ENERGY SUPPLY, DEMAND/NEED AND THE GAPS BETWEEN

VOLUME I: AN OVERVIEW

by

James W. Meyer, William J. Jones,
and Myer M. Kessler

Energy Laboratory Report No. MIT-EL 75-012
December 1, 1974; Amended June, 1975

Final Report to:
The M.W. Kellogg Co.
and
The Environmental Protection Agency
under Task 27 of EPA Contract 8-02-1308

VOLUME I

FINAL REPORT ON

Energy Supply, Demand/Need and the Gaps Between

to

The M. W. Kellogg Co.
Houston, Texas

and

The Environmental Protection Agency

under

Task 27 of EPA Contract 8-02-1308

Prepared by:

James W. Meyer
William J. Jones
Myron M. Kessler

December 1, 1974

Energy Laboratory
Massachusetts Institute of Technology
Cambridge, Mass. 02139

James W. Meyer
Principal Investigator

William J. Jones

Myron M. Kessler

ABSTRACT

This paper is a summary, based on a critical review of selected literature pertaining to energy supply, demand, supply/demand imbalances and the operational/technological developments needed to redress imbalances. Crises have been a recurrent feature of man's history. There was a crisis based on a shortage of wood fuel in the early 17th century. Whale oil was so short during the Civil War that the price doubled, yet it then dropped by a factor of six before the end of the century as kerosene became an alternate option. Energy demand growth soared in the U.S. over the last two decades not because of need but because real energy prices dropped. Energy was substituted for labor and material which were costing more. Now we have materials as well as energy shortages and massive unemployment.

There is little agreement regarding our future supply of fossil fuels and no consensus on the best way to reduce demand. History tells us that the imbalance will be resolved. It is our task to make sure that the resolution occurs with the lowest possible social and environmental cost. Price can resolve the imbalance, but because price does not often reflect all costs this resolution can be very disruptive. Alternatives must be developed and options broadened. Opportunities for conservation should not be overlooked for the marginal barrel of oil saved is of greater value than the marginal barrel of new production.

A series of working papers and monographs which discuss certain aspects of this review more broadly are included in Volume II of this report.

TABLE OF CONTENTS

(Volume I)

LIST OF FIGURES

(Volume I)

ENERGY SUPPLY DEMAND/NEED AND THE GAPS BETWEEN

VOLUME I: AN OVERVIEW

INTRODUCTION

Energy Consumption

In 1972 the U.S. consumed over a half billion tons of coal, nearly six billion barrels of oil, over twenty two trillion cubic feet of natural gas, over fifty four billion kilowatt hours of nuclear power. Utility electricity (derived from all sources fossil fuel, hydro, nuclear and geothermal) amounted to 1.6 trillion kilowatt hours. Average rates corresponding to the above figures are 1.44 million tons per day of coal, 16.4 million barrels per day of oil, and 61.5 billion cubic feet of gas a day.

It is a little difficult to bring such large numbers into one's personal context. For example our annual consumption of coal would cover the District of Columbia to a depth of about ten feet! The Catskill Aqueduct of the New York City water supply with a capacity of 600 million gallons of water a day would not be able to handle the nearly 700 million gallons of oil a day. The container for our annual natural gas consumption would be a tank 10 miles in diameter and 2 miles high.

Energy consumption grew at an average rate of 4.5% annually from 1965 reaching 75.6 quadrillion (10^{15}) Btu's* in 1973. Per capita energy consumption in the United States exceeds by a factor of two or three that of similarly developed nations.

Forecasting Methods, Factors, and Problems

Forecasting of growth of energy consumption has often been based on projections of historical trends--past experience in population growth and increases in the gross national product. In the absence of disruptions such projects can be reasonably accurate, but with disruptions which increase differences of opinion as to probable population growth rates, uncertainties about saturation of markets for energy consuming products and lead to irregular or no growth, accurate projections become extremely difficult. The 1973 embargo had a major impact on our economy, producing a $10-20 billion drop in GNP and a half million additional unemployed at its peak. The subsequent increase in world oil prices continues the depressing effect on economic activity. The past year has seen dramatic changes in patterns of supply and demand growth. Orderly growth which allowed simple projections into the future has been replaced with highly interactive supply/demand patterns. We have observed effects without fully understanding their causes; because in reaction to the embargo, multiple crises actions were taken. There has been little chance to disentangle the interactions of these numerous actions, to disaggregate the effects. We do know that consumption has been reduced, but we do not know the relative importance in reducing consumption of factors such as price, anticipated scarcity, conservation, availability, patriotism, or emergency atmosphere. The current, substantially zero, growth in total petroleum consumption and in electric power production, the declines in home-

---

* The British Thermal Unit (Btu) is a measure of heat energy in common use by engineers in England and the United States. A Btu is the amount of heat required to raise one pound (about a pint) of water one fahrenheit degree in temperature. One Btu is equal to 252 calories (the amount of heat required to raise one gram of water one degree Celsius in temperature).

building starts, automobile sales, and motor gasoline sales, are striking examples of problems facing today's forcaster of future energy demand and the growth or dimunition of that demand.

A search of the literature reveals that very few of the forecasts prepared during the past few years were truly original. Most refer to the same basic data sources. One of the contributions of the work on the Project Independence Blueprint has been to vastly improve the data base needed for energy analyses and forecasts. Studies prepared by the fuel industry are usually limited in that they do not consider the possibility of alternate sources, conservation and improved efficiency of utilization. Their growth projections are traditionally on the high side. All demand projections must be reevaluated in light of current price conditions and the growing interest in conservation, efficiency and diversification of fuel sources.

The National Energy Kaleidoscope

In considering the sources of energy from fuels it can be misleading to take only the aggregated whole of the United States. In Figure 1, for example, where energy sources for New England and for the United States are compared, striking differences are revealed. New England is 85% dependent on petroleum products compared with only 46% for the country as a whole. Similar differences are shown in Figure 2 illustrating electric power generation fuel sources. Sector fuel use, Figure 3, also shows dramatic differences between New England and the United States as a whole. New England's heavy dependence on petroleum products combined with a lack of regional petroleum resources make it particularly vulnerable to disruption of imports.

Imports

In Figure 4, major sources of import in 1973 are shown. Of the 1,847 million barrels imported, over half comes from Canada, Venezuela, and the Netherlands Antilles. Saudi Arabia supplied less than 10% of our imports and less than 3.5% of the total national consumption. However, New England's dependence on petroleum, and indeed on imported petroleum, makes the region

SOURCES OF ENERGY
1972

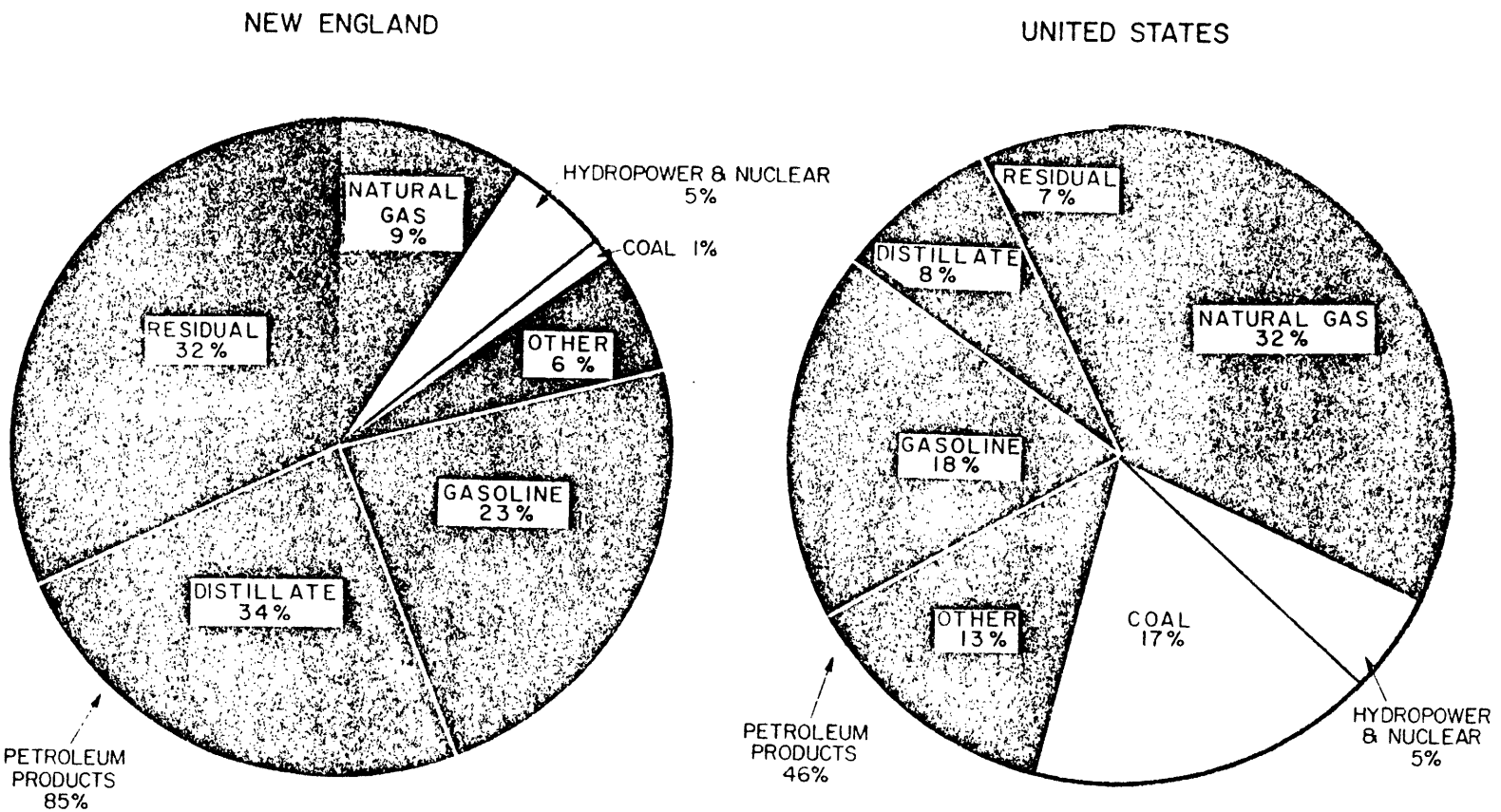


Figure 1*

* Federal Energy Administration, Boston, Massachusetts

ELECTRIC GENERATION FUEL SOURCES
1972

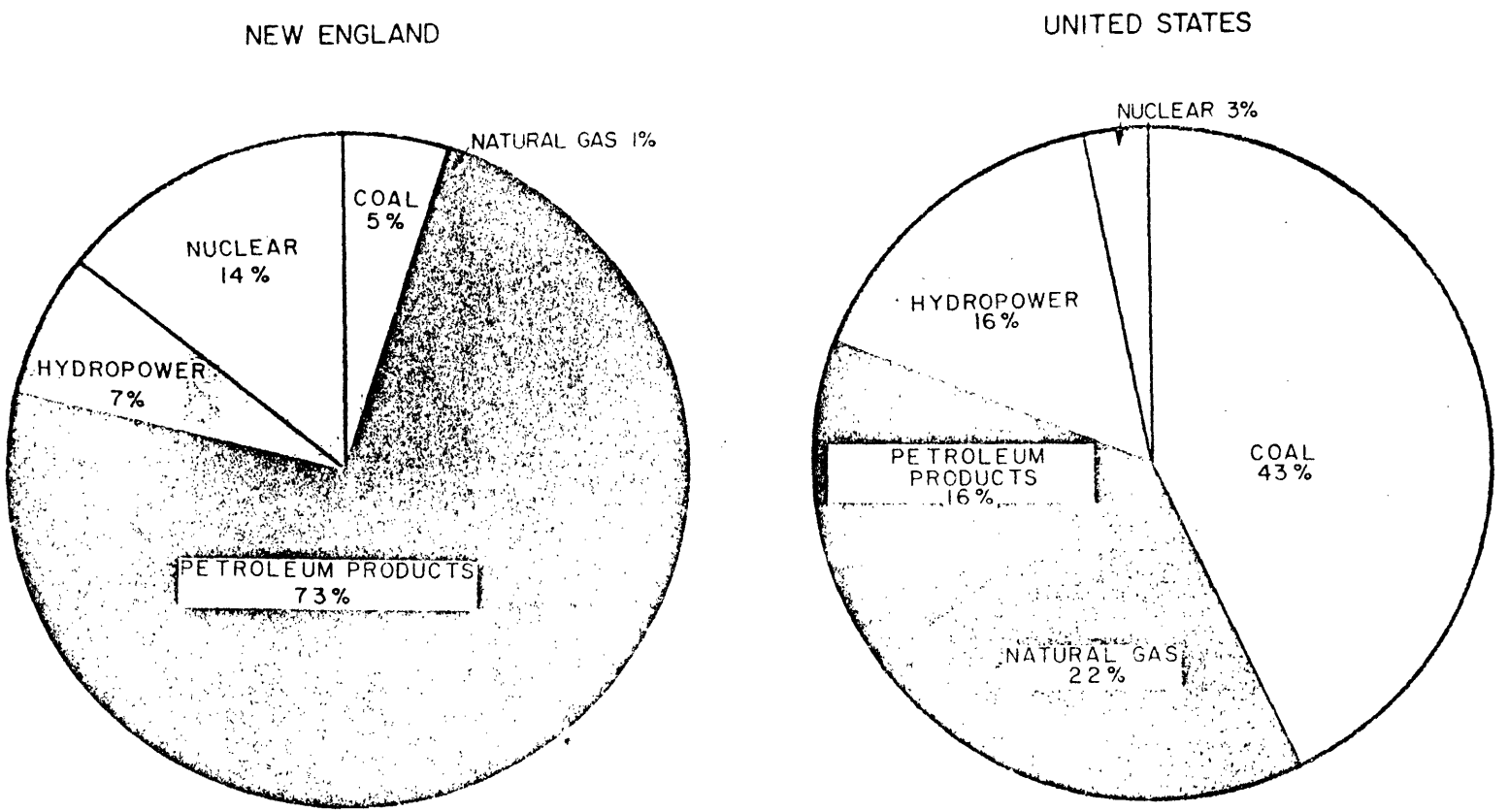


Figure 2*

* Federal Energy Administration, Boston, Massachusetts

SECTOR FUEL USE
1972

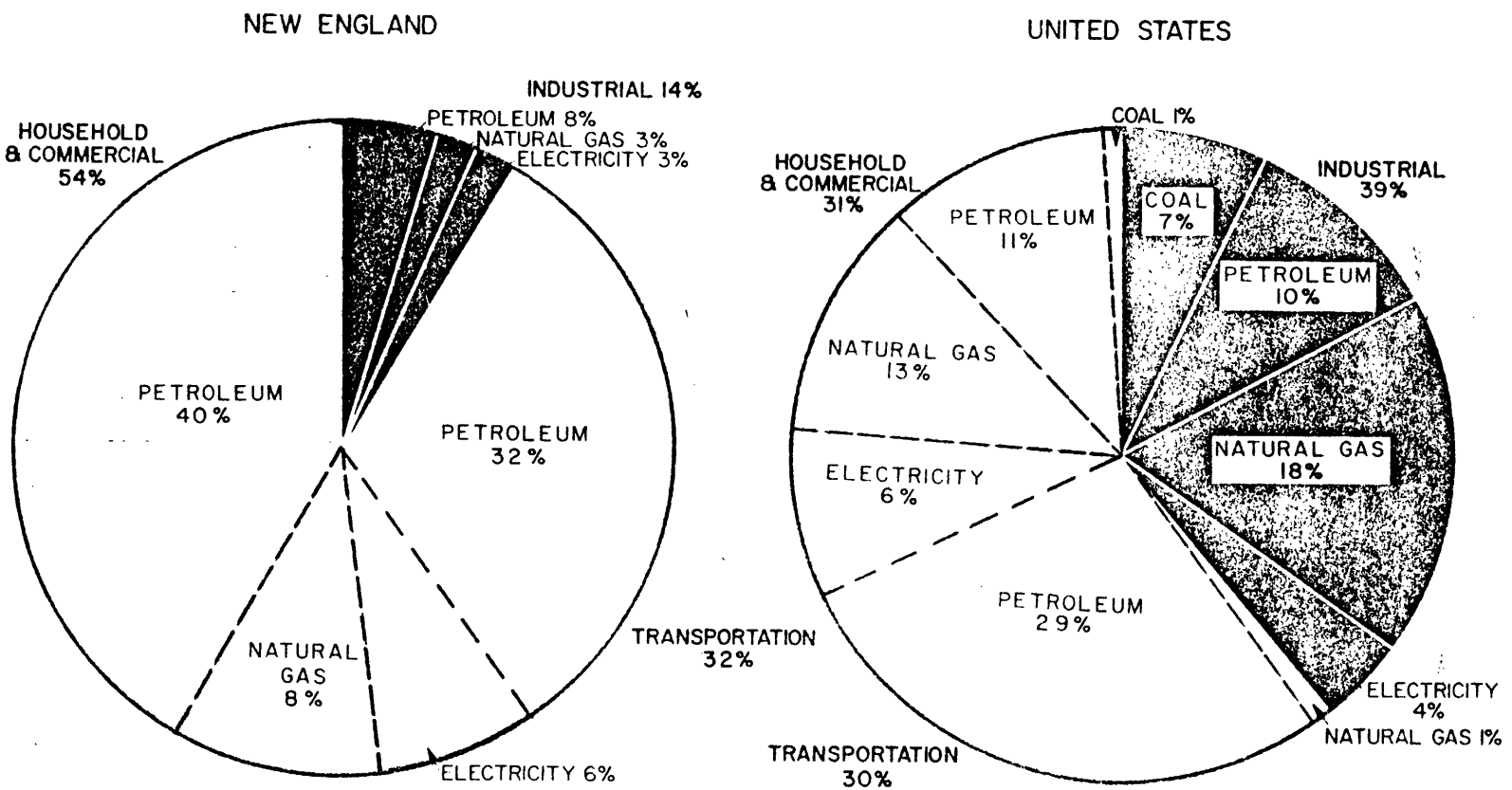
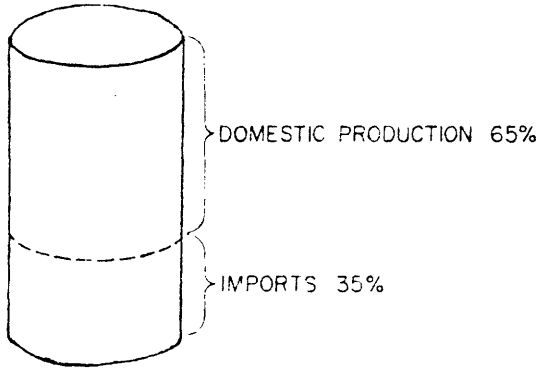


Figure 3*

* Federal Energy Administration, Boston, Massachusetts

UNITED STATES OIL IMPORTS
1973



MAJOR SOURCES OF IMPORTS
MILLIONS OF BARRELS

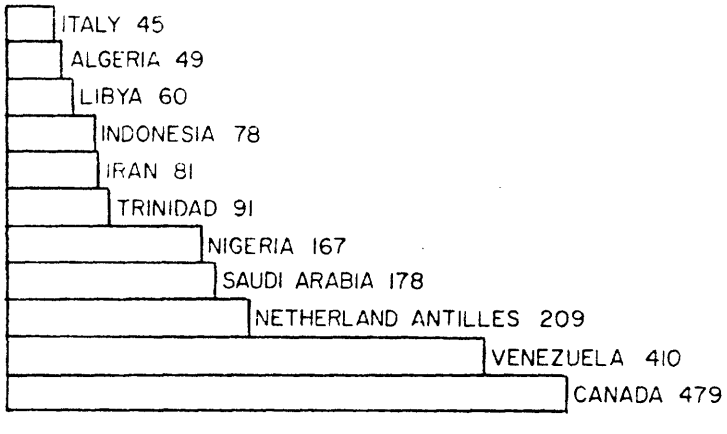


Figure 4*

* Federal Energy Administration, Boston, Massachusetts

especially susceptible to embargoes. As is illustrated in Figure 5 the 30% more New England paid for energy than the United States is more a result of New England's exceptional dependence on oil than the differences in oil prices. This specific comparison has been made to illustrate the importance of using detailed local or regional considerations when assessing energy problems.

Fuel Flexibility

Because natural gas and oil have been cheap, the trend has been toward specialization rather than diversification in energy fuels. Most large users of fuels with diversification can switch only between natural gas and residual oil. Many electric utilities formerly able to burn coal have switched to oil for environmental or other reasons and no longer have the facilities for a return to coal.

To many of the users, the logical way to increase the substitution of coal is to convert it into gaseous or liquid fuel meeting the requirements of both the installed facilities and the environment. There has been essentially no growth in coal production since the forties. If, for example, synthetic natural gas from coal is to be a significant factor, say 20% of current consumption, coal production would have to be doubled over current levels and about 60 coal gasification plants would have to be built requiring capital of an estimated $25 billion.

As we face the problems of converting coal to clean fuels to meet the needs of existing plants, we must not ignore the potential for converting existing plants to burn moderately beneficiated coal in an environmentally acceptable way or for using coal to produce feedstocks for industry.

Indigenous Supply and Utilization

The intensely urbanized Eastern Seaboard of the United States has little proven petroleum and gas reserves. To correct this, pressures are mounting to do exploratory drilling on the outer continental shelf. Some geologists

CRUDE OIL PRICES & RESULTING GASOLINE PRICES
(GASOLINE PRICES INCLUDE TAX)
MAY, 1974

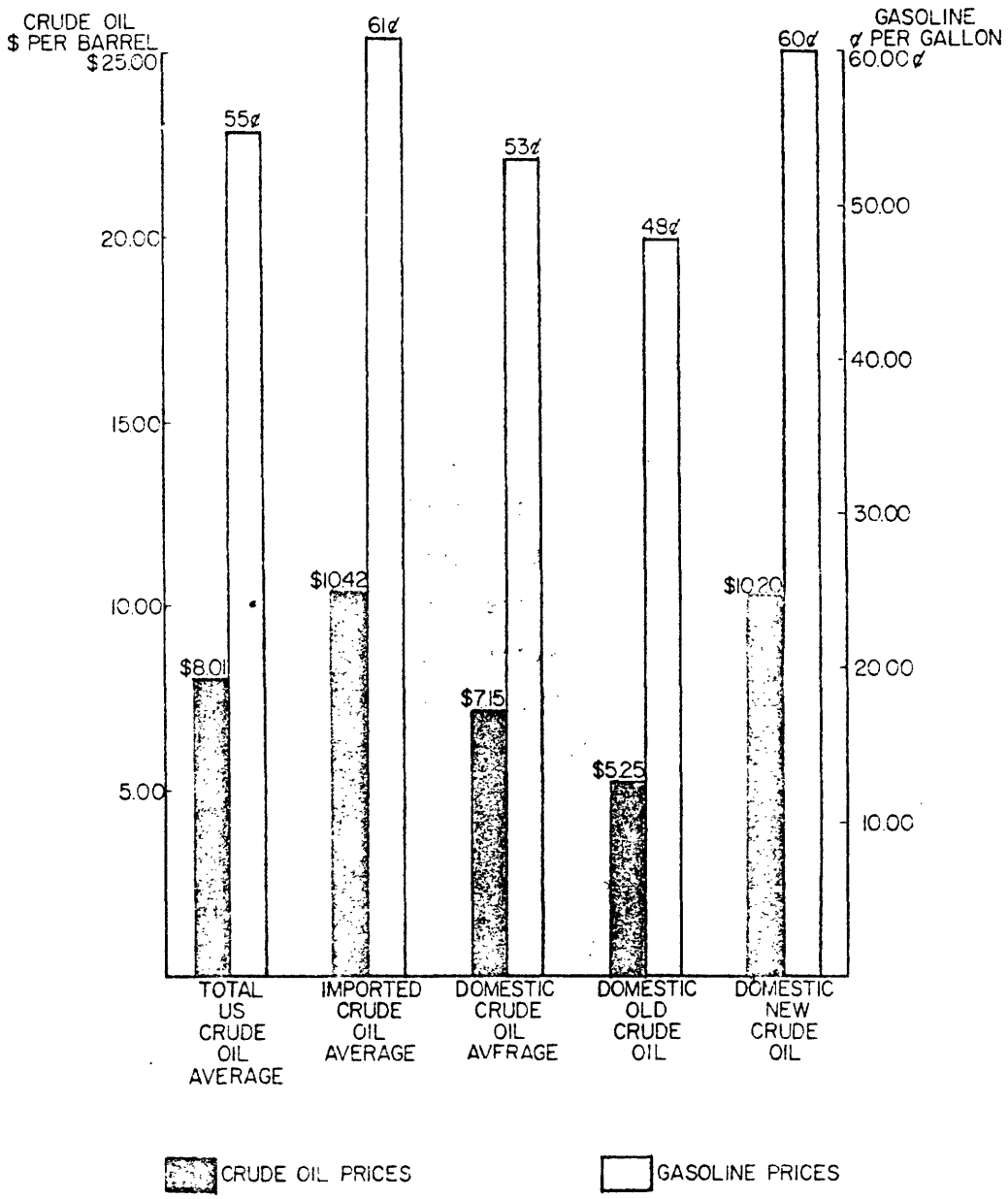


Figure 5*

* Federal Energy Administration, Boston, Massachusetts

believe that major finds will be made, others do not. Environmentalists are concerned about the hazards of such development. The discovery of large reserves and safe production on the outer continental shelf could make a radical change in the import requirements of the region and could have a major influence on the national picture.

Fuel Supplements

With urbanization comes the concentration of vast quantities of solid waste and sewerage. Both represent a small but significant source of energy. Both have to be disposed of in an environmentally acceptable manner which is becoming increasingly difficult by conventional methods. These sources have little sulfur content. Their conversion to synthetic fuels can be accomplished by many of the same processes utilized for coal. Other by-product sources such as industrial process waste, waste heat, and used lubricating and industrial oils are also potential energy sources for urbanized areas. Yet, none of these sources can be considered more than supplementary sources to the basic energy supply.

Solar energy, too, has to be viewed as a supplementary source, albeit a potentially important one. This basically renewable resource has several manifestations other than direct radiation, such as wind and ocean temperature gradients. The distributed nature of solar energy and its variability make it one requiring some form of storage.

Distributed Storage

Geographically distributed storage can be important to the temporal smoothing of energy or fuel demand. One of the major problems of electric utilities is full utilization of capital intensive installed capacity. Their basic load is often little more than half their peak load. Localized storage such as pumped water, compressed air, or fuel is now used to help meet peak demands. Distributed storage at end-use locations, installed for other purposes, such as storage of heat from solar collectors could also be used to reduce peak demand on electric utilities and to foster more efficient utiliza-

tion of the plant installed capacity.

The doubling of the storage capacity of fuel oil at individual residences is another form of distributed storage than can improve efficiency (by reducing the number of delivery truck trips per heating season) in fuel use and lessen the vulnerability of the householder to supply interruptions. Ideally, each residence should be able to store a heating seasons supply of fuel oil.

Project Independence: "Blueprint" and Economics

The recently released results of the FEA Project Independence Study does not, as anticipated by some, provide a "blueprint" for reaching zero imports by 1980. It is rather an evaluation of the nation's energy problem contrasting broad strategic options, viz.

- o Increasing domestic supply
- o Conserving and managing energy demand
- o Establishing standby emergency programs

which are evaluated in terms of their impact on:

- o Development of alternative energy sources
- o Vulnerability to import disruptions
- o Economic growth, inflation and unemployment
- o Environmental effects
- o Regional and social impacts.

No policy recommendations are made. Rather the analytical and factual bases are presented for illuminating choices and alternatives in selecting a national energy policy.

The Policy Study Group* of the M.I.T. Energy Laboratory made an economic evaluation of Project Independence and concluded that "Complete independence from foreign energy supplies is a form of insurance against energy disruption

---

*The Policy Study Group, "Energy Self-Sufficiency: An Economic Evaluation," Technology Review, May 1974 pp. 23-58.

or price increase which the U.S. could purchase only at very high cost." There is growing concensus that reduction of imports to an acceptable risk level rather than to attempt their elimination is the preferred course.

Petroleum Price and Cost

The political climate for the oil importer today produces highly uncertain world oil prices. Economic pressures on many major oil exporters are minimal because greater revenues are not needed to support their economic growth. World oil prices are currently far above production costs of the key suppliers in the Middle East who have 60% of the world reserves. Foreign sources of oil and their prices are likely to be quite unpredictable through 1985. The development of domestic substitutes in the U.S. will be costly, requiring revenue for the product approaching or exceeding current world crude prices at $11 per barrel. With such foreign leverage on world oil prices the U.S. will be forced to subsidize in one form or another the development of domestic substitutes.

If world oil prices remain at or near $11 per barrel the FEA study projects total demand growth at less than 3% per year until 1985 when the expected demand will be about 175 billion barrels (103 quadrillion Btu's or "quads"*), 20-37 billion barrels (12 to 22 quads) below earlier forecasts. Electric demand growth is also expected to be below its recent high rates and petroleum demand is expected to remain constant until 1977 and thereafter to grow only 1-2% per year.

Substitutes

Synthetic fuels and shale oil are not expected to be major contributors before 1985. Neither will be geothermal, solar and other advanced technologies. Nuclear electric power could increase its share of generation from 4.5% to 30%. At this writing, the magnitude of contribution by nuclear generation is still speculative. Quite a few orders for reactors have been

*The term "quad" is often used to represent a quadrillion or 10^{15} Btu's.

cancelled and many that were contemplated are being replaced with coal-fired units.

Problems: Near Term and Long Term

An immediate problem facing the nation is how to deal with emergencies in the near term. Programs would involve conservation, both voluntary and mandatory, fuel switching and fuel allocation, storage and stock-piling capacity, shut-in reserves of oil and gas, and short term measures to increase energy productivity.

The long range approach must include a return to diversification of energy supply as an essential feature. The past concentration on single fuel/energy sources, the inflexibility of our machines and processes with regard to acceptable fuels must be countered with increasing versatility and multiple options in fuels. This diversification can be approached from two directions: the development of alternate fuels for existing equipment and the development of versatile equipment or the modification of existing equipment for greater flexibility in fuel use. Alternate fuels can be utilized immediately upon becoming available, but the time lag for new versatile and use equipment puts that approach farther into the future. The production of alternate fuels will require new plants too, hence there will be delay in their widespread availability.

ENERGY SUPPLY --- ENERGY RESOURCES

Some Definitions

Critical to reasonable projection of future energy supplies is an understanding of the nature and extent of our energy resources. There is a complicated and often confusing terminology associated with estimates of our resources. A few definitions are in order. There is a distinction, for example, between resources and reserves. Reserves are known, identified deposits of minerals that can be extracted profitably with existing

technology and under present economic conditions. Resources include, in addition to reserves, other deposits that may eventually become available---either known deposits not now economically or technologically recoverable, or presently unknown deposits that may be inferred to exist but as yet have not been discovered. For most minerals, current reserves are only a small part of the total resource. However, no potential resources can be produced until they have been converted into the category of reserves by discovery, improvements in technology, or by changes in economic conditions. Supplies are the quantities that could be produced per day or per year. Many factors influence, for example, the supplies of domestic oil and gas that can be developed and produced economically and among them are the drilling rate and the finding rate.

Drilling rates are expressed in millions of feet per year drilled both for exploratory and development purposes. The finding rate is the volume of oil and gas found per unit of drilling effort.

The Evolving Supply Picture

Early in the development of an oil or gas field the finding rates are characteristically high. Within three years after World War II, domestic petroleum was plentiful. A much lower cost source of oil then became available in the Middle East in the 1950's. Drilling activity logically followed the high finding rates overseas so that over the last 10 to 15 years, drilling in the U.S. has declined at a rate of about 4 to 5 percent per year. Production costs in the Middle East were so low that crude oil could be delivered to the United States more cheaply, including transportation costs, than could crude from domestic fields. To protect domestic oil producers, oil import quotas were established in 1959 and maintained until 1973.

Estimates of Proven Reserves

Proven reserves, by definition, are a strong function of market price. Most current estimates however, based on prices substantially lower than the current world market, are lower than they should be. Moreover, there are

striking differences in estimates of total petroleum reserves in the United States causing 30 to 35 year differences in the peaks of cycles of crude oil production. Figure 6 shows U.S. crude oil production in barrels per year up to 1972.* Figure 7 projects production rates into the future for different estimates of the total resource base. An estimate of total reserves based on finding rate came quite close to the figures obtained from the analysis of production, discovery, and proved-reserves data. The complete cycle of crude oil production in the conterminous United States as of 1971 is shown in Figure 8.

Associated Natural Gas, a Bonanza

In the early days of the U.S. petroleum industry, as it is in the Middle East today, natural gas was produced as an unused byproduct of crude oil production. There were no pipelines covering substantial distances and only a small fraction of the gas produced could be marketed locally. The remainder was burned in the open air (flared) at the field. Flaring continued as late as 1945 until the laying of the "Big-inch" pipelines opened markets in the Midcontinent, Northeast, North-Central, and Pacific Coast areas to Gulf Coast natural gas. A Supreme Court decision in 1954 required the Federal Power Commission to regulate prices at the wellhead of natural gas to be sold in interstate commerce. The Federal Power Commission initially set prices at an average level of about 16 cents per 1,000 standard cubic feet (at a pressure of 14.73 lbs/in^2 and 60 degrees fahrenheit). These prices were gradually increased to about 20 cents per 1,000 cubic feet by 1973. The cost of energy from natural gas at 17 cents per thousand ft^3 was about 10% less than from bituminous coal at $4.79 per ton, but only a third that of crude oil at $2.90 per barrel. This cost advantage, in addition to the ease of transportation and utilization and the pollution free character of its burning, produced an accelerated growth in natural gas consumption. This aberration made it necessary to estimate ultimate gas reserves on the basis of a gas to oil

*U.S. Energy Resources, a Review as of 1972, Serial No. 93-40 (92-75), Senate Committee on Interior and Insular Affairs, Committee Print.

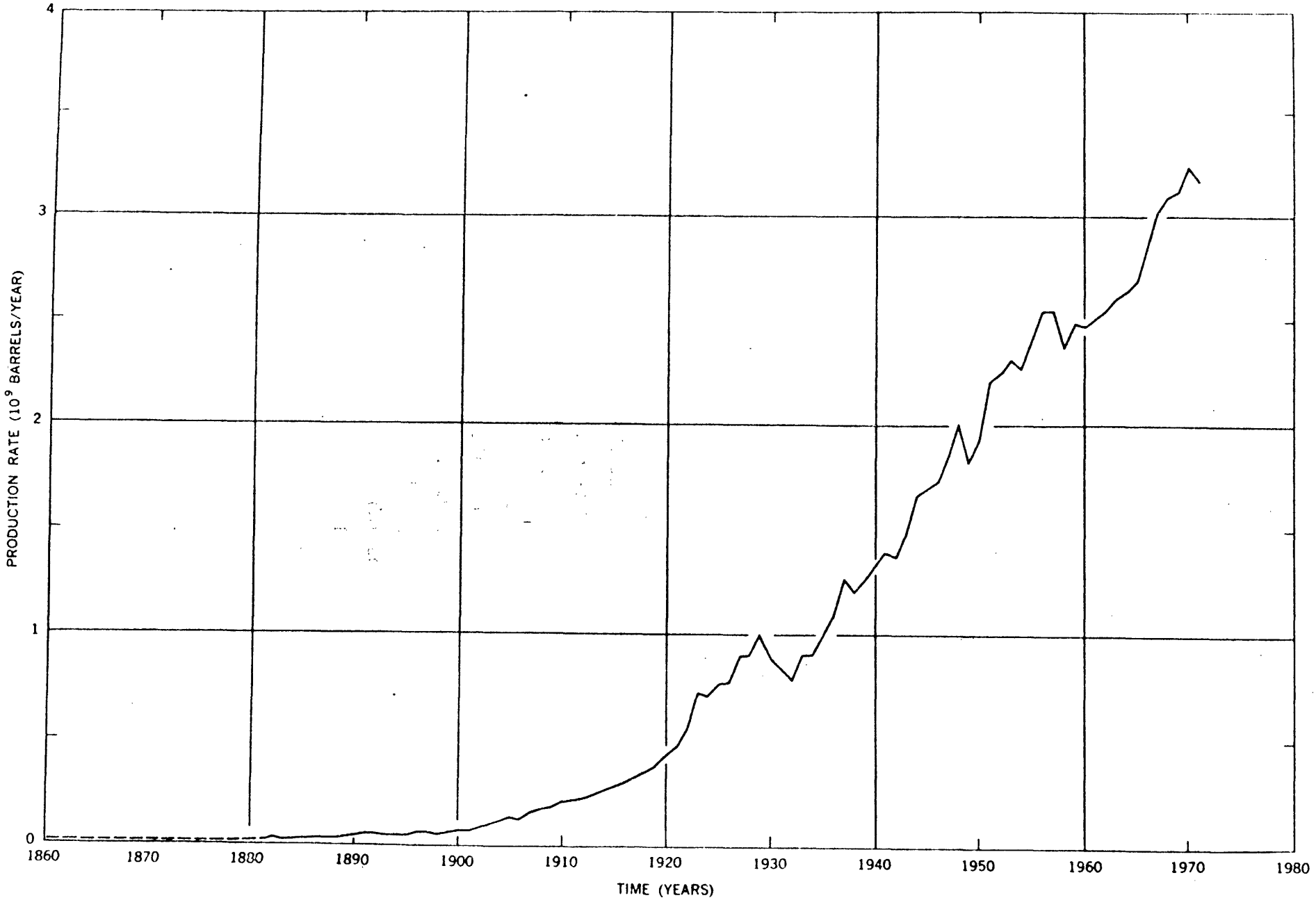


Figure 6: U.S. Crude Oil Production

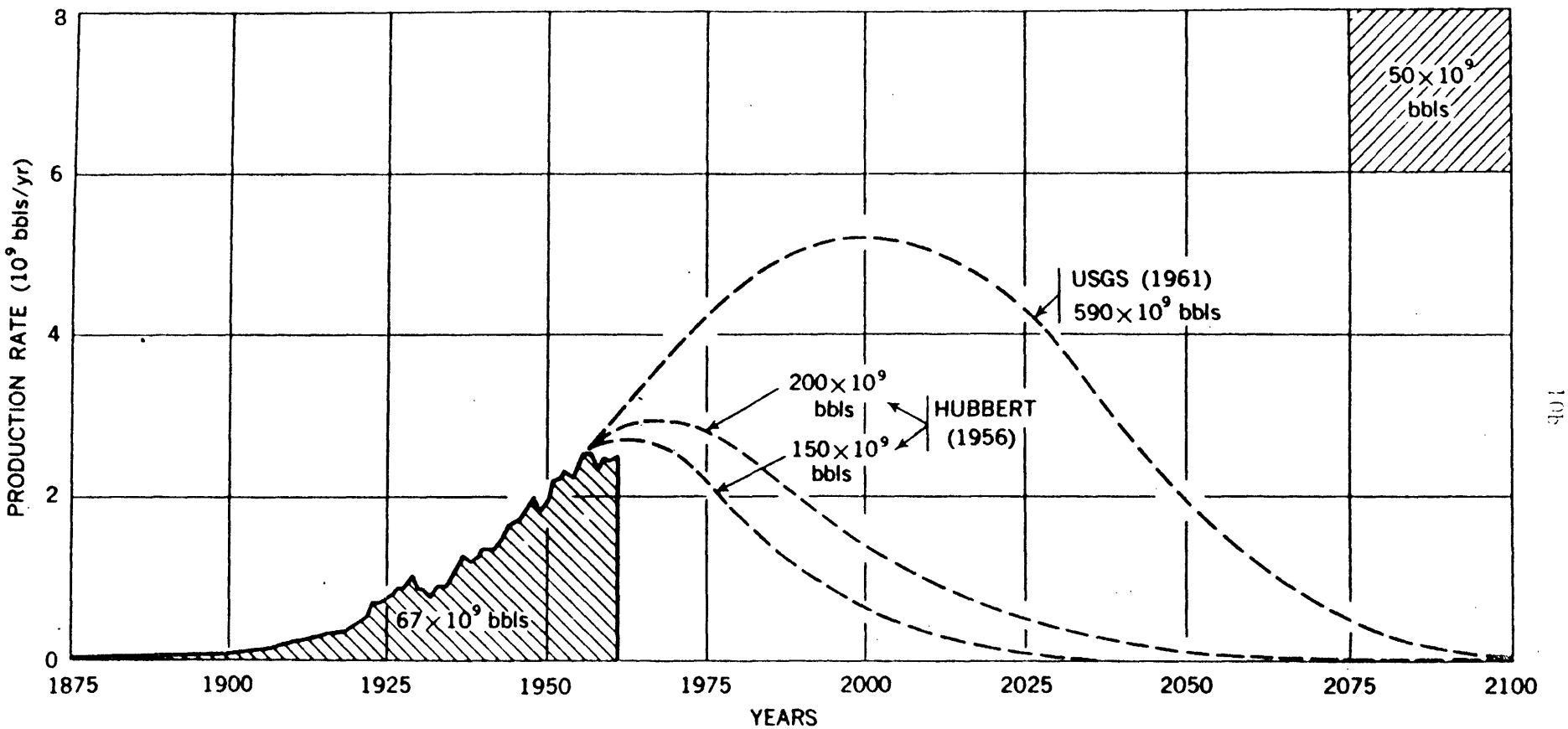


FIGURE 7: Comparison of complete cycles of U.S. crude-oil production based upon estimates of 150–200 and 590 billion barrels for Q_∞.

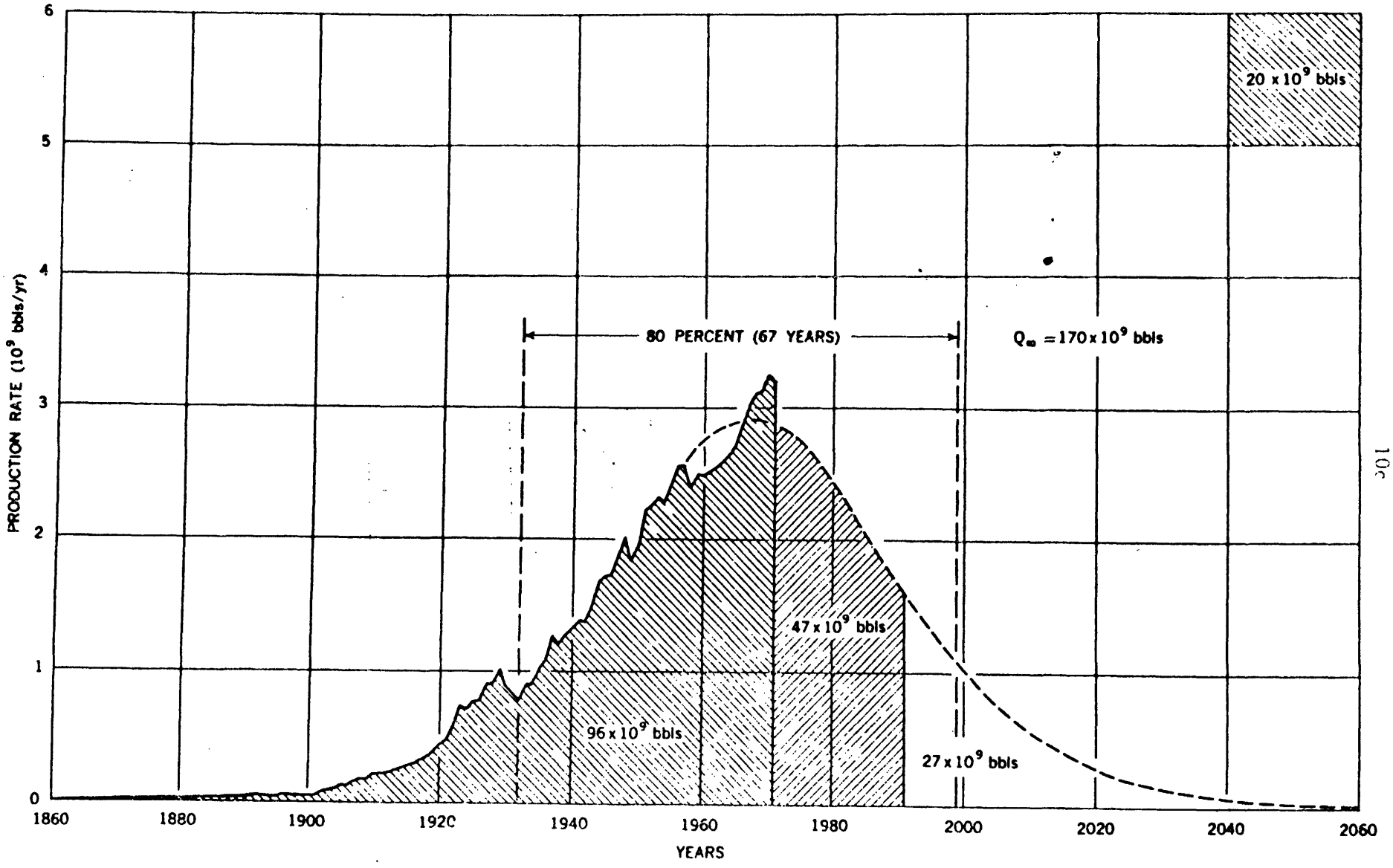


FIGURE 8: Complete cycle of crude-oil production in conterminous United States as of 1971.

ratio. Experience has shown a fixed ratio of gas to oil produced by a field. Multiplying the number for resources of barrels of oil by this ratio gives an estimate of the resources of gas expected. Figures between 6,250 ft^3/bbl and 7,500 ft^3/bbl were used for the conterminous United States to estimate ultimate resources at one quadrillion ft^3. Figure 9 shows the predicted cycles for 2.65×10^{15} ft^3 and for 10^{15} ft^3 total resources.

An attempt to derive a gas-to-oil ratio for another region, the Middle East for example, will be confused by an undeveloped gas market or transport facilities or both. Unlike in the United States where gas, oil, and mixed gas and oil wells of promise are brought into production, a gas well, or one with little oil, is not brought into production in the Middle East. Gas associated with the production of oil is either flared, pumped back into the ground to repressurize the field, or used locally as a fuel. One could use the ratio derived for the United States in estimating gas reserves elsewhere but such an estimate might be very unreliable.

The Cloudy Crystal Ball

To give some perspective to the uncertainties of such predictions let us go back to the petroleum situation as of 1951 and projections as of that time for the period 1952-1965. As shown in Figure 10, the U.S. supply was to have begun a decline in about 1955 and to have dropped from 7 million barrels per day to 5.5 million barrels per day by 1965. In fact, U.S. production increased over that period to about 7 million barrels per day. The point we wish to make is that we should not give undue credence to forecasts (and become alarmed or reassured as the case may be) nor should we ignore the results of the forecasts if we truly understand the bases upon which they were made.

Production of Energy Fuels

There are many common factors in fuel production and consumption. They may be listed as:

- Location

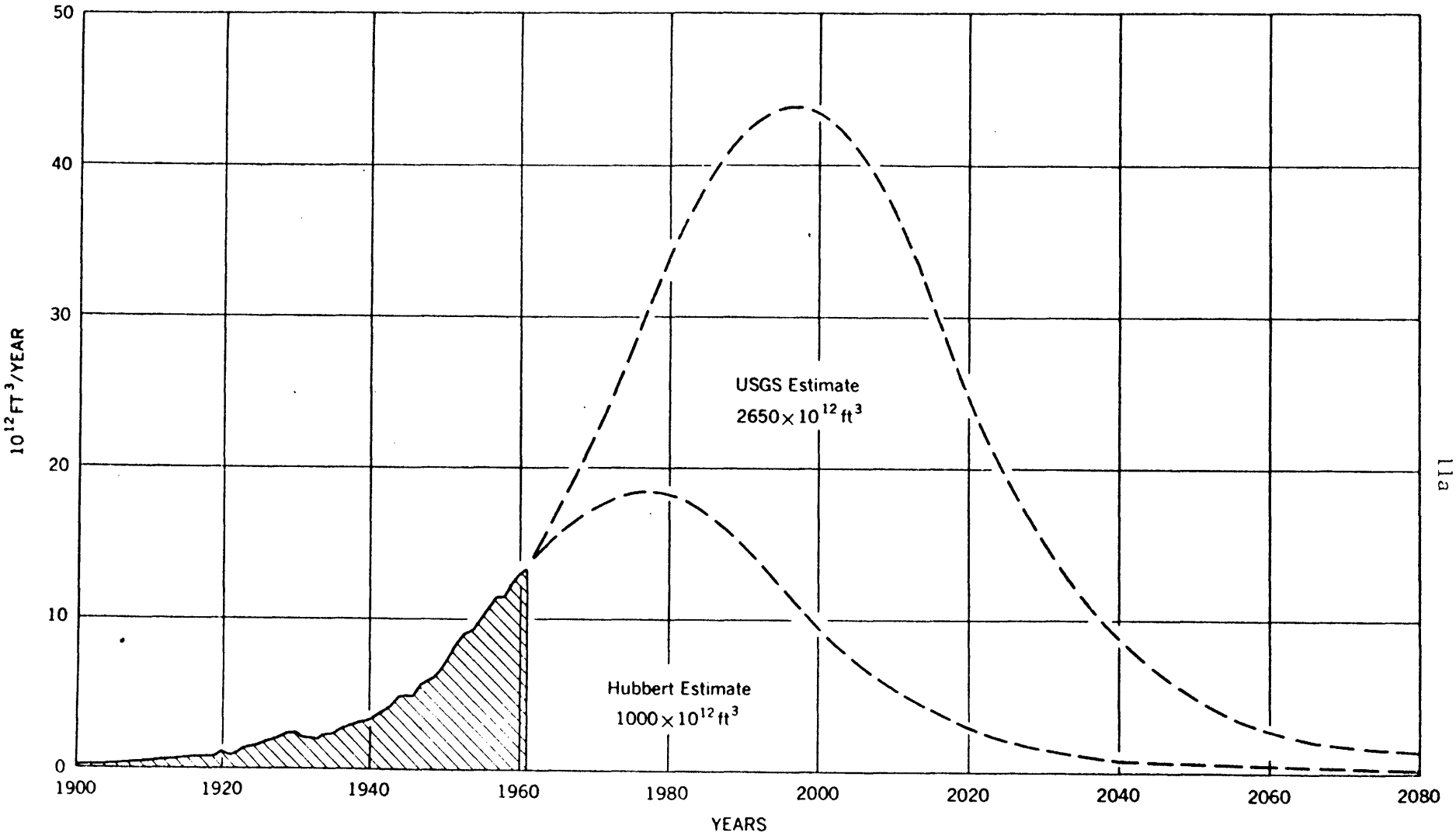


FIGURE 9: Comparison of predicted cycles of natural-gas production for conterminous United States based on estimates as of 1961 of $1{,}000 \times 10^{12}$ ft^3 and $2{,}650 \times 10^{12}$ ft^3 for Q_∞.

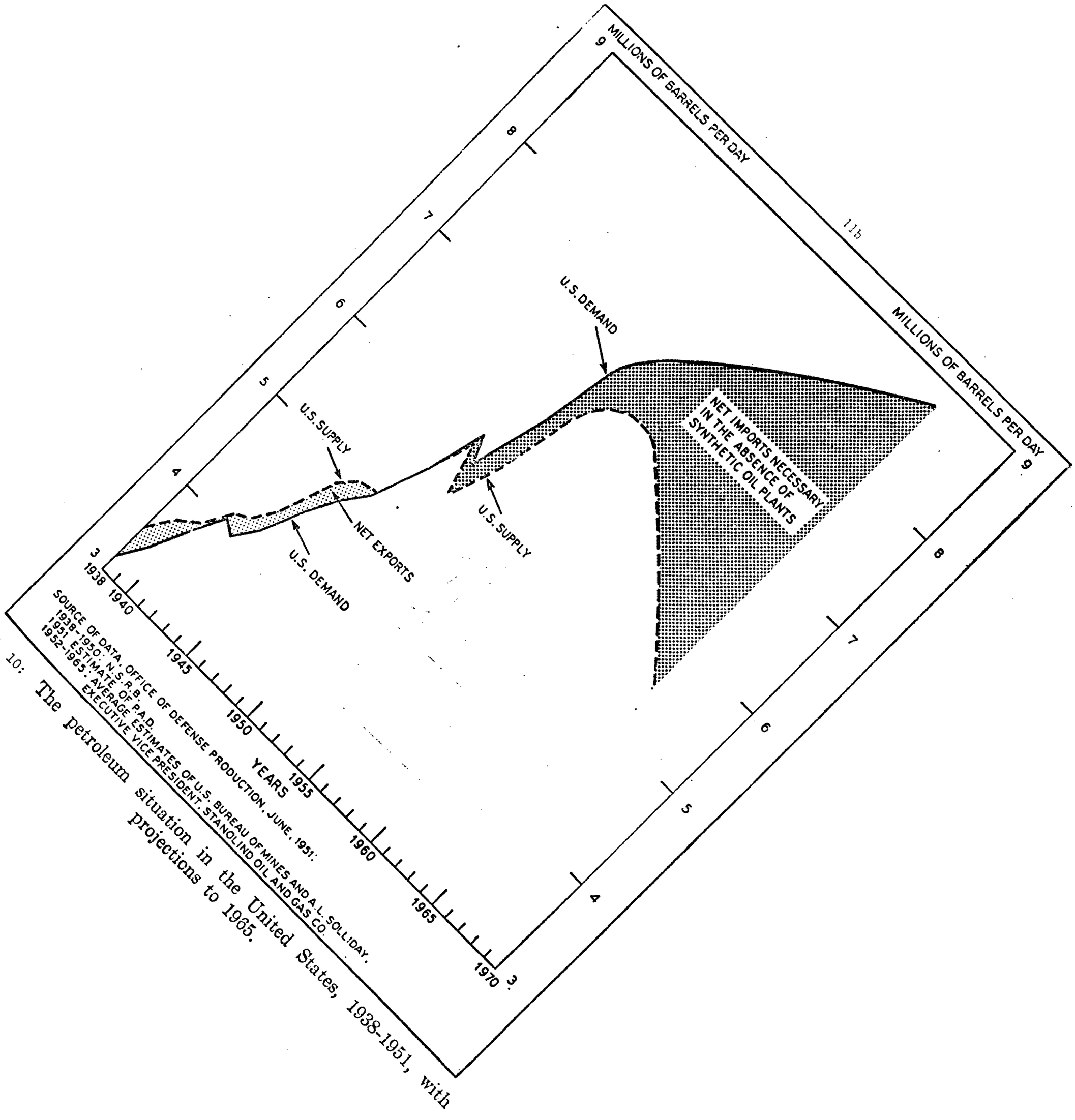


Fig. 10: The petroleum situation in the United States, 1938-1951, with projections to 1965.

- o Extraction
- o Transportation
- o Physical and/or Chemical Processing
- o Refining
- o Storage of Product
- o Transportation to User
- o Storage at User Site
- o Utilization
- o Use or Disposition of By-Products.

In considering the production of alternate fuels to those in common use, the existence of and the commonality of some of the factors can have important implications to the viability of the alternates. Those fuels that can exploit existing facilities have a better chance of early acceptance.

There will also be inter-fuel competition for production resources:

- o Capital
- o Manpower
- o Materials
- o Manufactured Products
- o Energy or Other Fuels
- o Transport and Storage.

All alternatives under consideration will require vast amounts of capital, much the same skilled manpower for the construction of plants, and many of the same materials, for example steel. There will also be competition for pipe, valves, compressors, boilers, and similar components of the modern processing plant. This competition directly affects costs of construction and can escalate them. There will be some projects which can begin and finish on schedule some which will be delayed and others not started at all.

Alternative Fuels from Coal

Coal can be converted to either gaseous or liquid form. Routes to

clean fuels from coal are shown in Figure 11.* If the simple gasification step involves combustion with air, the result is low Btu gas containing considerable nitrogen from the combustion air. If oxygen is introduced for combustion, medium Btu gas results as it does in the case of hydro-gasification. These products can be converted to synthetic natural gas through a methanation step, to a clean liquid by conversion to methanol, or to liquid hydrocarbons by the so-called Fischer-Tropsch process.

Liquefaction can be accomplished through pyrolysis and hydrotreating to remove sulfur and improve the hydrocarbon product. The coal can also be dissolved in a solvent from which ash, including pyritic sulfur, can be filtered. The solvent is then removed leaving a heavy synthetic crude oil which can be treated with hydrogen to remove organic sulfur and to improve the product quality. The various techniques for making fuels from coal are difficult to compare because some processes produce very different mixes of products which might vary over a considerable range, while others primarily make synthetic natural gas or primarily synthetic crude oil.

All these processes involve environmental problems associated with the enormous plants that must be located to have access to huge quantities of coal and the necessary process water. Run-off waters from wastes will carry dissolved contaminants which also represent an environmental problem.

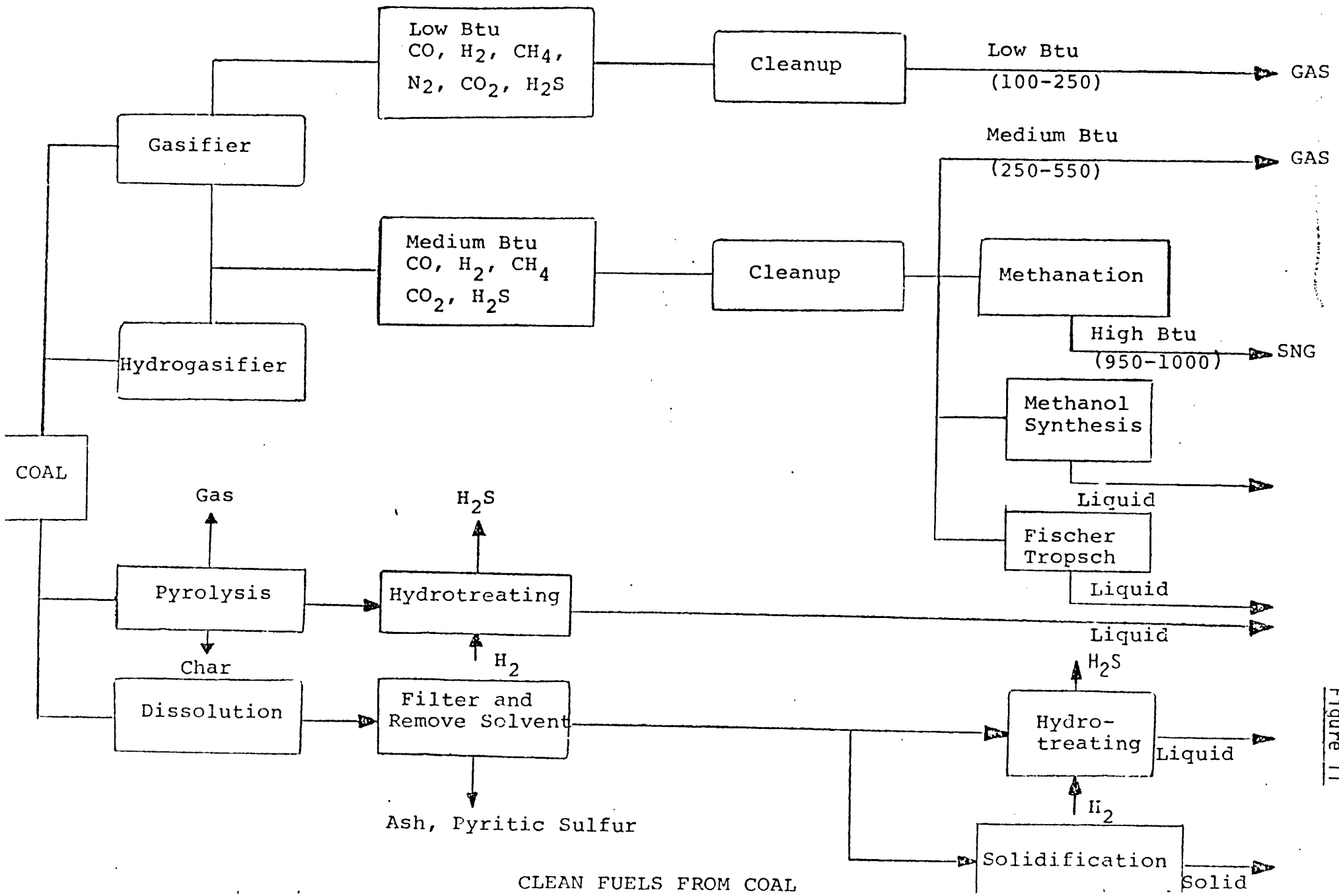
The associated mining facilities will be correspondingly large, especially when strip mining is practiced. See Figures 12a,b. Large quantities of coal ash must be disposed of. The coals used will produce five to twenty percent of their weight in ash.

A Basis for Comparison

For comparison purposes, synthetic fuel plants are generally taken to

---

* W.W. Bodie, and K.C. Vyas, "Clean fuels from coal", The Oil and Gas Journal, August 26, 1974, pp. 73-88.



CLEAN FUELS FROM COAL

Figure 11

Example of Large Equipment Used in Area Type Surface Mining in West Kentucky.
Courtesy of Bureau of Mines, U.S. Dept. of the Interior

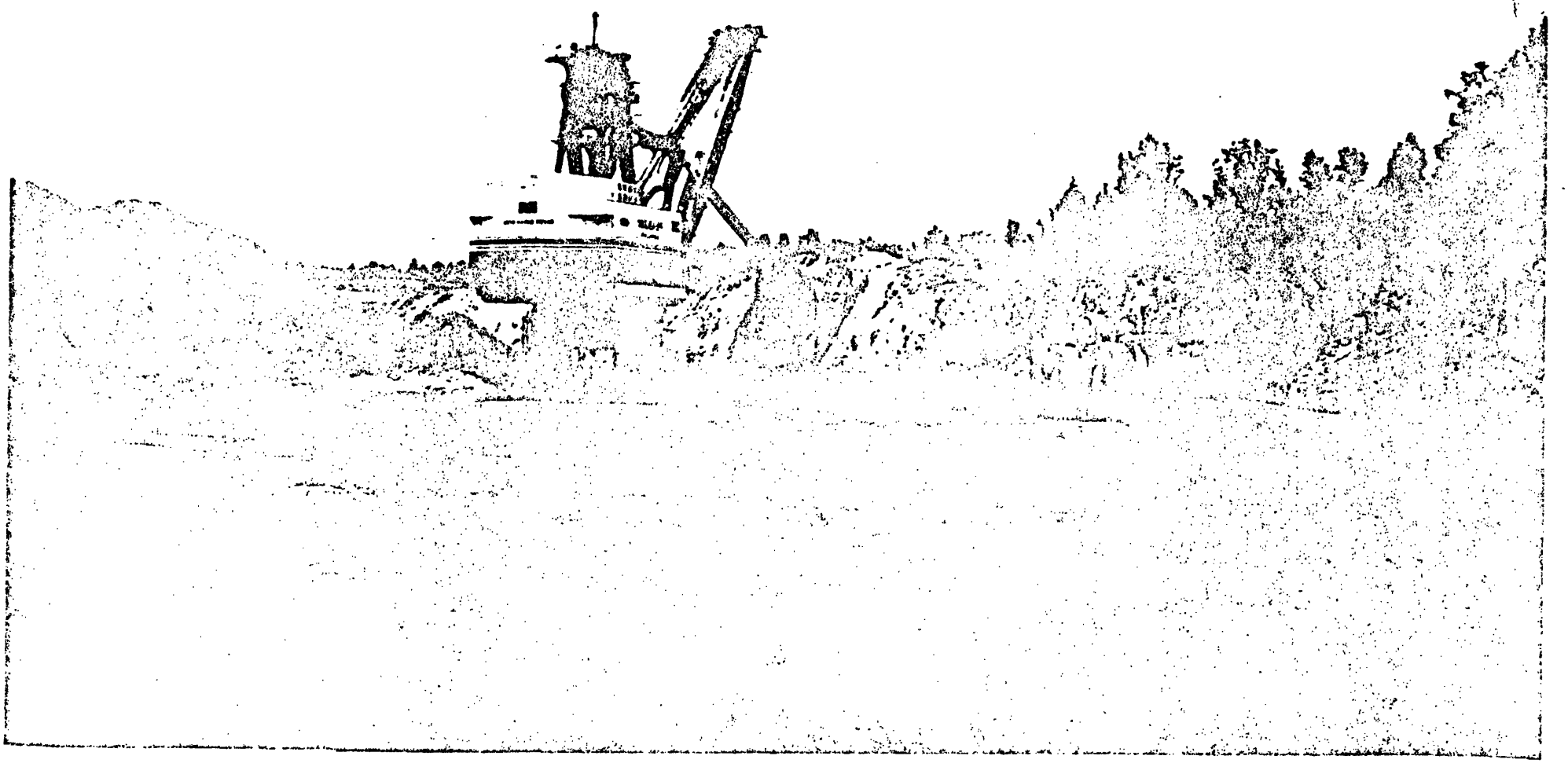


Figure 12a

Aerial View of Contour Strip-Mining
in Tennessee
Courtesy of Bureau of Mines, U.S.
Dept. of the Interior

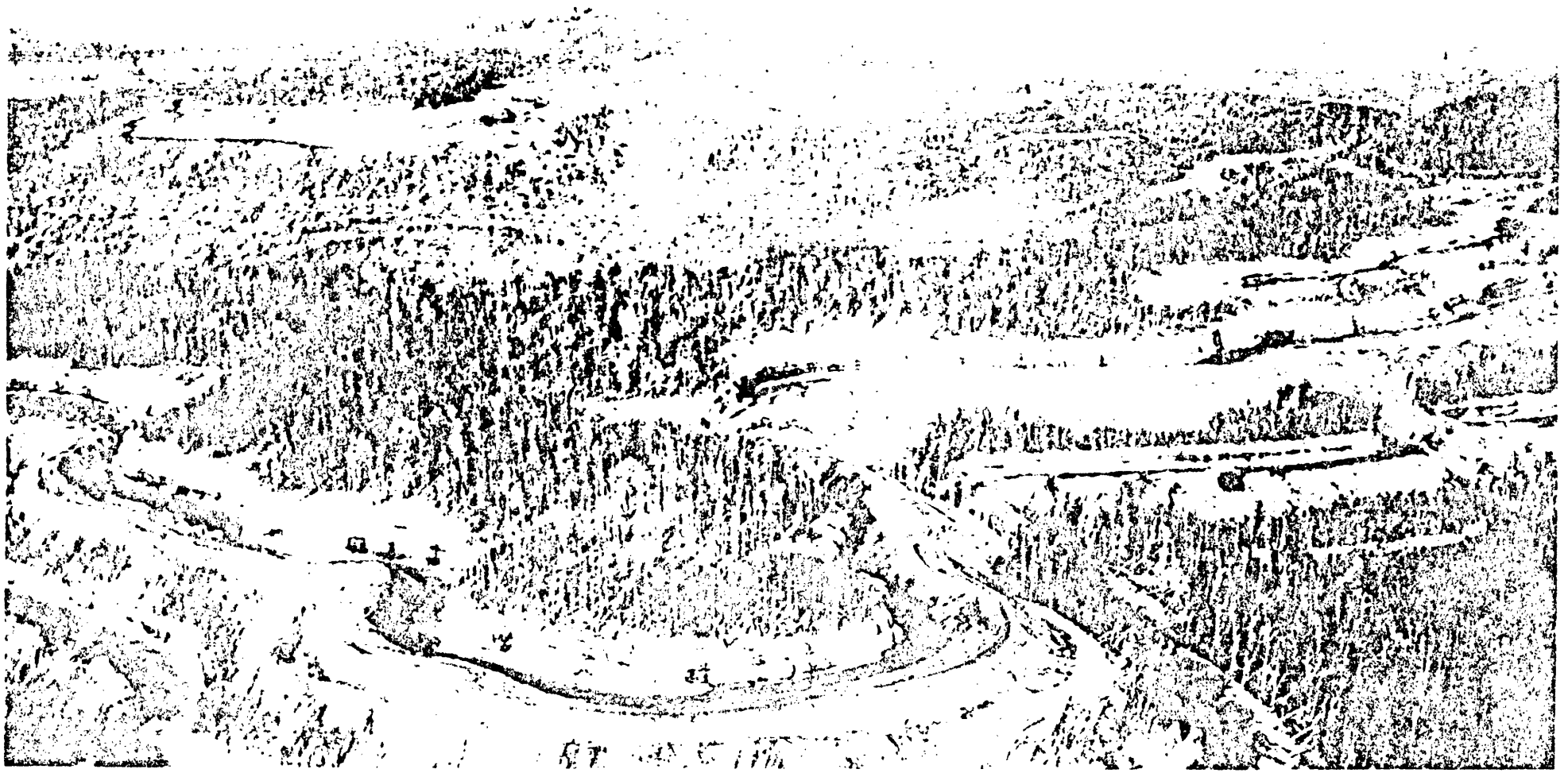


Figure 12b

have a production capacity of a fuel having a total heating value of 250 x 10^9 Btu/day. (The heating value required to operate a 1000 megawatt electric generating plant full time.) A synthetic natural gas plant of this capacity (250 million cu. ft./day) would consume perhaps 16,000 tons of bituminous coal daily. A 40,000 barrel per day synthetic crude oil (syncrude) plant is equivalent to the gas plant in heating value and would consume perhaps 10% less coal.* To produce a major fraction of our daily consumption of either gas or crude oil, say 1/4 or 1/3, would require 100 each of the coal-to-gas and coal-to-oil plants.

The costs of synthetic fuel plants are remarkably similar for all processes under consideration, with capital costs falling into a range of $300 to $500-million for the plant size considered.

These capital, operating and feedstock costs of synthetic fuel plants are pushing product costs to values between $1.50 and $2.00 per million Btu which is equivalent to oil in the $9.00 to $12.00 per barrel range. See Figure 13. If one allows for profit and return on capital investment, the cost to the consumer is estimated at between $12.50 and $16.50 per barrel equivalent of oil. This is a high price indeed considering the far lower production costs of much of the world's natural crude and in particular that of the Middle East. In light of this foreign leverage on the market place it is likely that if synthetic fuel plants are to be built using today's technology some form of subsidy will have to be provided.

Building U.S. Synthetic Fuel Capacity

Because most of the "second generation" processes for synthetic natural gas (SNG) and syncrude are still in pilot stages at best, design and construction of large commercial size plants, using one of these processes without benefit of experience gained in incremental stages of size would involve

*These factors depend upon the energy contents of the feed coal used and the efficiency of the plant as operated.

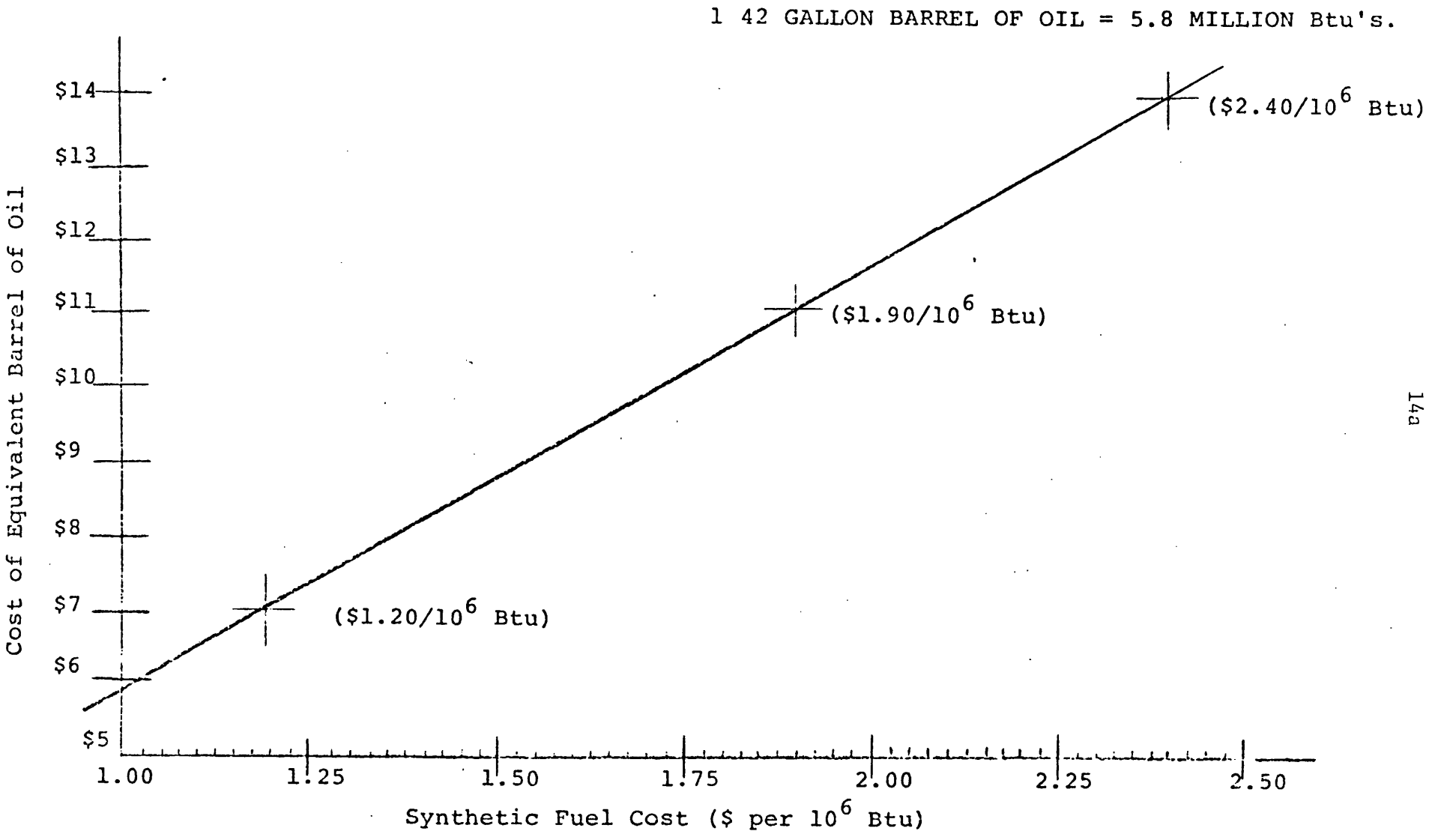

1 42 GALLON BARREL OF OIL = 5.8 MILLION Btu's.
Cost of Equivalent Barrel of Oil
$14
$13
$12
$11
$10
$9
$8
$7
$6
$5
($2.40/10^6 Btu)
($1.90/10^6 Btu)
($1.20/10^6 Btu)
1.00
1.25
1.50
1.75
2.00
2.25
2.50
Synthetic Fuel Cost ($ per 10^6 Btu)

Figure 13

serious risks. Operations might limp along at a fraction of design capacity, for example, and could thus incur very high costs. In light of this there is serious question as to the degree of process scaling that can be done to ensure confidence in a plant size where economies of scale become effective. What degree of scaling can we live with? 10:1 or 2:1? We cannot expect to get off scot-free with energy refineries on the scale contemplated. There is no experience in any related field that would lead us not to expect developmental difficulties. Nuclear power, for example, has been twenty years in the maturing process and still has problems.

The time to design and construct a typical syncrude plant, once prototype experience is available, is about five years and requires 1.5 million man hours of technical labor and 10 million man hours of craftsman and manual labor. Because product costs are so similar for most of the processes now being put forward there would be little benefit derived from exhaustive development of them all. The thrust of new technology should be in the direction of the development of new processes which can substantially reduce product costs. One advance of extreme importance to the whole of the synthetic fuel industry is the large scale, low cost production of hydrogen, preferably from water. Not only is hydrogen a clean synthetic fuel, but also it plays an important role in the synthesis of all other synthetic fuels and many essential chemicals such as ammonia.

An Example from History

In 1924, Germany faced an energy crisis. World petroleum supplies were dwindling and were not expected to last more than a few decades. Neither did Germany want to become too dependent on foreign sources. Germany's largest chemical concern, I.G. Farben, with a strong background in the development of processes and production plants for synthetic ammonia and methanol decided to make a heavy investment into development of processes for making gasoline from coal. Projections of gasoline price as of 1924 in light of forecast dwindling supplies showed heavy increases. Because problems had arisen with the process, one far more complex than anticipated, it took five years of

intensive work and heavy investment to surmount technological problems and to approach cost objectives. However, the depression of 1929 and the discovery of abundant crude oil in Texas made the price in Germany of domestic synthetic gasoline many times the price of imported gasoline---an economic disaster for the company. It was only the Nazi interest in an indigenous gasoline supply that saved the Farben project by guaranteeing them in 1933 an acceptable price for synthetic gasoline.

Crude oil is no longer considered abundant in Texas, but the state's energy reserves in the form of lignite exceed by a significant margin its total oil reserves.

Oil From Shale

There are vast resources of shale in the western United States. The Green River Formation of Eocene age in western Colorado, northeastern Utah, and southwestern Wyoming, a total area of about 16,000 square miles, is estimated to contain 1,800 x 10^9 barrels of oil. Of this, only 5% (90 x 10^9 barrels) is considered sufficiently high grade and accessible enough to be worth present consideration.

There are a number of extraction processes under consideration. In one for an assumed capacity of 10^5 barrels per day of synthetic crude oil production, two mines of capacity 62,500 tons/day each would be required. The shale is retorted at temperatures above 1,100°F which in addition to releasing the kerogen forms highly alkaline by-product waste. The water requirements are estimated to be 16,000 acre-feet (7.0 x 10^8 ft^3) per year.*

The above capacity would not support a very large fraction of present crude consumption. If 10 such plants were operated, the production rate would be 1 million bbl/day but would involve the mining of 1.25 million tons of oil shale per day which is almost the present annual coal production of the United States. The daily volume of shale required would be 523,000 m^3.

*This applies specifically to a narrow section of the "Mahogany Ledge of the Green River formation, a small fraction of the total.

What would be the effects of this exploitation on the local environment and upon water supply of the Colorado River drainage basin in which all of the oil shale deposits are located? Spent shale is highly alkaline and far more water permeable than the kerogen impregnated shales. There is a good chance that large amounts of alkaline-saturated water would find its way into local streams of the Colorado River system.

The available water supply in the region is already doubtful for a shale-oil production rate of 10^5 bbl/day to say nothing of an operation rate ten or more times larger.

In light of the above, there is increasing skepticism about the viability of extensive surface production of oil from shale expressed by companies having bid hundreds of millions of dollars for their leases and by Montana Governor Thomas L. Judge who warns that land and water supplies cannot support both an expanded agricultural economy and a full scale energy development.

Nevertheless, Morton M. Winston, President of The Oil Shale Corporation (TOSCO) has announced that the first commercial oil shale complex located at Parachute Creek, Colorado will begin operation by spring of 1975.* The plant will produce 46,000 bbl/day of refined products which is equivalent to the production of 51,000 bbl/day of crude. Operation at this scale will help evaluate the process and the technical and environmental problems involved. The disposal of spent shale in an environmentally acceptable way may or may not be demonstrated in this commercial scale operation.

In situ retorting of shale, on the basis of very preliminary information, appears to be essential to substantial growth of shale oil production in the last decade of this century. Fundamental to future success is the development of an environmentally acceptable process of improved efficiency.

*Problems will delay start-up.

UNCONVENTIONAL ENERGY SOURCES

Conservation as a Source of Supply

In the same sense that a penny saved can be considered a penny earned a unit of energy saves is at least a unit of energy produced. Since electric generation by thermal processes (steam turbines, gas turbines, etc.) is only about 33% efficient, a unit of electrical energy saved is in fact 3 units of fuel (oil, gas, coal, etc.) energy. The "at least" enters because we must make an allowance for the environmental effects of our production of energy and/or fuels. Whether by frugal practice, improved efficiency, or an alternate substitute, the fuel/energy saved can do more good for the environment than tightening antipollution requirements. Clearly more parsemony and less prodigality is needed in our use of energy resources.

Advances in efficiency and development of alternative sources will permit economic growth in spite of reduced consumption of exhaustible resources. Improved efficiency also implies a lessening of the environmental impact of energy use. For example, a 10% improvement in efficiency, certainly a nominal improvement, of a previously 40% efficient plant means a 25% savings in fuel! There is much to be gained by small improvements in the efficiencies of our least efficient energy consuming devices. Moreover, these least efficient end uses offer the greatest opportunity for improvement.

Incentives

Many believe that the increased price of fuels and energy is an adequate incentive for conservation. For the first time in many decades we have seen a break in the trend of increased energy consumption in late 1973 and 1974. Because oil has shown the greater reduction in consumption and has more than tripled in price, it is tempting to infer price elasticity in demand. However, it is still too early to say how much of this curtailment of consumption was a result of increased price and how much a result of shortage of supply. The consumption of motor fuel in the U.S. has shown the first decline since 1943 and is expected to be about 100 billion gallons in 1974, a decrease of

3.5% over 1973. There were no shortages in the later months of 1974 yet daily average sales were consistently below those of a year earlier.

With gasoline shortages fresh in the public's mind, and with grave uncertainties about future supplies and their cost, the American car buyer decided to stand pat. Inventories of unsold cars began to grow. Cars built for inventory are frequently loaded with options, many like air conditioning and additional weight, reduce fuel economy. With many production lines shut down, the customer faced a long wait for the small car stripped of options he only recently decided he should have. The impact of this on the automobile industry has been devastating.

Conservation/Productivity in Industry

Industry, it is believed, can and will be more responsive to increased energy costs than can the individual or small group consumer. Potential savings in five of the most energy intensive industries have been identified in a report by the Thermo Electron Corporation.[‡] A summary of their results is in Table II. With today's technology, the study indicates that specific energy consumption can be reduced by 35% in iron and steel, by 25% in petroleum refining, by 39% in paper, by 20% in primary Aluminum Production, and by over 40% in Cement.

‡Thermo Electron Corporation, "Potential for Effective Use of Fuel in Industry." Thermo Electron Corporation, Waltham, Mass., April, 1974.

Table II[‡]

COMPARISON OF SPECIFIC FUEL CONSUMPTION OF KNOWN PROCESSES WITH THEORETICAL MINIMUM FOR SELECTED U.S. INDUSTRIES
(Btu/ton)

	1968 Specific Fuel Consumption	Potential with 1973 Technology	Theoretical Thermodynamic Minimum
Iron & Steel	26.5	17.2	6.0 millions
Petroleum Refining	4.4	3.3	0.4 millions
Paper	*39.0	*23.8	**Greator than -0.2 millions Smaller than +0.1 millions
Primary Aluminum Production***	190	152	25.2 millions
Cement	7.9	4.7	0.8 millions

*Includes waste products consumed as fuel by paper industry
**Negative value means that no fuel is required
***Does not include effect of scrap recycling

‡Thermo Electron Corporation, "Potential for Effective Use of Fuel in Industry." Thermo Electron Corporation, Waltham, Mass., April, 1974.

A former British Government body established in 1954 to assist in the improvement of efficiency of energy use is now a successful private company. The National Industrial Fuel Efficiency Service. Ltd. Activities over two decades permit the company to offer an enormous amount of experience in fuel saving techniques. In their first 15 years of operation it is estimated that measures implemented or recommended by them saved at least 20 million tons of coal equivalent. Heat and power surveys carried out over a reasonable sample of industrial groups indicate the potential savings realizable in a number of British industries:*

Potential Fuel Savings

Industrial Group	Average Savings (%)
Ceramics , brick, glass	15.0
Chemicals	18.0
Iron and steel	20.0
Engineering and metals	18.0
Textiles and leather	15.0
Food, drink and tobacco	15.0
Other manufacturing	21.0

*W. Short, "Making energy value for money," Nature, Volume 249, June 21, 1974, p. 715.

Petroleum refiners have committed themselves to reducing internal fuel consumption 15% or about 200,000 barrels daily by 1980. The FEA is seeking similar commitments from producers of cement, aluminum, chemicals, steel and paper.

Operational Methods

Substantial progress has been reported by industry in using essentially operational methods of reducing energy use per unit of production. These efforts are described in Senate Commerce Committee, Print 35-814, "Industry Efforts in Energy Conservation."

Most industries have established energy management programs which are considered by the National Petroleum Council to offer the major potential for energy conservation. The NPC identified conservation constraints as:

- o Capitol
- o Technical Manpower
- o Environmental Standards

and incentives as:

- o Increased Fuel Costs
- o Potential Shortages.

An appropriate conservation program for individual industries can only be established on the basis of a detailed and comprehensive energy audit of operations. There is a need to develop further field measurement technology that will permit reliable, rapid, accurate, and inexpensive audits of energy use.

In increasing numbers, operators of commercial buildings are establishing building energy management systems which result in significant energy savings. The EXXON building in New York and One IBM Plaza in Chicago are but two examples of this growing trend. In the EXXON building electrical demand (kilowatts) was reduced by 27%, electrical energy (kilowatt hours) by 32%, and steam quantities (used in heating, ventilation and air conditioning) by about 40%. At the all-electric IBM building in Chicago annual savings of

$140,000 for electric power and $73,000 for manpower were realized with a computer controlled conservation system. There was an $18,000 charge for computer maintenance, supplies and power. Net annual savings came to $195,000.

Consumer Conservation

It will be more difficult to develop and implement conservation strategies in the consumer market. A first step is to develop information on consumer energy use patterns and on causes of excessive use. Generalized recommendations are to be avoided. If the resources the consumer has to lessen his energy needs are limited, as they undoubtedly are, it is essential that he use these resources to correct his most serious problems. It would be inappropriate, for example, for a homeowner to install additional insulation when air infiltration was his major problem and weatherstripping, caulking, or other measures to improve building tightness would produce a greater return in fuel savings for his investment.

Unfortunately, the consumer does not have a technological advocate. His purchasing power for conservation techniques is neither concentrated nor adequately identified to represent an attractive enough market to foster the development of a conservation service industry. There is no "product" in the ordinary sense. Improved energy productivity techniques (getting more for less) at the individual consumer level apparently does not appear to many as a "marketable item". In aggregate he consumes a substantial fraction of our energy, but in detail his needs can be diverse.

Regional Factors

New England, the Middle Atlantic and East North Central states consume about half the petroleum and natural gas used in the Household/Commercial sector. In New England, for example, 75% of residential and commercial space heating is done with oil. As was pointed out earlier, the region is heavily dependent upon imported oil. Improvements in the efficiency of operation of oil burning furnaces can be a major source of "saved" oil for the region. It is important that attention be paid to the extant furnace stock because it

would take twenty to thirty years for codes and efficiency requirements for new buildings to have a significant effect on fuel consumption. This is but one example of the need to examine energy use on a regional basis to identify those areas where improved energy productivity can have a most important effect on regional fuel consumption.

ALTERNATIVES AND SUPPLEMENTS

Urban Solid Waste

In areas of high population density, urban solid waste can be an important supplementary source of energy. We already have in operation electric generating plants that use solid waste to supplement regular fossil fuels, and solid waste is used as a source of energy for a municipal district heating/cooling system.

It is estimated that Americans produce between 200 and 300 million tons of solid waste a year, about a ton for every man, woman and child in the country.‡ At present we dispose of 90% of our waste in landfills, 8% in incinerators, and 2% by other means. Urban solid waste consists typically of 40-45% paper, 20-25% organic materials, and the remainder, metals and glass. Experience at the St. Louis-Union Electric Co.* has shown that solid waste, sampled over a 10-month period with only magnetic metal removed, had an average heat content a little less than half that of Illinois coal. Union Electric Co. currently fires a mix of 10% solid waste with coal to produce electricity. Solid waste is a supplement. The large power generating facilities frequently cited as the best example of refuse burning, usually obtain less than half their total heat input from refuse. The new $70-million plant

---

‡Heat equivalent to 80,000 tons coal, 300,000 barrels of oil.

*F.E. Wisely, "City of St. Louis-Union Electric Co. Energy Recovery Process Solid Waste as a Boiler Fuel", presented at the U.S./Japan Energy Conservation Seminar, San Antonio, Texas, February 1974.

being built by Union Electric to derive about 6% of its electric power production from solid waste will draw trash from St. Louis plus six adjoining Missouri and Illinois counties.

Pros and Cons of Direct Combustion

Solid waste must be considered a supplementary, not a substitute fuel. Even in the most heavily urbanized areas, where solid waste is concentrated, the energy to be drived from waste will be only a fraction, albeit an important one, of energy needs. Because of solid waste's low sulfur content, it can be burned with higher sulfur coal (the percentage depending upon the mix) and yet meet sulfur emission standards. Solid waste is a growing problem for most major metropolitan areas because they are running out of places to put it all. New York City for example, expects to overflow its available disposal grounds in the next few years. More than twenty cities are looking for solutions.

The economics of solid waste management have to be considered in the total context. Environmental costs such as land use by continued expansion of landfills, the failure to recycle resources, the effects of landfill drainage on water resources and many others must be factored into cost-benefit analyses. Annual operating costs of the Union Electric facility are expected to be about $11.00/ton of solid waste at a 100,000 ton yearly rate. For this $11-million annual operating expenditure Union Electric could save up to $10-million in fuel, while helping solve the urban area's solid waste disposal problem.

Clean Fuels from Urban Solid Waste

Solid waste can be converted to other clean fuels with processes nearly identical with those used for coal gasification or liquefaction. The chemistry is substantially the same, only the pre-processing and handling is different. Technological advances in coal processing can have an important impact on the economic and technical feasibility of clean fuels from solid waste plants. It is not inconceivable that solid waste from the East Coast

megalopis could be transported to coal refineries near Appalachian mines for concurrent transformation with coal to clean fuels. The same transport that delivered coal to urban industry might return to the mines loaded with solid waste to be processed into clean fuels.

Rural Waste to Supplementary Fuels

Rural waste products such as manure, crop by-products, tree farming by-products are also potential sources of clean fuels. Manure can be readily converted to methane gas. Because of the dispersed nature of these products, their use in large scale energy plants is quite limited, though some farms and feedlots could be energy fuel self-sufficient. The converters, however, would have to be designed, manufactured and distributed in a consumer oriented market. For widespread applications of such techniques, a whole industry would have to be developed including marketing and servicing. It takes years under ideal conditions to develop such an industry.

Solar Energy Supplements

Solar radiation can be used to generate electricity and heat. The application of solar energy closest to commercial practice is for domestic hot water and space heating. The use of solar energy for cooling of living space is possible and a demonstration program in an elementary school in Atlanta, Georgia has been begun. These applications of solar energy are also consumer oriented and require the development of a consumer oriented industry to fully exploit the potential of solar space heating and cooling.

The variability and availability of solar energy makes some form of energy storage essential or else conventional energy sources must be available for "stand by." Experience has shown that for most areas of the United States it is not economical to build a large enough thermal storage system to accommodate all the sunless days that might be encountered. An auxiliary heating system is needed. Two of the most practical thermal storage media are water and crushed rock. Water storage is readily adaptable to hot water heating systems and rock to hot air systems. On the basis of first cost,

electric resistance heating is the most economical supplementary system. As reliable heat pumps become widely available, solar supplemented systems operating in conjunction with heat pump heating and cooling could offer significant reductions both in life cycle costs and in demand for conventional fuels.

The development of reliable, consumer oriented components for solar heating and cooling systems is required to realize the full potential of solar energy in this sector.

Distributed Energy Storage

If solar supplement heating were widely adopted, and electric power used for make-up, the electric utilities would in fact have a form of distributed storage for electrical energy in the form of heat. Demand for supplementary electric heat for storage could be limited to off-peak demand periods, and use of heat from storage during peak demand periods could lighten the utility's peak load and permit more economical production of electricity. Electric heating systems with thermal storage are in use in Europe at the present time.

Solar Electric Power

Direct solar derived electric power is farther away. Inexpensive, reliable, mass-produced solar cells are needed. Electric power conversion equipment has to be developed to handle the transformations of power necessary to run our domestic electrical equipment, and to store surplus electric energy for the sunless periods. Substantial progress is being made in these areas, but the consumer oriented product is still years away.

Solar energy converted to heat and thence to electric power requires large areas of focusing collectors which have to track the sun in one dimension at least. A central power plant to develop 1000 megawatts of power continuously would require a collector area of at least 22 square kilometers in the relatively sunny southwest, and would be twice that large for a New

England location. Focusing collectors require direct rays. Sunlight passing through overcast conditions can not be used. Flatplate collectors can operate on diffuse light but the temperatures achieved are too low for practical thermal electric power generation.

Wind, a Solar Derivative

The wind is a solar derived source of energy which is also diffusely distributed. Unlike the sun, the wind can be present night and day. The wind has greater average speeds in temperate and polar latitudes than in the tropics. Wind driven electric generators for remote locations and farms have been used for years. The aerodynamic design of efficient windmills is not difficult, but the mechanical design of windmill structures to withstand gusts, turbulence, and the wide range of wind speeds encountered is a challenging problem. The Rural Electrification Act, however, made conventional utility power available, and led to diminished use of windmills on the farms, even for pumping water. Power conversion and storage problems for wind driven generators are similar to those encountered for solar electric power. The development of appropriate components for consumer use is required, as is manufacturing, distribution and servicing facilities.

There appears to be an earlier opportunity to use wind to develop supplementary heat for space heating than for the electric power application. The windmill driven electric generator would be used to power an electric resistance heater which is coupled either to the domestic hot water system or to the thermal storage system as in the case of solar heating. The generator could be simple and need not be controlled in output power, frequency, or voltage. Unlike the sun, the wind is often available at night or when clouds are present. Perhaps more importantly, when the wind is high most homes are more difficult to heat.

NATURE'S SOLAR COLLECTORS

Solar Ponds

There are a number of natural solar collectors receiving attention by investigators. Shallow ponds appear to work well for modest temperatures. In salt ponds with a strong gradient in salinity it is possible to get a temperature inversion in the pond, i.e., the hotter more saline water is at the bottom. Most of these are investigatory in nature with an occasional feasibility test being planned or under construction.

Ocean Thermal Gradients

There is a natural thermal gradient in ocean water which can be large in tropic and subtropic oceans. The temperature difference encountered is about 20°-25°C. With such a small difference, the efficiency of any heat engine will be quite low. It is expected that practical efficiencies would be the order of 2%. To produce much electric power from this system, say 1000 megawatts, would require a water flow in the heat engine over one third that of the Mississippi River. Feasibility studies are in progress. A major problem is the design of efficient heat exchangers capable of handling huge flow rates and not be susceptible to fouling.

Ocean Currents

Solar heat in the ocean also creates currents. The Gulf Stream is an example. It has been suggested that a series of turbines anchored in the Gulf Stream could develop energy from these ocean currents.

Other Geophysical Sources

Other geophysical energy sources are waves, tides, and geothermal heat. Tidal power operates the 240 megawatt Rance project in France. A few sites, the Bay of Fundy (Canada and U.S.), the Severn Estuary (England) and the Ile de Chausey (France) have spring tides in the 14-15 meter range and neap tides of about half that. Compared with solar, wind and wave sources, the tides are more predictable, but not much more available. Nor can one, without

storage, make tidal power available during peak demand periods. If tidal power were to be used to feed electric power distribution networks equivalent capacity electrical generating system would have to stand by to carry the load when the tide was not suitable for generation. The combination of tidal power and pumped water storage has been suggested,‡ but costs are high, and environmental problems could be severe. Passamaquoddy Bay is a most frequently investigated potential site in the United States.

Many ideas have been brought forward for the harnessing of wave energy. Recent successful applications have been to supply small amounts to buoys and lighthouses.* Measurements of waves off the Hebrides have indicated an average power potential of nearly 100 kilowatts per linear meter of wave frontage. It would be difficult to design a system to exploit all that wave energy because some of that average is made up of very large waves in severe weather which would endanger the integrity of the wave power plant. The basic problem of harnessing wave power is the hydromechanical conversion of dispersed, random, alternating forces into a concentrated direct force with a machine that is both efficient and can withstand the wide range forces and frequencies it will be subjected to.

While wave power uses well known and relatively simple technology, no system has been designed or built and tested on a large enough scale to demonstrate the feasibility of wave power to meet a significant fraction of our energy needs. Again there is need of storage. The conversion of wave power to hydrogen has been suggested.**

Geothermal energy, in the broadest sense, is the natural heat of the

---

‡T.L. Shaw, "Tidal energy from the Severn Estuary", Nature (London), Vol. 249, June 21, 1974, pp. 730.

*S.H. Salter, "Wave Power", Nature (London) Vol. 249, June 21, 1974, pp. 720.

**S.H. Salter, Loc. cit.

earth. The normal heat flow of the earth is about 1.5 calories per square centimeter per second and occurs everywhere on earth. Because of morphological anomalies such as hot rock intrusions which make substantially more energy available near the surface of the earth there are areas called geothermal resource areas in which steam or hot water emerge from the surface, or hot regions can be reached by drilling to not more than 9000 feet. Geothermal resource areas in the continental United States are in Alaska, the West Coast, and the Virginias.

Currently there is geothermal energy powered electric generation in three areas: Larderello in Italy, The Geysers in California, and Wairakei in New Zealand. World-wide geothermal powered generating capacity is about 0.1% of the world generating capacity. Because typical geothermal systems operate at temperatures under 500°F, efficiencies of these generating plants are low, less than half that of fossil fuel plants. The low efficiency can contribute to high sulfur emissions from the plant because the much larger volumes of low temperature steam with only 0.05% sulfur have emissions equivalent to the same output capacity fossil fuel plant burning about 2% sulfur content oil. Geothermal plants have to be operated at the "wellhead". Geothermal energy is not widely available in the United States but where it is, it can provide significant amounts of electric power. Like many other sources, geothermal must be exploited with appropriate environmental precautions and constraint. If such resource development is encouraged, other fuels can be released to regions without such resources.

ELECTRIC POWER PRODUCTION; AS A SOURCE OF ENERGY SUPPLY AND AS AN ELEMENT OF ENERGY DEMAND

Electricity, A Domestic and Commercial "Fuel"

In the Project Independence Blueprint it has been suggested that electricity in time should become the universal domestic and commercial "fuel". One way to encourage this trend would be to require that all new housing be

electrically heated. This suggestion has predictably drawn the fire of the oil and gas industry who point out that electric power generation facilities are currently about 35% efficient while domestic heating plants operated on oil or gas can be 80% efficient. The contrast cannot be that great for a number of reasons. One, home heating systems rarely operate at or near their design efficiencies at the consumer's location. Two, heat transfer efficiencies between the combustion chamber and the living space are not included and can be substantially lower than heat transfer from electric resistance heating elements installed in individual rooms and having individual controls. Three, electric power transmission losses are significantly lower than home heating oil distribution costs particularly where the consumer has limited available storage (typical storage capacity is only 275 gallons) and somewhat less than distribution costs of natural gas. With these factors taken into consideration, the overall fuel efficiency of all these systems is about the same.

With electric heating there are opportunities for improved efficiencies coming from improved fossil fuel generating plant efficiencies, and the potential availability of reliable heat pumps. These factors coupled with the provision of some thermal storage at the consumer's location can provide badly needed load-smoothing for the electric utilities as discussed in connection with solar and wind above. (The storage system can also store "cold" which would help immensely to diminish peak air conditioning demand in summer.)

If the electric power is derived from sources other than scarce or depletable fossil fuels, electric heating is a bonus. As pointed out earlier, electric heat is an ideal complement to solar or wind heating systems.

Storage to Broaden Base Load Utilization

The electric power industry is currently emphasizing large "base load" installations in their construction plans. Economies of scale tend to dominate, particularly for nuclear plant construction. Typical capacities

are in the 1000 and 2000 megawatt range. Storage, principally pumped water, has also been located at or near the generating plant. These factors produce the concentration of central power stations. In the future it will be possible to complement this centralized system with a distributed system both for storage and for generation capacity to meet local peak needs. Storage as sensible heat has already been discussed. Fuel cell systems of 26 megawatt capacity are nearing commerical availability. These systems are ideally suited to a distributed generating system for meeting peak loads. If fuel, such as hydrogen is produced on site during off peak periods and stored for later fuel cell use, distributed storage is accomplished and valuable by-products, oxygen and water, are produced.

The developments of reliable, high capacity storage batteries will provide further options for distributed energy storage and load smoothing.

Maximum plant utilization is a most important factor in a capital intensive industry such as the electric power industry. Load factors for the industry as a whole have varied between 60% and 65% for the past decade. The reduction of idle time can increase the effective capacity of the installed plant and ensure full utilization of the more efficient "base load" installations.

Waste Heat Utilization

All large electric power plants produce large quantities of waste heat, the disposition of which presents a major environmental challenge. There have been numerous suggestions for utilizing this waste heat, or at least a significant portion of it, as process heat for manufacturing, as district heat for industrial, commercial or residential complexes, and as heat to generate a fuel or additional electricity with so-called "bottoming cycle".

If the technical heat transfer problems of harnessing the ocean thermal gradient for electric power production are solved, the system would also have immediate application to the further utilization of waste heat from large

power plants. The remote siting of power plants has made extensive utilization of waste heat in the form of district heating difficult. A closed transport system using the surplus heat, has been suggested‡ whereby methane and water are converted to hydrogen and carbon monoxide. These gases are then piped to the consumer where they are "burned" to produce water and methane once more, with the liberation of heat. Both the water and the methane can be recycled to the plant or only the methane returned and the water added on site. No methane is consumed in the process, it is only used as a transport mechanism for the waste heat.

Hydroelectric Power

In mid-1974 the total conventional hydroelectric power developed in the contiguous United States averaged 260 billion kilowatt-hours annually from a capacity of 55,000 megawatts. Almost one-half of this capacity and more than one-half of the generation is in the Pacific states (Washington, Oregon and California). Nearly 7000 megawatts of capacity are now under development, 90% of which is in the same Pacific states.

A review of potential sites* for hydroelectric development with capacities of 100 megawatts or more, or additions of 25 megawatts or more found 44 new sites and 26 potential additions that might be completed through 1993.

Forty existing hydro facilities could be expanded to add 12,700 megawatts of capacity. Most of these facilities use all available water now, so that expanding capacity could only be done at the cost of reduced operating time.

The number of favorable sites available for conventional development is limited. There are many issues involved in the development of remaining

---

‡Wolf Haefele, "Energy Choices that Europe Faces: A European View of Energy", Science, Vol. 184, 19 April 1974, pp. 369.
*Staff Report on the Role of Hydroelectric Developments in the Nation's Power Supply, Federal Power Commission, Bureau of Power, May 1974.

potential such as the production of power without consuming fuel versus the replacement of flowing streams with reservoirs and changing the character of a scenic valley. Hydro plants are especially suited for providing peak and reserve capacity for utility systems.

Pumped storage, a form of hydro power, offers the opportunity to store energy using excess capacity from fossil fueled or nuclear plants to fill the reservoir (the total developed pumped storage capacity in the contiguous United States is just over 8,000 megawatts). Pumped storage also presents controversial issues. Consolidated Edison Company of New York has been involved for a decade in proceedings and litigation over its proposed 2,000 megawatt hydroelectric facility in the Hudson River highlands, the "Cornwall Project".*

Nuclear Fission Electric Power

Nuclear fission power is the only mineral, but non-fossil fuel, source currently available that is backed by a fully developed industry structure to manufacture, install, operate and deliver power to consumers. The past twenty years of development and operating experience had brought this industry to a point of maturity where it can be a major energy supply source. There are problems of siting, licensing, safety, construction costs, and social acceptance which must be solved for this industry to fully develop its potential.

It has been observed that "any developing technology looks worse the farther we get into it!" We must keep this truism in mind as we are tempted to abandon a technology in late stages of development for one which has as yet not had all its problems uncovered. To the present heated and often irrational dialogues on both sides, there is little that can be added in a short paragraph other than to draw a comparison between this developed industry with most of its problems glaringly revealed and the as yet infant

*Luther J. Carter, "Con Edison: Endless Storm King Dispute Adds to its Troubles", Science, Vol. 184, June 28, 1974, pp. 1353-1358.

synthetic fuel industry. There seems to be no inherent advantage of synthetic fuel plants over nuclear plants in terms of costs, environmental impacts, desirability to have in densely populated urban areas, etc. To believe that the synthetic fuel industry can develop faster with fewer problems and be more acceptable is mixing fact with fantasy. Past experience has proven many times over such fantasy is always expensive.

Utilization of Nuclear By-product Heat

While electricity can be expected to play an ever increasing role in the energy mix, we must look beyond the use of nuclear reactors solely to generate electricity towards possible contributions elsewhere:

- o Waste heat generation of electricity using low temperature heat engine cycles
- o Direct and waste nuclear heat as process heat in chemical industrial processes
- o Nuclear heat to directly or indirectly produce synthetic fuels
- o Waste heat for distribution in district heating and space conditioning.

The average efficiency of energy conversion of today's reactions is about 1/3. There are, therefore, prodigious amounts of heat to be disposed of and we must seek means of turning at least a portion of this environmentally embarrassing surplus into a benefit.

Some Nuclear Power Issues

David J. Rose has recently discussed* the major issues of nuclear power. These issues involve comparison with alternatives, e.g., coal or other fossil fuels, on the basis of:

- o Economic cost
- o Environmental and social impacts, site selection,

---

*David J. Rose, "Nuclear Electric Power", Science, Vol. 184, April 19, 1974, pp. 351.

waste heat management

- o Accidents
- o Security and illegal diversion of nuclear fuels
- o Radioactive waste storage.

In terms of capital costs, nuclear electric power is the most expensive even when compared with coal and oil-fired plants equipped with sulfur and particulate removal systems. Operation and maintenance costs are expected to be less for oil, but not less for coal than for nuclear. It is in fuel costs that nuclear shows its greatest advantage over both oil and coal, an advantage that might be expected to improve with time. To wipe out this cost advantage, the cost of uranium oxide would have to increase nearly an order of magnitude from the current $10 a pound to nearly $100 a pound. As is the case for most of our resources, as was explained in connection with oil and gas reserves, the magnitude of uranium reserves are a strong function of price.

Siting problems and waste heat management are a result of the trend in nuclear plant construction to take advantage of economies of scale. Large plants appear to require that the site be remote from urban areas. A study published in Sweden* in July deals with the implications of urban siting of nuclear stations with special attention to both safety and to the potential of the use of steam from nuclear stations for district heating in large population centers. The committee compared four different sites at distances of 5, 20, 40 and 100 kilometers between the nuclear power plant and the center of a model city of 1 million population. Risk probability multiplied by consequence, was assessed. Released radioactivity that causes serious injuries in the neighborhood of a nuclear power plant occurs only for accidents in which the reactor is almost totally destroyed. The probability of such a catastrophic rupture of the reactor is calculated to be between 1 and 10 per million reactor-years.

It must be understood that the quotation of probabilities does not pre-

---

*"Taking the Heat out of the Swedish Arguments", Nuclear Engineering International, September 1974, Vol. 19, No. 220, pp. 687.

clude the accident happening in the first year, the first decade, or the first hour for that matter. The whole matter of public acceptability of risk appears to revolve around differing acceptabilities for voluntary and involuntary risk. We voluntarily accept far greater risk each time we drive an automobile, but are reluctant to accept a far lesser risk at the behest of others.

We have little good data on the cost of pollution from non-nuclear sources, but in the Swedish study, estimated environmental costs of fossil fuel alternatives gave the nuclear alternative a 60 million Swedish Kroner advantage.

In a study‡ called an "Assessment of Accident Risks in the U.S. Commercial Nuclear Power Plants" by a team headed by Norman Rasmussen of MIT calculations indicated that the probabilities of accidents having ten or more fatalities is predicted to be about one in 2500 per year per hundred plants. For fatalities to reach a hundred or more, the probability is about one in 10,000. Other findings concluded that the consequences of potential reactor accidents are no larger and in many cases much smaller than anticipated by earlier studies such as the Brookhaven Report of 1957; the chances of a major nuclear accident are the same as that of a meteor falling on a large U.S. city; society is already exposed to non-nuclear accidents ten thousand times more likely to produce large numbers of casualties than nuclear accidents; and nuclear plants are far less likely (100 to 1000 times) to cause accidents resulting in large economic costs than other sources. These conclusions are based on the belief that people can be evacuated out of the path of the airborne radioactivity in the event of an acccient, and it is on this point that substantial controversy might ensue.

Security against the diversion of nuclear fuels, particularly the

---

‡AEC Report WASH-1400, "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants" (August 1974).

plutonium resulting from breeder reactions, is a most serious problem for world security as a whole. Clandestine nuclear weaponry and blackmail, if not destruction, could take place. Additional security will be costly and will depend heavily on international efforts (not the U.S. alone). World security in this matter is no better than its weakest part. Present reactors contain significant amounts of plutonium and breeders will contain far more---nearly a million curies. Security considerations may provide the main urgency for developing fusion reaction. Fusion cannot solve the radioactive waste problem however because fusion reactor structures become radioactive in use and will require periodic replacement and storage until they "cool off".

Nuclear waste disposal is also a formidable problem whose solution becomes more urgent with each new nuclear plant coming into operation. It is essential that the heavier elements in the radioactive waste be recycled where they can eventually become fission products with lifetime short enough to become innocuous in a reasonable period of storage. This recycling will add cost, but not excessive compared with the benefits to waste disposal.

The technical and social costs and problems described are but part of the problem of expanding supply through the nuclear energy route. The extreme capital intensiveness of the nuclear-electric industry is well known. The industry has had considerable difficulty of late in attracting the necessary capital investment for plant expansion. Long delays in licensing can be costly---$50-million a year in interest and other expenses on a completed but non-operating plant. It will take a lot of money, technology and satisfaction of social concerns to permit the thirty- to forty-fold expansion of our nuclear generating capacity by AD 2000.

DEMAND/NEED

The difference between demand and need can be expressed in terms of reducible waste or misuse of our energy resources. The elimination of this

waste or misuse will bring demand closer to actual need and our economy and national well being will be the better for it. The difficulty of reversing trends and styles created by cheap energy is great, but the penalty for not doing so is worse. The reversal can be accomplished without economic contraction or social hardship, but to do so will require the dedication of all citizens to solving the problem not unlike that we require in time of war. Indeed, we must declare war---this time, a war on waste.

Demand Factors

Demand is strongly influenced by cost and availability, the fuel flexibility (versatility) of user systems, convenience, portability, existing distribution systems, environmental, institutional and historical factors. Measures to reduce demand to be more closely aligned with need must be applied with care and planning. We already have an indication of what conservation can do. The potential for demand reduction is great, but the potential for concomitant disruption is also high. As we realign our energy using habits we may provide relief for localized economic disasters in a manner comparable to our relief programs for the victims of natural disasters. If, for example, we decide to eliminate conventional sulfur mining as we meet our needs for this mineral by removing it from fossil fuel, we must be prepared to help those affected meet the requirements of change.

In transportation we have a foremost example of demand patterns affected by inflexibility in fuel use. The motorist today either uses gasoline (a very few have other options) or he doesn't drive. The trucking, railroad, and air industries are also tied to distillates or gasoline with few options for other fuels. Technology can provide alternatives and can improve efficiency in fuel use. Modal shifts, operational/regulatory procedures, and load factor improvement in all vehicles can reduce demand.

In the past few months we have seen the difficulty of forecasting demand. The Federal Energy Administration forecast of energy demand through 1985 is lower than most forecasts published heretofore. With oil at $11 a

barrel demand is not expected to outpace supply. However, if oil were to drop to $7 a barrel, demand is expected to exceed supply and more than double the required imports. The high level of imports necessary at $7 is attributed to:

- o High cost domestic petroleum production
- o Limited expansion of nuclear power
- o Little contribution by 1985 from new technologies
- o Limited increases in coal production

SUPPLY, DEMAND/NEED AND THE GAPS BETWEEN

At a price, $11 a barrel and upwards for oil or its equivalent, there is no gap. Supply has been stimulated and demand brought closer to need. The gap at $7 a barrel requires over twice the imports for $11 oil. We have discussed the problems of nuclear expansion, and the present unlikelihood of a significant contribution from shale or coal conversion technologies, particularly at $11 a barrel. Environmental protection regulations and available facilities will hinder expanded use of coal. The problems of expanding coal production and transportation facilities are formidable. A contribution by more exotic forms of energy will only be significant long after 1985.

CONSERVATION AS A MEANS FOR ENVIRONMENTAL CONTROL

Business Week* quoted Carl Gerstacker, chairman of Dow Chemical Co., as follows: "I cringe everytime I hear a company say how much it's costing to clean up pollution. The opposite is true. We expect to make a profit at it." Other companies were not as optomistic. Dow's approach is to reduce--eliminate if possible---waste, and to balance such gains against pollution abatement costs.

* Anon. "Dow cleans up pollution at no net cost" Business Week, January 1, 1972, pp. 32-35.

Conservation can be a powerful tool in environmental quality control. The fuel not consumed because conservation measures were taken cannot pollute anywhere in its life cycle---from search, discovery and production through to the rejection into the environment of the by-products of its end use. The value of the marginal barrel of oil saved is equal to the value of the marginal barrel of oil produced. Unfortunately, the costs are not always equal---often because of the differing ways we do accounting for energy supply and energy demand. The incentives for saving---for improving energy productivity---are not yet a match for those for increasing supply. Burgeoning fuel costs are helping close the gap but with devastating effects on the economy.

Improved energy productivity is essential to our meeting national goals for both energy and the environment. Consider, for example, the fuel burning process that is 40% efficient. Only two fifths of the fuel consumed in the process is useful---three fifths is waste and must be disposed of. Suppose we are able to improve the efficiency of that process by only ten percent. Where ten units of fuel were originally required, eight will now do the job---a twenty percent saving of fuel, an identical curtailment of pollutants.

From the above it is clear that the most dramatic savings can be made by relatively small improvements in the efficiencies of our least efficient processes. Moreover, it is for these least efficient processes that we might logically expect to be able to make the greatest improvements.

Electric power production is another case in point. Today's generating facilities convert only about one-third of the fuel consumed into useful electric power---two-thirds is wasted and adds to pollution. A ten percent improvement would mean a twenty-three percent saving of fuel!

Peak demand for electric power is ordinarily met by the least efficient generating capacity. Efficiencies of peaking equipment can be as low as 20%-25%. Curbing peak demand and leveling the load on generating facilities by conserving, load shedding, storage or other means can, in effect, increase the efficiency of electric power generation by eliminating the need of the lower efficiency equipment.

The fuel efficiency of the automobile is also very low. The reasons for this include inefficiencies in converting energy in the fuel into tractive power on the road, poor payload to gross vehicle weight ratios, poor passenger load factor, and the grossly inefficient performance of gasoline automobiles in urban traffic patterns.

The three examples just cited, combustion of fuels for heat (process heat and space conditioning), electric power generation, and transportation in gasoline driven automobiles comprise major components of U.S. energy use and are major contributors to environmental pollution. Because their efficiencies are low, small improvements can effect substantial savings in fuel and therefore pollution. Such low efficiencies are attractive targets for both energy management and technological fixes. The rewards can be great.

TECHNOLOGIES FOR CLOSING THE GAP

Conservation and improved energy productivity are having, and can have, a major effect on demand and thereby help close the gap. The energy saved by improving process efficiencies is a continuing saving for as long as the process is used. Plentiful alternative fuels can reduce the demand for scarce supplies. Substantial technical advance is required to build the necessary versatility into our fuel consumption patterns and to provide the alternative fuels.

The costs of domestic fossil fuel production and processing are high. In the past these costs have diverted search and refining operations to foreign countries. Plant costs for synthesizing petroleum and gas equivalents from coal or waste are also high. Clean, direct combustion of coal needs immediate attention. Of the many second generation coal liquefaction or gasification techniques being investigated none stands out as the most economical and most productive. Product costs for all appear to be about the same. What is needed now is a commercial scale plant for one or two of these processes, no more, to really uncover the technical and environmental problems associated with full scale production technology. Research effort

is needed into low cost processes to produce clean fuels from coal. The production of low cost hydrogen, more than a fuel---a basic ingredient in fuel synthesis and conversion, and development of distribution and handling facilities, would contribute greatly to the clean fuels from coal as well as others. Forecast costs of synthetic gas and oil do not compete with the "saved fuel" cost from conservation measures taken to close the demand/supply gap.

Post combustion cleaning equipment is being demonstrated and is being adopted with increasing frequency. Proving this equipment at commercial capacity level will provide operational facts to help convince current on-lookers that stack gas scrubbing is both reliable and economical.

Nuclear energy will have problems expanding at the rate necessary to make it an effective gap closer. The technology needed here is that to promote this expansion in a socially and environmentally acceptable way. We must attack the problems uncovered by a maturing technology and solve them satisfactorily rather than turn away to a technology far less mature with problems as yet not very evident.

Unconventional sources can make important contributions to closing the supply/demand gap by the turn of the century. By their very nature, unconventional sources must play the role of supplements rather than substitutes. Their application will have important regional implications. We must use solar energy where it is most appropriate, geothermal where it is available, fusion when it becomes commercial, wind where a supplementary source is needed and wind is prevalent. Among all the unconventional sources waste, while limited in its potential, but ubiquitous in its availability, must be reclaimed for its energy or clean fuel content plus the essential raw materials it can provide.

There need not be a gap, but the gap cannot be closed with a single approach. Diversity is called for, each effort becoming a part of the whole--a marshaling of our human, technical, and natural resources to achieve a goal.

BIBLIOGRAPHY

BIBLIOGRAPHY

Primary Sources

1. Abrahamson, Dean E., and Emmings, Steven, eds. (May, 1973). "Energy Conservation. Implications for Building Design and Operation." Proceedings of a Conference, Bloomington, Minn. University Council on Environmental Quality and School of Public Affairs. Vol. 6.

2. Anon (July, 1971). "A Closed-Loop Approach to Industrial Plastics Wastes." Modern Plastics, pp. 44-45.

3. Anon (July, 1974). "Liquefaction and Chemical Refining of Coal." A Battelle Energy Program Report, Battelle Columbus Laboratories.

4. Auer, Peter (1974). "The Nuclear Option in an Integrated National Energy Research and Development Program." Science Vol. 184, p. 300.

5. Barton, W. R., and Harvey, A. H. (1974). "Coal Analysis Report." New Market, N.H., U.S. Bureau of Mines.

6. Beall, Sam E. (March, 1973). "Total Energy; A Key to Conservation." Consulting Engineer Vol. 40, no. 3, pp. 180-185.

7. Beaton, Leonard (1967). "Nuclear Fuel for All." Foreign Affairs Vol. 45, p. 662.

8. Berg, Charles (April, 1973). "Conservation Via Effective Use of Energy at the Point of Consumption." NBSIR 73-202.

9. Blackwood and Hedley ( ). "Efficiencies in Power Generation - Final Report." Monsanto Research Corp.

10. Blaney, Harry C. (August, 1973). "The Energy Crisis and International Cooperation." Foreign Service Journal Vol. 50, pp. 12-14, 29-30.

11. Bodle, W. W., and Vyas, K. C. (August 26, 1974). "Clean Fuels from Coal." The Oil and Gas Journal Vol. 72, pp. 73-88.

12. Bureau of Mines (August 28, 1973). "Technology of Coal Conversion." Prepared by Energy Research, U.S. Bureau of Mines, Dept. of the Interior, Washington, D.C.

Primary Sources

13. Carnegie Mellon University and the National Science Foundation (October, 1973). "A Program of Research Development and Demonstration for Enhancing Coal Utilization to Meet National Energy Needs." Workshop on Advanced Coal Technology.

14. "Can Technology Meet Our Future Energy Needs with Necessary Protection of the Environment?" (June, 1973). Chemical Engineering Progress Vol. 69, no. 6, pp. 21-58.

15. Casazza, J. A., et al (1974). "Possibilities for Integration of Electric, Gas, and Hydrogen Energy Systems." CIGRE International Conference on Large High Voltage Electric Systems, Paris Session, August 21-29, 1974.

16. Cheney, Eric S. (Jan. - Feb. 1974). "U. S. Energy Resources: Limits and Future Outlook." American Scientist, pp. 14-22.

17. Chute, N. E. (1942). "Coal Resources of Southeastern Massachusetts." Mass. Dept. of the Interior Geologic Survey.

18. Congressional Quarterly, Inc. (1973). "Energy Crisis in America." Bibliography, p. 93.

19. Connor, James E. (Dec. 2, 1973). "Prospects of Nuclear Power" in The National Energy Problem, The Academy of Political Science Proceedings, ed., Robert E. Connery and Robert S. Gilmour. Vol. 31, p. 63.

20. Cornell University (Dec. 1973). "Report of the Cornell Workshops on the Major Issues of a National Energy Research and Development Program." (Sept. 14 - Oct. 17). College of Engineering, Ithaca, N. Y.

21. David, Edward E. (June, 1973). "Energy: A Strategy of Diversity." Technology Review pp. 26-31.

22. Davis, Warren B., and McLean, John Godfrey (1973). "Guide to National Petroleum Council Report on U. S. Energy Outlook." National Petroleum Council.

23. Dawson, A. D. (1974). "Earth Removal and Environmental Protection." Environmental Law Center, Boston, Massachusetts.

24. Dugas, Doris J. (Oct. 1973). "Fuel from Organic Matter: Possibilities for the State of California." Rand Publication P-5107.

Primary Sources

25. Dupree, Walter G. Jr., and West, James A. (Dec. 1972). "U. S. Energy through the Year 2000." U. S. Dept. of the Interior.

26. "Energy: Demand, Conservation, and Institutional Programs" (1973). Proceedings of a conference held at Mass. Inst. of Tech., Feb. 12-14, 1973. Cambridge, Mass.: M.I.T. Press.

27. "Energy, Economic Growth, and the Environment" (1971). Papers presented at a forum conducted by Resources for the Future, Inc., Washington, D.C., April 20-21. Baltimore, Md.: Johns Hopkins University Press, 1972.

28. E.P.A. (July, 1973). "Energy Conservation Strategies, Socioeconomic Environmental Studies Series." EPA-R5-73-021.

29. E.P.A. (March, 1974). "EPA's Position on the Energy Crisis." A release of the U.S. Environmental Protection Agency.

30. E.P.A. (May, 1974). "How SO_x Emission Problems Appear to EPA." Professional Engineer, pp. 27-28.

31. Farmer, M. H. (June 12, 1973). "Energy Scenarios Supply Considerations by: Government Research Laboratory of Esso Research Company."

32. Federal Power Commission (1970). National Power Survey, Part I, Chap. 6, "Nuclear Power," Part II, pp. 28-29.

33. Federal Power Commission, Bureau of Power (Sept., 1973). "A Staff Report on the Potential for Conversion of Oil-Fired and Gas-Fired Electric Generating Units to Use of Coal."

34. Federal Power Commission (1974). "National Power Survey." Washington, D.C.: U.S. Government Printing Office.

35. Foley, Gary J. (1973 ?). "Energy Supply and Demand Forecasts." EPA Control Systems Laboratory, unpublished memorandum.

36. Ford Foundation (Feb. 22, 1974). "Exploring Energy Choices." Preliminary Report of the Ford Foundation's Energy Policy Report.

37. Foster, John S. (1973). "Nuclear Weapons," Encyclopedia Americana Vol. 20, Americana Corp.

38. Friedlander, G. D. (May, 1973). "Energy: Crisis and Challenge." IEEE Spectrum Vol. 10, No. 5.

Primary Sources

39. Gillette, R. "Nuclear Safety." Science: (1973) 179, 360; (1972) 177, 1080; (1972) 177, 970; (1972) 177, 771.

40. Gillette, R. (July 12, 1974). "Oil and Gas Resources: Did USGS Gush Too High?" Science, Vol. 185, pp. 127-130.

41. Giovannitti, E.F. "Control of Pollution from Deep Bituminous Coal Mines of Pennsylvania." Dept. of Environmental Resources, Harrisburg, Pa., Commonwealth of Pennsylvania.

42. Glicksman, Leon R., and White, David C. (August, 1973). "National Benefits of Energy Conservation." Mass. Inst. of Tech., Energy Lab.

43. Grove, Noel (June, 1974). "Oil, the Dwindling Treasure." National Geographic Vol. 145, no. 6, pp. 792-825.

44. Gulf Atomic (Sept., 1973). "Self Sustaining Power Plant Combination Systems Consisting of High Temperature Gas-Cooled Reactors and Gas-Cooled Fast Breeder Reactors." San Diego Gulf General Atomic.

45. Hafele, Wolf (July - Aug., 1974). "A Systems Approach to Energy," American Scientist Vol. 62, pp. 438-447.

46. Hafele, Wolf (August 19, 1974). "Energy Choices that Europe Faces: A European View of Energy." Science Vol. 184, p. 360.

47. Hall, E. H., et al. (Sept. 15, 1974). "Clean Fuels and Energy Technology, A State-of-the-Art Review." Battelle Columbus Laboratories Report to EPA.

48. Hammond, Allen L., Metz, William D., and Maugh, Thomas H. (1973). "Energy and the Future." Washington, D.C.: American Association for the Advancement of Science.

49. Hammond, A., Metz, T., and Maugh II. "Energy and the Future." Science Ed.

50. Harrison, H., Hobbs, P. V., and Robinson, E. (March 8, 1974). "Atmospheric Effects of Pollutants." Science Vol. 183, pp. 909-954.

51. Hawkes, N. (1974). "Energy in Britain: Shopping for a New Reactor." Energy in Britain Vol. 183, p. 57.

52. Herrera, Philip, and Holdren, John P. (1971). "Energy; a Crisis in Power." San Francisco: Sierra Club.

53. Hirst, Eric, and Moyers, John C. (March 30, 1974). "Efficiency of Energy Use in the United States." Science Vol. 179, no. 4080.

Primary Sources

54. Hirst, Eric "Resources for the Future, Inc." in Energy Conservation Research, ed. Joel Darmstuder, Oak Ridge National Laboratory.

55. Hubert, M. King (1971). "Energy Resources for Power Production," in Symposium on Energy, the Environment, and Education, Robert L. Seale and Raymond A. Sierka, eds. Tuscon, Arizona: University of Arizona Press, 1973.

56. "International Conference on Nuclear Solutions to World Energy Problems, Washington, D.C. 1972." Proceedings, Hinsdale, Ill., American Nuclear Society, 1973.

57. InterTechnology Corp. (July 11, 1973). "Energy Scenarios Consumption Considerations."

58. InterTechnology Corp. (June 12, 1973). "Energy Scenarios Consumption Considerations Esso to EPA." The U. S. Energy Problem Summary Vol. 1, Appendices A-C Vol. 2 Part A, Appendices H-U Vol. 2 Part B NTIS PB-207 517.

59. Jonakin, James, and Van Ness, R. P. (May, 1974). "Calcium Hydroxide Scrubbing: Louisville Electric Takes the Plunge." Professional Engineer, pp. 25-26.

60. Journal of Science and Technology (Fall, 1973). "Energy Sources." Vol 1, no. 1. New York: Crane, Russak and Co., Inc.

61. Kenward, Michael (Sept. 19, 1974). "The Problems of a Powerful Industry." New Scientist, pp. 716-717.

62. Krasnoyarov, N. V. (1973). "The Status of Fast Reactors in the USSR, May 1973." IAEA Int. Working Group on Fast Reactors, Vienna.

63. Lapp, Ralph E. (Feb. 4, 1973). "The Ultimate Blackmail." The New York Time Magazine, p. 13.

64. "Laser Fusion: A New Approach to Thermonuclear Power" (1972). Science Vol. 177, p. 1180.

65. M. W. Kellog, Co. Research and Engineering Development (Jan. 21, 1974). "Evaluation of R & D Investment Alternatives for SO_x Air Pollution Control Processes." Houston, Texas.

66. Marsham, T. N. (1973). "A United Kingdom View of Fast Reactors." Atom. pp. 150-163.

Primary Sources

67. Massachusetts Energy Conservation Contingency Plan (Jan., 1974). Governor Francis W. Sargent.

68. Metzger, N., ed. "The Future of Fusion," and "The Tarnished Dream of Nuclear Power." Science Tapes.

69. Mass. Inst. of Tech. Energy Lab. Policy Study Group (March 15, 1974). "Project Independence: An Economic Evaluation."

70. Morris, Deane N. and Salter, Richard G. (Oct., 1973). "Energy Conservation in Public and Commercial Buildings." Rand Publication P-5093.

71. Mudge, L. K. et al (July, 1974). "The Gasification of Coal." A Battelle Energy Program Report, Battelle Pacific Northwest Laboratories.

72. National Academy of Engineering "Engineering Research of Energy-Environmental Dilemma." Appendix A. Nuclear Power Plants, pp. 68-72, and Environmental Radiation.

73. National Academy of Engineering "U.S. Energy Prospects, an Engineering Viewpoint." Washington, D.C.

74. National Bureau of Standards Joint Emergency Workshop on Energy Conservation in Buildings and National Conference of States on Building Codes and Standards (July, 1973). "Technical Options for Energy Conservation in Buildings."

75. National Economic Development Office (1974). "Energy Conservation in the United Kingdom." London: Her Majesty's Stationery Office.

76. National Petroleum, Committee on U.S. Energy Outlook (1972). "U.S. Energy Outlook; a Report." John G. McLean, Chairman of Committee, Washington, D.C.

77. National Petroleum Council (Feb. 22, 1974). "Energy Conservation in the United States, Short-term Potential 1974-78." An interim report.

78. National Power Survey (Nov. 12, 1973). "Report of the Task Force on Practices and Standards to the Technical Advisory Committee on Conservation of Energy."

79. NATO (Oct. 8-12, 1973). "Technology of Efficient Energy Utilization." Report of a NATO Science Committee Conference at Les Ares, France.

80. Oak Ridge National Laboratory (Jan., 1974). "A Collection of Papers Presented at the Nuclear Utilities Planning Methods Symposium," ORNL-TM 4443.

Primary Sources

81. "Our Energy Supply and Its Future" (1972). Battelle Research Outlook Vol. 4, no. 1.

82. Over, J. A., ed. (June 12, 1974). "Energy Conservation: Ways and Means." Future Shape of Technology Foundation, The Netherlands.

83. Perry, Harry (1972). "Conservation of Energy." Washington, D.C.: U.S. Government Printing Office.

84. Plotkins, Steven E., Rock, Robert O., and Seidel, Marquis R. (July, 1973). "Energy Conservation Strategies." Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Monitoring.

85. Proceedings of the Academy of Political Science (Dec., 1973). "The National Energy Problem Vol. 31, no. 2.

86. Quig, Robert H. (May, 1974). "Recycling SO_2 from Stack Gas: Technology Economics Challenge." Professional Engineer, pp. 22-24.

87. "Radioactivity in the Atmospheric Effluents of Power Plants that Use Fossil Fuels." Science. (April 17, 1964).

88. Rand, Christopher T. (Jan., 1974). "The Arabian Fantasy." Harper's Magazine, p. 42.

89. "Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies" (May, 1972). Upton, N. Y.: Associated Universities, Inc.

90. Report of the Cornell Workshops on the Major Issues of a National Energy Research and Development Program. Atomic Energy Commission (1973), Oak Ridge, Tennessee.

91. Rochelle, Gary T. (March, 1973). "A Critical Evaluation of Processes for the Removal of SO_2 from Power Plant Stack Gas." Environmental Protection Agency.

92. Rochelle, Gary T. (May, 1973). "Economics of Flue Gas Desulfurization." Environmental Protection Agency.

93. Rose, D. J. (April 19, 1974). "Nuclear Electric Power." Science Vol. 184, p. 331.

94. Ryan. Charles J. (1972). "Materials, Energy and the Environment: The Need to Produce, Conserve and Protect." Report on the University Forums of the National Commission on Materials Policy, Washington, D.C.

Primary Sources

95. Sagan, L. A. (1972). "Human Costs of Nuclear Power." Science Vol. 177, p. 487.

96. Science (July 13, 1973). "Energy Conservation through Effective Utilization." Vol. 181, pp. 128-138.

97. Science (April 19, 1974). "Science Energy Issue."

98. Shell Oil Papers (Oct., 1973). "The National Energy Problem: Potential Energy Savings."

99. Sherrill, Robert (June 26, 1972). "Energy Crisis. The Industry's Fright Campaign." Nation Vol. 214, no. 26, pp. 816-820.

100. Smith, Dan (July 7, 1973). "The Phony Oil Crisis; a Survey." Economist Vol. 248, pp. 1-42.

101. Starr, Chauncey (Sept., 1973). "Realities of the Energy Crisis." Bulletin of Atomic Scientists Vol. 29, pp. 15-20.

102. Symposium on energy, resources and the environment. Salines de Chaux Conference Center, Arc-et-Senans, France (May 12-14, 1972). McLean, Va., Mitre Corp., May 12, 1972.

103. Szego, G. C. "Economics, Logistics and Optimization of Fuel-Cells." Institute for Defense Analysis, U.S.A.

104. Thomas, Trevor M. (April, 1973). "World Energy Resources: Survey and Review." The Geographical Review. Vol. 63, no. 2, pp. 246-258.

105. Transportation Systems Center (Sept., 1972). "Research and Development Opportunities for Improved Transportation Energy Usage." Cambridge, Massachusetts.

106. Turk, Richard "Survey of Existing Projects and Plans Relating to Energy Conservation in Buildings." Architectural Student and Summer Intern Development Division Office of Planning and Development, Office of Facilities Engineering and Property Management Dept. Health, Education, and Welfare.

107. Udall, Steward L. (May 8, 1973). "The Energy Crisis: A Radical Solution." World Vol. 2, pp. 34-36.

108. U.S. Atomic Energy Commission: "Current Status and Future Technical and Economic Potential of Light Water Reactors, WASH-1082" 1968.

Primary Sources

109. U.S. Atomic Energy Commission (1972). "Environmental Survey of the Nuclear Fuel Cycle."

110. U.S. Atomic Energy Commission (March, 1974). "Environmental Survey, Liquid Metal Fast Breeder Reactor Program." WASH-1535, Vol. 1-4.

111. U.S. Atomic Energy Commission "Updated 1970 Cost Benefit Analysis of the U.S."

112. U.S. Atomic Energy Commission (1972). "Updated 1970 Cost Benefit Analysis of the U.S. Breeder Reactor Program." WASH-1184.

113. U.S. Congress (1972). "House Committee on Science and Astronautics. Subcommittee on Science, Research, and Development." Energy research and development. Hearings, Ninety-second Congress, second session. Washington, D.C.: U.S. Government Printing Office.

114. U.S. Congress (1971-1972). "House Committee on Science and Astronautics. Task Force on Energy." Briefings, Ninety-second Congress. second session. Washington, D.C.: U.S. Government Printing Office.

115. U.S. Congress (1973). "Joint Committee on Atomic Energy. Certain Background Information for Consideration When Evaluating the 'National Energy Dilemma.'" Washington, D.C.: U.S. Government Printing Office.

116. U.S. Congress (1973). "Joint Committee on Atomic Energy. Understanding the National Energy Dilemma." Washington, D.C.: U.S. Government Printing Office.

117. U.S. Congress (May 1, 2 and June 2, 1973). "Joint Economic Committee. Subcommittee on Consumer Economics." The Gasoline and Fuel Oil Shortage. Hearings, Ninety-third Congress, first session. Washington, D.C.: U.S. Government Printing Office.

118. U.S. Congress (1971). "Senate, Committee on Interior and Insular Affairs." Fuel shortages. Hearings, pursuant to S. Res. 45, a National Fuels and Energy Policy Study, Ninety-third Congress, first session. Feb. 1, 1973. Washington, D.C.: U.S. Government Printing Office.

119. U.S. Congress (1971). "Senate Committee on Interior and Insular Affairs." Goals and Objectives of Federal Agencies in Fuels and Energy; prepared at the request of Henry M. Jackson, Chairman, pursuant to S. Res. 45, a National Fuels and Energy Policy Study. Washington, D.C.: U.S. Government Printing Office.

Primary Sources

120. U.S. Dept. of the Interior (1972). "U.S. Energy; a Summary Review." Washington, D.C.: U.S. Government Printing Office.

121. U.S. Energy Study Group (1965). "Energy R & D and National Progress." Prepared for the Interdepartmental Energy Study under the direction of Ali Bulent Cambel. Washington, D.C.: U.S. Government Printing Office.

122. U.S. General Accounting Office (1973). "How the Federal Government Participates in Activities Affecting the Energy Resources of the United States." Report to the Congress by the Comptroller General of the United States. Washington, D.C.

123. U.S. House of Representatives (June, 1973). "Individual Action for Energy Conservation." Prepared by Subcommittee on Energy of the Committee on Science and Astronautics.

124. U.S. Office of Emergency Preparedness (Oct., 1972). "The Potential for Energy Conservation -- A Staff Study."

125. U.S. Office of Emergency Preparedness (1973). "The Potential for Energy Conservation: Substitution for Scarce Fuels -- A Staff Study." Washington, D.C.: U.S. Government Printing Office.

126. Veerhoff, Alfred B. (Aug. 27, 1973). "Energy Crisis: Fuel Shortage Characterized by Many Causes, Few Solutions." Transport Topics Vol. 15.

127. Weidenfeld, Edward L. (1972). "This Nation's Supply of and Demand for Fuel and Energy Resources." Washington, D.C.: Committee on Interior and Insular Affairs, U.S. House of Representatives.

128. Weinberg, A.M. (1972). "Social Institutions and Nuclear Energy." Science Vol. 177, p. 27.

129. Whittemore, F. Case (Sept., 1973). "How Much in Reserve?" Environment Vol. 15, no. 7, pp. 16-20 and pp. 31-35.

130. Wilson, Richard (April, 1975). "Notes on the Case for the Fast Breeder Reactor." Expanded version of remarks at the European Nuclear Conference, Paris.

Books

1. Atomic Fundamentals, DASA, Field Command Saudia Base, New Mexico (1963). Washington, D.C.: U.S. Government Printing Office.

2. Clark, W. (1974). Energy for Survival. Garden City, N.Y.: Doubleday-Anchor Press.

3. Dupree, Waslter G. and West, James A. (1972). United States Energy Through the Year 2000. Washington, D.C.: Dept. of the Interior.

4. Edlund, Milton C., and Glasstone, Samuel (1952). The Elements of Nuclear Reactor Theory. New York: Van Nostrand.

5. Fischer, John C. (1974). Energy Crisis in Perspective. New York: Wiley-Interscience.

6. Hottel, Hoyt Clarke, and Howard, J.B. (1971). New Energy Technology--Some Facts and Assessments. Cambridge, Mass.: M.I.T. Press.

7. Hubbert, M. King (1969). "Energy Resources," National Research Council, Committee on Resources and Man. San Francisco, Calif.: W.H. Freeman, pp. 157-242.

8. Lapp, Ralph E. (1973). The Logarithmic Century. Englewood Cliffs, N.J.: Prentice-Hall.

9. Macavoy, P. W. (1969). Economic Strategy for Developing Nuclear Breeder Reactors. Cambridge, Mass.: M.I.T. Press.

10. Macrakis, Michael S., ed. (1974). Energy, Demand, Conservation and Institutional Problems. Cambridge, Mass.: M.I.T. Press.

11. Manne, A. S. (1974). "Electricity Investments under Uncertainty: Waiting for the Breeder," in Energy Demand, Conservation and Institutional Problems, ed. M. Macrakis. Cambridge, Mass.: M.I.T. Press.

12. National Geographic Society (1971). As We Live and Breathe -- The Challenge of Our Environment. Special Publications Division, Lib. of Cong. 14-141945.

13. Odum, Howard T. (1970, 1971). Environment, Power, and Society. New York: Wiley-Interscience.

14. Power Generation and Environmental Change; Symposium of the Committee on Environmental Alteration. American Association for the Advancement of Science (Dec. 28, 1969). Cambridge, Mass.: M.I.T. Press, 1971.

Books

15. Resources for the Future. U.S. Energy Policies; on Agenda for Research. Baltimore, Maryland: Johns Hopkins Press, 1968.

16. Ridgeway, James (1973). The Last Play; The Struggle to Monopolize the World's Energy Resources. New York: E.P. Dutton.

17. Ridgeway, James (1974). "The U.S. Energy Crisis." Britannica Book of the Year 1974. Chicago, Encyclopedia Britannica, Inc., pp. 259-260.

18. Rocks, Lawrence, and Runyon, Richard P. (1972). The Energy Crisis. New York: Crown Publishers.

19. Sporn, Philip (1971). The Social Organization of Electric Power Supply in Modern Societies. Cambridge, Mass.: M.I.T. Press.

20. Weinberg, A.M., and Wigner, E.P. (1958). The Physical Theory of Neutron Chain Reactors. Chicago, Illinois: University of Chicago Press.

Bibliographies

1. Averitt, Paul, and Carter, M. Devereux (1970). Selected Sources of Information on United States and World Energy Resources: An Annotated Bibliography. Geological Survey Circular 641. Washington, D.C.

2. Dean, Flora (1971). A Bibliography of Non-technical Literature on Energy. Prepared at the request of Henry M. Jackson, Chairman, Committee on Interior and Insular Affairs, United States Senate, pursuant to S. Res. 45, a National Fuels and Energy Policy Study. Washington, D.C.: U.S. Government Printing Office.

3. Ellingen, Dana C. (1972). A Supplemental Bibliography of Publications on Energy. Prepared at the request of Henry M. Jackson, Chairman, Committee on Interior and Insular Affairs, United States Senate, pursuant to S. Res. 45, a National Fuels and Energy Policy Study. Washington, D.C.: U.S. Government Printing Office.

4. The Energy Index: A Select Guide to Energy Information Since 1970 (1973). New York: Environmental Information Center, Inc.

5. Landsberg, Hans H., and Schurr, Sam H. (1968). Energy in the United States; Sources, Uses, and Policy Issues. New York: Random House.

6. Perry, Harry, and Weidenfeld, Edward L. (1972). Selected Readings on the Fuels and Energy Crisis. Washington, D.C.: U.S. Government Printing Office.

7. Saskatchewan, Provincial Library. Regina (1973). Bibliographic Services Division. Regina.

8. Suggested Energy Readings from the Energy Information Center of the Battelle Energy Program (Dec., 1973). Columbus, Ohio: Battelle Memorial Institute.

Additional Sources of Information

1. American Petroleum Institute Library
   1801 K Street, N.W.
   Washington, D.C. 20006

2. Energy Information Center
   Battelle Memorial Institute
   505 King Avenue
   Columbus, Ohio 43201

3. Federal Energy Office
   New Executive Office Building
   Washington, D.C. 20506

4. National Petroleum Council
   1625 K Street, N.W., Suite 601
   Washington, D.C. 20006

5. Office of Public Information
   U.S. Federal Power Commission
   825 North Capitol Street, N.E.
   Washington, D.C. 20426

6. Technical Information Center
   U.S. Atomic Energy Commission
   P.O. Box 62
   Oak Ridge, Tennessee 37830