337	2.153	1.903	-0	2.033
	I	1.136	1.094	0	1.456	-0.406	1.233
N. Gas	D	2.817	3.757	4.031	2.732**	0	2.792
	I	2.018	2.495	0	2.241	-0.457	2.156
Hydro.	I	1.876	2.579	0	1.732	-0.641	1.928
Nuclear	I	239.685	287.680	0	266.771	87.777	254.807
Tidal	I	0	0	0	0	0	0
Solar	I	0	0	0	0	0	0
Geoth.$^{\Delta}$	I	32.2	25.3	0	43.2	0.3	102
Wind	I	0	0	0	0	0	0
							2.938

D = Direct use
I = Indirect (Electric power)
*The number incluses syncrude.
**The number includes direct transportation fuel from N. Gas.
- => Decreaee.
+ => Increase.
Δ Assuming Geothermal energy consumption is 10 trillion BTU's in 1970.

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APPENDICES

APPENDIX A

Table A-1

1970

Energy Demand: Trillion BTU

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	399.0		9.0	5560.0	1.6	5969.6
	I	2616.4	1719.0	0.0	3216.0	270.6	7813.0
*Petro.	D	3434	3434	15756.0	5069.0	180.0	27354.0
	I	756.7	497.2	0.0	930.3	78.8	2263.0
N. Gas	D	4515	2257	671.0	11171.0**	0.0	18521.0
	I	1346.0	884.3	0.0	1654.7	140.0	4025.0
Hydro.	I	885.1	581.5	0.0	1088.3	92.1	2647.0
Nuclear	I	69.9	45.7	0.0	85.5	7.2	208.0
Tidal	I	0.0	0.0	0.0	0.0	0.0	0.0
Solar	I	0.0	0.0	0.0	0.0	0.0	0.0
Geoth.	I	0.0	0.0	0.0	0.0	0.0	0.0
Wind	I	0.0	0.0	0.0	0.0	0.0	0.0

68810.0

D = Direct use
I = Indirect (Electric power)
*This number includes syncrude.
**The number includes direct transportation fuel from N. Gas.

Table A-2

1975

Total Energy Demand: Trillion BTU

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	0.0	0.0	42.0	5034.0	0.0	5076.0
	I	2904.0	2097.0	0.0	4021.0	240.0	9262.0
*Petro.	D	3434.0	3434.0	17490.0	5291.0	228.0	29877.0
	I	445.0	281.0	0.0	624.0	25.0	1385.0
N. Gas	D	4515.0	2757.0	865.0	12165.0**	0.0	20784.0
	I	1214.0	881.0	0.0	1697.0	98.0	3890.0
Nuclear	I	1047.0	756.0	0.0	1450.0	87.0	2646.0
Hydro.	I	840.0	621.0	0.0	1130.0	3.0	120.0
Geoth.	I	38.0	27.0	0.0	52.0	0.0	0.0
Wind	I	0.0	0.0	0.0	0.0	0.0	0.0
Tidal	I	0.0	0.0	0.0	0.0	0.0	0.0
Solar	I	0.0	0.0	0.0	0.0	0.0	0.0
							76380.0

D = Direct use
I = Indirect (Electric power)
*This number includes syncrude.
**The number includes direct transportation fuel from N. Gas.

Table A-3

1980

Total Energy Demand: Trillion BTU

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	0.0	0.0	17.0	4663.0	0.0	4680.0
	I	3498.0	2603.0	0.0	4824.0	242.0	11167.0
*Petro.	D	3803.0	3804.0	18848.0	5902.0	81.0	32438.0
	I	447.0	293.0	0.0	692.0	31.0	1463.0
N. Gas	D	6638.0	3318.0	1108.0	14573.0**	0.0	24559.0
	I	1434.0	1077.0	0.0	1999.0	94.0	4604.0
Nuclear	I	2972.0	2212.0	4100.0	205.0	205.0	9490.0
Hydro	I	951.0	738.0	0.0	1240.0	35.0	2964.0
Geoth	I	107.0	80.0	0.0	148.0	8.0	343.0
Wind	I	0.0	0.0	0.0	0.0	0.0	0.0
Tidal	I	0.0	0.0	0.0	0.0	0.0	0.0
Solar	I	0.0	0.0	0.0	0.0	0.0	0.0
							91708.0

D = Direct use
I = Indirect (Electrical Power)
*This number includes syncrude.
**The number includes direct transportation fuel from N. Gas.

Table A-4

1985
Total Energy Demand: Trillion BTU

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	0	0	0	4130	0	4130
	I	4228	3206		5786	245	13456
*Petro.	D	3398	5068	21648	6615	0	36729
	I	540	329	0	806	30	1705
N. Gas	D	7252	4832	1407	17488**	0	29572
	I	1675	1295	0	2330	86	5386
Nuclear	I	6751	5119	0	9239	391	21500
Hydro.	I	1083	881	0	1368	8	3340
Geothermal	I	161	122	0	221	10	33
Wind	I	0	0	0	0	0	0
Tidal	I	0	0	0	0	0	0
Solar	I	0	0	0	0	0	0
							115860

D = Direct use
I = indirect (electric power)
*This number includes syncrude.
**The number includes direct transportation fuel from N. Gas.

Table A-5

1990

Total Energy Demand: T illion BTU

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	0	0	0	3584	0	3584
	I.	5250	4030	0	7116	265	16661
*Petro.	D	3790	5684	25051	7468	0	41993
	I	603	388	0	966	30	1987
N. Gas	D	8450	5634	1748	21027**	0	35111
	I	1969	1546	0	2711	81	6307
Nuclear	I	8949	6869	0	21130	452	28400
Geoth.	I	241	165	0	290	11	680
Wind	I	0	0	0	0	0	0
Hydro.	I	1245	1048	0	1515	0	3808
Tidal	I	0	0	0	0	0	0
Solar	I	0	0	0	0	0	0
							138310

D = Direct use
I = Indirect (electric power)
*This number includes syncrude.
**The number includes direct transportation fuel from N Gas.

Table A-6

1995

Total Energy Demand: Trillion BTU

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	0	0	0	2722	0	2722
	I	6011	4673	0	8106	261	19051
*Petro.	D	3551	7102	29081	8465	0	48199
	I	700	448	0	1141	31	2320
N. Gas	D	10572	7018	2182	25318**	0	42863
	I	2306	1846	0	3163	73	7388
Nuclear	I	13568	10548	0	18296	588	40500
Geoth.	I	270	210	0	364	11	855
Hydro	I	1434	1253	0	1686	60	4433
Wind	I	0	0	0	0	0	0
Tidal	I	0	0	0	0	0	0
Solar	I	0	0	0	0	0	0
							168331

D = Direct use
I = indirect (electric power)
*This number includes syncrude
**The number includes direct transportation fuel from N. Gas.

Table A-7

2000

Total Energy Demand: Trillion BTU

		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	0	0	0	1643	0	1643
	I	7150	5611	0	9588	270	22619
*Petro.	D	4014	8027	33929	9649	0	55619
	I	860	544	0	1355	32	2791
N. Gas	D	12721	8480	2705	30527**	0	51728
	I	2717	2207	0	3709	64	8697
Nuclear	I	16754	13147	0	22467	632	53000
Hydro.	I	1661	1500	0	1886	59	5106
Geoth.	I	322	253		432	13	1020
Wind	I	0	0	0	0	0	0
Tidal	I	0	0	0	0	0	0
Solar	I	0	0	0	0	0	0

202223

D = Direct use
I = indirect (electric power)
*This number includes syncrude.
**The number includes direct transportation fuel from N. Gas.

Table B-1

1980 CO Emission (tons)

Source	End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	600	176,700	0	177,300
	D **	0	0	600	176,700	0	177,300
	I *	66,300	49,300	0	1,400	4,600	211,600
	I **	66,300	49,300	0	1,400	4,600	211,600
Petro.	D *	68,500	13,200	7,874,320	13,400	0	7,969,420
	D **	68,500	13,200	(54,554,823)	13,400	0	(54,649,923)
	I *	60	40	0	90	0	190
	I **	60	40	0	90	0	190
N.Gas	D *	66,400	33,200	200	2,700	0	102,500
	D **	66,400	33,200	200	2,700	0	102,500
	I *	2,900	2,200	0	40	100	9,200
	I **	2,900	2,200	0	40	100	9,200
							* 8,470,210
							** (59,871,575)

*Projected

**( )In 1970 Trend

Table B-2

1990 CO Emission (tons)

Source	End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	135,800	0	135,800
	D **	0	0	0	135,800	0	135,800
	I *	99,500	76,400	0	134,900	5,000	315,700
	I **	99,500	76,400	0	134,900	5,000	315,700
Petro.	D *	68,200	4,032	10,756,246	5,274	0	10,843,058
	D **	68,200	4,032	(64,734,299)	5,274	0	(64,821,111)
	I *	80	60	0	130	0	270
	I **	80	60	0	130	0	270
N. Gas	D *	84,500	56,400	300	3,900	0	145,100
	D **	84,500	56,400	300	3,900	0	145,100
	I *	3,900	3,100	0	5,400	200	12,600
	I **	3,900	3,100	0	5,400	200	12,600
Total							*11,452,528 ** (72,444,960)

*Projected

**( )In 1970 Trend

Table B-3

2000 CO Emission (tons)

Source \ End-use		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	62,300	0	62,300
	D **	0	0	0	62,300	0	62,300
	I *	135,500	106,300	0	181,700	5,100	428,600
	I **	135,500	106,300	0	181,700	5,100	428,600
Petro.	D *	72,300	5,666	14,715,798	6,734	0	14,800,498
	D **	72,300	5,666	(82,639,729)	6,734	0	(182,724,429)
	I *	110	90	0	170	0	370
	I **	110	90	0	170	0	370
N. Gas	D *	127,200	84,800	500	5,600	0	218,100
	D **	127,200	84,800	500	5,600	0	218,100
	I *	5,400	4,400	0	7,400	200	17,400
	I **	5,400	4,400	0	7,400	200	17,400
Total							*15,527,268 **(93,390,134)

*Projected

**( )In 1970 Trend

Table B-4

1980 SO_2 Emission Emission (tons)

Source		End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	*	0	0	10,126	2,785,397	0	2,795,523
		**	0	0	10,126	2,785,297	0	2,795,523
	I	*	1,742,004	1,296,294	0	2,402,352	120,516	5,561,000
		**	(2,159,039	1,29[illegible],294	0	2,402,352	(149,367)	(6,892,507)
Petro.	D	*	554,933	1,258,408	899,738	841,035	0	3,554,115
		**	554.933	1,258,408	899,738	841,035	0	3,554,115
	I	*	50,274	13,659	0	78,888	3,534	166,782
		**	50,274	13,659	0	(98,515)	(4,413)	(182,767)
N. Gas	D	*	2,000	1,000	300	4,000	0	7,300
		**	2,000	1,000	300	4,000	0	7,300
	I	*	400	300	0	600	100	1,400
		**	400	300	0	600	100	1,400
Total								*(12,086,220) **(13,433,712)

*Projected

**( )In 1970 Trend

Table B-5

1990 SO_2 Emission (tons)

Source	End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	2,140,902	0	2,140,902
	D **	0	0	0	2,140,902	0	2,140,902
	I *	2,615,486	2,006,940	0	3,543,768	131,970	8,297,178
	I **	(3,241,645)	(2,487,401)	0	(4,382,146)	(163,563)	(10,111,192)
Petro.	D *	553,036	809,970	1,243,577	1,064,190	0	3,670,773
	D **	553,036,	809,970	1,243,557	1,064,190	0	3,670,773
	I *	68,742	44,232	0	110,124	3,420	226,518
	I **	(85,845)	(55,236)	0	(137,507)	(4,270)	(282,858)
N. Gas	D *	2,500	1,700	0	500	5,800	10,500
	D **	2,500	1,700	0	500	5,800	10,500
	I *	600	500	0	800	0	1,900
	I **	600	500	0	800	0	1,900
Total							*(14,347,771) **(16,218,125)

*Projected

**( )In 1970 Trend

Table B-6

2000 SO_2 Emission (tons)

Source	End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	981,475	0	981,475
	D **	0	0	0	981,475	0	981,475
	I *	3,560,700	2,794,278	0	4,774,824	134,460	11,264.262
	I **	(4,413,131)	(3,463,228)	0	(5,917,916)	(166,648)	(13,960,924)
Petro.	D *	585,722	1,143,847	1,328,118	1,374,982	0	
	D **	585,722	1,143,847	1,328,118	1,374,982	0	
	I *	98,040	62,106	0	154,470	3,648	319,659
	I **	(122,432)	(77,455)	0	(192,902)	(4,555)	(397,344)
N. Gas	D *	3,800	2,500	800	8,300	0	15,500
	D **	3,800	2,500	800	8,300	0	15,500
	I *	800	700	0	1,100	2	2,600
	I **	800	700	0	(1,000)	2	(2,600)
Total							*17,868,083) **(20,643,430)

*Projected

**( )In 1970 Trend

Table B-7

1980 NO_x Emission (tons)

Source \ End-use		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	*	0	0	4,800	1,324,800	0	1,329,600
	D			4,800	1,324,800	0	1,329,600
	**	0	0				
	*	122,400	91,100	0	168,800		390,800
	I						
	**	(1,192,468)	(887,360)	0	(1,644,501)	(82,497)	(3,806,826)
Petro.	*	163,500	536,831	2,759,967	830,122	0	4,290,420
	D						
	**	163,500	536,831	(2,896,843)	830,122	0	(4,427,296)
	*	66,200	43,900	0	103,800	4,700	219,500
	I						
	**	(156,673)	(102,696)	0	(242,546)	(10,865)	(512,780)
N. Gas	*	165,900	165,900	66,500	807,900	0	1,206,200
	D						
	**	165,900	165,900	66,500	807,900	0	1,206,200
	*	143,400	107,700	0	199,900	9,400	460,400
	I						
	**	(265,290)	(199,245)	0	(368,815)	(17,380)	(815,740)
Total							*(7,896,920) **(12,098,462)

*Projected

**( )In 1970 Trend

Table B-8

1990 NO_x Emission (tons)

Source \ End-use			Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	*	0	0	0	1,018,200	0	1,018,200
		**	0	0	0	1,018,200	0	1,018,200
	I	*	183,800	141,000	0	248,000	9,300	583,100
		**	(1,789,725)	(1,373,827)	0	(2,425,844)	(90,338)	(5,678,734)
Petro.	D	*	162,900	802,176	3,791,590	1,045,202	0	5,801,868
		**	162,900	802,176	(4,375,554)	1,045,202	0	(6,385,832)
	I	*	90,500	58,200	0	144,900	4,500	298,100
		**	211,351	(135,944)	0	338,585	(10,515)	(696,393)
N. Gas	D	*	211,300	281,700	104,900	1,156,700	0	1,754,600
		**	211,300	281,700	104,900	1,156,700	0	1,754,600
	I	*	196,900	154,600	0	271,100	8,100	630,700
		**	196,900	286,010	0	501,535	(14,985)	(1,166,795)
Total								*(10,086,568) **(16,721,354)

*Projected

**( )In 1970 Trend

Table B-9

2000 NO_x Emission (tons)

Source			Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D	*	0	0	0	466,800	0	466,800
		**	0	0	0	466,800	0	466,800
	I	*	250,300	196,400	0	335,600	9,500	791,700
		**	(2,437,435)	(1,912,789)	0	(3,268,549)	(92,043)	(7,710,816)
Petro.	D	*	172,600	1,132,372	5,146,430	1,344,877	0	7,796,279
		**	172,600	1,132,372	(5,146,430)	1,344,877	0	(8,567,043)
	I	*	129,000	81,600	0	203,300	4,800	418,700
		**	(301,430)	(190,672)	0	(474,927)	(11,216)	(978,245)
N. Gas	D	*	312,000	424,000	162,300	1,669,300	0	2,573,600
		**	312,000	424,000	162,300	1,669,300	0	2,573,600
	I	*	271,700	220,700	0	370,900	6,400	869,700
		**	271,700	220,700	0	370,900	6,400	869,700
Total								*(12,916,779) **(21,905,449)

*Projected

**( )In 1970 Trend

Table B-10

1980 Particulate Emission (tons)

Source		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	14,600	4,018,300	0	4,032,900
	D **	0	0	14,600	4,018,300	0	4,032,900
	I *	34,900	26,000	0	48,200	2,400	111,700
	I **	(68,571)	(51,084)	0	(94,703)	(4,715)	(219,073)
Petro.	D *	136,900	292,146	1,931,211	361,634	0	2,721,891
	D **	136,900	292,146	1,931,211	361,634	0	2,721,891
	I *	11,900	7,900	0	18,700	800	39,500
	I **	(11,888)	(7,892)	0	(18,681)	(800)	(39,460)
N. Gas	D *	63,100	31,500	9,900	121,200	0	225,700
	D **	63,100	31,500	9,900	121,200	0	225,700
	I *	10,800	8,100	0	14,900	700	345,000
	I **	10,800	8,100	0	14,900	700	345,000
Total							*(7,166,191) **(7,272,564)

*Projected

**( )In 1970 Trend

Table B-11

1990 Particulate Emission (tons)

Source	End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	3,088,500	0	3,088,500
	D **	0	0	0	3,088,500	0	3,088,500
	I *	52,500	40,300	0	71,200	2,700	166,600
	I **	(103,152)	(79,181)	(0)	(139,893)	(5,304)	(327,530)
Petro.	D *	136,400	342,055	2,160,388	468,825	0	3,107,688
	D **	136,400	342,055	2,160,388	468,825	0	3,107,688
	I *	16,300	10,800	0	26,100	800	53,600
	I **	(16,283)	(10,789)	0	(26,073)	(800)	(53,945)
N. Gas	D *	80,300	53,500	15,700	173,500	0	323,000
	D **	80,300	53,500	15,700	173,500	0	323,000
	I *	14,800	11,600	0	20,310	600	47,300
	I **	14,800	11,600	0	20,310	600	47,300
Total							*(6,786,668) **(6,947,598)

*Projected

**( )In 1970 Trend

Table B-12

2000 Particulate Emission (tons)

Source	End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	1,415,900	0	1,415,900
	D **	0	0	0	1,415,900	0	1,415,900
	I *	71,500	56,100	0	95,900	2,700	226,200
	I **	(142,448)	(110,225)	0	(188,424)	(5,304)	(446,401)
Petro.	D *	144,500	484,519	3,054,980	617,844	0	4,180,543
	D **	144,500	585,519	3,054,980	617,844	0	4,180,543
	I *	23,200	14,700	0	36,600	900	75,400
	I **	(23,176)	(14,685)	0	(36,563)	(900)	(75,324)
N. Gas	D *	120,800	80,600	24,300	250,400	0	476,100
	D **	120,800	80,600	24,300	250,400	0	476,100
	I *	20,400	16,600	0	27,800	500	65,200
	I **	20,400	16,600	0	27,800	500	65,200
Total							*(6,439,343) **(6,659,544)

*Projected

**( )In 1970 Trend

Table B-13

1980 Hydrocarbon Emission (tons)

Source \ End-use		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	300	88,400	0	88,700
	D **	0	0	300	88,400	0	88,700
	I *	23,800	17,700	0	32,800	1,600	75,900
	I **	23,800	17,700	0	32,800	1,600	75,900
Petro.	D *	41,100	41,100	2,996,450	63,700	900	3,143,250
	D **	41,100	41,100	(4,097,782)	63,700	900	(4,244,582)
	I *	3,000	2,000	0	4,600	200	9,800
	I **	3,000	2,000	0	4,600	200	9,800
N. Gas	D *	26,500	13,300	22,200	269,300	0	331,300
	D **	26,500	13,300	22,200	269,300	0	331,200
	I *	28,700	21,500	0	39,900	1,900	92,100
	I **	28,700	21,500	0	39,900	1,900	92,100
Total							*(3,741,050) **(4,842,382)

*Projected

**( )In 1970 Trend

Table B-14

1990 Hydrocarbon Emission (tons)

Source	End-use	Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	67,900	0	67,900
	D **	0	0	0	67,900	0	67,900
	I *	35,700	27,400	0	48,400	1,800	113,300
	I **	35,700	27,400	0	48,400	1,800	113,300
Petro.	D *	40,900	61,400	4,651,067	80,700	0	4,834,067
	D **	40,900	61,400	(5,957,899)	80,700	0	(6,180,899)
	I *	4,000	2,600	0	6,500	200	13,300
	I **	4,000	2,600	0	6,500	200	13,300
N. Gas	D *	33,800	22,500	34,900	385,600	0	476,800
	D **	33,800	22,500	34,900	385,600	0	476,800
	I *	39,400	30,800	0	54,200	1,600	126,100
	I **	39,400	30,800	0	54,200	1,600	126,100
Total							*(5,631,467) **(6,938,299)

*Projected

**( )In 1970 Trend

Table B-15

2000 Hydrocarbon Emission (tons)

Source \ End-use		Res.	Comm.	Trans.	Ind.	Mis.	Total
Coal	D *	0	0	0	31,100	0	31,100
	D **	0	0	0	31,100	0	31,100
	I *	48,600	38,200	0	65,200	1,800	153,800
	I **	48,600	38,200	0	65,200	1,800	153,800
Petro.	D *	43,400	86,700	6,756,781	104,200	0	6,991,081
	D **	43,400	86,700	(8,425,081)	104,200	0	6,991,081
	I *	5,700	3,600	0	9,100	200	18,700
	I **	5,700	3,600	0	9,100	200	18,700
N. Gas	D *	50,900	33,900	54,100	556,400	0	695,300
	D **	50,900	33,900	54,100	556,400	0	695,300
	I *	54,300	44,100	0	74,200	1,300	173,900
	I **	54,300	44,100	0	74,200	1,300	173,900
Total							*(8,063,881) **(9,732,181)

*Projected

**( )In 1970 Trend

Table C-1

Annual CO Emission (Transportation)

Year / Source		1980	1990	2000
Gasoline	Auto	31,584,458 (54,554,823)	37,418,867 (64,734,229)	4,776,863 (82,639,729)
	Truck	948,242	937,909	952,726
	Bus	66,156	29,309	26,464
	Airp.	30,251	0	0
Jet fuel	Airp.	2,964,601	4,985,650	7,260,806
Res. Oil	Ship	479	604	795
	Rail	181,412	221,826	326,556
	Bus	36,282	67,512	326,566
Dis. oil	Ship	43,538	57,867	78,375
	Truck	449,901	713,702	1,162,577
Total		7,874,320 (59,270,685)	10,756,246 (71,748,678)	14,715,798 (92,578,664)

Unit: Tons

( ): 1970 trend

Table C-2

Annual NO_x Emission (Transportation)

Source		1980	1990	2000
Gasoline	Auto	371,946 (508,822)	441,348 (1,045,112)	563,424 (1,334,188)
	Truck	111,844	110,625	112,372
	Bus	7,803	3,457	3,121
	Airp.	5,824	0	0
Jet fuel	Airp.	570,755	959,854	1,397,874
Res. oil	Ship	472,707	457,606	158,533
	Rail	310,992	380,274	559,828
	Bus	62,198	115,735	223,931
Dis. oil	Ship	74,638	99,206	134,358
	Truck	771,260	1,223,490	1,992,989
Total		2,759,967 (2,896,843)	3,791,590 (4,395,354)	5,146,430 (5,917,194)

Unit: Tons

( ): 1970 trend

Table C-3

Annual SO_2 Emission (Transportation)

Source	Year	1980	1990	2000
Gasoline	Auto	161,715	192,892	244,967
	Truck	48,627	48,097	48,857
	Bus	3,392	1,503	1,357
	Airp.	2,318	0	0
Jet fuel	Airp.	227,193	382,077	556,435
Res. oil	Ship	279,327	351,716	48,688
	Rail	45,706	55,888	82,277
	Bus	9,141	17,009	32,911
Dis. oil	Ship	10,969	14,579	19,746
	Truck	111,351	179,816	292,880
Total		898,739	1,243,577	1,328,118

Unit: Tons

Table C-4

Annual Particulate Emission (Transportation)

Source / Year		1980	1990	2000
Gasoline	Auto	287,045	340,605	434,817
	Truck	86,314	85,373	86,722
	Bus	6,021	2,667	2,408
	Airp.	9,160	0	0
Jet fuel	Airp.	911,545	1,532,970	2,232,528
Res. oil	Ship	50,006	69,261	91,201
	Rail	22,146	27,080	39,866
	Bus	4,429	8,241	15,946
Dis. oil	Ship	5,315	7,064	9,567
	Truck	549,230	87,127	141,925
Total		1,931,211	2,160,388	3,054,980

Unit: Tons

Table C-5

Annual Hydrocarbon Emission (Transportation)

Source	Year	1980	1990	2000
Gasoline	Auto	380,032 (1,481,364)	450,943 (1,757,775)	575,673 (2,243,973)
	Truck	114,275	113,030	114,815
	Bus	7,972	3,532	3,189
	Airp.	2,657	0	0
Jet fuel	Airp.	1,939,459	3,261,640	4,750,060
Res. oil	Ship	7,162	9,018	11,875
	Rail	139,004	169,971	250,220
	Bus	27,800	51,730	100,090
Dis. oil	Ship	33,360	44,340	60,054
	Truck	344,729	546,863	890,805
Total		2,996,450 (4,097,782)	4,651,067 (5,957,899)	6,756,781 (8,425,081)

Unit: Tons

( ): 1970 trend