Chapter 1

EXPECTED ENERGY USAGE IN THE UNITED STATES TO THE YEAR 2000

Introduction

One of the most important factors in the economic development of the United States is the availability of an adequate supply of power to maintain and improve its mechanized society. The availability of conveniently usable energy is a result of the many available fossil fuel resources, the ability to convert these resources into easily distributed and usable forms, and a willingness to invest in natural resources such as nuclear fission processes. In 1972 the U.S. supplied about 87% of its energy needs from domestic sources.[1] However, for a combination of reasons, not the least of which is a continuing growth in demand, this percentage is expected to decrease in the immediate future. Presently, with 6% of the world population, the U.S. uses one third of the world energy production.[2] Over the decade 1960-1970, the U.S. use of energy rose from 4.5×10^{16} to 6.8×10^{16} Btu/yr., an increase of 4.3% compounded annually. A

1. Battelle Research Outlook, "Our Energy Supply and Its Future," Editor; A. B. Westerman, Battelle, Columbus, Volume 4, Number 1, 1972, p. 3.

2. Joint Committee on Atomic Energy, "Certain Background Information for Consideration When Evaluating the National Energy Dilemma," U.S. Printing Office, Washington, 1973.

continuing yearly increase in demand for energy through 1985 between a high of 4.5 and a low of 3.3% per year is expected.[3] If the supply is to increase concomitantly problems and challenges must be faced such as; offshore oil development, power plant siting, nuclear power safety, coal mine safety, sulfur and particulate emission control, strip mining, increased prices and increased quantities of imported oil and gas, development of new energy sources, and a host of other environmental, political sociological, and economic factors.

This book is concerned with the potentiality that the solar energy will be used to significantly enhance the supply of conveniently usable energy within this century. More specifically, it deals with the direct production of electricity through absorption of sunlight by appropriate semiconductors in which this photo energy is effectively converted into electrical energy—the photovoltaic effect. This method circumvents the lengthy processes of conversion of sunlight by photosynthesis to stored energy in plants, fossilization, recovery, burning, and using the heat to power electricity generators. It is also a more direct method than using solar energy to heat liquids

3. National Petroleum Council, "U.S. Energy Outlook, A Summary Report of the National Petroleum Council," December 1972, p. 15.

or gases for running generators. The basic objectives of this study are:

1. To illustrate the scope of energy requirements in the U.S. until 2000 and the relative magnitude of solar energy available.
2. To review and clarify the scientific principles of photovoltaic energy conversion as related to its potential for technological development.
3. To determine the state-of-the-art and problems which limit massive utilization of photovoltaic converters.
4. To realistically estimate the trends in economic and technological parameters which will influence the development of photovoltaic conversion.
5. To project the probable range of business opportunities in the manufacture of photovoltaic converters in the next 25 years.

Energy Demand

Detailed studies of the expected demand for energy in the U.S. in the future have been made recently.[4,5,6,7]

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4. National Petroleum Council, "U.S. Energy Outlook, A Report of the National Petroleum Council's Committee on U.S. Energy Outlook," December 1972.

5. Shell Oil Company, "The National Energy Outlook," March 1973.

6. U.S. Department of the Interior, "United States Energy Through the Year 2000," December 1972.

The predictions of energy demand up to 1980 seem reasonable barring major long term changes in national or international policies. Energy patterns are already committed in many ways in that most of the electrical capacity that can be functioning by 1980 has already been ordered; every major mass transit system that can be functioning has been ordered; and the consumption of energy by automobiles and for space heating can be predicted with a high degree of confidence.[2] The main factors which might affect them would be a sustained shortage of importable petroleum, as in the winter of 1973-1974, which could cause an awareness of the societal dependence upon energy and the need to conserve it. This and the concomitant increase in price of energy could decrease the demand, although the latent demand may still be present if price and supply conditions similar to the past decade were re-established. The predictions of demand from 1980 to 2000 are rather uncertain because of the many factors which can change over the long term. It is significant that by 1980 nearly 50% of the U.S. oil requirements may have to be imported, i.e., 22% of the total energy demand.[2,8,9]

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7. Associated Universities, Inc., Report "Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies," April 1972. Report to U.S. Office of Science and Technology, under Contract OST-30; Document AET-8.

Projections of the energy demand to the year 2000 are shown in Figure 1. This figure is a modification of fold-out M of reference 2 which summarizes the projections in references 4,5,6,7,8. Projection A represents an average growth of 4.2% per year. Projection B, C, and D correspond to the projections of reasonable high, intermediate, and low growth rates estimated by the Shell Oil Company,[5] and F is by the Department of the Interior.[6] The projections by the National Petroleum Council actually were made only through 1985 and the extensions of 2000 represent about a 3.3% annual growth rate. Projection B was based upon an annual growth rate of 4.5% 1970-1981, 4.3% 1981-1985, and about 3.3% 1985-2000. In projection D there was assumed an annual growth rate of 3.5% 1970-1981, 3.3% 1981-1985, and about 2.9% 1985-2000. The annual demand volume is expressed in British thermal units (Btu) which is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. This unit of energy is used because of its universality. The other units such as tons of coal, barrels of oil, etc., can easily

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8. National Petroleum Council, "U.S. Energy Outlook, An Initial Appraisal 1971-1985," July 1971.

9. Lawrence Livermore Laboratory, "Energy: Uses, Sources, and Issues," UCRL-51221 May 30, 1972.

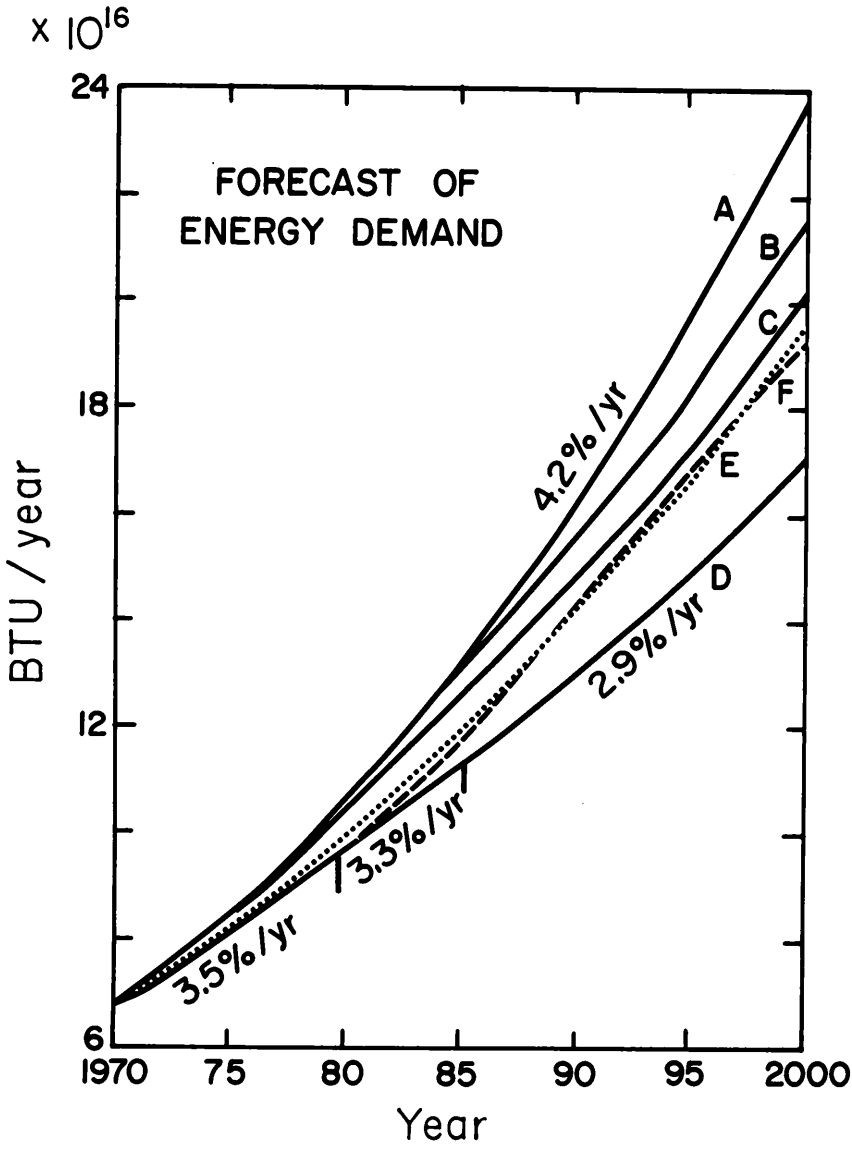

Figure 1. U.S. Energy Demand Forecast. (Data from Ref. 2)

be converted into their Btu equivalents as follows:

Crude Oil:	1 Barrel (Bbl)=42 gallons (gl)= 5,800,000 Btu
Electricity:	1 KiloWatt hour (kWhr)= 3,412 Btu
Coal:	1 Ton = 26,000,000 Btu (average)
Natural Gas:	1 Cubic Foot = 1,032 Btu

In arriving at the majority of the above projections, the most significant long range determinants of energy demand were deemed to be: (1) economic activity (GNP); (2) cost of energy; (3) population; and (4) environmental controls. Of course, these are not the only determinants, but these were found to explain most of the past changes in energy demand.[4] Factors which may become very important, such as supply limitations and political decisions, are not reflected in the projections shown in Figure 1. A substantial reason for the lowest estimate of demand (curve D) is the assumption that consumers will improve the efficiency in which energy is used by better home insulation, increased engine fuel economy, better machinery,...etc. The impetus for this would be the increased costs of energy and the normal technological developments.

The basic assumptions for the intermediate growth rate, curve C, from 1970-1985 were:

(a) Average annual growth in real GNP of 4.2%.

(b) Average annual growth in population of 1.1%.

(c) Energy used for environmental development increasing from 2% in 1970 to about 5% of our total usage in 1985.

(d) Negligible change in real prices for energy.

(e) Improved technology for fuel substitution.

(f) No capital limitations or other restrictions on total energy supplies.

The above parameters are not independent variables and it should be obvious that if (f) were not true and energy shortages arose; (a), (c), and (d) could be affected. During 1974 both (a) and (b) were lower, and (d) higher, than the above assumptions. Hence, considerable judgment must go into deductions based upon these projections. Sensitivity analyses for energy demand with regard to the major assumptions are available in reference 4.

The demand for energy may be subdivided into major use areas to get better insight into future trends. The studies referred to so far are not all in strict agreement even on historical data, but do not disagree significantly for purposes of this discussion. Figure 2 is derived from fold out B of reference 2 and illustrates the flows of energy into electrical energy generation and the residential and commercial, industrial, transportation, and nonenergy sectors during 1970. The units are arbitrary and the numbers represent the percentage of total input primary energy (before exports and field use) employed in that

particular phase of energy utilization. About 22% of the energy went into residential and commercial uses predominantly for conditioning the indoor atmosphere. Twenty-nine percent went to industry, 23% to transportation, 6% to nonenergy (synthesis of petrochemicals, fertilizers, plastics,...etc.), and 21% to electricity generation. It may be noted from Figure 2 that the transportation and electrical energy generation sectors are very wasteful. About 75% of fuel which goes into transportation is wasted through inefficient processes. Sixty-five percent of the primary energy which goes to produce electricity, a secondary but very convenient form of energy, is lost. By the time the electricity is utilized and partially lost through inefficiencies, this figure is even higher. The expected average annual growth rates[4] in these sectors from 1970 to 1980 under assumptions for energy demand C in Figure 1 are as follows:

Residential and Commercial; 3.4%

Industrial; 2.9%

Transportation; 3.9%

Electricity Generation; 6.9%

Nonenergy; 5.1%

This indicates that the largest growth rate will be in a very inefficient sector; electricity generation. This is largely due to the relative ease of distribution of electricity to the residential/commercial, and industrial sectors, the high demand for the convenience

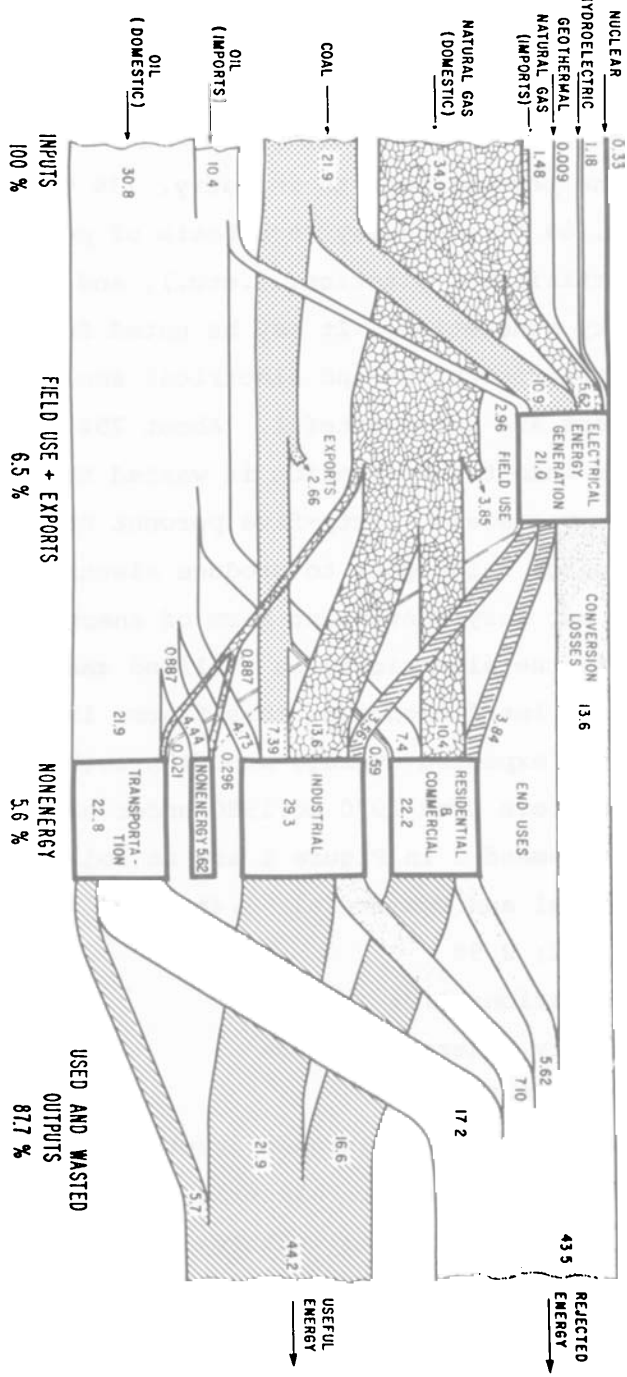

Figure 2. Normalized U.S. Energy Flows in 1970. (Data from Ref. 2)

of electricity, and its usage in pollution abatement. The substitutability of primary fuels in electricity production also makes it probable that electricity may be an increasingly utilized form of "end use" energy so users do not have to change their facilities from, say oil burning to coal burning as the relative costs and supplies change. The expected energy use "mix" from 1960 to 1985 is illustrated in Figure 3 which was derived from illustrations in reference 2. This implies a relatively high expected dependence upon electricity in the near future. The percentage of total energy used within the U.S. for power purposes which is devoted to electricity generation will increase from about 25% in 1970 to nearly 36% in 1985.[10] Although direct end use of primary fuels will increase considerably, electricity generation will account for an increasing proportion of the total primary fuel usage. This projection is consistent with past experiences. From 1950 to 1970 electricity consumption increased[11] at an average annual growth rate of 7.5%. In 1970 about 55% of the 5.1×10^{15} Btu of electricity generated was used in the residential

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10. National Petroleum Council, "Guide to National Petroleum Council Report on the United States Energy Outlook," December 1972.

11. S. H. Schurr, "Energy Research Needs," Resources for the Future, Inc., Washington, D. C., October 1971, p. I-6.

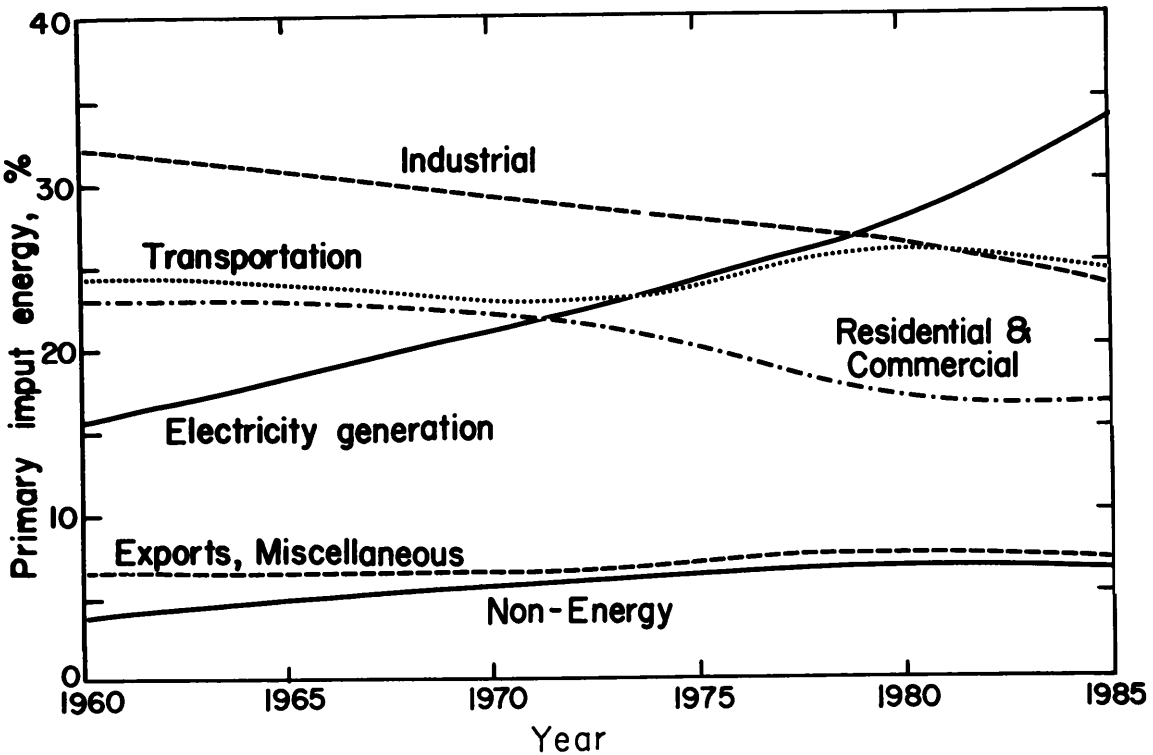

Figure 3. Past and Expected U.S. Energy Use by Sector. Electrical Energy is Recounted in End-Use Sectors. (Data from Ref. 2)

and commercial sector while the rest went into industry.[4] This percentage is expected to remain nearly constant through 1985, with a relatively small amount going into transportation by 1985. It would appear then that the product of photovoltaic energy conversion, electricity, will be in increasing demand in this century.

Energy Supply

In 1972 the United States' energy consumption[12] of 7.5×10^{16} Btu was supplied from the following primary fuels; nuclear 1%, hydro 4.1%, coal 18.6%, natural gas 31.8%, and oil 44.4%. About 84-87% came from domestic sources. Thirty-two percent (1.8×10^{9} Bbl) of the oil and 4.4% (10^{12} ft^3) of the natural gas was imported. **This represents an increasing dependence upon oil stimulated in large measure by pollution abatement and the Clean Air Act.[13] The increasing dependence upon imports and recent large increases in prices makes predictions of supplies rather tenuous. However, many studies[4,5,6,7,8,9,10,11] have been devoted** to predictions of what the domestic supplies can be under various price and regulation policies. As a result of historical developments and policies, and

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12. British Petroleum Company, "1972 Statistical Review of the World Oil Industry."

13. D. C. White, Technology Review, 76, No. 2, 11 (1973).

the long delay periods involved in producing primary fuels from new discoveries and producing electricity from nuclear sources, it is probable that domestic supplies will not be able to meet demand in an economically efficient fashion for the rest of this century. Hence, there probably will be considerable importation of energy with concomitant outward financial flows, or shortages.

Estimates of the U.S. resources of coal, petroleum, natural gas, uranium, geothermal energy and oil from oil shale are made periodically by the U.S. Geological Survey.[14] Accuracy of the estimates range from 20 to 50% for identified recoverable resources to about an order of magnitude for undiscovered-submarginal resources. Estimates are affected considerably by assumptions of market price and technological capability. As price increases, estimates of recoverable resources increase because it becomes economically feasible to extract low grade or hard-to-recover sources of energy from the earth. Less expensive and more efficient recovery processes also tend to increase the quantities considered recoverable. The coal resources are estimated at 3.2×10^{12} tons (8.3×10^{19} Btu), about 1000 times our present annual

14. P. Theobald, S. Schweinfurth, and D. Duncan, "Energy Resources of the United States," Geological Survey Circular 650, Washington 1972.

energy usage. Of this, 2—3.9 x 10^{11} tons are considered identified and recoverable presently. Production of coal is expected to increase by as much as 6.7% annually from 0.59 x 10^{9} tons in 1970 to about 1.6 x 10^{9} tons in 1985.[4] About one third of the latter figure would be used for exportation and making synthetic gas and liquids. It would appear that the coal supplies could last at least 100 years and possibly reduce the reliance on imported energy.

The total resource base[14] for petroleum liquids is estimated at 2.9 x 10^{12} barrels (1.7 x 10^{19} Btu). However, only 5.2 x 10^{10} Bbl is identified and recoverable at the price and technological conditions of 1972. The National Petroleum Council's estimates are somewhat lower at 0.81 x 10^{12} Bbl resource base. Annual production is expected to go from 4.1 x 10^{9} Bbl in 1970 to 5.7 x 10^{9} Bbl in 1985 under reasonably favorable development conditions. If present conditions prevail, this production may be as little as about 3.8 x 10^{9} Bbl in 1985. In this case, only 20% of the energy demand would be met by domestic oil while about 38% would have to be met by importation.[10]

The 1972 U.S. Geological Survey estimates that the U.S. resources in natural gas total 6.6 x 10^{15} ft^3 (6.8 x 10^{18} Btu) of which 0.29 x 10^{15} ft^3 is identified and recoverable. If the conditions under which 2.2 x 10^{13} ft^3 were produced in 1970 prevail, the production in 1985 may fall to about 1.5 x 10^{13} ft^3.

However, under favorable exploration, price and regulation conditions,[4] the production could be as high as 3.1×10^{13} ft^3.

The demand for nuclear fuels is derived from demand for electricity. As more electricity is demanded and if environmental and safety restrictions are as at present with respect to coal and nuclear fuels, a sharp increase in the demand and respondent supply of uranium oxide will be in store for the rest of the century. In conventional deposits where U_3O_8 is the major product there are about 1.6×10^6 tons of which 2.5×10^5 are identified and recoverable.[14] In 1970 about 7×10^9 Watts of electricity was supplied by nuclear generation. This is expected[15,16] to grow to about 3×10^{11} by 1985. The National Petroleum Council projects that this will grow to 9.8×10^{11} by 2000. By this projection the annual usage of U_3O_8 in 1985 would be 7.1×10^4 tons and the **total reserves** used up to that time would be about **5×10^5 tons.** The **heat input provided by the 7.1×10^4 tons in 1985 would be about 2×10^{16} Btu (a relatively small portion of demand) of which two-thirds would be lost in generating 2×10^{12} kWhr of electricity. Thus, it can**

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15. Atomic Energy Commission, "Nuclear Power Growth 1971-1985," Washington, December 1971.

16. Federal Power Commission, "The 1970 National Power Survey Part 1," December 1971.

be seen that more exploration for minerals and research in nuclear processes for electricity generation will be required if the hoped-for growth and sustaining of a major nuclear power industry is to be achieved. Most experts believe that this will develop and the breeder reactor will make nuclear power generation much more efficient with respect to mineral usage.

The potential geothermal energy sources are thought to exceed 4×10^{19} Btu of which only 10^{16} can be considered identified and recoverable.[14] Considerable exploration, deep drilling, and research and development will be required for geothermal energy to contribute significantly to the U.S. needs by 2000.

Oil shale could possibly produce about 1.5×10^{20} Btu. It is not economically feasible at present to extract the oil, but if prices increase and stay at the 8-10 dollar per Bbl region, up to 6×10^{11} Bbl (3.5×10^{18} Btu) could be considered identified and recoverable.[14] Under the most favorable conditions, about 2.7×10^{8} Bbl (1.5×10^{15} Btu) may be produced[4] in 1985. However, water used in the process of oil extraction may limit production over the long term. Tar sands from which oil may be extracted are in very small quantities in the U.S. and are not expected to contribute significantly to the domestic energy supply. Canada has vast tar sands resources which are beginning to be developed.

Hydroelectric energy presently accounts for about 4% of the U.S. needs. Because most of the suitable dam sites have been developed, the growth of hydroelectric power will be only 1.6% per year[4] until 1985 as smaller sites are utilized. The portion of the U.S. energy needs it will supply will decrease from 4% in 1970 to 3% in 1985. It may be used in conjunction with other electricity generating means, however, as a means of energy storage (pumped water storage). In off-peak hours the fossil or nuclear powered generators will provide electricity for pumping water upward, and in peak load hours the water will be used to run additional turbines. This and combined-cycle (Brayton-Rankine) plants which utilize the presently wasted hot exhaust from gas turbines to generate steam for conventional steam-electric generators will serve to increase the efficiency of electricity generation and storage. The combined-cycle plants which are expected by 1985 will use about 30% less fuel[4] than conventional plants built in 1972.

Other unconventional and undeveloped sources of energy may be utilized by 1990 to 2000 but are unlikely to be significant contributors to the U.S. energy supplies before 1985. These include use of nuclear fusion, fuel cells, magnetohydrodynamics, thermionic devices, and agricultural energy. Solar energy, as will be discussed in more detail, is a

bountiful source which may compete economically with more "conventional" sources within this century.[17]

The supply of energy to meet the U.S. demand is illustrated in Table 1. The trends in supplies of energy to meet U.S. demand from 1970 to 2000 are depicted in Figure 4 for one set of assumed conditions[18] which seem reasonable and in near agreement with other sources.[4,5] It would appear that much dependence is expected on nuclear processes and importation. This Atomic Energy Forum[18] estimate was developed as a maximum which would be feasible if many present limitations are diminished and a massive national effort is made to develop nuclear systems. The term imports and/or shortages is used to describe the expected deficit between demand and domestic supply because there is some concern that the national economy may not support outward monetary flows for energy of over about $20 billion per year. At a "real" price of $8 per Bbl of foreign crude oil, this would be 2.5 billion Bbl per year; 1.5×10^{16} Btu, about double the 1970 level.

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17. W. E. Morrow, Jr., Technology Review, 76, No. 2, 31 (1973).

18. Joint Committee on Atomic Energy, Atomic Industrial Forum Informal Report on March 7, 1973, (see reference 2).

Table 1. Estimated Energy Resources* in the United States and 1970 Usage

Resource	Estimated Resources*, Btu	1970 Usage, Btu
Petroleum	1.7×10^{19}	2.1×10^{16}
Natural Gas	6.8×10^{18}	2.2×10^{16}
Coal	8.3×10^{19}	1.3×10^{16}
Hydropower	4×10^{15} per yr.	0.3×10^{16}
Nuclear	5×10^{17} (plus)	0.02×10^{16}
Geothermal	4×10^{19}	0.0007×10^{16}
Shale	1.5×10^{20}	negligible
Tar Sands	minor	negligible
Solar	5×10^{19} per yr.	negligible
Total Domestic 1970		5.9×10^{16}
Imported Oil		0.8×10^{16}
Imported Gas		0.1×10^{16}
Total used 1970		6.8×10^{16}

*Estimates from references 4 and 14, 1970 usage from references 2 and 4. The total estimated resources would only be developable under considerably higher price conditions and then not completely recoverable. Economic conditions and capacity related to energy production in 1970 allowed only the production listed: some had to be imported.

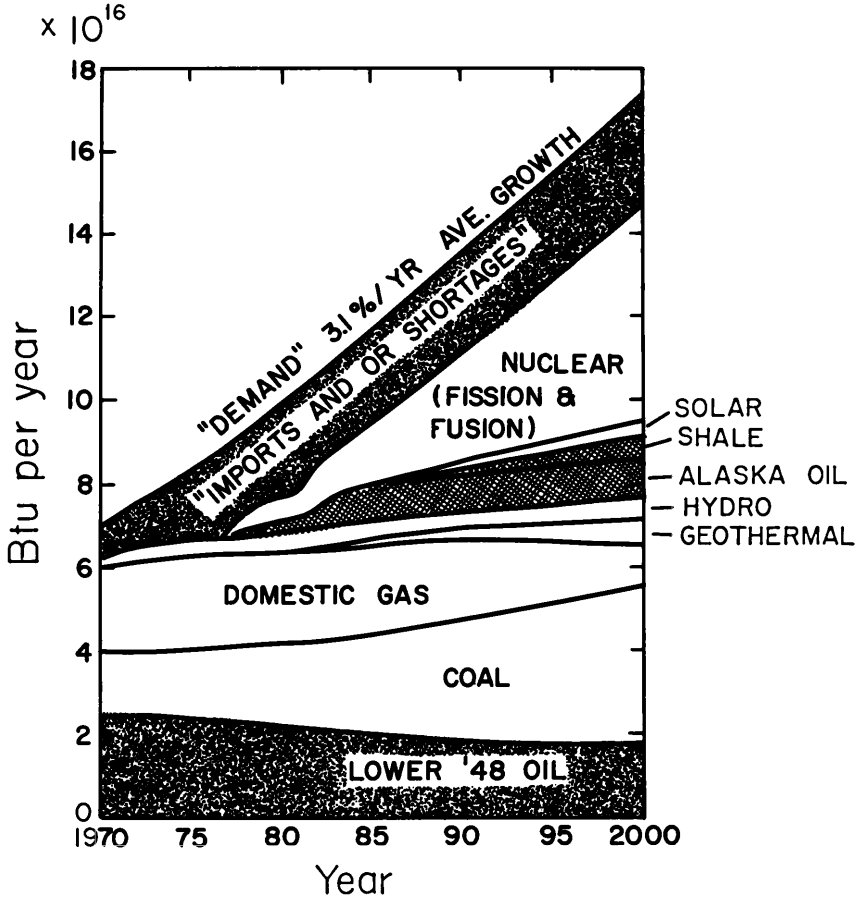

Figure 4. Expected Trends in U.S. Energy Supplies Until 2000. (Data from Refs. 2 and 18)