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Consensus Forecast of U.S. Energy Supply and Demand to the Year 2000

J. A. Lane

OAK RIDGE NATIONAL LABORATORY

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PROGRAM PLANNING AND ANALYSIS

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CONTENTS

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ABSTRACT

Methods used in forecasting energy supply and demand are described, and recent forecasts are reviewed briefly. Forecasts to the year 2000 are displayed in tables and graphs and are used to prepare consensus forecasts for each form of fuel and energy supply.

Fuel demand and energy use by consuming sector are tabulated for 1972 and 1975 for the various fuel forms. The distribution of energy consumption by use sector, as projected for the years 1985 and 2000 in the ERDA-48 planning report (Scenario V), are normalized to match the consensus energy supply forecasts. The results are tabulated listing future demand for each fuel and energy form by each major energy-use category.

Recent estimates of U.S. energy resources are also reviewed briefly and are presented in tables for each fuel and energy form. The outlook for fossil fuel resources to the year 2040, as developed by the Institute for Energy Analysis at the Oak Ridge Associated Universities, is also presented.

1. DESCRIPTION OF FORECAST METHODS

1.1 Methodology of Energy and Electricity Forecasting

Methods used to project future energy and electricity demand are, for the most part, based on some form of extrapolation of past trends. However, in some cases forecasts have been based on the consensus of experts who presumably also used an extrapolation method. Types of trend extrapolation are discussed in order of complexity in the following paragraphs.

1.1.1 Intuitive

In this case an expert looks at past consumption trends and makes an intuitive forecast of future demand.

1.1.2 Trend Extrapolation (Trend)

Overall Growth Trends

Historical data on total energy and electricity consumption are extrapolated using analytical or graphical techniques. The most commonly observed approach involves an exponential function (i.e., a linear relationship on semilogarithmic graph paper). Extrapolations based on declining exponents have also been used. The validity of this approach depends, of course, on the selection of the time period over which trends are to be fitted and on the type of fitting method used.

Per Capita and Population Growth Trends (Per Capita Trend)

In this approach, the per capita consumption of energy and/or electricity is projected and combined with population growth forecasts to give total energy and electricity forecasts. In most cases, the population growth is based on forecasts of others (e.g., U.S. Bureau of the Census). A refinement of this approach involves elimination of a segment of the population (e.g., children under 14 years of age).

1.1.3 Sector Analysis

A detailed analysis of energy and electricity consumption by each consuming sector (residential, commercial, industrial, transportation, other) is used to forecast sector trends. These forecasts are subsequently combined to give overall projections. Subdivision of sectors into component parts (e.g., transportation into trains, planes, trucks, private automobiles, etc.) represents a refinement of this forecasting method.

One of the main problems of sector analysis is to ensure that the sectors are appropriately chosen to avoid overlap and ensure comprehensiveness. Sectoral projections, on the other hand, have particular value in providing models of the economy and of energy-intensive industries. These models can be critically evaluated and provide data for analysis of individual industries.

1.1.4 Energy Source Analysis

Trends in energy consumption by source of supply (e.g., wood, coal, petroleum, natural gas, hydroelectric power, nuclear) are extrapolated and converted, according to the energy content of each source, into total energy forecasts.

1.1.5 Regression Analysis (Econometric Model)

Correlation of energy and electricity growth either on an overall basis or by individual sectors relative to economic variables, such as the gross national product (GNP), consumer spending, investment outlook, labor force, and productivity, provides input data for regression analysis equations or econometric models. This is considered to be the most sophisticated forecasting approach. As in the case of population growth, the related projection is usually carried out by a group other than that doing energy projections.

The most commonly used approach in this category of forecasting relates energy consumption to the GNP forecast. Most such GNP forecasts involve the regression of historical GNP on such factors as population, labor force, and productivity. Each of the individual factors in the GNP regression equation must be extrapolated to arrive at the GNP projection. Thus, although determination of the relationship between energy consumption and GNP seems simple on the surface, in reality many uncertain underlying factors affect GNP and consequently the energy projection.

1.1.6 Consensus

Energy and electricity forecasters often use the consensus approach. Included in this approach are methods such as the averaging of forecasts of others, obtaining the consensus of a panel of experts, or conducting polls of experts. In some cases polls are taken in which any one expert is ignorant of the estimates of the others.

1.1.7 Market Analysis

Market analyses are usually carried out by sending questionnaires to individual suppliers (fuel companies, equipment manufacturers, utilities, etc.), who project individual future markets. These are combined by those conducting the survey to yield an overall forecast.

1.2 Methodology of Nuclear Growth Projections

Nuclear power growth projections usually start with a forecast of future electricity generation (total output of utilities). If the forecast is for total U.S. electricity generation, correction is made for that portion self-generated by industry. Utility generation is then converted into future capacity requirements by considering future load factors and reserve requirements. The market for new capacity is computed after allowing for existing capacity, including plants already on order and plants to be retired. Various methods are then used to establish the portion of this capacity that will be nuclear.

2. REVIEW AND ANALYSIS OF RECENT ENERGY FORECASTS

Recent forecasts of U.S. energy consumption have been reviewed. The forecasts covered have been divided into two groups, as shown in Tables 1 and 2. The first group is based on the assumption that historical growth in the demand for energy will continue through the end of the century. This scenario assumes that the nation will not impose policies that might affect our ingrained habit of energy use, but will make a strong effort to develop supplies at a rapid pace to meet rising demand.

The second group of forecasts assumes that a determined conscious national effort to reduce demand for energy through application of energy-saving technologies will be successful and that continued high world oil prices will keep domestic energy prices high, resulting in lower demand. Some forecasters in this group even go so far as to project achievement of a zero energy growth rate by the year 2000.

Although many of the forecasters present intermediate-growth scenarios that fall between the extremes of the historical growth rate basis and the conservation basis figures, these are not shown in Tables 1 and 2. Figure 1 shows a plot of the average of each group of forecasts.

According to recent trends, the lower conservation-oriented forecasts appear to represent the most likely future total energy requirement. A suitable range of values in quads (10^{15} Btu) would be as follows:

	1975	1980	1985	2000
Low	73	85	95	120
High	79	95	110	150

2.1 Associated Universities, Inc., *Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies*, PB-221 422 (also AET-8), May 1972

A projection of future energy demand to the year 2020 is made on the basis of each end use of energy,

Table 1. Historical growth forecasts of U.S. total energy consumption (preembargo)

Forecaster	Date of forecast	Energy consumption (quads)[a]					Growth rate (percent per year)		
		1975	1980	1985	2000	2020	1975–1985	1986–2000	2001–2020
Associated Universities, Inc.	May 1972	80	98	118	179	302	4.0	2.8	2.7
Intertechnology Corporation	Nov. 1972	75	87	99	150	260	2.8	2.8	2.8
National Petroleum Council	Dec. 1972	83	108	125	200		4.2	3.2	
Department of the Interior (Dupree–West)	Dec. 1972	80	96	117	192		3.9		
Stanford Research Institute	May 1973	79	101	131			5.2		
Westinghouse (P. N. Ross)	June 1973				206				
Joint Committee on Atomic Energy Staff	Aug. 1973	81	102	125	212		4.4	3.6	
NASA/ASEE TERRASTAR	Sept. 1973	80	97	119	206	377	4.1	3.7	3.1
U.S. Atomic Energy Commission (D. L. Ray)	Dec. 1973	81	98	121	197	280	4.1	3.3	1.8
Ford Foundation	Early 1974	81	95	115	185		3.6	3.2	
U.S. Atomic Energy Commission (Office of Planning and Analysis)	Feb. 1974	81	98	117	195		3.8	3.5	
L. T. Blank and R. K. Riley	Mar. 1974	88	198	127	187	288	3.7	2.5	2.2
National Petroleum Council	Mar. 1974	82	98	114			3.4		
National Academy of Engineering	May 1974	84	101	123			3.9		
Average		81	99	120	192	301	4.0	3.2	2.3

[a]One quad = 10^{15} Btu.

Table 2. Conservation-oriented forecasts of U.S. total energy consumption (postembargo)

Forecaster	Date of forecast	Energy consumption (quads)[a]					Growth rate (percent per year)		
		1975	1980	1985	2000	2020	1975–1985	1986–2000	2001–2020
NASA/ASEE TERRASTAR	Sept. 1973	80	93	106	132	149	2.9	1.5	0.6
Environmental Protection Agency	Nov. 1973	77	90	105	154		3.2	2.6	
U.S. Atomic Energy Commission (D. L. Ray)	Dec. 1973	78	90	106			3.1		
Ford Foundation technical fix	Early 1974	81	90	96	118		1.7	1.4	
Ford Foundation (zero energy growth)	Early 1974	81	88	93	100		1.4	0.5	
U.S. Atomic Energy Commission (Office of Planning and Analysis)	Feb. 1974	78	86	96	135		2.0	2.3	
L. T. Blank and R. K. Riley	Mar. 1974	75	84	96	140	218	2.7	2.5	2.3
Council on Environmental Quality	Mar. 1974	76	84	92	121		1.9	1.8	
MIT (Hudson–Jorgenson)	May 1974	78	88	101			2.6		
MIT (judgmental)	May 1974	81	97	110			3.1		
National Academy of Engineering	May 1974	76	90	104			3.2		
NASA/ASEE MEGASTAR	Sept. 1974	79	94	108	120		3.2	0.7	
Federal Energy Administration Project Independence	Dec. 1974	77	87	98	120	160	2.4	1.4	1.4
ERDA (Office of Planning and Analysis)	Feb. 1975	78	86	96	135		2.1	2.3	
E. Teller	Apr. 1975	76	84	103	170		3.1	3.4	
Average[b]		78	89	100	132	176	2.5	1.9	1.5

[a]One quad = 10^{15} Btu.
[b]Average excludes Ford Foundation zero energy growth forecast.

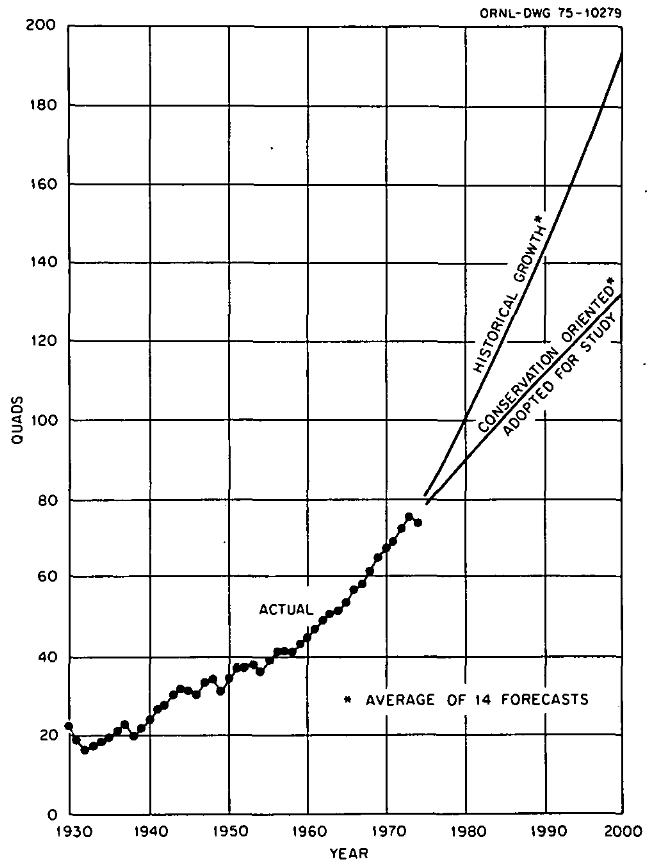

Fig. 1. United States total energy consumption.

broken down into 27 individual consuming sectors. Historical trends, adjusted for possible saturation effects, were used to establish a growth trend for each sector. Reference energy systems to define sources and end uses of energy for the years 1969, 1977, 1985, 2000, and 2020 were then established. Total resource consumption was estimated to reach 177 quads by the year 2000 and 299 quads by 2020. The possible effect of high energy costs on energy demand was not taken into consideration.

2.2 Intertechnology Corporation, *The U.S. Energy Problem*, for NSF-RANN, November 1972

This report surveyed 56 separate projections and used curve-fitting techniques to develop a total-energy–time equation:

$$E_T = 65.57 \times 10^{15} \times 1.028^{(\text{year} - 1970)} \text{ Btu/year} .$$

This equation continues the exponential growth of total energy consumption of the past 30 or more years. The forecasts surveyed in this study were made in the early to mid-1960s.

2.3 National Petroleum Council, *Guide to NPC Report on U.S. Energy Outlook*, December 1972

In July 1971, the National Petroleum Council issued an initial appraisal of the U.S. energy outlook based on optimistic assumptions of what could occur without major changes in the political and economic climate. The projected total energy demand of 125 quads by 1985 (up from 68 quads in 1970) was still considered a valid intermediate casé as of December 1972, the date of publication of the report. This projection was based on an economic growth rate of 4.2% per year (real GNP), no future changes in real energy costs, and a population growth of 1.1% per year. An accompanying longer range projection indicated a consumption of 200 quads by the year 2000.

2.4 W. G. Dupree and J. A. West, *United States Energy Through the Year 2000*, Department of the Interior, U.S. Government Printing Office, December 1972

This report was written prior to the current high oil prices and represents a forecast of future energy demand based on conditions existing in 1972. It gives a wealth of historical data and a good analysis of energy consumption by sources of energy and by consuming sectors. Thus it is an excellent background paper for any study of future energy supply. The actual projected consumption of total energy in quads is 80.3 in 1975, 96 in 1980, 116.8 in 1981, and 191.9 in 2000.

2.5 S. Field, Stanford Research Institute, "The U.S. Energy Puzzle," paper presented at 38th midyear meeting of Division of Refining, Philadelphia, May 1973

A sectoral analysis of the demand for energy led to a forecast total energy demand of 131 quads by 1985. Limited domestic supplies, however, might reduce this figure to 119 quads.

2.6 P. N. Ross, Westinghouse Electric Corporation, "The Nuclear Electric Economy," paper presented at the Conference on the Hydrogen Economy, Miami, Fla., March 1974

"The Nuclear Electric Economy" scenario was prepared in 1973 and modified after the oil embargo. It is based on the premise that any realistic approach to solving the energy crisis should be based on reducing U.S. dependence on oil and gas. It therefore proposes that a shift be made to a more abundant fuel base. In particular, the scenario suggests an economy that is strongly dependent on the electricity generated by nuclear fission and coal. In this scenario the production of electricity by the year 2000 is up 50%, while the use of oil and gas is down by a factor of 3. The use of coal is up over 70%, and total energy end-use consumption is down more than 30%. The paper suggests that this trend in consumption would be possible if the end uses of electricity could be made more efficient. Technological changes necessary for such a trend include the use of heat pumps for space-heating applications and the use of electric-powered vehicles in the transportation sector. Despite the greater end-use efficiencies postulated, the nuclear electric economy approach requires essentially the same total energy input as the "business as usual" case (200 quads in the year 2000 compared to 206 quads). Required imports of oil and gas, however, would be zero by the year 2000.

2.7 Joint Committee on Atomic Energy, *Understanding the National Energy Dilemma*, Joint Committee Print, August 1973

Recent appraisals of the nation's energy demand through the year 2000 were evaluated and used as a basis for "option exercise" projections by the Joint Committee staff. The staff believed that one particular exercise, option exercise 7-A, was one of the more balanced of the several exercises examined. This option calls for a depressed demand of 82 million bbl/day oil-equivalent (174 quads) by the year 2000. This amount is 25% below what would result if the United States were to continue its current growth rates in energy use. Even with this figure, however, imports and/or shortages were forecast by the staff to amount to 13 million bbl/day oil-equivalent.

2.8 NASA/ASEE–Auburn University, *Terrestrial Applications of Solar Technology and Research (TERRASTAR)*, September 1973

Ten forecasts of energy consumption in the United States are reviewed and an upper and a lower limit to consumption defined. The probable impacts of following either of these two energy-growth scenarios are discussed. The conclusion is that a third scenario, involving a national energy policy aimed at rational conservation-oriented energy use, would be preferable. The annual growth in energy consumption with this scenario would decrease from a current rate of about 3.6% to about 1% by the year 2000 and 0.5% by 2020. The corresponding forecast of energy consumption is 132.2 quads by the year 2000 and 148.8 quads by 2020.

2.9 Environmental Protection Agency, *Alternative Futures and Environmental Quality*, Office of Research and Development, November 1973

The scenario presented by the Environmental Protection Agency provides a good explanation of the interactions between population, GNP, pollution, and energy consumption. The four possible futures described are high population and high economic growth, low population and low economic growth, and two intermediate alternatives. The low-population and low-growth case projects an energy consumption of 158 quads in the year 2000.

2.10 D. L. Ray, *The Nation's Energy Future*, WASH-1281, U.S. Atomic Energy Commission, December 1973

This report was prepared in response to President Nixon's directive in his June 29, 1973, energy message. Its purpose and scope are to recommend a national energy research and development program needed to regain and maintain energy self-sufficiency. The report was developed under the guidance of the Energy Policy Office in conjunction with various government departments and agencies having energy responsibilities. A five-year R&D program involving five tasks was suggested as a means of achieving the desired objectives. These tasks are: (1) conserve energy and energy resources, (2) increase domestic production of oil and gas, (3) substitute coal for oil and gas, (4) validate the nuclear option, and (5) exploit renewable resources. In order for the United States to achieve self-sufficiency by 1985, the growth in energy demand would have to be held to 90 quads by 1980 and 106 quads by 1985.

2.11 Ford Foundation, *Exploring Energy Choices*, preliminary report of Energy Policy Project of the Ford Foundation, early 1974

This report describes the following three scenarios (alternative energy futures), which are based on different assumptions regarding possible growth patterns our society might adopt.

	Energy consumption (quads)					
	1975	1980	1985	1990	1995	2000
Historical growth	80	95	115	136	160	185
Technical fix	80	87	96	104	110	118
Zero energy growth	80	87	93	95	98	100

The *historical growth* scenario assumes that the nation will not impose policies that will influence traditional habits of energy use. The *technical fix* scenario reflects a determined conscious national effort to reduce energy demand through conservation while still maintaining a quality of life comparable to that of historical growth. The *zero energy growth* scenario represents a real break with our accustomed way of living; however, it does not preclude economic growth. Also it allows the less privileged to catch up on the comforts of life.

2.12 Office of Planning and Analysis, *Nuclear Power Growth 1974–2000*, WASH-1139(74), U.S. Atomic Energy Commission, February 1974

Four scenarios of future energy demand and associated nuclear generating capacity are evaluated, ranging from a minimum forecast of 135.3 quads (nuclear capacity of 47.8 quads) to a high of 199.6 quads (nuclear capacity of 78.5 quads) by the year 2000. The minimum forecast assumes a slowdown in the rate of economic growth due to an increase in the efficiency of energy use and a reduction of demand. The high forecast, on the other hand, assumes a continuation of the past relationship between energy consumption and GNP together with an increase in the importance of electricity as a secondary energy source. The cases discussed are not intended to specify precise future situations, but rather to provide a reasonable range of estimates of probable demands for energy and the contributions of nuclear energy to the supply.

2.13 L. T. Blank and R. K. Riley, "Future U.S. Demand Patterns and Use of Hydrogen," paper presented at the Conference on the Hydrogen Economy, Miami, Fla., March 1974

The demand forecasts in this paper do not follow any of the conventional methods but use a method of saturation forecasting applicable to most areas of energy use. The saturation concept reflects the inability of an individual or household to use more than a certain amount of energy because of time and spatial constraints. The results of this approach, therefore, provide an upper limit to the growth in energy demand. This upper limit amounts to 187 quads by the year 2000 and 288 quads by 2020. The authors also make a conservation demand forecast by taking into consideration environmental factors, scarcity of energy sources, and costs. This latter approach indicates a demand for 140 quads by the year 2000. Hydrogen convertibility for each use area is also estimated, based on results of a 1973 NASA/ASEE Summer Design Institute.

2.14 Council on Environmental Quality, *A National Energy Conservation Program – The Half and Half Plan*, March 1974

The scenario presented by the Council on Environmental Quality is a response to the energy crisis of 1973–1974 and is based on the assumption that unrestrained growth of energy consumption is impossible and environmentally undesirable. The council proposes that the projected growth in energy consumption be cut by half through conservation and that the remaining half be met through expansion of domestic energy sources. The scenario is essentially a future based on an electric economy, with petroleum used almost exclusively for transportation. The postulated energy demand reaches 121 quads by the year 2000.

2.15 National Petroleum Council, *Energy Conservation in the United States – Short Term Potential, 1974–1978*, March 1974

The National Petroleum Council's (NPC) intermediate demand projection in their December 1972 report *U.S. Energy Outlook* was adopted as a starting point for a Consumption/Energy Demand Task Group study; however, the projection was reduced to allow for a 1% per year population growth rate instead of a 1.1% rate and an energy price increase in constant dollars of 100% between 1970 and 1985. The resulting projection indicates an energy consumption growth of 3.8% per year to 1977, 3.5% per year from 1978 to 1980, and 3.3% per year from 1981 to 1985. These growth rates lead to a projected total energy consumption of 114.4 quads by 1985.

2.16 M. A. Adelman et al., "Energy Self Sufficiency, An Economic Viewpoint," *Technol. Rev.* 76(6), 22 (May 1974)

This Massachusetts Institute of Technology study seeks to evaluate the state of the economy under energy self-sufficiency. On the assumption that the United States meets all its energy demands from internal sources by 1980, forecasts are made of the energy prices at which supply and demand will be in equilibrium. The results indicate that prices of $10 to $12 per barrel (oil-equivalent) will be necessary to reach the stated goal. Econometric supply and demand models taking price elasticity into consideration are compared with judgmental models that generally ignore price response. Because each approach has its own weakness, judgmental and econometric methods should be used to complement one another. On this basis, one might expect the energy supply and demand to balance out at about 90 quads by 1980 with the above energy prices.

2.17 R. C. Seamans, *U.S. Energy Prospects: An Engineering Viewpont*, National Academy of Engineering, May 1974

This report summarizes the findings of a task force appointed to provide an informal, measured, and prompt assessment of the technological range of actions that would have to be taken if the United States chose to become as independent as possible of foreign sources of energy by 1985. The results indicate that on the basis of historical trends, the United States would consume the equivalent of 58 million bbl/day of oil by 1985 (123×10^{15} Btu). However, if major incentives are undertaken to conserve the use of energy, this demand could possibly be reduced to about 51 million bbl/day of oil. In 1972, it was projected that domestic sources could supply about 40 million bbl/day of oil-equivalent by 1985. This 1974 study finds that if appropriate and timely actions are taken, domestic production could be increased to about 49 million bbl/day of oil by 1985. In the meantime, however, oil imports will probably rise from a current level of about 6.6 to 8 or 9 million bbl/day of oil by 1977 or 1978. The task force considered the possibility, as well as desirability, of ceasing oil importation altogether by 1985 to be questionable.

2.18 NASA/ASEE–Auburn University, *MEGASTAR (The Meaning of Energy Growth: An Assessment of Systems, Technologies and Requirements)*, Report NASA/CR-120338, September 1974

This study reviews recent energy consumption forecasts and chooses two as particular futures to evaluate – the nuclear electric economy described by Westinghouse in June 1973 and the Ford Foundation technical fix base case published early in 1974. The former is considered to be representative of historical energy growth forecast, while the latter is representative of a future based on a national effort to reduce demand through the application of energy-saving technologies. The study group analyzed one additional scenario in detail, which, though similar to the Ford technical fix base case, had the additional assumption that a zero energy growth rate might be achieved by the year 2000. Energy consumption according to this latter scenario was projected to reach 108 quads by 1985, 116 quads by 1990, and 120 quads by 2000.

2.19 Federal Energy Administration, *Project Independence Report*, November 1974

This study contrasts the U.S. energy supply and demand situation based on world oil prices of $7 per barrel and $11 per barrel. At the lower price, total energy demand would grow at 3.2% per year through 1985 and reach a level of 109.6 quads. Petroleum consumption would reach 23 million bbl/day. At $11 per barrel world oil prices, total energy demand would be reduced to a growth rate of 2.75% per year, resulting in a 1985 energy demand of 103 quads in the base case and 96.3 quads with energy conservation. Petroleum consumption in this latter case would be reduced to 18 million bbl/day. The domestic supply of energy would also be influenced by world oil prices. At $7 per barrel, domestic supply would reach 84.2 quads in the base case and 88.5 quads with an ambitious program to accelerate supply. At $11 world oil prices, economic forces would push domestic energy supplies to 96.3 quads, resulting in a no-oil-import situation.

2.20 Office of Planning and Analysis, *Total Energy, Electric Energy and Nuclear Power Projections, United States*, Energy Research and Development Administration, February 1975

The Office of the Assistant Administrator for Planning and Analysis has completed a new examination and prepared new projections of energy, electric power, and nuclear power for the United States through the year 2000. These estimates update the forecasts published in *Nuclear Power Growth, 1974–2000* [WASH-1139(74)], prepared in February 1974.

The total energy and electric power projections are derived through the use of econometric analyses and energy network flows developed by Brookhaven National Laboratory. The econometric work relates population, employment, and productivity factors to project GNP. Total energy resource consumption and energy inputs to the electrical sector are related to GNP growth to provide aggregate values for guiding the more detailed fuel substitution possibilities.

The three total energy cases developed are the same energy projections used in cases A, D, and B in the previous forecast. For the year 2000 the forecasts are as follows: high, 195 quads; moderate, 174 quads; and low, 135 quads.

2.21 E. Teller, *Energy – A Plan for Action*, report to the Energy Panel of the Commission on Critical Choices for Americans, April 1975

In this paper Teller presents, not a forecast of future energy demand, but a target for what demand should be. A proposed plan for achieving a target figure of 103 quads by 1985 and 170 quads by the year 2000 is presented. The elements of the plan are

1. economic and effective use of energy,
2. increased domestic oil and gas production,
3. much greater use of coal,
4. public acceptance of and greater use of nuclear energy.

3. ENERGY CONSUMPTION BY SOURCE

3.1 Method of Approach

Recent studies[1-24] of the U.S. future energy supply and demand problem were critically reviewed as a basis for establishing a "most likely" energy supply and demand scenario to the year 2000. Forecasts of total energy consumption were used as the starting point. These forecasts were grouped into two classes, representing historical-growth (preembargo) and conservation-oriented (postembargo–high oil price) conditions respectively. The averages for selected years of 15 conservation-oriented forecasts were judged to be representative of the most likely future energy demand.

The next step involved the development of an electricity demand forecast. Because one might expect that the same conservation-oriented forces that inhibit total energy demand would likewise influence electricity demand, electricity was correlated as a function of percentage of total energy demand for both the historical-growth and conservation-oriented forecasts.

Use of this correlation revealed that all forecasts were in fairly close agreement and that the four forecasts given in the 1975 version of WASH-1139[22] generally covered the spread of the forecasts. The averages of these four cases were adopted for this study.

Applying these average percentages to the previously derived total energy projections gave the electricity

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1. Associated Universities, Inc., *Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies*, PB-221 422 (also AET-8), May 1972.

2. Intertechnology Corporation, *The U.S. Energy Problem*, NSF/RANN-71-019, November 1971.

3. National Petroleum Council, *Guide to NPC Report on U.S. Energy Outlook*, December 1972.

4. W. G. Dupree and J. A. West, *United States Energy Through the Year 2000*, Department of the Interior, U.S. Government Printing Office, December 1972.

5. S. Field (Stanford Research Institute), "The U.S. Energy Puzzle," *Proceedings of the Division of Refining, 1973, Philadelphia, Pennsylvania*, American Petroleum Institute, Washington, D.C., May 1973.

6. P. N. Ross, Westinghouse Electric Corporation, "The Nuclear Electric Economy," paper presented at the Conference on the Hydrogen Economy, Miami, Fla., March 1974.

7. Joint Committee on Atomic Energy, *Understanding the National Energy Dilemma*, Joint Committee Print, August 1973.

8. NASA/ASEE–Auburn University, *Terrestrial Applications of Solar Technology and Research (TERRASTAR)*, NASA/CR-129012, September 1973.

9. Environmental Protection Agency, *Alternative Futures and Environmental Quality*, Office of Research and Development, November 1973.

10. D. L. Ray, *The Nation's Energy Future*, U.S. Atomic Energy Commission, WASH-1281, December 1973.

11. Office of Planning and Analysis, *Nuclear Power Growth 1974–2000*, WASH-1139(74), U.S. Atomic Energy Commission, February 1974.

12. L. T. Blank and R. K. Riley, "Future U.S. Demand Patterns and Use of Hydrogen," paper presented at the Conference on the Hydrogen Economy, Miami, Fla., March 1974.

13. Council on Environmental Quality, *A National Energy Conservation Program – The Half and Half Plan*, March 1974.

14. National Petroleum Council, *Energy Conservation in the United States – Short Term Potential, 1974–1978*, March 1974.

15. M. A. Adelman et al., "Energy Self Sufficiency, An Economic Viewpoint," *Technol. Rev.* 76(6), 22 (May 1974).

16. R. C. Seamans, *U.S. Energy Prospects: An Engineering Viewpoint*, National Academy of Engineering, May 1974.

17. NASA/ASEE–Auburn University, *MEGASTAR (The Meaning of Energy Growth: An Assessment of Systems, Technologies and Requirements)*, NASA/CR-120338, September 1974.

18. Federal Energy Administration, *Project Independence Report*, November 1974.

19. Ford Foundation, *A Time to Choose – America's Energy Future*, final report of the Energy Policy Project, Ballinger Publishing Co., Cambridge, Mass., 1974.

20. J. W. Duane and M. A. Karnitz, "Domestic Gas Resources and Future Production Rates," *Power Eng.* 79(1), 36–39 (January 1975).

21. C. E. Whittle and D. B. Reister, *The IEA Energy Simulation Model: A Framework for Long-Range U.S. Energy Analysis*, Institute for Energy Analysis, January 1975.

22. Office of Planning and Analysis, *Total Energy, Electric Energy and Nuclear Power Projections, United States*, Energy Research and Development Administration, February 1975.

23. J. D. Moody and R. E. Geiger, "Petroleum Resources – How Much Oil and Where?" *Technol. Rev.* 77(5), 38–45 (March–April 1975).

24. E. Teller, *Energy – A Plan for Action*, report to the Energy Panel of the Commission on Critical Choices for Americans, April 1975.

demand forecast. The corresponding electrical generating capacities were calculated from the demand data using ERDA's projected system heat rates and capacity factors.[22]

A nuclear generation capacity forecast was obtained by averaging the ERDA low and moderate/low forecasts.[22] The corresponding nuclear power generation was then calculated using ERDA's forecast heat rates for nuclear plants and assuming that nuclear plant capacity factors would level off at 70% (same as the ERDA high case). This assumption should be valid, since the projected installed nuclear capacity reaches only 50% of the total installed capacity by the year 2000.

Using the same approach as for electricity projections, a coal consumption forecast was obtained by plotting coal forecasts as a percentage of total energy for both the preembargo and postembargo forecasts. Here the agreement was not good between the two types of forecasts; therefore, only the postembargo forecasts were used to obtain an estimate of future coal consumption.

Forecasts of domestic natural gas and petroleum production were plotted, and a judgment (best guess) forecast was made for each of these sources of supply. In the case of natural gas supply, the judgment forecast was the same as that of Duane and Karnitz of Consumers Power Company[20] based on a total resource of 1500×10^{12} ft^3.

The projected contribution of hydroelectric power was based on an average of available forecasts. This average is close to the Office of Planning and Analysis's moderate projection and represents a continuation of the recent growth of hydroelectric power.

The contribution of geothermal and solar energy was estimated, based on an average of various forecasts for the years 1985 and 2000.

Wood and waste materials consumption was assumed by the year 2000 to reach a level equal to wood in the early 1950s.

The requirements for imported oil were obtained as an end result by subtracting the combined contribution of domestic energy supplies from the forecast total energy demand.

3.2 Total Energy Consumption

Forecasts of total energy consumption are given in Tables 1 and 2. The historical-growth forecasts for 1985 are generally in the range of 115 to 130 quads, which corresponds to an annual growth rate of about 4%. With this scenario, energy consumption would reach 180 to 210 quads by the year 2000 and 300 quads by 2020. The conservation-oriented forecasts shown in Table 2, on the other hand, project a demand of only 90 to 110 quads by 1985 and about 120 to 140 quads by the year 2000. Average annual growth rates with these forecasts would be 2.5% up to 1985 and 1.9% from 1986 to 2000. The averages of the two types of forecasts are plotted in Fig. 1 along with historical data on total energy consumption. In view of the current oil price situation, the conservation-oriented forecast appears to represent the most likely trend of future energy demand.

3.3 Coal Consumption Forecasts

Forecasts of U.S. coal consumption (which, in some cases, are also production figures) in terms of energy content are listed in Table 3 and plotted in Fig. 2. Because of the wide spread of data it was not possible to obtain a consensus type of correlation. Figure 3 shows a second plot of selected coal consumption forecasts in terms of percentage of total energy used. Forecasts that did not take into consideration an increasing dependence on coal for the production of electricity and synthetic liquid and gaseous fuels were not included in this plot. The correlation indicated by dots in Fig. 3 was adopted for this study. These percentages were applied to the total energy forecast to obtain the coal consumption forecast shown in Table 4. The average heat content data used in this table were obtained from a straight-line extrapolation of the 25-year trend in the United States from 1950 to 1974.

3.4 Domestic Natural Gas Production

Forecasts of domestic natural gas production are plotted in Fig. 4. With a few exceptions, the forecasts show that natural gas production will peak in the late 1980s and reach a maximum production level in the range of 20 to 30 quads/year. The height of the peak will depend on the magnitude of the total recoverable resources. Assuming these recoverable resources to be of the order of 1500×10^{12} ft^3 or 1545 quads (estimates range between 1200 and 1800×10^{12} ft^3), the forecast by Duane and Karnitz of Consumers Power Company appears to represent the maximum production that may be expected under even the best of conditions. This forecast indicates a peak production of 26 quads in 1986 and a reduction to 20 quads by the year 2000. A recent U.S. Geological Survey publication on U.S. oil and gas reserves[25] indicates that measured,

25. B. M. Miller, H. L. Thomsen et al., *Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States*, U.S. Geological Survey Circular 725, (1975).

Table 3. Forecasts of coal consumption

Key to Fig. 2	Forecaster	1985 Quads	1985 Percent of total energy	2000 Quads	2000 Percent of total energy
1	Associated Universities, Inc.	21.6	18.3	36.5	20.3
2	MIT (Hudson–Jorgenson)	16.5		26.9	
3	Westinghouse (Ross)	34.0	30.9	66.0	31.9
4	NASA/ASEE TERRASTAR	21.2	19.9	40.7	30.8
5	U.S. Atomic Energy Commission (D. L. Ray)	29.4	27.8		
6	Ford Foundation technical fix[a]	15.0	16.3	25.5	20.7
6	Ford Foundation historical growth[a]	24.3	21.1	42.0	22.4
7	U.S. Atomic Energy Commission/Office of Planning and Analysis				
	WASH-1139(74) – case A	19.3	20.1	23.6	17.4
	WASH-1139(74) – case B	22.3	19.1	28.9	14.8
	WASH-1139(74) – case C	26.0	21.7	29.1	14.6
	WASH-1139(74) – case D	20.0	19.1	26.1	15.0
8	Department of the Interior (Dupree–West)	21.5	18.4	31.4	16.3
9	National Academy of Engineering	25.3	25.6		
10	NASA/ASEE MEGASTAR	21.2	18.3	24.8	20.7
11	Federal Energy Administration				
	Project Independence (business as usual)	22.9	22.2		
	Project Independence Task Force (business as usual)	25.0	24.3	29.6 (1990)	
	Project Independence Task Force (accelerated supply)	46.9	43.0	63.8 (1990)	
12	E. Teller	33.0	28.0		
13	ERDA (synopsis from Coal Scenario II)	23.3	21.7	49.8	30.1

[a] Average of alternative scenarios.

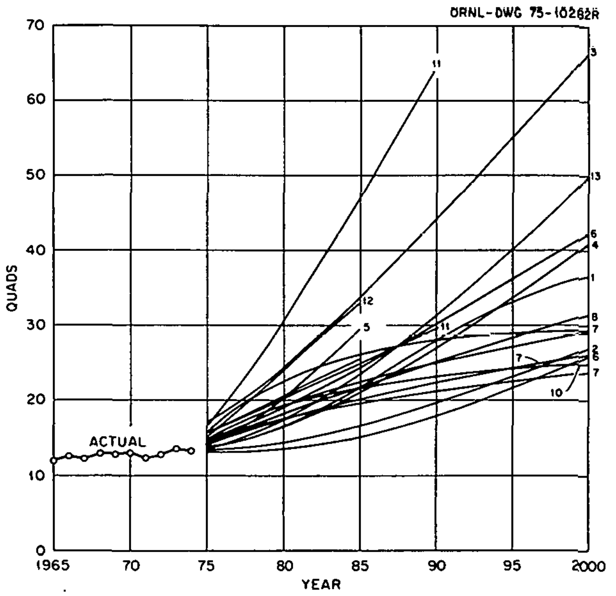

Fig. 2. Coal consumption and production forecasts. Note: See Table 3 for reference numbers.

inferred, and undiscovered recoverable reserves with a 95% probability of discovery amount to 1242 quads. This publication states that there is only a 5% probability of discovering as much as 1575 quads[25] (see Sect. 5 below). Table 5 gives the selected forecast of natural gas production.

3.5 Domestic Oil Production

Forecasts of domestic oil production (including natural gas liquids and shale oil) are plotted in Fig. 5. As in the case of natural gas production, most forecasts show that domestic oil production from all sources might peak in the late 1980s, reaching a level in the range of 22 to 30 quads/year (10 to 14 million bbl/day). According to Geiger and Moody[23] the total domestic recoverable resources of crude oil (including undiscovered potential sources) may amount to 230 × 10^9 bbl, of which 100 × 10^9 bbl were produced up to 1974. The curve shown in Fig. 5, adopted for the study, would utilize 85% of this potential resource by the year

Table 4. Selected forecast of U.S. coal consumption

Year	Percent of total energy	Quads	Average heat content (millions of Btu per ton)	Millions of tons per year
1975	18.7	14.1	23.8	590
1980	21.2	18.7	23.4	800
1985	23.3	23.3	23.0	1010
1990	25.7	28.3	22.6	1250
1995	27.9	33.8	22.2	1520
2000	30.0	39.9	21.7	1825

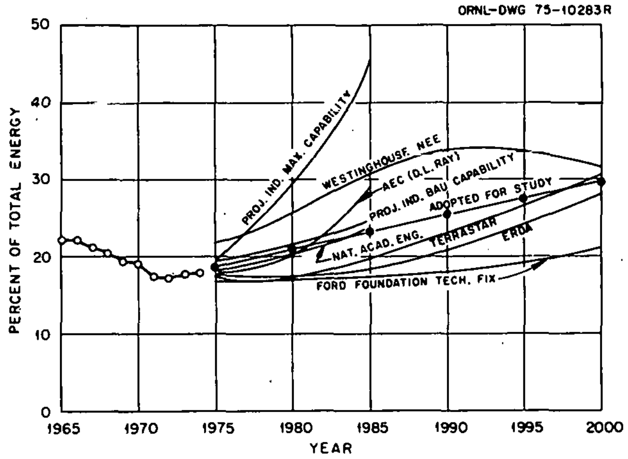

Fig. 3. Coal consumption as percentage of total energy.

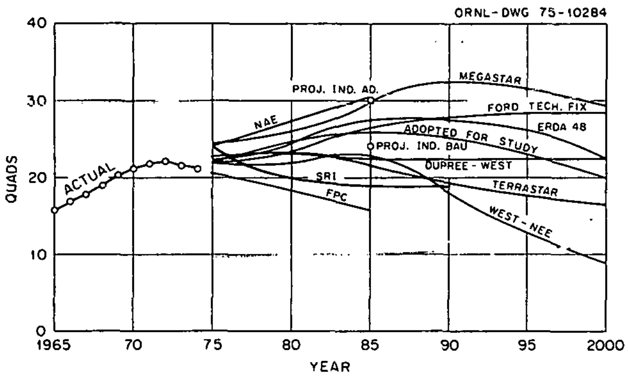

Fig. 4. Domestic natural gas production.

2000 and the remainder by 2010. Using this same resource figure as a basis, the Project Independence estimate of an unconstrained accelerated development production of 20 million bbl/day (at $11 per barrel) by 1985[18] would lead to exhaustion of domestic oil resources by the mid-1960s. The domestic oil production forecast selected for this study is given in Table 5.

Table 5. Selected forecasts of domestic gas and oil production

Year	Natural gas production		Crude oil plus natural gas liquids	
	Quads	Trillion cubic feet per year	Quads	Millions of barrels per day
1975	22.0	21.4	22.0	10.4
1980	24.5	23.8	26.1	12.3
1985	25.8	25.0	28.0	13.2
1990	25.0	24.3	27.0	12.7
1995	23.0	22.3	23.0	10.9
2000	20.0	19.4	17.6	8.3

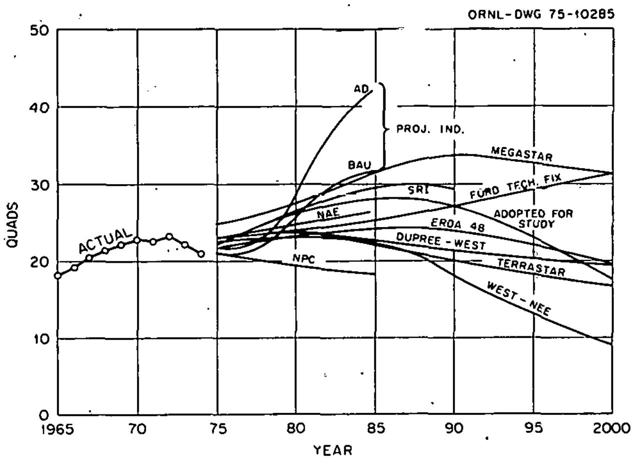

Fig. 5. Forecasts of domestic oil production (including natural gas liquids).

3.6 Nuclear Power

Because the contribution of nuclear power is likely to be almost entirely in the electrical sector, ORNL/TM-5370 covers the development of a nuclear power forecast.[26] This development projects an installed nuclear capacity of 700 GW(e) in the year 2000, which corresponds to a thermal generation of 43.7 quads in that year.

3.7 Hydroelectric Power

Hydroelectric power is also covered in ORNL/TM-5370.[26] An average of recent forecasts indicates that hydroelectric generation might level off at 410 billion kWhr by the year 2000. The fuel equivalent of this generation at 33% efficiency would be 4.2 quads.

26. J. A. Lane, *Electricity Consensus Forecast of Supply and Demand to the Year 2000*, ORNL/TM-5370 (to be published).

3.8 Solar Energy

Forecasts of the possible contribution of various applications of solar energy to the U.S. energy supply system in the year 2000 are given in Table 6. Applications other than thermal electricity generation and photovoltaic central station plants are shown for purposes of comparison. Only forecasts made during the past 2½ years are included since prior energy supply projections, such as those made by the Bureau of Mines[27] or by the Department of the Interior,[4] made no mention of solar energy. Although most of the forecasters gave projections for 1985, the projections in general indicated a small or negligible contribution of solar energy in that year. Some of the forecasters projected a large contribution by solar energy by the years 2020–2025 (115 to 144 quads). The most important aspect of the data in Table 6 is the extremely wide range of the forecasts, which vary from 1 quad in the year 2000 to 94 quads (1.25 times present total U.S. energy consumption). For this reason the data are not suitable as a basis for a consensus-type projection. In the absence of a clear picture of the competitive position of solar electric plants, any forecast of the future contribution of such plants is pure conjecture.

As a guess, one might say that the contribution of solar plants (thermal electric and photovoltaic) in the year 2000 could reach an installed peak output of 10 GW(e) [10^7 kW(e)], assuming an economic breakthrough. Such plants would operate at an average plant factor of about 31% and generate about 2.7×10^{10} kWhr of electricity per year. The fuel equivalent of this electricity is about 0.3 quad.

With regard to wind-generated electricity, if one excludes the offshore applications because of technical and cost uncertainties and the Aleutian arc because of its remoteness, the wind potential (over the Great Plains) would be reduced to 210×10^9 kWhr [80 GW(e)], or approximately 2 quads equivalent. A reasonable upper limit to the utilization of this source of energy appears to be not more than 1 quad by the year 2000.

Other applications of solar energy, such as the heating and cooling of buildings, might contribute on the order of 2.5 quads by the year 2000. This would be equivalent to supplying 70% of the energy requirements of 20 million residential units.

3.9 Geothermal

Estimates of the rate of expansion of the U.S. geothermal power industry vary over wide limits. For example, Rex and Howell judge that "40,000 MWe of geothermal capacity could be discovered and developed in the Western United States in 20 years by the resource industry."[10] Their projection is based on the assumption that hot dry rock systems are technically and economically exploitable. The Hickel Panel in 1972[28]

27. W. E. Morrison and C. L. Readling, "An Energy Model for the U.S. Featuring Energy Balances for the Years 1947 to 1965 and Projections and Forecasts to the Years 1980 and 2000," Bureau of Mines Infomation Circular, IC-8384, July 1968.

28. U.S. Senate, Committee on Interior and Insular Affairs, Hickel Panel statement, 2d session on the role of geothermal energy resources and research, June 15 and 22, 1972.

Table 6. Forecasts of solar energy applications in the year 2000

In quads

Forecaster	Date of forecast	Thermal photovoltaic electricity	Wind and ocean thermal gradient	Other solar	Total
NSF/NASA	Dec. 1972	3.1	2.4	6.5	12.0
NASA/ASEE TERRASTAR	Sept. 1973	0	0	3.5–6.1	3.5–6.1
Subpanel IX	Nov. 1973	5.3	15	4.5	24.8
Mitre Corporation	Dec. 1973	7–18	11–27	18	36–63
Council on Environmental Quality	Mar. 1974	0	0	1	1
Ford Foundation	Late 1974	1	1	2	4
Project Independence Task Force	Nov. 1974	6–27	19–40	8–27	34–94
Institute for Energy Analysis	Jan. 1975	0–1.7	0	0.2	0.2–1.9
E. Teller	Apr. 1975	0	0	5	5
ERDA-48	June 1975	1.3–6.1	0	5	6.3–11.1
ERDA-49	June 1975	3.1	1.8	6	10.9
Hudson Institute	Aug. 1975	6–9	6–9	6–9	18–27

was also very optimistic about the future of geothermal energy and projected an installed geothermal capacity of 395,000 MW(e) by the year 2000 with an accelerated research program.[28] More recent projections, shown in Table 7, are considerably more conservative. These indicate that the geothermal capacity in the United States might reach about 8600 MW(e) by 1985 and about 43,000 MW(e) by the year 2000. Assuming a central station efficiency comparable to that of nuclear and fossil-fueled plants, these installed capacities would contribute 0.6 and 3.0 quads in 1985 and 2000 respectively.

3.10 Wood and Waste Materials

Few forecasts of the future contribution of wood and waste materials were available for evaluation. Since the total energy generation from these sources will be relatively small, one can project a linear growth reaching a level equal to that of wood in the early 1950s. This results in a contribution of 1.1 quads by the year 2000.

3.11 Summary of U.S. Energy Consumption by Source

The selected forecasts of energy consumption for each of the alternative sources of energy are summarized in Table 8. The total contribution of these sources provides an indication of a consensus-type U.S. energy supply forecast. One can now subtract this energy supply from the overall energy demand forecast given in Table 2 to obtain an indication of the future requirements for imported oil under conditions of enhanced coal production, reasonable conservation, and the most likely contribution of the remaining domestic energy sources. Under the assumed conditions, self-sufficiency will not be reached until late in the century; however, oil imports will be reduced to manageable proportions by about 1985.

4. ENERGY USE BY CONSUMING SECTOR

4.1 Reference System

Table 9 summarizes the U.S. energy supply and demand system for 1972. Figure 6 shows a flowsheet of energy supply to end use based on the data in Table 9. The reference consuming sectors in 1972 had the following levels of demand:

Residential

66.7×10^6 households (208.8×10^6 population)
space heating – 48.8×10^6 Btu/unit
air conditioning – 21.7×10^6 Btu/unit (38% of saturation)
water heating and cooking – 23×10^6 Btu/unit
miscellaneous electric – 4235 kWhr/unit (14.5×10^6 Btu/unit)

Table 7. Forecasts of geothermal contribution to U.S. energy supply

Forecaster	Date of forecast	Forecast geothermal contribution (quads)[a]			
		1980	1985	1990	2000
Hickel Panel	June 1972	0.7–2.4	1.3–8.8	2.3–16.1	5.0–26.3
National Petroleum Council	Dec. 1972	0.3	0.5		
Stanford Research Institute	May 1973		0.3		
NASA/ASEE TERRASTAR	Sept. 1973	0.3	0.6		2.5
U.S. Bureau of Mines	Oct. 1973		0.3		2.7
U.S. Atomic Energy Commission (D. L. Ray)	Dec. 1973		1.5		6.0
Council on Environmental Quality	Mar. 1974				2.0
National Academy of Engineering	May 1974		0.5		
NASA/ASEE MEGASTAR	Sept. 1974	0.1	0.2	0.3	0.5
Project Independence Task Force	Nov. 1974	0.06	0.3–2.3	3.9–7.4	
Ford Foundation	1974		1.0		2.0
ERDA-48	June 1975		0.3–1.4		0.7–7.0
E. H. Willis (ERDA)	Oct. 1975		0.5		4.1
Average[b]			0.6		3.0

[a]MW(e) converted to quads assuming 1000 MW(e) = 0.07 quad.
[b]Excluding upper limit values.

Table 8. Consensus forecast of U.S. future energy supply and demand

Domestic supply by type of energy source	Quads					
	1975	1980	1985	1990	1995	2000
Coal	13.2	18.7	23.3	28.3	33.8	39.9
Natural gas	20.2	24.5	25.8	25.0	23.0	20.0
Domestic oil and natural gas liquids	22.0	26.1	28.0	27.0	23.0	17.6
Nuclear	1.7	4.3	11.1	19.5	30.7	43.7
Hydroelectric power	3.1	3.4	3.7	3.9	4.1	4.2
Solar electric			0.2	0.4	0.7	1.0
Solar heating and cooling		0.04	0.4	0.7	1.3	2.5
Geothermal		0.06	0.4	0.8	1.4	2.0
Wood, biomass, and waste	0.2	0.3	0.5	0.7	0.9	1.1
Total domestic supply	60.4	77.4	93.4	106.3	119.1	132.0
Estimated domestic demand[a]	71.1	88.0	100.0	110.0	121.0	132.0
Implied level of oil imports	10.7	10.6	6.6	3.7	1.9	0

[a]Based on conservation-oriented forecasts (Table 2); excludes 1.5 quads of coal exports. Data for 1975 are from the U.S. Bureau of Mines (preliminary as of Feb. 6, 1973).

Commercial

23.5×10^9 ft² floor space
space heating – 86,500 Btu/ft²
air conditioning – 40,700 Btu/ft² (50% of saturation)
miscellaneous thermal – 18,000 Btu/ft²
miscellaneous electric – 12 kWhr/ft², (39,400 Btu/ft²)

Industrial

miscellaneous electric – 642×10^9 kWhr (2.19 quads)
primary and scrap aluminum – 10.1×10^9 lb. 7.0 kWhr/lb
iron (84.5×10^6 tons) plus steel (133×10^6 tons) – 189 kWhr/ton plus 9.33×10^6 Btu/ton
process heat and miscellaneous – 7.61 quads
petrochemicals – 4.19 quads

Transportation

automative (gasoline engines) – 992×10^9 vehicle miles, 13.6 mpg
air transport (gas turbine) – 153×10^9 passenger miles, 15 passenger-miles/gal; 4×10^9 ton-miles, 45 ton-miles/gal
bus, truck, rail – 89×10^6 bus passenger-miles, 461×10^9 truck ton-miles, 171×10^9 vehicle miles
ship – 0.71 quad

4.2 Allocation of Losses to Consuming Sector

The distribution of energy consumption in Table 9 treats energy losses incurred in generating electricity in refining oil and gas, and in producing coal as separate consuming sectors. In Table 10, these losses have been distributed to each sector in proportion to the amount consumed. Similarly, in Sect. 4.1, the differences in efficiency of using the various energy sources by the sector itself have not been taken into consideration. Table 11 shows the distribution of end use consumption by source after allowing for differences in use efficiency. Table 12 summarizes the distribution of energy consumption by sector for both input and end use.

4.3 Preliminary Energy Data for 1975

Preliminary data on the distribution of energy consumption in 1975 by source and consuming sector were obtained from the U.S. Bureau of Mines[29] and are given in Table 13. These data were matched to a supply and demand scenario using 1972 individual sector distributions of consumption as a basis. The results are shown in Tables 14 and 15.

4.4 Forecast of Energy Consumption by Sector – Year 1985

The distribution of energy consumption by consuming sector was assumed to be the same as that given in ERDA-48 Scenario V;[30] however, the end use demands were increased 3% to adjust to the 1985 consensus forecast of 100 quads (see Table 2). The results are given in Table 16.

29. C. E. Whittle, Institute for Energy Analysis, telephone call to C. Readling, Department of the Interior, Feb. 3, 1976.

30. Energy Research and Development Administration, *A National Plan for Energy Research, Development and Demonstration – Creating Energy Choices for the Future*, ERDA-48, June 1975.

Table 9. Summary of energy demand and fuel mix, 1972

In quads

	Natural gas	Oil	Coal	Nuclear	Hydroelectric[a]	Electric[b]	Methane[c]	Total direct use
Residential								
Space heating		3.094				0.202	3.835	7.131
Air conditioning						0.214	0.004	0.218
Water heating and cooking		0.355				0.495	1.473	2.323
Miscellaneous electric						0.964		0.964
Subtotal		3.449				1.875	5.312	10.636
Commercial								
Space heating		2.149	0.320			0.096	1.564	4.129
Air conditioning						0.148	0.019	0.167
Water heating and cooking						0.097	0.565	0.662
Miscellaneous electric						0.924		0.924
Subtotal		2.149	0.320			1.265	2.148	5.882
Industrial								
Aluminum			0.082			0.242	0.050	0.374
Cement		0.077	0.192			0.036	0.230	0.535
Iron and steel		0.177	2.025			0.139	0.679	2.960
Process heat		1.365	1.266				7.545	10.176
Electrical drive						2.155		2.155
Electrical generation		0.414	0.330				0.366	1.110
Feedstocks		3.389	0.127				0.674	4.190
Subtotal		5.422	4.022			2.572	9.544	21.500
Transportation								
Automotive		9.121						9.121
Bus		0.125						0.125
Truck		3.668						3.668
Rail and subway		0.597				0.018		0.615
Air		2.201						2.201
Pipelines		0.045					0.041	0.086
Ship		0.713						0.713
Subtotal		16.470				0.018	0.041	16.529
Electric utility		3.141	7.827	0.576	2.890	(5.730)	4.102	12.806
Methane production	23.12							2.053
Coal production			0.435					0.435
Refinery use		2.339						2.339
Total resources consumed	23.12	32.970	12.604	0.576	2.890	(5.730)	(21.147)	72.240

[a]Also includes geothermal. Hydroelectric power resource consumption is based on a conversion efficiency of 37%; geothermal is based on a conversion efficiency of 15%.

[b]Gives energy consumed as electricity at 3412.8 Btu/kWhr. For fuels consumed in producing electricity, see row labeled "electric utility."

[c]Includes natural gas and gasified coal. See row labeled "methane production."

Source: K. C. Hoffman et al., *Current BNL Reference Energy System (RES) Projections,* draft report, Brookhaven National Laboratory, Sept. 19, 1975.

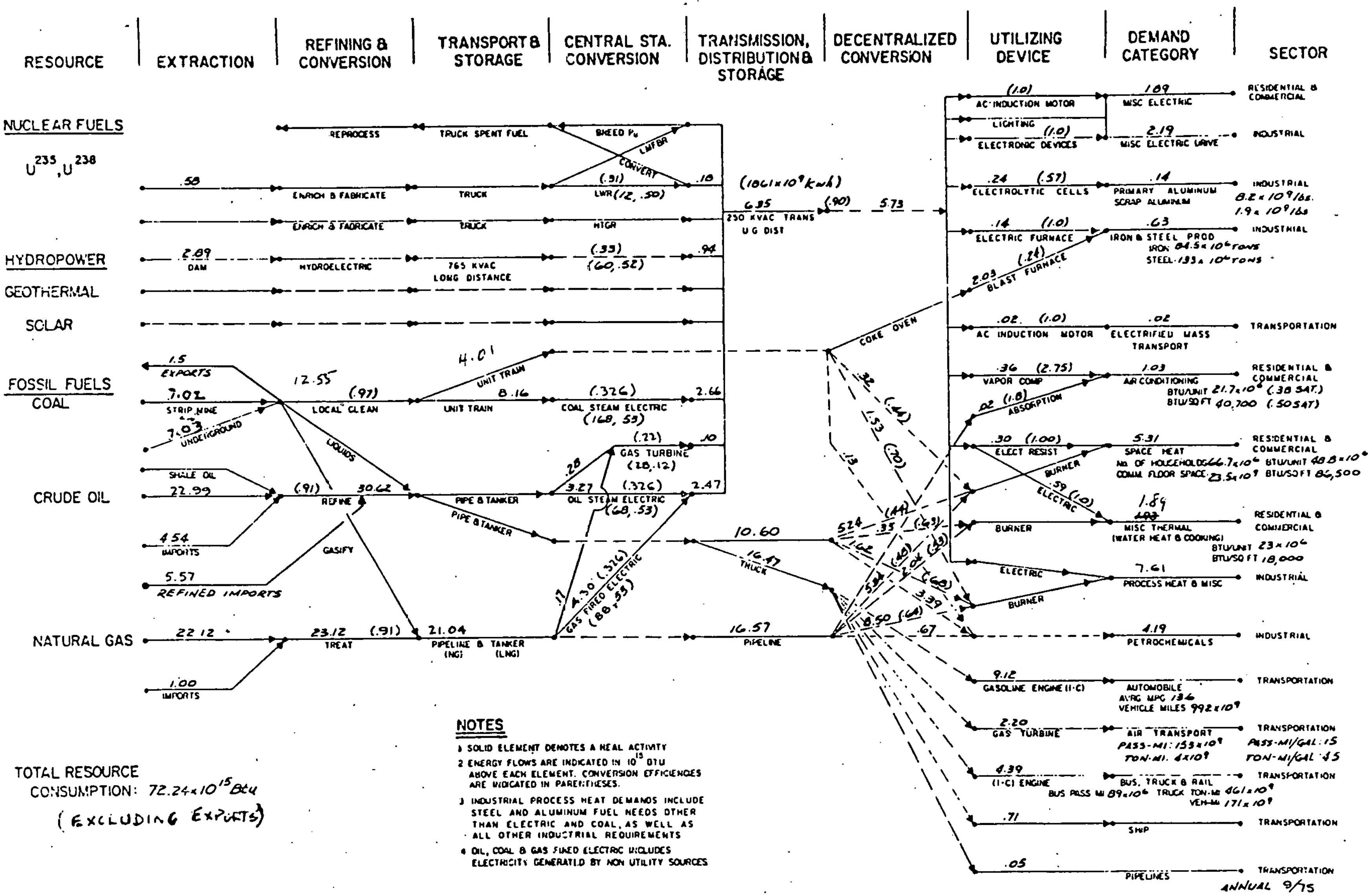

Fig. 6. Flowsheet for reference U.S. energy system (1972). Source: Associated Universities, Inc., Upton, L.I., New York 11973.

Table 10. Summary of reference (1972) energy input by source.

In quads

Consuming sector	Direct use			Electric	Total
	Coal	Oil	Gas		
Residential/commercial					
Space heating	0.33	5.66	5.87	1.08	12.94
Air conditioning			0.02	1.30	1.32
Water heating and cooking		0.38	2.24	2.13	4.75
Miscellaneous electric				6.81	6.81
Subtotal	0.33	6.04	8.13	11.32	25.82
Industrial					
Aluminum				0.86	0.86
Iron and steel	2.09			0.50	2.59
Process heat	1.58	1.75	9.34		12.67
Miscellaneous electric				7.89	7.89
Petrochemicals	0.14	3.66	0.74		4.54
Subtotal	3.86	5.41	10.08	9.25	28.55
Transportation					
Automotive		9.86			9.86
Air transport		2.38			2.38
Bus, truck, rail		4.74			4.74
Electric mass transport				0.07	0.07
Ship		0.77			0.07
Pipelines		0.05			0.05
Subtotal		17.80		0.07	17.87
Total	4.19	29.25	18.21	20.64	72.24

Table 11. Summary of reference (1972) energy end use by source

In quads

Consuming sector	Direct use			Electric	Total
	Coal	Oil	Gas		
Residential/commercial					
Space heating	0.32	5.24	5.34	0.30	11.20
Air conditioning			0.02	0.36	0.38
Water heating and cooking		0.35	2.04	0.59	2.98
Miscellaneous electric				1.89	1.89
Subtotal	0.32	5.59	7.40	3.14	16.45
Industrial					
Aluminum				0.24	0.24
Iron and steel	2.03			0.14	2.17
Process heat	1.53	1.62	8.50		11.65
Miscellaneous electric				2.19	2.19
Petrochemicals	0.13	3.39	0.67		4.19
Subtotal	3.69	5.01	9.17	2.57	20.44
Transportation					
Automotive		9.12			9.12
Air transport		2.20			2.20
Bus, truck, rail		4.39			4.39
Electric mass transport				0.02	0.02
Ship		0.71			0.71
Pipelines		0.05			0.05
Subtotal		16.47		0.02	16.49
Total	4.01	27.07	16.57	5.73	53.38

Table 12. Summary of reference (1972) energy system by consuming sector

Consuming sector	Energy input (quads)	Percent of total	End use (quads)	Percent of total
Residential/commercial				
Space heating	12.94	17.9	11.20	21.0
Air conditioning	1.32	1.8	0.38	0.7
Water heating and cooking	4.75	6.6	2.98	5.6
Miscellaneous electric	6.81	9.4	1.89	3.5
Subtotal	25.82	35.7	16.45	30.8
Industrial				
Aluminum	0.86	1.2	0.24	0.5
Iron and steel	2.09	2.9	2.17	4.1
Process heat	13.17	18.2	11.65	21.8
Miscellaneous electric	7.89	10.9	2.19	4.1
Petrochemicals	4.54	6.3	4.19	7.8
Subtotal	28.55	39.5	20.44	38.3
Transportation				
Automotive	9.86	13.6	9.12	17.1
Air transport	2.38	3.2	2.20	4.1
Bus, truck, rail	4.74	6.6	4.39	8.2
Electric mass transport	0.07	0.1	0.02	0.1
Ship	0.77	1.1	0.71	1.3
Pipelines	0.05	0.1	0.05	0.1
Subtotal	17.87	24.7	16.49	30.9
Total	72.24	100.0	53.38	100.0

Table 13. U.S. Bureau of Mines energy consumption data for 1975

In trillions of Btu[a]

Consuming sector	Coal	Natural gas	Petroleum	Hydroelectric	Nuclear	Gross inputs	Utility electricity distributed	Gross electricity[b]	Gross inputs
Residential/Commercial	282	7,373	5,829			13,484	3,783	(11,671)	25,155
Industrial	4,287	8,991	5,703	36		19,017	2,708	(8,354)	27,371
Transportation	1	635	17,857			18,493	19	(59)	18,552
Electric generation	8,824	3,174	3,312	3,122	1,652	20,084			
Total	13,394	20,173	32,701	3,158	1,652	71,078	6,510	20,084	71,078

[a]Estimates of consumption rates for nonutility industrial electricity are as follows:
1974 – hydroelectric power, 3,537.1 × 10^6 kWhr; fuels, 98,904.5 × 10^6 kWhr
1975 – hydroelectric power, 3,460 × 10^6 kWhr; fuels, 81,000 × 10^6 kWhr.
[b]Numbers in parentheses are indirect energy inputs to the process of generating electricity for the consuming sector indicated.

4.5 Year 2000 Energy Consumption by Consuming Sector and Source

The forecast of energy consumption for the year 2000 was assumed to be the same as that in ERDA-48 Scenario V (99 × 10^6 households, 42 × 10^9 ft^2 of commercial floor space, etc.). These demands, however, were matched against the previously derived forecasts of energy supply by source (see Table 8) and against the electricity generation forecast given in ref. 31. End use demands were also adjusted for differences in utilization efficiencies of fuels and electricity. Table 17 shows the resulting distribution of energy consumption by end use. The corresponding distribution of energy inputs (including production losses) is shown in Table 18.

31. Ref. 26, Table 1.

Table 14. Summary of 1975 energy input by source

In quads

Consuming sector	Coal	Oil	Gas	Utility electricity	Industrial electricity	Total
Residential/commercial						
Space heating	0.28	5.46	5.32	1.12		12.18
Air conditioning			0.02	1.33		1.35
Water heating and cooking		0.37	2.03	2.14		4.54
Miscellaneous electric				7.08		7.08
Subtotal	0.28	5.83	7.37	11.67		25.15
Industrial						
Aluminum				0.78		0.78
Iron and steel	2.36			0.44		2.80
Process heat	1.65	1.71	7.74		0.84	11.94
Miscellaneous electric				7.13	0.04	7.17
Petrochemicals	0.16	3.86	0.66			4.68
Subtotal	4.17	5.57	8.40	8.35	0.88	27.37
Transportation						
Automotive		9.90				9.80
Air transport		2.38				2.38
Bus, truck, rail		4.76				4.76
Electric mass transport				0.06		0.06
Ship		0.77				0.77
Pipelines		0.05	0.64			0.69
Subtotal	0.00	17.86	0.64	0.06		18.56
Total	4.45	29.26	16.41	20.08	0.88	71.08

Table 15. Summary of 1975 energy end use by source

In quads

Consuming sector	Coal	Oil	Gas	Electric	Total
Residential/commercial					
Space heating	0.27	5.07	4.99	0.33	10.66
Air conditioning			0.02	0.39	0.41
Water heating and cooking		0.34	1.90	0.64	2.88
Miscellaneous electric				2.07	2.07
Subtotal	0.27	5.41	6.91	3.43	16.02
Industrial					
Aluminum				0.23	0.23
Iron and steel	2.29			0.13	2.42
Process heat	1.57	1.63	7.36	0.80	11.36
Miscellaneous electric				2.11	2.11
Petrochemicals	0.15	3.58	0.63		4.36
Subtotal	4.01	5.21	7.99	3.27	20.48
Transportation					
Automotive		9.18			9.18
Air transport		2.21			2.21
Bus, truck, rail		4.41			4.41
Electric mass transport				0.02	0.02
Ship		0.71			0.71
Pipelines		0.63			0.63
Subtotal		17.14		0.02	17.16
Total	4.28	27.76	14.90	6.72	53.66

Table 16. Summary of 1985 energy consumption by sector

Consuming sector	Energy input (quads)	Percent of total	End use (quads)	Percent of total
Residential/commercial				
Space heating	13.1	13.1	5.6	9.5
Air conditioning	2.9	2.9	2.7	4.6
Water heating and cooking	6.0	6.0	2.5	4.3
Miscellaneous electric	9.1	9.1	2.6	4.4
Subtotal	31.1	31.1	13.4	22.8
Industrial				
Aluminum	1.6	1.6	0.3	0.5
Iron and steel	3.7	3.7	0.9	1.5
Process heat	18.9	18.9	11.7	19.9
Miscellaneous electric	11.9	11.9	3.4	5.8
Petrochemicals	8.6	8.6	7.8	13.2
Subtotal	44.7	44.7	24.1	40.9
Transportation				
Automotive	11.3	11.3	10.3	17.0
Air transport	6.0	6.0	5.5	9.3
Bus, truck, rail	4.8	4.8	4.4	7.5
Electric mass transport	0.6	0.6	0.2	0.3
Ship	1.4	1.4	1.2	2.0
Pipelines	0.1	0.1	0.1	0.2
Subtotal	24.2	24.2	21.4	36.3
Total	100.0	100.0	58.9	100.0

Table 17. Forecast of energy end use consumption by source for the year 2000

In quads

Consuming sector	Solar, geothermal, and waste heat	Coal	Oil	Gas	Electric	Total
Residential/commercial						
Space heating	1.0			5.11	2.48	8.59
Air conditioning					1.65	1.65
Water heating and cooking	1.0			0.97	1.37	3.34
Miscellaneous electric					3.10	3.10
Subtotal	2.0			6.08	8.60	16.68
Industrial						
Aluminum					0.75	0.75
Iron and steel		2.14			0.32	2.46
Process heat	4.3	10.17		1.51	2.96	18.94
Miscellancous electric					6.10	6.10
Petrochemicals		0.78		10.25		11.03
Subtotal	4.3	13.09		11.76	10.13	39.28
Transportation						
Automotive			8.15		0.64	8.79
Air transport			7.33			7.33
Bus, truck, rail			7.13			7.13
Electric mass transport					0.23	0.23
Ship			1.62			1.62
Pipelines			0.20	0.35		0.55
Subtotal			24.43	0.35	0.87	25.65
Total	6.3	13.09	24.43	18.19	19.60	81.61

Table 18. Forecast of energy input by source for the year 2000

In quads

Consuming sector	Solar and geothermal	Coal	Oil	Gas	Electric	Total
Residential/commercial						
Space heating	0.6			5.5	8.3	14.4
Air conditioning					5.5	5.5
Water heating and cooking	0.6			1.1	4.2	5.9
Miscellaneous electric					10.2	10.2
Subtotal	1.2			6.6	28.2	36.0
Industrial						
Aluminum					2.6	2.6
Iron and steel		2.2			1.0	3.2
Process heat	2.3	10.5		1.6	9.9	24.3
Miscellaneous electric					20.1	20.1
Petrochemicals		1.1		11.4		12.5
Subtotal	2.3	13.8		13.0	33.6	62.7
Transportation						
Automotive		4.3	5.9		2.0	12.2
Air transport		3.8	5.3			9.1
Bus, truck, rail		3.7	5.1			8.8
Electric mass transport					0.60	0.6
Ship		0.8	1.2			2.0
Pipelines		0.1	0.1	0.4		0.6
Subtotal	0.0	12.7[a]	17.6	0.4	2.6	33.3
Total	3.5	26.5	17.6	20.0	64.4	132.0

[a]Synthetic crude.

Table 19 gives the percentage distribution of energy input and end use consumption for the year 2000.

5. SUMMARY OF U.S. ENERGY RESOURCES

5.1 Coal

The current estimate for total identified and hypothetical remaining U.S. coal is 3968 billion tons.[32] If one deducts 388 billion tons of coal at depths greater than 3000 ft, eliminates 42% for thin seams less than 14 in., and assumes that 50% of the remainder is recoverable, the result is 1038 billion tons available for future use as needed. It is assumed here that only 60% of this amount (600 billion tons) will be recoverable in the next 50 years. More than one-third of the 600 billion tons is recoverable with current technology. Two recent publications[33,34] on Alaska's abundant coal resources indicate that the amounts given here may not be sufficiently optimistic in the long run.

5.2 Oil and Gas

New data on the remaining recoverable U.S. oil and gas reserves have been published recently.[25] These revised estimates have been made on the basis of a careful review of current geological sampling data. The results are given with 95%, 5%, and mean probability estimates for total remaining recoverable oil and natural gas. These new estimates are given in Tables 20 and 21.

5.3 Shale Oil

The estimates of shale oil by deposit, shown in Table 22, have not changed since 1973.[35,36] Over 2000 billion bbl of oil is estimated to be in identified deposits of a grade of 10 gal/ton or higher. Assuming in-situ recovery at a 30% rate, the recoverable oil is estimated

32. P. Averitt, *Coal Resources of the United States, January 1, 1974*, U.S. Geological Survey Bulletin 1412, 1975.

33. D. L. McGee and K. M. O'Connor, *Coal, Alaska Open File Report 51*, April 1975.

34. I. L. Taillour and W. P. Brosge, *Possible Order of Magnitude Increase in Coal Resources for Northern Alaska*, U.S. Geological Survey draft report, April 1974.

35. W. C. Culbertson and J. K. Pitman, "Oil Shale," United States Mineral Resources, U.S. Geological Survey Professional Paper 820, 1973.

36. National Petroleum Council, *Oil Shale Availability, U.S. Energy Outlook*, 1973.

Table 19. Summary of energy consumption by consuming sector for the year 2000

Consuming sector	Energy input (quads)	Percent of total	End use (quads)	Percent of total
Residential/commercial				
Space heating	14.4	10.9	8.6	10.6
Air conditioning	5.5	4.2	1.7	2.1
Water heating and cooling	5.9	4.5	3.3	4.0
Miscellaneous electric	10.2	7.7	3.1	3.8
Subtotal	36.0	27.3	16.7	20.5
Industrial				
Aluminum	2.6	2.0	0.8	1.0
Iron and steel	3.2	2.4	2.5	3.1
Process heat	24.3	18.4	18.9	23.1
Miscellaneous electric	20.1	15.2	6.1	7.5
Petrochemicals	12.5	9.5	11.0	13.4
Subtotal	62.7	47.5	39.3	48.1
Transportation				
Automotive	12.2	9.2	8.9	10.9
Air transport	9.1	6.9	7.3	9.0
Bus, truck, rail	8.8	6.7	7.2	8.8
Electric mass transport	0.6	0.4	0.2	0.2
Ship	2.0	1.5	1.6	2.0
Pipelines	0.6	0.5	0.5	0.6
Subtotal	33.3	25.2	25.6	31.4
Total	132.0	100.0	81.6	100.0

Table 20. Current U.S. Geological Survey estimates of U.S. resources of crude oil and natural gas liquids

One barrel of liquid = 5.8×10^6 Btu

	Crude oil (10^6 bbl)	Natural gas liquids (10^6 bbl)	Total (10^6 bbl)
Cumulative production – Dec. 31, 1974	106,136	15,730	121,866
Reserves			
Measured	34,250	6,350	40,600
Indicated	4,636	NA	4,636
Inferred	23,100	6,000	29,100
Undiscovered recoverable			
95% probable	50,000	11,000	61,000
Mean	82,000	15,800	97,800
5% probable	127,000	22,000	149,000
Reserves plus undiscovered recoverable			
95%	111,986	23,350	135,336
Mean	143,986	28,150	172,136
5%	188,986	34,350	223,336
Total past and future production			
95%	218,122	39,080	257,202[a]
Mean	250,122	43,880	294,002[b]
5%	295,122	50,080	345,202[c]

[a]1,491 quads.
[b]1,705 quads.
[c]2,001 quads.

Table 21. Current U.S. Geological Survey estimates of U.S. resources of natural gas (dry)

	Trillion cubic feet
Cumulative production – Dec. 31, 1974	480.824
Measured reserves	237.132
Subtotal	717.956
Inferred reserves	201.600
Undiscovered recoverable	
95% probable	322
Mean	484
5% probable	655
Total past plus probable future production	
95%	1,242[a]
Mean	1,404[b]
5%	1,575[c]

[a]1,280 quads.
[b]1,447 quads.
[c]1,624 quads.

here to be 600 billion bbl with 1 gal of water required for each gallon of oil recovered. The development of the most economical recovery technology for protecting the environment and minimizing the water requirements is needed.

5.4 Uranium and Thorium

The best estimates for uranium oxide (U_3O_8) ore at a concentration greater than 1000 ppm have been increased to 3.6 million tons.[37] This represents a 50% increase over the previous estimates. The uranium reserve could still increase to 7.5 million tons in the next 50 years if additional ore down to 60 ppm U_3O_8 is included. Estimates for U.S. thorium resources are of the order of 150,000 tons of thorium dioxide (ThO_2) for ores containing more than 0.1% ThO_2 or recoverable as a by-product.[38]

5.5 Geothermal Heat

New estimates for the U.S. geothermal resources were published recently in a U.S. Geological Survey bulletin.[39] The total recoverable fuel equivalent of identified and inferred reserves is estimated to be 2000 quads. About one-half of this amount is from hydrothermal convection systems and the rest from geopressurized and other deeper rock systems. Table 23 gives a summary based on the recent report.

5.6 Summary of Resource Estimates

Table 24 gives a summary of the current estimates for the U.S. energy resources reviewed in the previous sections. These estimates need to be further evaluated and reviewed periodically; particular attention should be given to the economics of production and interfuel competition.

6. LONG-TERM OUTLOOK FOR DOMESTIC FOSSIL FUEL SUPPLY

6.1 Coal

If one considers the next 65 years as the long term, it is not likely that the use of coal to produce electricity, heat, or synthetic fuels will be limited by its unavailability (at competitive costs). Using the maximum

37. Energy Research and Development Administration, *Report of the Liquid Metal Fast Breeder Reactor Program Review Group,* ERDA-1 (January 1975); personal communication, National Uranium Resource Evaluation Program, December 1975.

38. W. I. Finch et al., "Nuclear Fuels," United States Mineral Resources, U.S. Geological Survey Professional Paper 820, 1973.

39. D. F. White and D. L. Williams, *Assessment of Geothermal Resources of the United States – 1975,* U.S. Geological Survey Circular 726, 1975.

Table 22. Shale-oil resources of the United States by grade

Deposit	Billions of barrels of oil by grade					
	Identified		Hypothetical		Speculative	
	25–100 gal/ton	10–25 gal/ton	25–100 gal/ton	10–25 gal/ton	25–100 gal/ton	10–25 gal/ton
Green River formation (Colorado, Utah, and Wyoming)	418	1400	50	600		
Chattanooga shale (central and eastern U.S.)		200		800		
Marine shale (Alaska)			250	200		
Other deposits					600	23,000
Total	418	1600	300	1600	600	23,000

Table 23. Geothermal resource estimates

Resource	Identified		Inferred		Total	
	Electric or heat	Fuel equivalent (quads)	Electric or heat	Fuel equivalent (quads)	Electric or heat	Fuel equivalent (quads)
Hydrothermal convection systems >150°C electric[a]	7000 MW-centuries	65.6	23,000 MW-centuries	216	30,000	282
Hydrothermal >150° nonelectric[b] and 90° to 150°C	91 quads	140	365 quads	562	456 quads	702
Geopressured systems plan 3 Electric[a,c]	9250 MW-centuries	87.5	28,000 MW-centuries	260	37,000 MW-centuries	350
Other Hot dry and molten igenous rocks	160 quads		480 quads			640

[a]Fuel equivalent for electric output was obtained by converting electrical estimates using an efficiency of 0.32.
[b]Fuel equivalent for beneficial heat was obtained by converting heat estimates using an efficiency of 0.65.
[c]These estimates do not include the heat content of methane in these systems.
Source: Based on an analysis of D. F. White and D. L. Williams, *Assessment of Geothermal Resources of the United States – 1975,* U.S. Geological Survey Circular 726, 1975, by Gregg Marland of the Institute of Energy Analysis.

Table 24. Summary of recoverable resource estimates
In quads

Resource	Demonstrated reserves	Estimated additional	Estimated total
Coal	4800	7200	12,000
Petroleum	235	765	1,000
Natural gas	245	705	950
Shale oil	1160	2320	3,480
Uranium	1800	1800	3,600
Geothermal	200	1800	2,000

Table 25. Total annual U.S. production of crude oil, natural gas, and natural gas liquids
In quads

Year	Total	Crude oil and natural gas liquids	Natural gas
1910	1.8	1.22	0.55
1915	2.3	1.63	0.68
1920	3.5	2.57	0.88
1925	5.7	4.43	1.31
1930	7.4	5.21	2.15
1935	7.9	5.78	2.14
1940	10.8	7.85	2.98
1945	14.4	9.94	4.42
1950	18.3	11.45	6.84
1955	25.0	14.44	10.53
1960	28.8	14.66	14.14
1965	33.6	15.93	17.65
1970	43.9	19.77	24.15
1974	42.0	20.50	21.45

scenario of the Institute of Energy Analysis as a basis,[21] cumulative coal consumption would amount to about 10 billion tons by 1985, 50 billion tons by 2000, and 270 billion tons by 2040. These amounts are well within the estimated domestic resources.

6.2 Oil and Natural Gas

The Institute of Energy Analysis (IEA) has projected the total use of domestic oil and natural gas by fitting Hubbert-type curves to U.S. Geological Survey resource estimates.[40] Table 25 shows past production of these resources, and Table 26 shows the IEA estimates of future production. These results indicate that there is a 95% probability that production of crude oil and natural gas liquids will peak in 1980 at 21.7 quads and that there is a 5% probability that the peak production will amount to 27.1 quads occurring in 1990. Similarly, the 95% probability for natural gas is a peak production of 26.3 quads in 1980. The 5% probability case shows natural gas production peaking at 31.5 quads in 1985. Production of both liquids and gases drops essentially to zero by 2040.

40. C. E. Whittle, Institute for Energy Analysis, personal communication to J. A. Lane, Oak Ridge, Tenn., January 1976.

Table 26. Projected U.S. production of crude oil, natural gas, and natural gas liquids

Projections were made using fitted Hubbert-type curves without explicit prices.

(In quads)

Year	Crude oil and natural gas liquids			Natural gas		
	95%	Mean	5%	95%	Mean	5%
1980	21.7	23.8	25.9	26.3	28.5	30.4
1985	21.1	23.9	27.0	25.2	28.5	31.5
1990	19.7	23.2	27.1	22.3	26.4	30.3
2000	15.4	19.4	24.6	14.2	18.4	22.8
2010	10.6	14.3	19.5	7.6	10.4	13.8
2020	6.8	9.6	13.9	3.6	5.3	7.3
2030	4.1	6.1	9.2	1.7	2.5	3.6
2040	2.4	3.7	5.8	0.7	1.2	1.7

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