WORLD SOURCES OF ENERGY AND NEW ENERGY RESOURCE DEVELOPMENT IN IRAN

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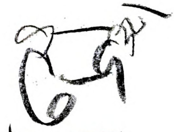

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ABSTRACT

WORLD SOURCES OF ENERGY AND NEW ENERGY RESOURCE DEVELOPMENT IN IRAN

By

Hooshang Ashraf

Constraints on economic growth and/or development exist. Availability of energy is decisively important for economic development in developing nations and sustained growth in industrialized countries. It represents a major constraint on growth.

Iran shares this restraint with others. In the long run, she faces shortages, and ultimately, depletion of existing nonrenewable energy resources. Energy policy must begin to consider this. It is necessary to review alternative sources of energy, evaluate them, select the best alternative or combination of alternatives from a cost viewpoint, and establish a timetable for integrating these resources with the existing energy supply mix.

The major thrust of this research was to compare potential alternative sources of energy. A standard basis of comparison was selected: cost of producing one kilowatt hour of electricity. Data was gathered from an intensive survey of existing literature on general energy resource

development and specific literature on alternative energy resources.

This research was divided into three phases. In phase one, current worldwide energy resources and reserves were determined. Fourteen alternative energy sources were analyzed in regard to quantitative levels and qualitative aspects of advantages and disadvantages of use. Supply and demand factors were considered. Following the evaluation of quantitative and qualitative elements, three were selected from the fourteen as representing the alternative sources of energy with the best potential for development, given current technological levels. Geothermal, solar, and nuclear power were selected.

In phase two, these three alternative sources were evaluated on the basis of cost to produce one kilowatt hour of electricity. Each alternative has factors, specific only to it, which must be included in determining the cost of electricity. However, sufficient similarity existed so that a general methodology, incorporating these differing factors, could be constructed and used for the analysis.

Initially, it was necessary to determine the probable capital outlays required for developing these energy sources. Total capital investment was computed by determining costs of land and construction, equipment, and fuel. Next, the total annual costs of the various plants were calculated. These costs included interest, amortization, and operation and maintenance. Finally, the total annual energy output of the plants was determined. This was based on both plant size and the plant factor.

Cost per kilowatt was calculated by dividing the total annual cost of the plant by the net power production in kilowatts. Cost per kilowatt hour was based on the working hours of the plant. It was determined by dividing the total annual cost per kilowatt by the working hours of the plant per year.

Each estimate was compared to the cost of producing electricity from fossil fuel. Results of research in phase two indicated the cost of geothermal, nuclear, and solar energy was competitive with fossil fuel.

Phase two research was of a general nature. Owing to the limitation of both cost studies and data on new energy resource development, it was not specific to Iran. In phase three, the data were related to Iran. Initially, the relevance of energy to economic development in Iran was established. Patterns of energy consumption, resources, and reserves were discussed.

The results of these cost studies were integrated with current levels of energy development and technology in Iran. Orders of magnitude established by the cost studies were used to provide general guidelines on new energy resource development. These guidelines were consolidated in a timetable for integrating geothermal, solar, and nuclear power within the energy sector in Iran.

WORLD SOURCES OF ENERGY AND NEW ENERGY RESOURCE DEVELOPMENT IN IRAN

By

Hooshang Ashraf

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CHAPTER I

INTRODUCTION

The importance of energy availability in both economically advanced societies and in modernizing societies has become well-known in the past few years. Increasing attention has been devoted to considerations of alternative sources of energy for a variety of reasons ranging from security to supply on the one hand to the realization that some sources are soon exhausted on the other.

The study of alternative sources of supply can be very complex because it involves physical aspects, economic aspects, and legal aspects. The physical and natural science dimensions and the engineering and technical considerations usually dictate the ultimate limits although it is not uncommon for new knowledge and for technological developments to change these constraints in substantial degrees. Economic factors are extremely important to consider in the study of alternative energies because they can be powerful forces on both the supply side and on the demand side. Legal specifications in the form of legislative rules and mandates sometimes can be more important than either the physical or economic dimensions.

Nevertheless, the study of alternative sources of supply is a necessary part of every study of the future. It would be unthinkable for any society today to plan for the future without a very serious study of energy alternatives.

Statement of the Problem

The most important basic resource or raw material problems for people today are energy and food: energy as an element of growth and food as energy for man to build and produce. The world's supply of fuel is declining. Any realistic plans for the development and use of future sources of energy must take into account the eventual depletion of these fossil fuel resources. Thus, the role of alternative sources of energy must be an integral part of studies of the future. Development of new sources of energy is essential if consumer needs are to be met.

However, the relative roles of alternative sources of energy are very much in question today and new statements appear with regularity concerning the advantages or disadvantages of almost every conceivable source of energy. This phenomenon will probably continue for years to come because of the long-term nature of needed definitive research and demonstration.

Thus, the problem stated simply is: Can an analysis of the available information on energy and energy alternatives yield realistic guidelines for energy policy formulation in Iran? Stated in another form, the guiding hypothesis of this study is: Available information today can provide a basis for energy policy recommendations for Iran.

Research Procedure

The major thrust of the research to be reported in this dissertation will be the review and synthesis of already published information. This information is contained in Iranian and United States Government documents, in United Nations publications, and in the monographs and publications of private organizations such as foundations, private corporations, and book publishing firms.

The present energy situation is reviewed in Chapter II. The very latest data on production and reserves from the most reliable sources of information is presented. This review covers a wide variety of alternatives.

An economic evaluation of "new" energy sources is reported in Chapter III. Solar energy, geothermal energy, and nuclear energy are examined in significant detail.

The energy resource, reserve, and consumption pattern in Iran is presented in Chapter IV. This description is based on the very latest data available.

The summary and concluding remarks are presented in Chapter V.

Objectives of the Study

The aim and purpose of this research is to contribute to a better solution to fundamental problems of new energy resource development in Iran. Research is one means of promoting the achievement of objectives set by an overall energy development plan. This plan would be based on the prospects of various technologies, on the extent and distribution of the different energy resources, and on the economic and industrial structure. The scientific and technological capacity of Iran would also have to be taken into consideration.

The objectives can be summarized as follows:

1. Analyze and determine current world energy resources and reserves.
2. Analyze and compare world energy supply and demand.
3. Analyze and determine energy resources, reserves, and consumption in Iran.
4. Select and develop new energy resources for Iran's future needs.
5. Meet Iran's needs through a technical and economic comparison of different sources of new energy resources to aid in their development.

Issues involved include costs and benefits promised by new technology using available energy, the alternatives involved in the utilization of natural energy resources, the availability and cost of technology for maintaining environmental quality in the face of enormous increases in absolute energy consumption, and the energy demand and supply relationships.

Assumptions

In the choice of new energy resources development, the following assumptions were made:

1. That there can be practical use and development of three new sources of energy such as geothermal, solar, and nuclear power in the near future.
2. That there are no limitations, of any reasonable proportion, on the availability of funds and personnel.
3. That the problems are clear and compelling in the urgency of new energy resources development for the near future.
4. That political and social systems in the international context do not influence energy resource development in terms of availability of raw material, research, and construction.

5. That there are common elements for optimum cost of alternative sources of energy in different countries, with respect to differing levels of technology and skilled manpower. The following guidelines concerning these elements can be used:
   a. Local manpower and resources will be used in new energy resource development.
   b. The use of new energy resources must be related to the cultural and social aspects of the country.
   c. The use of new energy resources must be related to the physical and biological aspects of man's environment, both locally and globally.

Limitations of the Study

As mentioned earlier, data on energy is changing almost daily. Announcements of new oil and gas discoveries, technological breakthroughs in more exotic energy areas, and new cost figures for solar, nuclear, and other sources are published regularly. This study will become obsolete in a relatively short time and it should be considered as having a limited life.

A rather limited economic analysis will be made. The goal will be to obtain reasonable "orders of magnitude" rather than precise figures for decision-making. Several

simplifying assumptions will be made. Much data that would be useful for this analysis is not available because it is either classified or is "proprietary" information. Thus, for the most part, secondary information that is readily available will be used.

It is recognized that conditions in Iran may result in some deviations from the conclusions that will be reached in this study, it is hoped that the differences will not be significant. In such a rapidly changing world, however, we can never be sure.

CHAPTER II

CONTEMPORARY ENERGY PERSPECTIVES

During the last decade, the world energy market has been marked by increased requirements. The demand for energy is expected to continue to rise in the future. Pressure is already being exerted on the supplies currently available from various energy sources.

In recent years, there has been a shift in consumption from solid fuels to petroleum and natural gas. This trend has been common to nearly all regions of the world.

The long-term inadequacy of conventional energy resources to satisfy greatly increased demand and the possible limitation this places on world economic growth has focused attention on evaluating new energy processes. Adequate development of new energy resources will ease the demand for nonrenewable sources and decrease environmental pollution. Currently, the issue is how to meet world energy requirements during the years ahead.

Aspects of the global energy situation and prospects are examined in terms of a brief review of the energy reserves. A perspective for the future and observations on the long-term adequacy of energy reserves to meet world

demand are included. The application of relevant technologies affecting improvement in efficiency of energy use is also discussed.

The following definitions will be used during the course of the discussion of reserves:

- Proved reserves: proved reserves are those reserves known to exist that are recoverable under existing economic conditions at current U.S. prices.[1]
- Recoverable resources: recoverable resources are resources in the ground as of the date of the estimate, that past experience suggests can actually be produced in the future.[2]
- Remaining resources: remaining resources are unmined resources remaining in the ground, as of the date of the estimate.[3]

Estimates of World Energy Resources and Reserves

The following discussion highlights the growth and past trends in energy consumption as well as the reserve

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[1]U.S., Congress, House, Subcommittee on Energy Research Development, and Demonstration, Energy Facts II, Series H (Washington, D.C.: Government Printing Office, 1975), p. 96.

[2]U.S., Department of Interior, "Coal Resources of the United States," U.S. Geological Survey Bulletins, No. 1275 (Washington, D.C.: Government Printing Office, 1967), p. 27.

[3]Ibid., p. 26.

situation of the major sources of energy and production. The main purpose of such an analysis is to relate the forecast of energy requirements to estimated reserves, thereby identifying discrepancies between the two. Positive policies and development programs can then be implemented to bridge the existing gaps.

Initially, a detailed assessment of energy resources is essential. This will provide valuable baseline data which will enable expected increases in demand to be met.

Three constraints must be considered when studying world energy reserves. First, existing information on energy reserves is not adequate. For example, documentation on coal resources in developing countries is insufficient. Second, in some cases, comparisons of reserves are difficult to make, due to a lack of international standards regarding categories of reserves. This is particularly true in the case of natural gas. Third, economic factors affect the estimates of certain categories of reserves. At one level of cost, the reserves may be considered recoverable, but not so at a different cost level. This is directly true of petroleum deposits.

Petroleum

Reserves. Once the field has been developed, the reserves of petroleum in a given field can be estimated with

a reasonable degree of accuracy. However, the volume of oil in place, even in a well-delineated field, can never be precisely estimated. In addition, the proportion which can be recovered is controlled in part by economic conditions. This further complicates any assessment of petroleum reserves.

In discussing reserves, Charles Issawi has noted: "Proven refers solely to those reserves that have been established by the exploring or producing companies or governmental agencies and are judged to be economically recoverable with existing technology."[1]

Using this definition, the world's proven oil reserves amounted to 67,100 million tons in January 1969. This compared to about 37,000 million tons a decade earlier.[2] The increase during this period is considered a result of increased onshore and offshore exploration.

Banquis et al.[3] estimated that the Middle East has 61.1 percent of the world's present proven reserves; North America has 11.4 percent; centrally planned economies of Eastern Europe, 8.6 percent; North Africa, 8.3 percent;

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[1]Charles Issawi, Oil, the Middle East, and the World (New York: Library Press, 1972), pp. 19-21.

[2]P. R. Banquis, R. Brasseur and J. Masseron, Bureau d'etudes Industrielles et de Cooperation (Paris: Institute Français du Petrole, 1970), pp. 79-92.

[3]Ibid.

Latin America, 6.1 percent; and 4.5 percent in the rest of the world.

Hubbert assesses the petroleum reserves of the world as follows: "Canada 95×10^9 barrels; U.S. 200×10^9; Latin America 225×10^9; Europe 20×10^9; Africa 250×10^9; Middle East 600×10^9; Far East 200×10^9; and USSR and China 500×10^9."[1]

The U.S. Department of Interior[2] estimated total world crude oil reserves to be 542.2 billion barrels in 1973 and distributed in this manner (in billions of barrels): U.S., 35.3; other Western Hemisphere countries, 36.4; Western Europe, 17.4; Africa, 57.2; Middle East, 316.1; Far East and Oceania, 15.7; Sino-Soviet bloc, 64.1. It was calculated that 58 percent of the total world reserves were located in the Middle East, 11 percent in Africa, and 7 percent in the United States.

For the future, there are indications that huge deposits of petroleum and gas reserves exist in offshore areas; that is, water deeper than 200 meters. It is extremely difficult to judge the extent or nature of global offshore petroleum and gas reserves, as well as their future cost of production.

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[1]M. King Hubbert, "The Energy Resources of the Earth," Scientific American, September 1971, pp. 64-65.

[2]U.S., Department of the Interior, Energy Perspectives (Washington, D.C.: Government Printing Office, 1974), pp. 14-15.

Demand. The demand for oil is a function of many factors. On the national level, demand will be affected by increasing population, national income, the level of industrialization or economic development, changes in the national transport structure, and the foreign exchange position when foreign supplies are being considered. Demand is certainly a function of the price of petroleum. In this sense, demand will be influenced by the availability of crude petroleum, its ease of transportation, changes in the prices of petroleum products in relation to competing energy sources, the nonavailability and nonsubstitutability of other resources and forms of energy, and advances in technology.

The choice between, or substitution of, different sources of energy is governed by both competitive and technical factors. The increase in demand for transportation and in the vehicle fleet in a given country, which usually accompanies economic development, do not pose the question of choice between competing forms of energy. In this case, the various energy forms are not substitutable. For heating purposes and for many stationary engines, coal, natural gas, and distillated and heavy petroleum fuels are substitutable for each other. This is the general area in which relative costs and prices as well as the level of industrial development play a role.

Once begun, the process of substitution cannot be easily reversed in developing countries in the short or medium term, through changes in price, particularly for solid fuels. This will affect demand.

In contrast with the developed market economy countries, there are few available projections of petroleum demand for developing countries, whether on a global or regional basis. Demand for petroleum in developing countries has reflected and continues to reflect, both the growth of the energy economy and the substitution of commercial and, particularly, noncommercial fuels.

Issawi[1] shows the projected demand for petroleum products for the world in 1980 to range from 3,269 million tons as a low estimate, to 4,317 million tons as a medium projection, and to 5,285 million tons as the high projection of consumption. The medium projection would appear to be the most realistic estimate.

In Table 1 these projections are compared to a consumption rate of 2,854 million tons in 1970.[2] Based on these figures, the average annual rate of increase in consumption may be expected to be between 1.45 percent, 5.1 percent, and 8.5 percent.

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[1]Issawi, p. 10.

[2]United Nations, World Energy Supplies 1961-70, Statistical Paper Series J, No. 15, 1972, p. 6.

Table 1. Estimates of World Consumption of Petroleum Products in 1980 (million tons)

	Estimated Consumption 1980		
Consumption in 1970	Low	Medium	High
2,854	3,269	4,317	5,285

Source: United Nations, World Energy Supplies 1961-70, Statistical Paper Series J, No. 15, 1972, p. 6.

Production. The production of crude petroleum increased to 3,340.423 million tons in 1972 over a total of 1,611.644 million tons in 1962. This represents an increase of 107 percent over 10 years, or an average annual growth rate of 10.7 percent (see Table 2).

As indicated by the Oil and Gas Journal,[1] world crude oil production rose to a new high production of 50,611,000 barrels per day in 1972. This was an increase of 5.3 percent or about 2,528,000 barrels per day over the 1971 output.

In noncommunist countries, including the United States, average output was 41,861,000 barrels per day. The output of the United States represented a 0.7 percent decline in production. The remainder of the noncommunist world had a 7.1 percent production increase.

[1] "World Crude Oil Production Climbs 5.3%," Oil and Gas Journal, 19 February 1973, p. 40.

Table 2. World Liquid Fuels Consumption, Production, and Per Capita (million metric tons coal equivalent), 1962-1972

	Years										
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Production	1,612	1,728	1,867	2,001	2,172	2,329	2,529	2,735	3,004	3,169	3,340.423
Consumption	1,517	1,652	1,784	1,921	2,075	2,218	2,414	2,611	2,854	3,017	3,220.366
Per Capita	1,433	1,433	1,550	1,592	1,649	1,648	1,734	1,811	1,897	1,932	1,984

Sources: United Nations, World Energy Supplies 1969-72, Statistical Paper Series J, No. 17, 1974, pp. 6-18; and United Nations, World Energy Supplies 1961-70, Statistical Paper Series J, No. 15, 1972, pp. 6-62.

Russia led the communist countries with an average of 7,880,000 barrels per day or a 6 percent increase in 1971. Mainland China's average production was 510,000 barrels per day for the same year. Total oil production for communist countries was 8.75 million barrels per day.

Persian Gulf countries expanded their production and the Middle East flow by 10.7 percent to an average of 5,643,000 barrels per day in 1971. Africa, Asia, and the Pacific gained also. However, Latin America experienced a decline over 1971 production totals.

These estimates should be viewed with caution since they are based on extrapolations of past trends. Probably only the orders of magnitude are relevant. According to these estimates, the world production of petroleum between 1972 and 1980 will be certain to increase.

This was not true, however, for 1974 and 1975. According to Mineral Industry Surveys,[1] the world crude oil production in 1974 was 20.5 billion barrels compared to 19.5 billion barrels in 1975. This represented a decrease of almost 5.2 percent. The Middle East countries in 1974 produced 7,986,831,000 barrels. In 1975, this total decreased by 10.6 percent to 7,143,494,000 barrels.

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[1] U.S., Department of Interior, Bureau of Mines, Mineral Industry Surveys, 9 June 1976, pp. 1-4.

United States production decreased by 4.7 percent while the USSR increased production by 7.0 percent.

The largest decrease occurred in Venezuela, the United States, Canada, Saudi Arabia, and Iran. Western Europe, especially the United Kingdom, Denmark, and Norway increased their production due to development of the North Sea fields. The decrease in world crude oil production was caused by many factors. Included were energy conservation, use of other sources of energy, the world-wide economic recession, and the world political situation.

Oil Shale

Oil shale is the term generally applied to rocks containing solid organic matter from which oil can be obtained by heating. Oil shale has a wide geographical distribution and the known reserves are very large. However, in many developing countries there has been no systematic exploration for oil shale; therefore, global reserves are probably much larger than present published estimates indicate. Global reserve estimates are difficult to compute because of a lack of detailed work on the extent and grade of oil shale in many parts of the world.

Commercial production of liquid fuels from oil shale began in France in 1938.[1] Between 1850 and 1950, oil shale

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[1]L. W. Schramm, "Shale Oil," Mineral Facts and Problems (Washington, D.C.: Government Printing Office, 1970), p. 184.

industries were established in different parts of the world such as Germany, South Africa, Spain, Sweden, Australia, Manchuria in mainland China and Estonia (USSR). As noted in Mineral Facts and Problems:

> Two countries have an oil shale industry at the present time: the U.S.S.R., with operations principally in Estonia, and mainland China. Total U.S.S.R. oil shale production for 1967 was 21.6 million metric tons.[1]

Oil shale can be broadly defined as a fine-grained, compact sedimentary rock, generally laminated and containing high-molecular weight organic matter called Kerogen. The organic matter of oil shale is found in sedimentary rocks. The matrix of these rocks is a combination of clay, quartz, and limestone.

Use. Oil shale has been used primarily as a raw material for manufacturing liquid fuels similar to those refined from petroleum. Apart from this, oil shale can be used as a low-grade fuel in conventional electrical generating stations or other plants requiring steam.

Important products from shale oil include gasoline, diesel fuel, domestic and industrial fuel oil, liquified fuel gases, and lubricants. Other products such as ammonium sulfate, sulphur, asphalt, coke, and detergents may also be obtained.

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[1] Ibid., p. 190.

Reserves. Energy Perspectives[1] estimates world recoverable reserves of oil shale and tar sands at approximately 10,351.5 quadrillion Btu.[2] The reserves are distributed as follows: 81.4 quadrillion Btu in Africa; 870.2 in Asia (less USSR); Europe (less USSR), 117.0; USSR, 139.0; North America, 9,111.0; South America, 23.7; and Oceania, 9.2 (see Table 3).

Economic factors of production. The economics of oil shale production are influenced mainly by the yield of oil from shale and the cost of shale mining. Oil shales are low-value minerals containing large quantities of useless material combined with the useful. This dominates the economics of oil shale utilization.

Factors entering into calculations of the economic feasibility of utilizing an existing deposit can be divided into the physical characteristics of the deposit, the technology available for its utilization, and the economic environment. Physical characteristics include the location of the deposit, its size, richness in terms of recoverable oil, caloric content, and recoverable by-products.

Decisions for exploitation must be made on the technological questions concerning plant size, location,

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[1]U.S., Department of the Interior, Energy Perspectives, p. 2.

[2]Each quadrillion Btu is equal to 500,000 barrels of petroleum per day for a year.

and mining methods. They will be influenced, in part, by the economic environment which includes size and proximity of markets, prices for shale oil, source of capital, rate of interest, and depreciation. Many of these factors vary greatly from one deposit to another.

Table 3. Estimated Oil Shale Reserves of the World in 1970, in Shales as Rich as 10 Gallons per Ton or Richer (billions barrels)

Region	Known Resources	Possible Extensions of Known Resources	Undiscovered and Unappraised Resources
Africa	100	--	84,000
Asia	104	3,700	111,400
Australia and New Zealand	1	--	21,000
Europe	76	300	27,200
North America other than the United States	--	150	23,950
South America	800	3,200	38,000
Total (rounded)	1,080	7,350	305,500

Source: L. W. Schramm, "Shale Oil," Mineral Facts and Problems (Washington, D.C.: Government Printing Office, 1970), p. 190.

Natural Gas

World consumption of the different forms of energy is increasing rapidly. The share of the oil and gas consumption sector is forecasted to expand to a much larger volume or portion by the end of the century. By any prediction, at the end of this century, the world will be consuming natural gas at a rate greater than it is today. In the future, natural gas will undoubtedly contribute a larger share of total energy requirements.

A forecast is required in order to assess the availability of natural gas in the future. Forecasts indicate the availability of adequate supplies of huge proven reserves of natural gas in the world. Behind these proven reserves, there are the ultimate reserves which are likely to be found and to be recoverable under realistic economic conditions.

Natural gas, as a source of energy, can be either found together with oil or independently from it. The exploration and production problems of natural gas are largely the same as for oil.

Natural gas has certain advantages. It is the cleanest and most flexible fuel. Natural gas which is not used can be reinjected or liquified. Reinjection helps to maintain pressure in the oil field and preserves the natural gas for future use.

One disadvantage of this energy form is that it is more difficult to store or transport than liquid or solid fuels. An additional drawback is that much of the natural gas produced together with oil, especially in the Middle East, is destroyed through burning. The most obvious solution to this wastage is to convert the gas into a fuel which can be easily transported and stored. The usual method today is to transport it by pipeline or in liquified form. However, a liquified form is not always the best solution. The gas can be converted into methanol. This is more expensive, but the transportation is less dangerous.

Natural gas market. Natural gas is a source for heating space in houses, etc. It can also be used for different purposes such as in the ceramic industry, cement industry, glass industry, or the iron and steel industry.

The marketing of natural gas depends on the cost of transporting it, to some extent on production requirements, and, naturally, on relative prices. Owing to the specific advantages of natural gas, in some countries at least, prices of natural gas have always tended, until recently, to move with the prices of heavy fuel oil, with a slight differential.

Marketing also depends upon certain aspects of the individual field. Every natural gas field has its own form of economic development which depends on the size of the reserves, the pressure, depth, temperature, nature of the drainage system, character of rock, and its geographical position with regard to the consuming centers.

The expected future energy mix will certainly affect marketing decisions made today. The importance of natural gas on the energy mix of the future will depend on the availability of supplies, the economics of supplies, alternative energy resources available to meet environmental as well as energy needs, and technological developments. It is expected that demand for natural gas in the world in the future will increase because of an expansion of transportation facilities and new technology.

Warner[1] forecasted that the world demand for natural gas in the year 2000 would be between 70 and 115 trillion cubic feet. Technological advances in exploration, production, pipelining, and the location of new reserves in various parts of the world, will place the amount of reserves to satisfy the needs within reach.

Reserves. Reserve data are less reliable for natural gas than for oil. There is, unfortunately, no entirely reliable information in current literature in regard to the amount of natural gas reserves. It is not

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[1]Arthur J. Warner, "Natural Gas," Mineral Facts and Problems (Washington, D.C.: Government Printing Office, 1970), pp. 111-112.

clear, in most cases, whether the reserves quoted are gross estimates or proven recoverables.

The known reserves present a constantly changing picture influenced by greater knowledge of existing fields, i.e., discovery of new fields, and improvements in recovery methods. In addition, the distribution of potential reserves of natural gas in different parts of the world is not uniform.

As estimated in Energy Perspectives:

> In 1973, 34% of 2,133.1 trillion cubic feet of world natural gas reserves were located in the Soviet bloc and 29% in the Middle East. The U.S. which produced 51% of world marketed natural gas in 1973, possessed 12% of the natural gas reserves of the world.[1]

Energy, the Ultimate Resource,[2] calculates that Algeria, with approximately 135 trillion cubic feet of natural gas reserves, has enough to supply 8 billion cubic feet per day of natural gas for more than 35 years. Iran, with 100 trillion cubic feet, has the fourth largest natural gas reserves in the world. However, in recent years new natural gas discoveries in Iran indicate that Iranian natural gas reserves rank behind the Soviet Union and the United States with 200 trillion cubic feet of reserves.

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[1]U.S., Department of the Interior, Energy Perspectives, pp. 18-20.

[2]U.S., Congress, House, Task Force on Energy, Energy the Ultimate Resource (Washington, D.C.: Government Printing Office, 1971), p. 79.

In 1973, the United Nations[1] estimated world reserves to be 62,846 thousand million cubic meters. World production of natural gas, in the same year, was about 1,274,800 million cubic meters. Latest estimates of reserves by the U.S. Department of the Interior have been shown in Table 4.

Table 4. World Natural Gas Recoverable Reserves, 1973

Region	Reserves (trillion cubic feet)
United States	249.9
Other Western Hemisphere	135.5
Western Europe	164.8
Africa	235.8
Middle East	626.1
Far East and Oceania	105.6
Sino-Soviet Bloc	715.5
Total	2,133.1

Source: U.S., Department of the Interior, Energy Perspectives (Washington, D.C.: Government Printing Office, 1974), p. 19.

Total world natural gas production in 1973 was 55 trillion cubic feet or about 3 percent of total world natural gas. The United States produced 44 percent and the

[1]United Nations, Department of Economic and Social Affairs, Statistical Office, Statistical Yearbook 1973, 1974, p. 178.

Sino-Soviet bloc 20 percent of the total world gross natural gas production in 1973.[1]

Coal

Coal is a solid, black mineral consisting mainly of carbon, hydrogen, and oxygen plus certain impurities such as water, ash, and sulphur. There are many varieties of coal which are distinguished primarily on the basis of their volatile matter content. The varieties include anthracite, bituminous, coking coals, and gas coals.

The principal advantage of coal, beyond its unique value as a source of coke, is its relatively high energy content per unit weight. This makes it transportable at a relatively low cost. Its drawbacks are that it tends to give off a good deal of smoke when burned. An ash residue remains which must be disposed of.

Coal was almost the only energy source of industry for some two centuries. It is still a source of energy in the developed as well as in a few developing countries of the world. At the present time, many countries wish to restore coal as an energy source to a more dominant role than it has had during recent years.

Reserves. Reserves of solid fuels are generally easier to compute than those of liquid or gaseous fuels.

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[1]U.S., Department of the Interior, Energy Perspectives, pp. 20-21.

For reasons associated with the geological nature of the deposits, most quoted figures for coal reserves carry an economic connotation, in that they represent mineable reserves known to exist in beds having more than a certain depth below the surface. Different criteria are used for estimating reserves in different countries, rendering comparisons difficult and the computation of a global figure uncertain.

As Energy Perspectives[1] indicates, world coal reserves were estimated to be 668 billion short tons in 1973. Of the total world recoverable reserves 46 percent were located in Sino-Soviet bloc countries. The United States possessed 32 percent of recoverable coal reserves and produced 24 percent of total world output. World total production was 2,486 million short tons. The Middle East did not have any recoverable coal reserves (see Table 5).

According to the U.S. Geological Survey Bulletin,

> as estimated, the original coal reserves of the world as determined by mapping and exploration is a total 9,500 billion tons, the additional resources in unmapped and unexplored areas total 7,330 billion tons and the amount potentially present in the full extent and thickness of known areas of coal-bearing rocks total to 16,830 billion tons.[2]

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[1]Ibid., p. 24.

[2]U.S., Department of the Interior, "Coal Resources of the United States," pp. 81-84.

Table 5. World Recoverable Coal Reserves, 1973

Region	Reserves (billion tons)
United States	217.00
Western Hemisphere	009.00
Western Europe	072.00
Africa	017.00
Far East and Oceania	046.00
Sino-Soviet bloc	307.00
Middle East	000.00
Total	668.00

Source: U.S., Department of the Interior, Energy Perspectives (Washington, D.C.: Government Printing Office, 1974), p. 25.

An appraisal in Energy Facts[1] in 1975, indicates that world supply for coal reserves is 9,500,000 million short tons, of which 1,577,000 million short tons is for the United States. Proved recoverable reserves of the world are 281,000 million short tons, of which 184,000 million short tons are in the United States. As mentioned earlier, world recoverable coal reserves in 1973 were assessed at 668 billion short tons.

Coal and pollution. In countries which have sufficient resources, coal will continue to gain and will increasingly be burned in power plants to generate

[1]U.S., Congress, House, Energy Facts II, pp. 95-96.

electricity. However, most experts agree that the traditional air polluting smoke stacks should not be allowed to return.

In many countries, regulations exist today which lay down a certain minimum height for smoke stacks, in order to insure the best possible evacuation of smoke and gas. This is not a permanent solution. Apparently, the most obvious solution is to burn coal conventionally, but to eliminate sulphur, ash, and particles from the stack gas before it is released into the atmosphere. Technically, this method seems to be more mature than others.

Peat

Peat is the partly carbonized remains of roots, tree trunks, twigs, reeds, shrubs, grasses, and mosses that have been covered or saturated with water so that decomposition is retarded. It contains a large proportion of the carbon of the original vegetable matter, and the plant structures of which it is composed generally are visible without the aid of a microscope.

According to Mineral Facts and Problems: "Peat is partially decomposed vegetable matter that has accumulated under water or in a water saturated environment."[1]

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[1]U.S., Department of the Interior, Mineral Facts and Problems (Washington, D.C.: Government Printing Office, 1965), p. 645.

Peat is fossil fuel. It can be grown like a crop and harvested as one. The Btu value of the peat is less than that of coal. Peat is an important fuel in Europe. However, only small quantities have been produced as commercial fuel in the United States because of the abundance and superiority of coal.

Ayres and Scarlott[1] estimate that about 60 percent of known peat reserves of the world are in Russia, and are being produced at the rate of 30 million tons per year. The United States has one-tenth of the world's peat, located mainly in Minnesota. World reserves are estimated at 139 million tons with a heat content of 1.4 Q.

Fuel Wood

Wood is still an important fuel. In some countries, especially in rural areas, wood is the major source of energy. Putnam[2] estimates that there are 3 billion acres of forest in use and 5 billion more acres of virgin forest in the world. Further, "the annual input to the world energy system would be $90{,}000 \times 10^{12}$ Btu: about 22 times the present input from the wood."[3]

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[1]Eugene Ayres and Charles A. Scarlott, Energy Sources, the Wealth of the World (New York: McGraw Hill, Inc., 1952), pp. 79-81.

[2]Palmer Putnam, Energy in the Future (New York: Van Nostrand, 1953), p. 172.

[3]Ibid.

The high demand for wood for other purposes such as lumber and pulpwood makes only about half of the total production available for use as fuel.

Atmospheric Electricity

According to Ayres and Scarlott,[1] there are a few varieties of atmospheric electricity.

Lightning, which can be readily seen, strikes the earth. The total energy in strikes to earth is about one kilowatt hour. If all lightning strikes could be collected into a flow of electricity, it would be about 30 million kilowatt hours.

Control of Biological Synthesis

Photosynthesis is the process by which the chlorophyll of plants or vegetation uses sunlight energy to reduce the carbon dioxide of the atmosphere in the presence of water releasing oxygen. These processes permit food production for plants, livestock, and humans.

Algae, a very efficient plant, is able to do all the above processes. A high quantity of sunlight at the earth's surface is available for photosynthesis and the growth of plants such as algae.

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[1]Ayres and Scarlott, Energy Sources, p. 275.

Fisher[1] notes that algae grow very well. He estimates the yield of algae as at least 50 tons per year, per acre.

The production of algae in shallow solution is capable of absorbing solar energy. Putnam[2] calculates that chlorella, when burned, gives up to 9,000 to 13,600 Btus per pound. Cultivating algae would enable energy to be produced for use. He further estimates the energy from algae would cost almost 150 times as much as the energy from coal.

Temperature Differences in Tropical Water

A few conceptual designs for power generation based on ocean thermal gradients have been proposed by scientists. The results from such studies indicate how energy from ocean gradients can best be utilized.

According to the National Science Foundation,

> by far the largest Solar Collector is the sea's surface. Tropical surface waters are a tepid 82 degrees to 85 degrees F, and they are separated by as little as 2,000 feet from a practically inexhaustible cold water reservoir at 35 to 38 degrees F. These dense, near freezing waters have traveled from the polar regions where they slide under the warm, buoyant surface waters moving poleward. The different densities keep the layers separated to our advantage, for even with two percent efficient

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[1]Austin W. Fisher Jr., Proceedings of the World Symposium on Applied Solar Energy, Phoenix, Arizona, 1955, p. 243.

[2]Putnam, Energy in the Future, p. 200.

heat engines, the Gulf Stream alone could provide 75 times the energy needs of the United States.[1]

Batelle Memorial Institute notes:

> Deep ocean water is always colder than its upper zones. This results from cold seawater being more dense than warm seawater, with the consequence that the cold water sinks.
>
> Sometimes the boundary between the two upper warm versus lower cold is quite abrupt, and is known in submarine lore as the "thermocline." It is possible, by using the cold water to condense water vapor from the warm water, to operate a sort of low-temperature vapor driven turbine, thus generating electricity.[2]

Ocean thermal difference is a constant source of energy. Thermal energy storage is unnecessary because the ocean itself is the storage reservoir. Ocean gradients might provide a renewable source of energy but their exploitation is limited to tropical seas with relatively high surface temperatures. Any attempt to assess the technical feasibility of such a conversion process is impossible at this stage. It is still doubtful whether or not it is economically viable for future use.

Hydroelectric Energy

Compared to the probable total hydroelectric power potential of the world, only a small fraction has thus far been harnessed for beneficial use. Hydroelectric power has

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[1] "Energy for America's Third Century," MOSAIC 5 (Spring 1974): 22.

[2] Battelle Memorial Institute, Energy Perspectives 13 (August 1974): 1.

the advantage of low operating expenses because of the absence of fuel use. However, total initial costs may be high.

According to the Battelle Memorial Institute, the advantages and disadvantages of hydroelectric projects are as follows:

Advantages:

1. Continuous low cost power production (except when droughts occur).
2. Low maintenance costs.
3. No consumption of irreplaceable fossil fuel.
4. No smoke.
5. Reservoirs can provide considerable, but not complete flood protection to downstream areas.
6. Reservoir lakes can be used for recreation in many, but not all, cases.
7. Downstream flow can be managed to aid in water-quality control, to level out the extreme of winter versus summer stream conditions.
8. Ground water reserves are increased by recharging from the reservoir.

Disadvantages:

1. High initial costs of construction.
2. Power production can be curtailed or even discontinued in time of drought.
3. Some water is lost by evaporation from the lake surface.
4. Flood protection can best be provided by an empty reservoir, while power production is best from a full reservoir. A full reservoir cannot retain

> a major flood, an empty reservoir generates no power. The compromise then is to retain enough water in a reservoir to insure continuous power generation, but leave a margin of free board to take the "sting" out of a sudden torrential rain storm.[1]

Despite these advantages and disadvantages, it has been the experience of many countries that hydroelectric power development has not been as rapid as wanted. This has made it necessary to construct alternative thermal power plants. Among the reasons for a relatively slower rate of progress of hydroelectric schemes in some countries is the lack of essential hydrological data which are necessary to prepare hydro power projects.

According to Energy Facts II,[2] energy inputs for world electrical generation increased at an annual rate of 7.6 percent between 1960 and 1972. Inputs are projected to increase at an annual rate of 6.4 percent between 1972 and 1990. World energy inputs to electrical sectors in 1960 for hydropower were 6.9 quadrillion Btu, in 1970, 11.8. In 1980 it will be 12.8 and in 1990 should reach 18.8 quadrillion Btu.

Estimates in Energy Facts II[3] indicate that world energy consumption increased at an annual rate of 4.9 percent

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[1]Battelle Memorial Institute, Energy Perspectives 14 (September 1974): 1.

[2]U.S., Congress, House, Energy Facts II, p. 28.

[3]Ibid., p. 46.

from 1960 to 1972. It is projected to increase at a 3.3 percent annual rate from 1972 to 1990. Hydropower is expected to increase at 2.1 percent. One estimate by the U.S. Department of the Interior[1] indicates that total world hydroelectric power, both developed and undeveloped in 1973, was 22,610 million kilowatts.

Developed and undeveloped hydroelectric power has been defined by Battelle Memorial Institute as: "There are two types of underdeveloped hydro potential--one where no dams have been built but sites exist, the other where dams have been built but the full generating capacity has not been installed."[2]

There are some sizeable hydroelectric sites in the world which could be developed, but so far these resources have remained largely undeveloped. Technical factors, high capital investment, and construction difficulties are the reasons for the undeveloped hydroelectric power.

Wind Power

Wind has been recognized as a source of energy for centuries. However, regardless of sustained efforts, it has not entered into the field of power generation in a major way. For many years, windmills and other small wind

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[1]U.S., Department of the Interior, Energy Perspectives, p. 26.

[2]Battelle Memorial Institute, Energy Perspectives 14, p. 2.

installations have been used in isolated areas in various countries to lift water for irrigation and other purposes.

There are a few areas on the earth where wind power could supply nearly a constant source of power. As a power source, wind can be usefully applied to pumping water or generating electricity in small capacity installations in isolated, windy areas. However, its development for large scale applications is limited by difficult engineering problems, high capital costs, and limited availability of easily reached sites. In spite of this, in rural areas where other sources of energy are scarce or costly, small wind power installations or small windmills may be highly economical.

According to the National Science Foundation, "between 1880 and 1930, over six million windmills pumped water, saved wood and generated electric power in the American West."[1] Wind power could again be used as efficiently as in the past.

Problems of wind power development. The problem of storage is perhaps the most difficult engineering problem to be faced. Many possible solutions must be considered in wind power installation. If the problem of producing a high capacity but low cost power accumulator is solved,

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[1]"Energy for America's Third Century," pp. 20-21.

wind power can be used extensively. The disadvantage of nonregular supply will have been overcome.

Two essential facts dominate the problem of the utilization of wind power. One is the diluting of this energy in space. The other is its considerable and unpredictable irregularity. Moment to moment fluctuations in wind speed have an influence on the running of the engine.

Lastly, one of the fundamental conditions for wind power utilization and development at low cost is the low cost of the equipment. For this reason, effort should be made to simplify design and reduce costs.

Utilization. The generation of electric energy and the pumping of water are the main applications of wind power. The utilization of wind power plants must be distinguished among household, community use, and use for electrical power networks. For household and individual use, the requirement is a small plant or installation. For community use the requirement is medium. A large plant can be used for electrical power.

Whether or not wind power plants can be built on a large scale depends, first, upon the price at which the plants can be erected. Second, the price at which electricity can be produced by conventional power works must be considered. Since the wind is not always blowing, it is necessary at all times to have the fuel effect available from other machinery to secure a continual supply of electricity.

Economic use. For the technical and economic evaluation of wind power plants, knowledge of the relationship between wind speed and power output is of greatest importance. This characteristic varies according to the type and magnitude of the wind power plants, and to the rated output of the generator.

The cost per kilowatt-hour depends on the number of kilowatt-hours produced per kilowatt, rates of interest, amortization applied to the investment, and, to a small extent, on the annual operating and maintenance costs.

From the economic point of view, a further distinction should be made between large wind power plants and small machines of less than five kilowatts, which can be used on individual farms. The cost of power from small machines would obviously be higher than that from large machines.

The cost of power per kilowatt-hour produced by large wind power machines can be compared favorably with diesel-generated power in the underdeveloped areas. Basing his calculations upon the Eilat wind power plant, Frenkiel[1] determined the price per kilowatt produced to be 10 cents.

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[1]United Nations, Proceedings of the United Nations Conference on New Sources of Energy at Rome 21-31 August 1961, vol. 7 (1964), p. 334.

The price per kilowatt of a comparable diesel set was estimated to be 18 cents. Thus, whenever small quantities of electricity are required, and the mean wind speed is sufficient, there can be a definite advantage in using wind power units rather than diesel generators. This type of small wind power application can be used in isolated houses that, until now, could not be supplied with electricity. A storage battery would enable rooms to be lighted and small appliances to be used.

Geothermal Energy

There is a deep reservoir of heat energy in the earth. Long ago it was discovered that the depth of the earth is warm and that the temperature rises with the depth. It is possible to use the temperature difference between the surface and the interior of the earth. The power from this source is enormous but there are technical difficulties and high capital costs in obtaining the underground heat.

Geothermal energy, at the present time, is being used in some parts of the world. The use of underground heat to drive steam turbines appears to be achievable only in a very small area of the world.

Geothermal fields differ in character and heat output. Therefore, a wide range of techniques must be used to exploit them. For this reason, good and reliable

information is required before any installation is used or capital investment made.

Utilization. One of the most serious limitations to its use is that little is known of the physical availability of geothermal energy, except where hot springs and other readily apparent surface evidence exists. More information in this area would facilitate the use of this energy form.

Other factors affect the utilization of geothermal resources. One is that the use of geothermal energy presents fewer pollution problems than nuclear power with its waste disposal problems or fossil-fuels. Another important aspect is that the production cost per unit of energy is lower for geothermal than other available sources. For example, the United Nations[1] found that in Iceland, at some fields, production costs of natural steam ranges from 20 to 30 cents per ton. This corresponded to 5 to 20 percent of the cost of imported oil in speaking of useful energy. Use of geothermal energy also depends on the amount of reserves available in the area, upon the complex problem of the exploitation of reserves, and upon the use of technology.

The use of geothermal energy as steam is well developed on the basis of experience with many types of

[1]Ibid., vol. 3, p. 471.

power plants in operation. Considering existing advanced technology and the promise of lower power costs, the possibility of increasing utilization now depends on the exploration for geothermal resources.

Much of the existing utilization of geothermal energy is to be found in relatively industrialized countries. However, it should not be thought that utilization will be limited to those countries.

Conversion into electrical energy is the most practical method of making this natural resource available for general use. The production of electrical energy from geothermal steam has been in process for many years in Italy, New Zealand, and recently in California. According to the Battelle Memorial Institute,

> the oldest commercial installation to generate electricity from natural steam is the Larderello development in Italy. . . . Here natural steam was first used to operate a small generator (250 kilowatts) sixty years ago. The district now produces 390,000 kilowatts and is currently the world's largest electric generating installation based on natural steam.[1]

Geothermal electric power stations are in operation in at least five other countries in the world. Iceland, Japan, New Zealand, the USSR, and the United States. According to H. Christopher H. Armstead, "the amount of power now being generated for public electricity supply

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[1]Battelle Memorial Institute, Energy Perspectives 3 (October 1973): 1.

purposes in various parts of the world from geothermal steam is over 700 megawatts. With plants now under construction, this figure will rise to 900 megawatts."[1]

Geothermal heat can be used in process industries in the form of steam or hot water. A limiting factor is that the steam sources must be in an area suitable for the construction of the industry. Steam and hot water can be used for such agricultural purposes as heating, drying, and distillation. Geothermal energy can be used in agriculture, for example, in greenhouses, for soil warming, or crop drying.

The Battelle Memorial Institute lists the following advantages for geothermal energy:

1. Geothermal sources of energy are long-lived.
2. The cost of harnessing natural steam is competitive with coal or oil burning installations.
3. There is no production of carbon compounds, fly ash and other products.
4. Disruption of the landscape can be minimal where geothermal is being used.[2]

A disadvantage of geothermal energy is surface corrosion and the accumulation of minerals on the soil surface.

Geothermal energy can compete with other available sources of energy, such as fossil fuels when used for

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[1]H. Christopher H. Armstead, ed., Geothermal Energy Review of Research and Development (Paris: UNESCO, 1973), p. 16.

[2]Battelle Memorial Institute, Energy Perspectives 3, p. 1.

heating and other purposes. The principal factors that affect the economic use of geothermal energy are drilling costs, transmission costs which are related with distance, and power station maintenance. The geographical limitation of resources in the different parts of the world is another factor that hinders use.

The rising level of interest being focused on environmental pollution in various parts of the world is of significance in geothermal development. Air pollution occurs with the use of fossil fuels if gases such as hydrogen sulphide are released into the air. Additional costs may be incurred in providing adequate means for their disposal. It was mentioned earlier that geothermal is less polluting than nuclear or fossil fuels.

<u>Reserves</u>. Geothermal resources can be distinguished by four types. First, the low temperature areas, which are characterized by hot water springs and a subsurface temperature. In this case, the surplus heat reservoir can be exploited by drilling. Second, is the hot water fields. These contain a water reservoir and can be useful for space heating, agriculture, and other industrial uses. The third is wet steam fields which contain a pressurized water reservoir at a high temperature. Fourth are dry steam fields containing super heated steam.

Geothermal steam can be found at shallow depths. However, the steam used for power or industrial purposes is usually found at deeper levels.

According to the United Nations,[1] about 50 countries have either commenced or are displaying an interest in geothermal development. For countries lacking significant deposits of fossil fuels, using geothermal energy is particularly attractive. The United Nations[2] further estimates total world geothermal generating capacity at 1,278.8 megawatts electric in operation and 563.5 megawatts electric under construction in 1975.

Economic use. The same elements which characterize the production of power from other fuels are found in the economics of geothermal power use. These elements, such as capital, include interest rates, depreciation, operation and maintenance costs, and the cost of fuel. The costs of production of geothermal energy includes drilling, the piping of the fluid to the point of collection within the thermal areas, well-completion and casing.

The growing interest in the development of geothermal energy is the result of its economic advantages over the utilization of fossil fuel alternatives. The fact

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[1]United Nations, Proceedings, Second United Nations Symposium on the Development and Use of Geothermal Resources (San Francisco, California, 1975), vol. 1, p. 3.

[2]Ibid., p. xxxiv.

that power plants are being built is important evidence that geothermal energy costs are competitive if the right geological and economic factors exist for the reserves to be exploited.

The United Nations further notes:

> Geothermal energy is not an expensive alternative fuel for making electricity. The economics of geothermal energy are complex and dependent upon the geologic setting of the reservoir and the reservoir's temperature.[1]

The quality and quantity of heat required for the exploitation of geothermal energy to be economic depends on the available market as well as the value per kilowatt hour of electrical energy in the particular area.

Geothermal costs may not be easy to project. Armstead[2] indicates that it is difficult to predict the cost of heat at the bores because of the difference in fields. However, he estimates the cost of heat to be 3.36 cents per one million Btu in New Zealand. This compares with 67 cents per one million Btu for oil fuel heat at the same place. This shows that geothermal can be very cheap relative to other fuels.

Geothermal heat to be of economic value, must be contained in gases or fluids. If it is contained in gases,

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[1]Ibid., p. cxxvi.

[2]Armstead, p. 166.

such gases must have adequate pressure to drive the engines for electricity.

Total power costs of geothermal energy depend on the annual interest and depreciation resulting from the investment in the plants. Production costs must be added to transmission costs, which can be high in cases where location is far from markets and loads are low. Construction costs of a geothermal plant are two-thirds to three-fourths of the cost of a comparable fossil fuel plant and less than half that of a nuclear plant.[1]

It is probable that power generation and space heating are the most important applications for geothermal energy in the future. The number of geothermal power plants in the world is expected to rise during the next decade because geothermal energy is able to compete economically with other fossil fuels' energy.

Solar Energy

Solar energy may be one of the largest sources of energy in the future. It is only available during daylight hours. The number of daylight hours vary with the area and season in different parts of the world.

Solar energy has the characteristics of being available everywhere, inexhaustible, and renewable. The quantity

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[1]Richard Bowen and Edward Groh, "Geothermal--Earth's Primordial Energy," Energy Technology to the Year 2000 (Cambridge: Massachusetts Institute of Technology, 1972), p. 45.

available at any one place changes with the season and weather. Unlike atomic energy and fossil fuel, it has no critical health hazards, environmental pollution, or waste products.

Technical difficulties involving conversion techniques and such things as equipment for energy collection have kept solar energy from being harnessed to any great extent. The direct collection of solar radiation through technological means and indirect collection through the natural photosynthesis process offers an optional energy supply for water and house heating, power generation, and synthetic fuels. The successful application of solar energy to water heating has been carried out by many countries in recent years.

Most applications of solar energy require considerable areas for collection and conversion. Some type of energy storage is usually also needed. Most solar applications are now at the experimental stage. In a few cases, they have reached a commercial status to bring them into market.

Possibilities for applying solar energy processes must be viewed in the context of the varying energy situations in differing parts of the world. The ideal zone for using solar energy is where the greatest annual number of days of sunshine exist, where its duration is constant, and

where conventional forms of energy are scarce and, therefore, expensive.

As applications of solar energy increase, different designs of such things as solar water heaters are emerging in different countries. This is because the designs are all influenced by the wide variation in solar radiation, temperature, interest rates, material, labor, availability of finance, and hot water demand.

Amount of solar heat. Energy from the sun can be divided into three categories based on its function. Energy from the sun can be regarded as a source of heating and cooling, of electricity, and photochemical phenomena.

Solar energy reaching the earth can be estimated in different ways, either daily or annually. Herwing[1] states that the solar energy falling in a year on a square foot of average land in the continental United States has a value of about $1.00, based on an energy unit value of $2.00 per million Btu. This has been based on the average United States insulation of 1,480 Btu per square foot per day (4,000 kilocalories per square meter per day).

Use. Solar collectors and energy storage units can be used for water heating, space heating, air conditioning, crop drying, cooking, and food cooling. For

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[1]Laloyd Herwing, Workshop Proceedings: Solar Cooling for Buildings (Los Angeles, Calif., 1974), pp. 6-8.

these purposes, units for single households or families can be operated without difficulty. In various countries energy from the sun has been used to supply hot water for family residences and other small buildings. Solar energy can be utilized in both industrial and developing countries.

The conversion of brackish water to fresh water is another use of solar energy. It can be used in coastal areas where fresh water and sources of energy are scarce. The economic conversion of sea water into fresh water is being researched by scientists throughout the world. Solar heat distillation appears to have a good future.

Solar energy offers a potential method of producing electricity. The direct conversion of solar energy into electric power has been successfully experimented with during the past.

Considerable progress has been made in regard to the photovoltaic devices which convert sunlight or high energy photons directly into electricity. Conversion of solar energy into electrical energy by means of silicon solar batteries is one of the best methods due to their light weight, reliability, and long life. However, at the present time, initial costs are relatively high for large power sources.

Economic use. Solar energy promises to be an abundant, clean source of energy. The economics of a

new source of energy, such as solar, can be considered from many sides. One way is to evaluate such things as solar heating and cooling systems on the basis of comparative costs with other available energy resources. Technically, there are no limitations to prevent solar power stations from being constructed now. However, there is a question as to whether it would be economically competitive. Therefore, a major goal of a solar energy conversion program is to establish the technology needed for a low-cost design and use. The program should be designed to permit commercial availability and low cost use of solar energy. A central factor limiting the adoption of solar energy, as compared to other sources, is the lack of a well-engineered and economically manufactured distribution system for solar energy in all areas. A positive factor affecting its adoption is that solar energy can be designed to have a minimum effect on the environment. In comparison, most power plants today cause significant amounts of pollution.

The cost per unit of energy obtained from a solar water heater is an essential factor which also affects the economic use of this resource. Isao Oshida[1] estimated that the cost of installation and the selling prices of various

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[1]United Nations, Proceedings of the United Nations Conference on New Sources of Energy at Rome, 21-31 August 1961, vol. 5 (1964), p. 6.

types of solar water heaters are between $52 and $200 in square meters of absorbers in different countries.

Robinson and Neeman note the following:

> The requirements of an average household heater are 2.4 million kilocalories per annum. For the purpose of our calculation, the year divided by 365 days will give 6,600 kilocalories per day as a yearly average equivalent to 7.65 kwh. Assuming the average yearly temperature increment obtained by using solar heating (approximately 40°C to 45°C), it becomes apparent that a solar heater with a capacity of 150 liters and a collector having four square meters of collecting surface, have to be used. The cost of such a heater in the U.S. is $400. The cost of a comparable electric heater will be $150 at most.[1]

Newsweek pointed to the following:

> International Solar Thermic Corporation of Nederland, Colorado is licensing manufacturers to build a toolshed sized solar furnace that produces hot air for space heating at an installed cost of about $4,500. In Pittsburgh, PPG Industries is fabricating flat-plate solar collectors for $30,000 to $50,000 homes being built in Columbus, Ohio. The extra cost per home runs from $4,000 to $6,000.[2]

Jardine[3] estimated that the Phoenix Corporation house will require 112 million Btus per year to heat it. At current gas rates, that would have cost $194. Heating the house by electricity costs $840. Solar heat costs $75, if heat can supply 80 percent of the house's needs. The

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[1]Ibid., p. 79.

[2]Newsweek, 24 February 1975, pp. 50-53.

[3]"Planning a Municipal Energy Future," MOSAIC 6(4), (July/August 1975): 27-28.

annual difference between solar and electric heat would be $765.

Thus, it can be said that there are certain economic advantages to the use of solar energy. However, predicting the future success or failure of the adoption of solar energy is difficult due to problems of making technological and economic forecasts. For example, solar water heaters are in commercial production in many countries. However, in those with less than ideal solar conditions, the need for auxiliary heating on overcast days results in increased total cost which raises the problem of economic feasibility of the solar energy system. If technical problems such as this can be overcome, the success of solar energy as an alternative energy resource will be easier to predict.

Nuclear Power

In recent years, nuclear power production has made great progress. The need for new sources of energy resulting from the changing world political and economic situation, the continuing depletion of nonrenewable energy sources, and advances in technology has been behind this program.

Various elements have decreased the use of nuclear energy for electricity production. Developing countries have been limited in its application by the relative scarcity of uranium resources, technical difficulties, manpower, and the availability of cheaper sources of energy. In

general, the availability of uranium and technology are not expected to be a limiting factor in industrialized countries.

The Nation's Energy Future indicates the validation of the nuclear option as a new source of energy for the future to substitute for fossil oil:

> A self-sufficiency, based on fossil fuels, can only be temporary. Moreover, oil, gas, and coal are important sources of raw materials for fertilizer and other petrochemical industries, and the world's growing demands for food preclude the continuous use of fossil fuels and finally concern has been expressed about the environment issue.[1]

Utilization. Nuclear energy provides particular advantages. It does not cause any air pollution. The cost of fuel transport and stock is lower per unit of energy content than for conventional fuels.

The world's total number of installed nuclear power plants is 374, with a total capacity of 262,754 megawatts of electricity. There are 124 nuclear power plants in operation and 143 under construction. Projected world nuclear capacity is 93,800 mwe in 1975, 263,800 mwe in 1980, and 567,300 megawatts in 1985.[2] These large electricity-producing reactors have demonstrated the

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[1]U.S., The Nation's Energy Future, Report to Richard M. Nixon, President of the United States, December 1, 1973 (Washington, D.C.: Government Printing Office, 1973), p. 49.

[2]U.S., Department of Interior, Bureau of Mines, Minerals Yearbook, vol. 1 (Washington, D.C.: Government Printing Office, 1973), p. 1277.

technical feasibility of nuclear power on an industrial scale.

One estimate by the United Nations[1] indicates that world nuclear power used for electricity in 1964 was 15,500 million kilowatt hours. In 1970 it was 77,700 million kwh, and in 1973, 181,300 million kwh. United States nuclear power use in 1964 was 3,343 million kwh; in 1970, it was 21,797 million kwh; and in 1973, it was 83,292 million kwh.

The _1975 World Almanac_[2] noted that a total of 42 nuclear power reactors were operable with light water reactors in the United States at the end of 1973. Their capacity was placed at 25.67 million kilowatts or about 5.6 percent of the nation's total electric generating capacity.

Nuclear power has been used for more than electric power generation in the world. Other uses include desalination of sea water. For desalination, it does not matter whether the energy comes from a fossil fuel burning plant or a nuclear plant. The choice of heat as a source can be based, therefore, upon economic considerations. Providing a source of adequate low-cost energy is only one part of the desalting water plant. The basic question is, how can

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[1]United Nations, _Statistical Yearbook 1974_, p. 380.

[2]Newspaper Enterprise Association, _1975 World Almanac and Book of Facts_ (New York: Newspaper Enterprise Association, 1975), p. 114.

saline water be most efficiently and economically converted to fresh water, making it useful for consumption purposes.

Preserving food is another use of nuclear power. During recent years, a great deal of attention has been directed toward the possibility of using radiation as a means of preserving food. The problem presented by the use of radiation is the possibility that some of the chemical changes included in irradiated food might result in the formation of substances toxic to man.

Future of nuclear power and uranium. Uranium is the only naturally occurring substance that can be used as a basic raw material for atomic energy. Uranium never occurs in its pure form in nature but is always combined with other substances to form a mineral. The most important uranium mineral is uranium oxide.

Nuclear power to make an important contribution to world energy, and for its running, needs uranium. The essential exploration and development of an adequate world uranium supply is a most important concern at the present time.

According to Energy Facts II,

> nuclear energy is expected to be the fastest growing energy input during the 1972-1990 period, increasing at an annual rate of 23.6%. In 1990, nuclear energy is projected to provide 37 percent of total energy inputs for electrical generation.[1]

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[1]U.S., Congress, House, Energy Facts II, p. 28.

The natural uranium demand for the near future to feed the nuclear power, according to a United States Atomic Energy Commission, estimate in 1974 for both the United States and the world was:

> The 1980 uranium requirements for the United States range from 21,000 to 27,000 metric tons of uranium and for the foreign countries range from 25,000 to 37,000 metric tons. The 1990 requirements for the U.S. and foreign countries will range from 60,000 to 90,000 and 99,000 to 140,000 metric tons of uranium, respectively. The requirements in the year 2000 are expected to range between 91,000 and 155,000 metric tons uranium in the U.S. and between 168,000 and 290,000 metric tons uranium in foreign countries.[1]

A uranium supply for these forecasts is essential and the commercial uranium industry has grown rapidly. However, the anticipated requirements have not developed and uranium purchases have exceeded actual requirements (see Table 6).

Uranium reserves. According to the United States Atomic Energy Commission,

> a typical light water reactor of 1,000 megawatts electric capacity, needs enrichment uranium produced from 550 to 625 tons of uranium oxide for the initial loading and about 200 tons of uranium oxide per year refueling.[2]

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[1]U.S., Atomic Energy Commission, Office of Planning and Analysis, Nuclear Power Growth, 1974-2000 (Washington, D.C.: Government Printing Office, 1974), pp. 27-28.

[2]U.S., Atomic Energy Commission, Division of Production and Material Management, Nuclear Fuel Supply (Washington, D.C.: Government Printing Office, 1973), p. 2.

Table 6. World Uranium Requirements Through 1985 (thousand tons)

Region	Uranium Oxide U_3O_8	Percentage
United States	474	47
Japan	106	10
United Kingdom	92	9
West Germany	65	7
France	40	4
W. Europe, others	107	11
Foreign, others	116	12
Total	1,000	100

Source: U.S., Atomic Energy Commission, Division of Production and Material Management, Nuclear Fuel Resources and Requirements (Washington, D.C.: Government Printing Office, 1973), p. 26.

According to the Department of the Interior, uranium resources can be divided into three subclasses:

1. Recoverable resource--those that can be extracted profitably under 1972 conditions.
2. Paramarginal resources--defined as those that might be extracted profitably with 50 per cent to 5 per cent fold increase in the prices of uranium oxide.
3. Submarginal resources--those that require more than a 5 fold price increase.[1]

The U.S. Department of the Interior[2] further notes that total recoverable resources of uranium oxide for the

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[1]U.S., Department of the Interior, United States Mineral Resources, Geological Survey Professional Papers No. 820 (Washington, D.C.: Government Printing Office, 1973), p. 462.

[2]Ibid., pp. 462-463.

United States in December 1971 was 273,000 tons. For the world, it was 1,605,880 short tons. Thus, the total recoverable uranium resources of the world is about 1.6 million tons of uranium oxide, which is enough to supply estimated world demand for the future.

Energy Facts II[1] estimates total world remaining recoverable uranium resources at 5,858 thousand short tons; 2,400 thousand short tons is in the United States and 3,458 thousand short tons is in the rest of the world. Proved recoverable uranium resources for the world is 1,001 thousand short tons, with 273 thousand short tons located in the United States.

In January 1973, the United Nations[2] estimated total world uranium reserves at 961,800 metric tons. United States reserves total 262 thousand metric tons. Total world uranium production in 1973 has been 19,480 metric tons, of which 10,164 metric tons has been by the United States.

There is not complete information on uranium reserves and production for all countries of the world. Even so, considering this information and the figures mentioned earlier, it appears that there is an adequate

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[1]U.S., Congress, House, Energy Facts II, pp. 421-422.

[2]United Nations, Statistical Yearbook 1974, p. 180.

supply of uranium available to meet the needs for nuclear power plants. However, the supply could be uncertain for the long term.

Economic use. The economic use of nuclear power depends on the operation and characteristics of the plant. Usually the economic use of an industrial nuclear power plant station varies with its capacity. The capital cost per kilowatt is directly related with installation capacity in relation to output electricity.

The major element in the cost of output electricity from nuclear power is the investment for nuclear power reactors which have to meet costs of shielding. Fuel costs, operation and maintenance, land, and safety measures are also important elements in the cost of electricity from these plants.

Uranium cost is another important element. Thus, uranium production and enrichment has a direct relation to the economic use of nuclear power.

As estimated by the Atomic Energy Commission,

> expansion of the nuclear raw material supply will necessitate substantial capital investment in exploration and construction of new mines and mills. Between 1973 and 1990, the capital investment needed is estimated at $10 billion, of which $6 billion would be for exploration, and $4 billion for new mines and mills.[1]

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[1]U.S., Atomic Energy Commission, Nuclear Fuel Supply, p. 9.

Other research has been done to determine the cost of uranium for nuclear power. It is noted in United States Energy Outlook:

> It is estimated that a capital investment of $4.9 billion will be required for exploration in the United States for providing necessary facilities for the domestic mining, milling, refining and conversion, enriching, fabricating and processing of uranium for use as fuel in nuclear power plants during the period of 1971-1985. This would be an investment of $16.71 per kilowatt for the 292,500 mwe of nuclear electric power generating capacity during the years of 1971-1985.[1]

As mentioned earlier, the most important factors in the fuel costs of nuclear plants are the cost of uranium, fabrication, and chemical processing. Significant reductions in nuclear plant capital costs can be done through improvement in core mining, as a result of technical advances, which will affect the major costs.

It was also noted previously that one of the most important uses of nuclear power was for desalination. An important reason for using nuclear power for desalting water has been its cheapness and convenience. The cost of desalting water by nuclear power in some areas of the world depends on the kinds of reactors. It is estimated as follows: "The cost of water desalination by 200 MW reactor

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[1]U.S., National Petroleum Council's Committee on U.S. Energy Outlook, U.S. Energy Outlook: An Initial Appraisal, 1971-1985, vol. 2 (Washington, D.C.: Government Printing Office, 1971), pp. 153-154.

site, cooled with water, would be 65 cents per thousand gallons, compared with an 8,300 MW reactor with high converter, the cost of water would be 23 cents per thousand gallons."[1]

A comparison between water plant costs of fossil fuel and nuclear power was given by the U.S. Atomic Energy Commission:

> The total capital and annual cost of fossil fuel would be $48,790,000 and for a nuclear power plant $107,190,000. Water production of fossil fuel plants per year would be 13,300,000 gallons with the cost of 65 cents per 1,000 gallons and a nuclear power plant produces 23,900,000 gallons per year, at the rate of 50 cents per 1,000 gallons of water.[2]

An essential point to consider for a water desalination plant, either fossil fuel or nuclear power, should be the cost of plant and its useful life. Thus, the decision must not be on the capital cost only, but on the lifetime of the plants also.

The major objective of the industrial countries in using nuclear power lies in its economic achievements. To achieve the economical use of nuclear power plants, requires the availability of low-cost fuel, technical manpower and low construction costs. The most important factor is the

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[1]U.S., Atomic Energy Commission, Division of Technical Information, Nuclear Energy for Desalination (Washington, D.C.: Government Printing Office, 1966), p. 36.

[2]Ibid., p. 38.

other alternative cheap sources of energy such as fossil fuel which will compete with nuclear energy development in the future.

CHAPTER III

ECONOMIC EVALUATION OF NEW SOURCES OF ENERGY

In this research, the main objectives of the economic evaluation of new energy resources are to bring out clearly the advantages and disadvantages of using solar, nuclear, and geothermal energy; to permit appropriate decisions to be made regarding the probable roles of solar, nuclear, and geothermal energy in the future energy economy; and, to enable adequate policies to be evolved to guide the energy economy under conditions existing in the future.

In order to evaluate these three forms of energy on a comparable basis, it is necessary to consider factors that are connected with the economic evaluation of each energy source and to establish criteria that will be adopted for this research evaluation. The method used in this research for evaluating these three forms of energy is to calculate the mean specific cost of each type of energy in the production of electricity. Alternatives will be chosen which will result in the lowest energy cost to the ultimate consumer.

To permit realistic evaluation, it is necessary to know the probable capital outlays required for the development of these three forms of energy; in addition, the costs of operation and maintenance are needed. These can be estimated by an analysis of cost data and trends for each of these energy resources. Suitable adjustments must be made for the scale of development and improvements in operating use efficiency.

Economics of Solar Power Plants

The elements required for the exploitation of solar energy such as collecting surfaces, converters, and storage equipment are relatively simple. An important advantage of solar energy systems is that they are usually easy to construct and operate. It is possible for them to be made locally because of this.

The possible use of this process to supplement energy supplies depends upon its costs in comparison with those of other forms of energy available in each area. The cost of solar energy will depend upon the expenses involved in the construction of the necessary apparatus, labor costs, the amount of reasonable distribution of sunshine at the location. These, of course, vary from area to area.

Other contributing factors to the cost of energy output from a solar power source are: collector efficiency, collector area, the degree of concentration of sunshine obtained by the collector, the storage-conversion process, plant size, capital charges, and operation and maintenance costs. The economic evaluation of solar energy, while depending on all these factors, depends mainly on the degree of concentration of sunshine and the resulting temperature ranges it is possible to achieve with a collector.

Estimation of the Economics of Solar Energy

Initial Capital Investment

The initial capital investment of solar energy installations varies greatly according to the plant and differing purposes. It can't be compared directly without taking into account the many factors involved. It is difficult to compare or calculate directly either the capital investment or the cost per unit of useful energy output.

It is important to know whether the initial capital investment is for solar cooking, home heating, or the distillation of water. Each of these involves different factors. Consequently, different amounts of investment are needed.

Naturally, the more solar units that are used, the greater the economic value and initial investment that will be required. Some installations may be used for more than one purpose. For example, air heating or hot water installations may also be used for refrigeration. In this case, costs will decrease because greater use will be made of the power.

The largest item in the capital investment of a solar plant is the collector, storage, and turbine generator units for a power plant. Labor costs are very small in comparison with the cost of materials.

Perhaps the most important capital investment in a solar energy plant is the amount of land needed and its price for the utilization of solar energy. This contrasts with both geothermal and nuclear power plants where land, because comparatively little is needed, is not a major portion of the capital investment.

Although solar radiation can be regarded as free, the land it falls upon is not. Whether the land is in a rural or urban area, there is a price attached to it. Of course, agricultural land or desert land would be less costly per acre. If the solar plant were to be located far from the town or industrial location, the cost of the land would decrease. However, the cost of transmission or transportation of energy to the town or industry would increase and probably eliminate any economic gain from using cheaper land.

Size of the plant. The construction costs of solar power plants increase with the size of the plant because of the changing amount of collector requirements and other expenses. In spite of this, the capacity and the size of solar power plants must be large enough to ensure demand from various places can be met.

For efficiency and the economic evaluation of solar plant power, the plant needs to be large. These large solar plants require more land so that more sunshine can be received and collected. In cities, the demand for electricity is so high that sufficient available land for solar power plants could hardly be obtained. Or, if it could be obtained, it would be very expensive.

Considering these elements, for this research a solar power plant size of 1,000 megawatts was selected because it is large enough to produce electricity with efficiency. In addition, it would not be valid to compare perhaps a highly inefficient 400 megawatt solar plant to a highly efficient 400 megawatt nuclear plant, for example.

According to Solar Energy as a National Energy Resource, "approximately 10 square miles are needed for a 1,000 megawatt power plant capable of operating on the average at 70% of capacity."[1]

Collectors. The collector is one of the most important factors in obtaining solar energy. It absorbs

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[1]U.S., National Science Foundation, NSF/NASA Solar Energy Panel, An Assessment of Solar Energy as a National Energy Resource (Washington, D.C.: Government Printing Office, 1972), p. 48.

the solar radiation and transfers the accumulated energy into the transfer fluid.

The absorption of radiation by collectors depends on collector efficiency, installation, and rate of sunshine. To a lesser extent it depends on the angle at which the sun's rays strike the collector, and the temperature of the absorbing plate. The net rate of useful heat collected in the system is the difference between the amount of solar energy absorbed inside the collector and the rate of outward heat loss.

Based on present technology, there are three categories of collectors:

1. The low concentrating temperature category or flat plate collector--for obtaining low temperature, which may be used for air heating, solar pumps, cooking, and water heating. This kind can be used for the application of 100°C temperatures. The probable range of collection efficiency of this type of collector is between 30 to 50 percent.
2. The medium concentration temperature, like a parabolic cylinder, used for over 100°C. It can be used in cooking or steam generators. It can be obtained by relatively simple solar concentrators. The probable range of collection efficiency is between 50 to 70%.
3. The high concentration categories exemplified by a parabaloid, with application temperature ranges between 1,000 and 3,500°C. These are very useful for metalographic studies. The probable range of collection efficiency is between 60 to 70%.[1]

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[1]U.S., National Science Foundation, Proceedings of the Solar Heating and Cooling for the Public Workshop, Part 1 (Washington, D.C.: Government Printing Office, 1973), p. 47.

Flat-plate collectors have been used for utilizing solar energy in heating houses and for heating water supplies in many countries.

Required collector area. Because the sun's radiation has such low density, it is necessary to collect its heat over a large area in order to get an amount of energy adequate to run even a small engine. The economic success of solar energy depends on cheap materials to cover large areas and on a means for obtaining high temperatures. This is one of the reasons that a large area of land is needed for solar plants.

Much cheaper and lighter collectors can be made for lower temperatures. Concentrating collectors could produce high temperatures, thus, permitting higher conversion efficiency. However, in this case, the land and collector equipment required would increase the capital investment in the plant.

In addition to the low density of sunlight, its intermittency affects the economics of direct solar conversion. Large areas must be devoted to the solar energy collector and a corresponding high capital investment in solar energy devices.

Efficiency of the collector. A good collector will be efficient in collecting high temperatures from the sun. The average efficiency of a collector is, ultimately, a function of the sunshine pattern.

As indicated by O. G. Lof,[1] collectors using water and air circulation to raise the temperature of solar radiation on their surfaces have been used often in solar water heating systems. In the form of heated water, temperatures of 150°F can be obtained on a sunny day, even when air temperatures are near freezing. He noted that on a clear day, 100 square feet of well-designed solar collector panels can deliver heat quantities approaching 100,000 Btu per day.

John A. Duffie and William A. Beckman[2] indicate that the amount of radiation that would be collected by flat plate collectors on a daily average per square meter in January and in July would be 6 kilowatt hours per square meter. If the efficiency of the collector is assumed to be 50 percent,[3] then the amount of radiation that each square meter of the collector will receive with 50 percent efficiency would be:

$$\frac{6 \text{ kwh} \times 50}{100} = 3 \text{ kwh per square meter per day.}$$

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[1]O. G. Lof, "Solar Energy: An Infinite Source of Clean Energy," The Energy Crisis: Reality or Myth (Philadelphia: American Academy of Political and Social Science, 1973), p. 57.

[2]John A. Duffie and William A. Beckman, "Solar Heating and Cooling," Science 191 (January 1976): 143-144.

[3]University of Maryland, Proceedings of the Solar Heating and Cooling for Buildings Workshop (Washington, D.C.: Government Printing Office, 1973), p. 47.

Conversion process. Solar heat can be converted to mechanical power for conversion to electricity by using piston and turbine engines. Until now, the process of solar energy for conversion of electric power has not been successful. The reasons lie in inadequate engine development, high collector costs, and inexpensive gasoline engines. One of the most important practical problems of converting solar energy into electricity has been solved by using the conventional mechanical steam power cycle.

According to Solar Energy as a National Energy Resource,[1] there must be five elements to convert solar energy to electricity:

1. Solar concentrator, to concentrate the sun's energy.

2. A receiver to absorb the concentrated sun's energy.

3. A means to transfer the heat to a thermal storage facility or to a turbogenerator.

4. Thermal storage elements to store thermal enegy for use at night and on cloudy days.

5. A turbogenerator to produce electrical energy.

Solar heat may be converted directly to electricity by means of thermoelectric converters. This requires relatively high temperature heat obtainable from concentrated

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[1]U.S., National Science Foundation, An Assessment of Solar Energy as a National Energy Resource, p. 48.

solar radiation. The costs are uncertain for thermionic converters.

Solar radiation coming as light may be converted to useful forms of energy through the various photochemical and photoelectric converters. Power from photocells is still too expensive for ordinary consumption.

From the preceding discussion, it appears that low cost production of electricity from solar energy will most likely come by using mechanical energy.

Solar energy storage. As mentioned previously, the collector is one of the most important factors in solar application, as it absorbs the solar radiation and transfers the accumulated energy into the transfer fluid. The costs associated with it are the largest part of capital investment in solar energy power.

Storage is a central problem in solar energy development. Storage of power is more difficult than the storage of heat. If the heat can be stored at a high temperature, it can be converted into power through the operation of engines.

Storage costs constitute a major difficulty in making it economical to use solar energy for either heat or power. Since no site on earth receives a constant flow of sunlight, either solar energy must be for operations which do not have to be continuous, or it must be stored for later use. Some progress has been made to solve the problem of power storage by using batteries.

Operation and maintenance. Operation and maintenance costs include salaries, wages, requirements, and maintenance. The expenses under operation and maintenance are partially related to both capacity and energy supplied. Wages and salaries are normally related to the actual size of the plant and energy generated.

Repairs and maintenance include routine work to keep the plant in order, including the replacement of parts. It does not include major replacement costs. A solar power plant, because it is complicated and involves a wide area of collectors, has a higher percentage of its costs going to operation and maintenance.

Duffie and Beckman[1] indicate the annual charge for operation and maintenance of a solar plant to be 12 percent. The same amount will be used in this research.

Rate of interest and plant factor. In general, the rate of interest varies from year to year, as well as with the kind and life of plant. As indicated by Duffie and Beckman,[2] the rate of interest for a solar power plant would be 10 percent per annum.

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[1]Duffie and Beckman, p. 149.

[2]Ibid.

The efficiency of power plants is different and varies with the size and type of plant. It is difficult to accept that plant power production could be done with 100 percent efficiency. Solar power plants because of their nature and the alternate change of sunshine in summer and winter, can be expected, in general, to operate at a capacity factor of 70 percent.[1]

Amortization. The cost of minor repairs and replacing of certain parts in a plant would be included in operation and maintenance. Major parts replacement and repairs are considered under the amortization of the plant. The annual amortization of the plant is assumed to be constant. Amortization is arrived at by dividing the total amount of initial capital and replacement cost of the parts by the number of years that the plant is expected to last. The life of the plant, as indicated by Duffie and Beckman,[2] is assumed to be 20 years. This has been accepted for use in this research.

Energy output and cost. As noted in Duffie and Beckman, the solar constant (the intensity of solar radiation outside of the earth at the mean distance between the earth and the sun) has been determined, by measurements

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[1]U.S., National Science Foundation, An Assessment of Solar Energy as a National Energy Resource, p. 50.

[2]Duffie and Beckman, p. 149.

from satellites and high altitude aircraft, to be 1,353 kilowatts per square meter per day.[1]

Further, Duffie and Beckman noted that in Madison, Wisconsin, on a clear January day, energy on a horizontal surface is typically 3 kilowatt hours per square meter per day, and on a July clear day, energy is typically 9 kilowatt hours per square meter per day. The average monthly energy of daily radiation on the horizontal surface is between 1.8 to 6.2 kilowatt hours per square meter per day. Flat plate collectors with slopes toward the south in Madison will have, on the average, a daily radiation of 3.4 kilowatt hours per square meter in January and 5.6 kilowatt hours per square meter in July. These data show the gains that can be obtained by using collectors.[2]

Hottel and Howard[3] have made a simple calculation of the cost of electricity produced by solar-operated steam engines. Assuming that steam is produced from a flat collector of glass, it was calculated that the optimum number of glass plates would be three to four, and the optimum temperature 240°F, the optimum thermodynamic efficiency 4 percent, with a yield of 15.5 kilowatt hours per square foot per year in El Paso, Texas.

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[1] Ibid., pp. 143-144.

[2] Ibid.

[3] H. C. Hottel and J. B. Howard, New Energy Technology, Some Facts and Assessments (Cambridge: Massachusetts Institute of Technology Press, 1974), p. 338.

Hottel and Howard noted further that,

> power could be produced for 1.3 cents per kwh if collector surfaces could be built for $2 per square foot. A study of solar energy patterns in other parts of the world (Lof, 1954) reached substantially the same conclusion as to costs of two cents per kwh if collectors cost $2.50 per square foot.[1]

An independent engineering re-estimate of the first of the proposals raised the projected cost several times.

Formulas Used in the Estimation of Costs of Power Plant and Production

To calculate the costs of electricity for geothermal, solar, and nuclear power, formulas have been applied to find the cost of electricity per kilowatt (kw), per kilowatt hour (kwh), and the capital investments for these three sources of energy. In the past, these formulas have been used for such things as the determination of the cost of water per cubic meter and the capital cost for water reservoirs.[2]

Total Capital Investment:

Total capital investment = C

- Land and construction costs;
- Equipment costs; and
- Fuel costs.

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[1]Ibid.

[2]Hooshang Ashraf, "The Relationship Between a Reservoir's Life and Sedimentation," Iranian Society of Engineers, October 1971, pp. 13-14. (In Persian.)

- Total Annual Costs:

  Total annual costs = TAC

  - Return on capital as rate of interest = C_r

    r = rate of interest

    $$\frac{C \times r}{100} = C_r.$$

  - Amortization = C_a

    $$\frac{\text{Capital}}{\text{Life of plant}} = \frac{C}{L} = C_a.$$

  - Operation and maintenance = C_{om}

    $$\frac{C \times OM}{100} = C_{om}.$$

- Total Annual Costs of Plant:

  $$C_r + C_{om} + C_a = TAC.$$

- Plant Factor:

  Plant factor = P_f, between 60 to 80 percent.

- Size of Plant:

  Size of plant = S_z.

- Total Energy Output:

  Total energy output = TEO

  $$\frac{S_z \times P_f}{100} = TEO.$$

- Total Cost Per Kilowatt:

  $$\frac{C_r + C_{om} + C_a}{TEO} = \frac{TAC}{TEO} = \text{cost per kilowatt.}$$

- Cost of Electricity per kwh:

$$\frac{8760 \times P_f}{100} = \text{annual energy output (AEO).}$$

$$\frac{kw}{AEO} = kwh.$$

Estimation of Costs of Solar Energy and Its Production

Complete cost data for a solar power plant designed for operation are not available. These estimates are based on existing data. The data have been obtained through these sources:

1. Land requirement for plant is 10 square miles.[1]
2. Size of plant is 1,000 MW.[2]
3. A plant factor equal to 70 percent capacity.[3]
4. The cost of solar collection parts, including energy storage is assumed to be $600 per kilowatt.[4]
5. The cost of a turbine generator unit and other power plant peripherals is assumed to be $150 per kilowatt.[5]

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[1]U.S., National Science Foundation, An Assessment of Solar Energy as a National Energy Resource, p. 48.

[2]Ibid.

[3]Ibid.

[4]Ibid., p. 50.

[5]Ibid.

6. The cost of land is assumed to be $1,000 per acre.[1]
7. Annual charge for operation and maintenance is assumed to be 12 percent.[2]
8. The rate of interest is assumed to be 10 percent per annum.[3]
9. The life of the plant would be assumed to be 20 years.[4]

Calculations of the capital cost of a solar power plant and the cost of electricity per kilowatt are as follows.

Total Capital Investment

Land requirement. The land needed for the plant is 10 square miles. Each square mile equals 640 acres. Then, 10 sqare miles x 640 square miles/acre = 6,400 acres or 26,000,000 square meters, the land requirement for plant.

Cost of land. The cost of land is assumed to be $1,000 per acre. Then, 6,400 acres x $1,000/acre = $6,400,000, the cost of the land for the power plant.

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[1]J. Richard Williams, Solar Energy Technology and Applications (Atlanta: Georgia Institute of Technology, 1974), p. 53.

[2]Duffie and Beckman, p. 149.

[3]Ibid.

[4]Ibid.

Equipment costs. The equipment cost of a solar plant includes the collector, storage, and turbine generator. Size of the plant is 1,000 MW (1,000,000 kw).

- 1,000,000 kw x $600/kw = $600,000,000, the cost of collection and storage.
- 1,000,000 kw x $150/kw = $150,000,000, the cost of turbine generator and other power plant needs.

Total capital investment. The total capital investment includes land, collector, and turbine generator. Therefore, the total investment for the plant is: $6,400,000 + $600,000,000 + $150,000,000 = $756,400,000.

Total Annual Costs

Interest. Return on capital at the 10 percent rate of interest is:

$$\frac{\$756{,}400{,}000 \times 10}{100} = \$75{,}640{,}000.$$

Amortization. The life of the plant is assumed to be 20 years; therefore, the amortization is:

$$\frac{\$756{,}400{,}000}{20} = \$37{,}820{,}000.$$

Operation and maintenance. Assumed to be 12 percent per annum, the operation and maintenance cost per year is:

$$\frac{\$756{,}400{,}000 \times 12}{100} = \$90{,}768{,}000.$$

Total Annual Cost of the Plant

The total annual cost of the plant includes the total interest, amortization, operation, and maintenance. Therefore, the total annual cost of the plant is: $75,640,000 + $37,820,000 + $90,678,000 = $204,138,000.

Production Output

If plant efficiency were 100 percent, then the electrical production of the plant would be 1,000,000 kilowatts of electricity. Since that is an impossible assumption to make, the plant factor must be used.

Plant factor. Rate of the plant factor for the solar plant is assumed to be 70 percent of total production. Then the net power production is:

$$\frac{1{,}000{,}000 \text{ kw} \times 70}{100} = \underline{700{,}000} \text{ kw.}$$

Total Annual Cost per Kilowatt

Total annual cost of solar energy per kilowatt would be:

$$\frac{\$204{,}138{,}000}{700{,}000 \text{ kw}} = \underline{\$291.62/\text{kw}}.$$

According to Fisher,[1] the annual capital cost for electric generation by solar steam has been estimated at $210 per kilowatt in the year 2000.

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[1]John C. Fisher, Energy Crisis in Perspective (New York: John Wiles and Son, 1974), p. 135.

Cost of Electricity per Kilowatt Hour (kwh)

Working hours of the plant:

- 365 days/year x 24 hours/day = 8,760 hours/year.
- Plant factor assumed to be 70 percent.
- Therefore, the number of total working hours per year is:

$$\frac{8{,}760 \times 70}{100} = \underline{6{,}132}.$$

Cost of electricity per kwh:

$$\frac{\$291.62 \times 100}{6{,}132} = \underline{4.75} \text{ cents per kilowatt hour (kwh).}$$

According to Retail Prices and Indexes of Fuel and Utilities Residential Usage,[1] the cost of 100 kwh of electricity in September 1976 for New York City was $10.45; for Buffalo, $7.54; and for San Francisco-Oakland, $4.48. For example, converting the costs to cents per kilowatt hour, the cost of one kilowatt hour of electricity in San Francisco would be 4.48 cents. This indicates that the cost of electricity from solar energy is almost equal to that of San Francisco.

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[1]U.S., Department of Labor, Bureau of Labor Statistics, Retail Prices and Indexes of Fuels and Utilities Residential Usage (Washington, D.C.: Government Printing Office, 1976), p. 4.

Economics of Geothermal Power Plants

The main purposes in developing geothermal power are not only to provide for the energy needs of an area but, at the same time, to produce new sources of energy cheaply. In order to be able to use geothermal energy, it must compete successfully with other alternative sources of energy such as petroleum, nuclear, natural gas, etc.

A geothermal power plant may need more capital investment than fossil fuel power plants. However, the cost of obtaining the energy is not higher than fossil fuel plants.

Basically, the price of geothermal energy depends on the costs of production and transportation. These costs are mainly related to the required expenditure on production, transportation facilities, the physical life of the plant, and operation and maintenance.

The capital investment needed for the production facilities is, of course, related to the physical location, as well as the amount of reserves, and pipeline facilities. Scale of development planned, labor, and material costs will also affect capital investment.

Capital investment for transportation depends on the location of the plant with respect to consumers and the distance from the wellhead.

In geothermal energy development, the largest factor in capital investment is for exploration, drilling, collection and pipelines, and wellhead equipment.

Cost Components

The cost components of geothermal power plants are related to the physical life of the facility and depreciation. These form an important part of the costs of production and transportation. Construction, drilling exploitation technology, intensity of operation, productivity of reserves and labor are all related to various elements of the cost components. In the case of geothermal energy consumed directly, there is only one stage of production and, also, one stage of transmission. The cost components of geothermal energy are divided among these stages.

The fixed cost component contains charges on capital investment, depreciation and, also, the fixed portion of operation and maintenance. Operating costs include such elements as fuel cost and portions of operation and maintenance costs involving the running of the plant. From the preceding, it can be seen that all the cost components are related with the production of the geothermal power plant.

Capital Costs

Capital costs of geothermal plants vary from place to place. They depend on the geothermal situation, as well as the number of wells, depth of wells, drilling cost, collection and pipework costs involved in developing the field. In addition to these large investment requirements, the total capital interest paid during the period of construction of the plant must be considered because the development of geothermal energy involves a long time.

The capital costs of producing geothermal energy include the following.

Exploration costs. The total cost of exploration programs varies greatly, depending upon geographic, economic and other factors such as the length of time before reserves are discovered. In addition, there are different stages in geothermal exploration. Each stage may involve different techniques and, therefore, changing unit costs. For these reasons, it is difficult to obtain very representative figures on exploration costs. However, it is very important before exploration begins to consider such factors as the economic costs of exploration and to attempt to estimate their unit costs.

The first step in any exploration program is to evaluate available geological surveys. These geological surveys will include the potential plant location, amount of reserves, kind of reserves, geological structure, drilling situation, number of necessary wells, and the size of plant related to the production of the wells. If the data doesn't exist already, it will have to be collected.

As mentioned previously, costs of exploration vary with location. However, an average of geothermal exploration projects in the Middle East, Latin America, and the Far East indicates the average cost of geothermal exploration to be $3,000,000 for 50 bores.[1] By division, the exploration costs may be expressed as $60,000 per bore. This amount will be used in this research.

Drilling costs. Drilling costs vary directly with the geological structure of the area. Of course, geological structures differ with each location. The geological problems presented by differing locations may be simple or difficult. This will influence the cost and amount of time required for drilling.

According to United Nations figures,[2] for a total drilling operation of 500 meters in depth, each meter costs $105; for 1,000 meters in depth, the drilling cost for each

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[1]H. Christopher H. Armstead, "Geothermal Economics," Geothermal Energy, Review of Research and Development (Paris: UNESCO, 1973), p. 163.

[2]United Nations, Department of Economic and Social Affairs, "The Economics of Geothermal Power," Natural Resources Forum, 1971, p. 47.

meter is \$98; and, for 1,500 meters depth, each meter would be \$90. By averaging these figures, the cost for each meter depth would be approximately \$100. These figures were estimated by drilling operations in New Zealand and California. The wide differences in costs indicated above are due not only to the differences in depth and well diameters but also to the geological structure, location, and other conditions encountered.

The figure of \$100 will be used in this research as the cost of the drilling of one meter depth in average geological structural conditions.

Collection pipework and other equipment costs. One of the most important factors in geothermal power plants is the collection pipework and other necessary equipment. When the natural steam or hot water is brought to the surface, it usually has to be piped over some distance to the point of either consumer use or power generation.

Collection pipework and wellhead equipment are the largest factors in the capital investment required of geothermal plants. The capital cost of wellhead and collector pipework is related to the distance and what the final use of geothermal reserves will be. As the distance increases, the capital cost of pipework will increase.

The production of geothermal fields is transported by pipelines. Most of the cost of transportation arises

from capital charges and fixed operating costs. In a producing field, the lines just from the wellhead to the gathering center may be pipelines of considerable diameter and length. In spite of the costs, pipeline transport still is the only practical way of moving geothermal production to the market.

One of the essential factors in the cost of transporting geothermal energy by pipeline is the load factor. The flow through a pipeline is not always regular because demand changes. To reduce transport costs, the pipeline should be operated at its maximum capacity.

As was mentioned previously, local geographical conditions and distances are a major factor in determining the scale of operations, the pipe and equipment used, and the capital investment required. Again, estimating any of these figures is very difficult because they will vary from field to field.

For the estimation of pipeline costs, the mean distance from the bore to the point of delivery must be calculated. Next, the number of bores and the total quantity of fluid carried out must be determined. The calculation is as follows:

cost of pipelines = number of wells x number of pipes x number of meters x cost per meter.

In this equation, a very important factor is the amount of fluid that is carried out by pipes. The amount of fluid is related to both the diameter of the pipeline and the size of the installed plant. Armstead[1] estimated for pipework of 20 inches internal diameter a cost of $120 per foot or almost $400 per meter to supply and erect it.

The average length of pipeline for each geothermal well varies depending on the distance from each well. For this research, an average of one mile or 1,600 meters has been assumed based on Armstead's estimates.[2]

Another important factor in geothermal energy transportation is wellhead equipment. This is used to direct the hot water or steam of the geothermal well to the pipelines. Wellhead equipment is one of the larger parts of the capital investment.

Cost of wellhead equipment varies with the number of wells. As the number of wells increase, the quantity of wellhead equipment will increase also. According to Armstead,[3] the cost of wellhead equipment for each individual well is about $35,000 per bore. This figure will be used in this research.

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[1]Armstead, p. 163.

[2]Ibid.

[3]Ibid.

Rate of interest and plant factor. The rate of interest is variable in different times and countries. In addition, it usually varies and is related to the kind of plant. For the purpose of the following calculations, a 10 percent rate of interest is assumed.

The plant factor, as the efficiency of the power plant, is assumed to be 80 percent. Armstead[1] noted 85 percent as a conservative figure for the geothermal plant factor. A more conservative figure of 80 percent was selected for this research, however.

Amortization. Amortization is the gradual transformation of capital investment into liquid funds. The cost of major repairs and total replacement of equipment are included here.

The annual amortization charge can be considered constant. It is arrived at by dividing the total amount of initial capital investment, or the replacement cost by the number of years that the equipment is expected to last. The annual charge should be enough to replace the capital which was originally invested by the end of the plant's lifetime.

In principle, capital investment should be amortized over a period equal to the economic life of the plant. Based upon experience in Italy and New Zealand, the

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[1]Ibid., p. 171.

estimated economic life of a geothermal plant is 25 years.[1] Therefore, it would be accurate to assume the capital investment and costs will be amortized over a period of 25 years.

Operation and maintenance. Operating charges depend on the technology used, intensity of operation, productivity, and cost of labor. Maintenance charges depend on durability of facilities, intensity of use, and technical know-how for proper operation and maintenance. The cost of the frequent replacement of certain parts and minor repairs is generally included in operation costs. A plant requires periodic attention to keep it running; thus, there are running costs for repairs and maintenance. Other costs such as fuel, wages, salaries, administration, interest, rents, and insurance, which keep the plant in a state of availability are also included. These costs all vary from plant to plant. They represent an important item in capital costs.

A figure of 2 percent per year of capital investment is assumed for this research. The figure includes repairs of pipeline work, wellhead equipment, and pumping equipment. A figure of 2 percent also per annum for routine expenses of operation such as wages and salaries is assumed.

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[1]Ibid., p. 164.

As indicated by Armstead,

> an allowance of 2% per annum would be a reasonable figure for covering attendance and the repairs and maintenance of wellhead equipment, pumping pipework and control equipment and instrumentation. . . . A similar allowance of 2% per annum would be reasonable for repairing mishaps and for routine inspection of bores.[1]

In some cases, some additional amount is required for management of the installation. Usually this amount would be between 5 to 10 percent per annum but this amount is not being considered in this research.

Energy Output, the Cost of Electricity, and Plant Size

The average cost of producing any commodity is usually determined by dividing the total cost to produce it by the quantity produced. In the earlier part of this research, an attempt was made to present a general idea of the capital required to undertake a geothermal power plant. The objective of this section is to determine the unit cost of electricity produced from each geothermal well, individually and as a total.

Power plant sources must be capable of supplying the quantity of power required when needed. In addition, power plant size must be economical, reliable, and capable of maintaining the voltage levels at the point of economic production. Potential power sources should be evaluated

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[1] Ibid.

according to the cost of the power unit produced and the availability where and when needed.

The following are the major items that must be considered in power production: cost of power, quality of power, reliability and availability of power. The size of the plant must be selected within the frame of the local situation, resource availability, and economic production of the plant, with efficiency of the plant and cost returns also considered.

Estimation of Costs of Geothermal Energy and Its Production

Appropriate data for geothermal plants are not available. For this research, the following data have been obtained through the following sources:

1. The average capacity of each well is assumed to be 8 MW.[1]
2. The average exploration costs per well are assumed to be $60,000.[2]
3. The average depth of each well is assumed to be 3,177 feet.[3]
4. Drilling costs are assumed to be $30 per foot.[4]

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[1]Bowen and Groh, p. 46.

[2]Armstead, p. 163.

[3]Ibid.

[4]Ibid.

5. The length of pipeline for each well is assumed to be one mile.[1]
6. The cost of the collector and pipeline is assumed to be $120.[2]
7. The costs of wellhead equipment and steam collection are assumed to be $35,000/well and $264,000, respectively.[3]
8. The rate of interest and operation and maintenance are assumed to be 10 percent and 4 percent, respectively.[4]

From a practical point of view, the most significant element is the cost per kilowatt of geothermal electricity produced. Based on actual experience, and on the conditions assumed, the capital cost per kilowatt of electricity production decreases with the increased size of power plants and the number of wells.

A geothermal plant producing 400 megawatts of electricity has been selected for the reasons given earlier. According to Bowen and Groh,[5] the average capacity for each

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[1]Ibid.

[2]Ibid.

[3]Ibid.

[4]Ibid., p. 164.

[5]Bowen and Groh, p. 46.

well is 8 MW or 8,000 kw. To obtain 400 MW of electricity approximately 50 wells are needed.

Size of the plant. Knowing that 50 wells are needed, then the size of the plant is:

50 wells x 8 MW/well = 400 MW.

Capital Investment

Capital investment includes such things as the following.

Exploration costs. Total cost of exploration for 50 wells bore is:

50 wells x $60,000/well = $3,000,000.

Drilling costs. The number of wells equals 50 bore. Average depth is assumed to be 3,177 feet or approximately 1,000 meters. Cost of drilling was given as $30 per foot or approximately $100 per meter, so drilling costs would be:

1,000 meters x $100/meter = $100,000/well and

50 wells x $100,000/well = $5,000,000 total drilling costs.

Equipment costs. Equipment costs include collector and pipeline costs, steam transmission costs, and wellhead equipment.

- Collector and pipeline costs: The average length of pipelines needed per well is assumed to be one mile or 1,600 meters. Cost of the pipelines per meter was given as $400. Therefore, total cost is:

1,600 meters x \$400/meter = \$640,000 cost per well.

50 wells x \$640,000/well = \$32,000,000 total cost.

- Steam transmission costs: Assumed to be \$264,000/bore, total cost of transmission pipe is: 50 wells x \$264,000/well = \$13,200,000.
- Wellhead equipment: Assumed to be \$35,000/bore, total cost of wellhead equipment for 50 wells is: 50 wells x \$35,000/well = \$1,750,000.

Total Annual Costs

Interest. Return on capital at a 10 percent rate of interest makes the total interest:

$$\frac{\$54{,}950{,}000 \times 10}{100} = \$5{,}495{,}000.$$

Amortization. Life of the plant is assumed to be 25 years. Therefore, annual amortization is:

$$\frac{\$54{,}950{,}000}{25} = \$2{,}198{,}000.$$

Operation and maintenance. A 4 percent rate is assumed (2 percent for wages and salaries; 2 percent for repairs/replacements). Therefore, the operation and maintenance totals are:

$$\frac{\$54{,}950{,}000 \times 2}{100} = \$1{,}099{,}000 \text{ total operation, and}$$

$$\frac{\$54{,}950{,}000 \times 2}{100} = \$1{,}099{,}000 \text{ total maintenance.}$$

Total Annual Costs of the Plant

Including interest, amortization, operation, and maintenance, the total annual cost of the plant is: $5,495,000 + $2,198,000 + $1,099,000 + $1,099,000 = <u>$9,891,000</u>.

Total Energy Output

If our plant efficiency is assumed to be 100 percent, then the electrical production of the plant would be 400,000 kw of electricity. As indicated earlier, plant efficiency is less than that. This efficiency is called the plant factor.

<u>Plant factor</u>. The plant factor is assumed to be 80 percent of the total production as noted earlier. Therefore,

$$\frac{400{,}000 \text{ kw} \times 80}{100} = \underline{320{,}000} \text{ kw is the total energy output.}$$

Total Annual Cost of Geothermal Production per kw

$$\frac{\$9{,}891{,}000}{320{,}000 \text{ kw}} = \underline{\$30.10} \text{ cost per kw of geothermal production.}$$[1]

[1]Compared with $25.34 per kw for 200 MW power plant as indicated by <u>Geothermal Energy</u>, p. 171.

Cost per Kilowatt Hour (kwh)

To obtain the cost per kilowatt hour, first the number of hours the power plant is working must be found. If it is assumed that the power plant will be operated 24 hours per day for 365 days, then,

365 days x 24 hours/day = 8,760 hours/year.

Usually it is impossible for a plant to work for 24 hours a day continuously; breakdowns, etc., will occur. If it is assumed the power plant works at the rate of 80 percent of the year (the plant factor), then,

$$\frac{8,760 \text{ hours/year} \times 80}{100} = 7,008 \text{ hours per year.}$$

Cost per kwh (in cents) would be:

$$\frac{\$31,10/\text{kw} \times 100}{7,008 \text{ hrs/yr}} = \underline{0.43 \text{ cents/kwh}}.$$

This compares with the Retail Prices and Indexes of Fuels and Utilities Residential Usage[1] which quotes the cost of one kwh of electricity from fossil fuel in San Francisco to be 4.48 cents.

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[1]U.S., Department of Labor, Retail Prices and Indexes of Fuels and Utilities Residential Usage, p. 4.

Economics of Nuclear Power Plants

There are different opinions as to when nuclear energy will become an economic power source for some countries in the world. Today, the harnessing of atomic energy has become a reality in several countries. Nuclear power stations with a capacity of more than one million kilowatts are now in operation.

Nuclear power utilization for most advanced countries in the world is concerned not only with the supply of electricity but also with building up a technologically advanced industry with the capacity to make and supply nuclear plants to foreign countries.

In the past, nuclear power, due to the cost of generation, was not able to compete with other forms of energy. However, today it is able to compete successfully with conventional thermal power plants. The reason lies partially in the increased price of oil. In 1973, crude oil was less than $3 per barrel. Less than a year later, the price had increased by 400% to $12 per barrel.

According to the International Atomic Energy Agency,

> estimated nuclear power plant investment costs expressed in constant dollars have increased over the last five years by 60% to 115%. Estimated capital costs of fossil fuel stations have also increased over the same period at rates which, on the average, are only marginally lower than those applying to nuclear stations.[1]

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[1]Rurik Krymm, "A New Look at Nuclear Power Costs," International Atomic Energy Agency Bulletin 18(2), (1976): 7.

If the price of fossil fuel continues to increase, the cost of power generation using nuclear power will become comparable to the cost of energy generated by conventional power stations.

Nuclear power plants have a higher capital cost than other thermal plants. However, the unit costs decrease with increases in the size of the plant. Nuclear plants of different sizes will compete differently with conventional thermal plants in various areas. The major element in the production of nuclear power plants is the availability and cost of the fuel.

As noted earlier, capital costs of fossil fuel, which depend on the size and condition of the plant, have increased. This has effectively decreased the gap between heavy capital investments required for nuclear power and fossil fuels.

Krymm notes:

> The approximate range of unit capital cost differentials between nuclear and coal appears to be $40 to $110 kw (e), and that between nuclear and oil $100 to $200 of mid-1974 purchasing power. To be conservative, the maximum differences of $110 against coal and $200 against oil might be retained as a general guide line.[1]

The utilization of nuclear power involves some particular scientific and technical problems. These include high capital investment, technology, safety, and

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[1]Ibid.

waste control. Success in solving these problems will lead to an increase in the use of nuclear reactors.

In any case, it must be recognized that with the rapid rate of increase in the demand for energy, petroleum resources will soon be exhausted. The capacity of other conventional thermal power plants will also reach an optimum limit, depending upon the maximum rate of exploration for fossil fuels. Unless some other discoveries are made, the world will have to be dependent, to a large extent, on nuclear energy.

Major Elements in Capital Cost

The major elements in the capital costs of nuclear power are the costs of uranium and thorium for nuclear power fuels. Another major element is the available supply of uranium resources. In addition, the geographical distribution of reserves, quality of deposits available, exploration costs, mining, processing, and enrichment costs must be considered. Transportation, operation, and maintenance are also important elements in the capital investment in nuclear power plants. The actual cost of planning and construction of the nuclear station are other important determinants of capital investment.

These elements and utilization of the power are the controlling factors that determine the amount of power plant

generating capacity required and production costs. These costs are described below.

Size and kind of power reactor. There is no doubt, at present, that it is technically feasible to build power reactors, including boiling water reactors, nonboiling water reactors, gas-cooled reactors, heavy water reactors, and light water reactors to use for the generation of electricity. This research will deal with nuclear power reactors that have been actually built in some countries. Light water reactors are good as they reduce capital and fuel costs.

According to Energy R & D,

> new nuclear electricity generating capacity to be introduced in the next ten years will mainly involve reactor types which already exist: principally light water reactors (LWR). These will account for 90 percent of installed nuclear capacity in 1980.[1]

In addition, Energy R & D[2] indicated that from 1972 on, electricity generated by power plants using light water reactors was competitive with that generated from other sources.

The size of plant usually depends on availability of resources, needs, and technology. In this research a medium size 400 MW nuclear plant was selected. This can

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[1]Organization for Economic Cooperation and Development, Energy R & D (Paris: Organization for Economic Cooperation and Development, 1975), p. 51.

[2]Ibid., p. 54.

be used either in industrial countries or nonindustrialized ones.

As stated by the International Atomic Energy Agency,[1] "in the range of 150 to 400 MWe (i.e., small and medium power reactors), there might be a market for 140 nuclear power plants which would, by 1990, represent around 38,000 MWe." Thus, an increased market for 400 MW reactors is indicated.

In addition, Iran for her nuclear power plant has selected a 400 MW reactor scheduled for commercial operation in 1981.[2]

Fuel costs. Fuel costs are one of the most important factors in the development of nuclear power and its production. There are a number of elements and conditions which are related to the reactor fuel costs that must be considered. If the fuel has to be bought, its cost and capitalization must be considered.

Uranium is the basic nuclear power fuel because it contains uranium 235. As indicated by the U.S. Atomic Energy Commission,[3] the natural concentration of uranium

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[1]Andre Polliart and Eli Goodman, "Prospects for Utilization of Nuclear Power in Africa," International Atomic Energy Agency Bulletin, February 1976, p. 40.

[2]U.S., Atomic Energy Commission, Nuclear Power Growth, 1974-2000, p. 70.

[3]U.S., Atomic Energy Commission, Nuclear Fuel Supply, p. 2.

235 in uranium is 0.7 percent, the remaining 99.3 percent of natural uranium is isotope uranium 238. The uranium used in light water reactors must be enriched in isotope U_{235} from its natural content of 0.7 percent to about 3 percent.[1]

A typical light water reactor of 1,000 MW electric capacity needs enriched uranium (uranium oxide, U_3O_8) produced in quantities between 550 and 625 tons for the initial loading and about 200 tons per year for refueling. Power plants normally have an operation life of 30 years.[2]

The cost of uranium has increased recently from $6 to $8 per pound in the past to $20 per pound presently.[3] The enrichment cost of uranium, as noted by the International Atomic Energy Agency, in mid-1974 was between $80 and $120 per kilogram maximum with adjustments to keep up with general inflation.[4] It was further stated that the fuel fabrication costs are now between $120 and $150 per kg of fabrication fuel.[5]

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[1]Ibid.

[2]Ibid.

[3]Krymm, p. 9.

[4]Ibid.

[5]Ibid.

Fuel storage costs have been estimated at \$10/kg per year. Fuel transport is between \$20 to \$35/kg uranium in 1975 value.[1]

Operation and maintenance. The safety and precautions required in nuclear power stations cause higher operation and maintenance costs than in conventional plants of similar output. The major operation and maintenance costs involve engineering difficulties which include shielding, design, life of fuel elements, and wastes.

Operation charges are to include labor, maintenance and supplies, operating fuel, fuel replacement fabrication, and processing. The salaries and wages involved in the actual operation of the generating station can be said to be constant because once the mining is fixed, there is little change from day to day.

Running costs include fuel handling. Fixed costs involve operation, repairs, maintenance, rent, insurance, administration, general interest, and depreciation.

Rate of interest and plant factor. The rate of interest varies with time, place, and the kind of plant. In this research, the rate of interest is assumed to be 10 percent per annum of capital investment.

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[1] R. B. Fitts and H. Fujii, "Fuel Cycle Demand, Supply and Cost Trends," International Atomic Energy Agency Bulletin, February 1976, pp. 22-23.

According to the U.S. Atomic Energy Commission, "the plant factor is expressed as a percentage and is the actual power produced during a period by a plant divided by the power it would have produced had it operated continuously at full capacity . . . a value of 80% is often used. . . ."[1] The figure of 80 percent will be used for the plant factor in this research.

Amortization. Depreciation charges are to be assigned by dividing the plant into four components such as the reactor, power plant, chemical plant, and building. These elements have different life times. As noted earlier, the life of the plant for nuclear power is given 30 years. The rate of depreciation would be based upon 30 years life for all parts of the plant.

Energy output and cost. The cost of producing electricity is considered in relation to these categories: capital costs, fuel costs, and operation and maintenance costs. This is convenient for studying investment costs per kilowatt.

For any given factor, cost per unit of power output decreases as the quantity of electricity production increases. The capital investment for nuclear power plants is higher per kilowatt of capacity in small rather than large capacity plants.

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[1]U.S., Atomic Energy Commission, The Growth of Nuclear Power, 1972-1985, p. 9.

Several key economic questions must be considered in studying the use of nuclear plants for power production and energy output costs. One of these is the question of determining what it costs to produce power in nuclear power plants. The second question concerns the suitability of nuclear power for the type of market. The first question will be answered in the following pages. The second question was answered in earlier pages.

Estimation of Costs of Nuclear Energy and Its Production

Appropriate data for nuclear power plants designed for operation, at the size of our assumption, are not available. The calculations of this research are based on existing data obtained through the following sources:

1. Figures to obtain approximate capital costs.[1]
2. Size of the plant and kind of power plant.[2]
3. Fuel supply and costs.[3]
4. Fuel storage and transportation.[4]

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[1]Krymm, pp. 4-5.

[2]Organization for Economic Cooperation and Development, Energy R & D, pp. 51, 54; Polliart and Goodman, p. 40; and John C. Fisher, pp. 135-137.

[3]U.S., Atomic Energy Commission, Nuclear Fuel Supply, p. 2; and Krymm, p. 9.

[4]Fitts and Fujii, pp. 22-23.

5. Rate of interest, operation, and maintenance costs.[1]

6. Life of the plant.[2]

As noted earlier, the use of light water reactors is expected to increase in the future. In addition, they also reduce capital and fuel costs. For these reasons, a light water reactor was selected to base the calculation of this research upon.

The International Atomic Energy Agency gives the following estimates of capital costs for LWR stations in the 1,000 MWe size range (expressed in current U.S. dollars, including escalation):[3]

Date of estimate	1972	1973	1974
Date of operation	1977	1977	1983
Unit capital cost (current $ per kw[e])	$350	$440	$720

The rapid increase in costs for different years is apparent. The reasons lie in the inflation rate, rate of interest, better safety measures, increased costs of manufacturing, etc. The impact of these factors on total capital costs is obvious from the above.

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[1]U.S., Atomic Energy Commission, The Growth of Nuclear Power, 1972-1985, p. 9.

[2]U.S., Atomic Energy Commission, Nuclear Fuel Supply, p. 2.

[3]Krymm, pp. 4-5.

The sum of $720 capital costs of the plant per kw include construction costs, safety and environmental costs, indirect construction costs, and the cost of interest during the one year period of construction.[1]

Fisher estimated the capital cost of nuclear power to be $280 per kw in the early 1970s.[2] It is evident that nuclear power is still in the early stages of development. Therefore, important cost reductions are still in evidence and more are possible as a result of technical advances based upon present research and development efforts. Although the costs of uranium may increase in the future, it is possible that there will be reductions in fuel cycle costs. Also, the costs of using other energy sources such as oil, may rise faster than those using nuclear power.

It is not possible, at the present time, to select any one type of reactor as most suitable in all circumstances for use in less industrialized countries. In addition, no existing reactor type can be considered to be so developed and tested that it can be safely recommended for immediate use for electric power production.

For this research, a medium-size light water reactor will be used. This size reactor can be applied to both industrialized and nonindustrialized countries. Cost

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[1]Ibid., p. 6.

[2]John C. Fisher, pp. 135-137.

data are based on the current status of a light water reactor of 400 MW.

Because of nonavailability of data on the real capital costs for nuclear power plants, the mean of previously cited estimates must be taken. Then, the average capital cost of nuclear power per kilowatt can be estimated. A figure of $447.50 is obtained by averaging the Fisher and International Atomic Energy Agency estimates of $280, $350, $440, and $720. For ease of calculation, $450 will be used as the capital cost per kw.

Capital Investment

Construction costs. Assuming a 400,000 kw plant at $450/kw cost, the capital cost of the nuclear plant would be:

400,000 kw x $450/kw = $180,000,000.

Fuel costs. The fuel cost of the plant has four stages: natural uranium; enrichment; fabrication processes; and storage and transportation. As indicated earlier, the fuel cycle requires between 550 and 625 tons of uranium for the initial loading of a 1,000 MW plant. For a plant with a 400 MW size, the initial loading is assumed to require 300 tons. Further, approximately 80 tons of uranium would be needed per year based on the requirements of 200 tons per year for a 1,000 MW plant, which was mentioned previously.

Then, the amount of uranium needed per year would be 80 tons. Thus, the amount of uranium needed for 30 years would be:

30 years (life of plant) x 80 tons = 2,400 tons.

Therefore, with the initial loading, the total uranium needed for the plant would be:

2,400 tons + 300 tons = 2,700 tons.

Conversion to kilograms and then to pounds would be:

2,700 tons x 1,000 kg = 2,700,000 kg.

2,700,000 kg x 2.2 lbs./kg = 5,940,000 lbs.

- Natural uranium costs: As noted earlier, the cost of natural uranium is between \$20 and \$30 per pound. The average would be \$25/lb. Therefore, the total cost of natural uranium would be:

  5,940,000 lb. x \$25/lb. = \$148,500,000.

- Enrichment cost: Uranium used in light water reactors must be enriched in the isotope of U_{235} from a natural content of 0.7 percent to 3 percent. As noted earlier, the cost of enrichment is between \$80 and \$120/kg. The average would be \$100/kg. Therefore, the total cost of enriched uranium for the plant would be:

  2,700,000 kg x \$100/kg = \$270,000,000.

- Fabrication cost: Another stage in the fuel cycle is fuel fabrication. Its cost was previously noted as between $120 and $150/kg. The average cost would be $135/kg. Therefore, the total cost of fabrication would be:

  2,700,000 kg x $135/kg = $364,500,000.

- Storage and transportation cost: Cost of storage, as mentioned earlier, is $10/kg. Transportation costs are between $20 and $35/kg of uranium. The average of this cost would be $28/kg. Therefore, the cost of storage and transportation per kilogram would be:

  $28 + $10 = $38/kg.

  Therefore, the total cost of storage and transportation would be:

  2,700,000 kg x $38/kg = $102,600,000.

Total Capital Investment

Total capital investment for the plant would include construction and fuel costs. Then, the total capital investment for the power plant would be:

$180,000,000 + $148,500,000 + $270,000,000 +

$364,500,000 + $102,600,000 = $1,065,600,000.

Total Annual Costs of the Plant

Interest. Return on capital at a 10 percent rate of interest would be:

$$\frac{\$1,065,600,000 \times 10}{100} = \underline{\$106,560,000}.$$

Amortization. Life of the plant is 30 years, so amortization would be:

$$\frac{\$1,065,600,000}{30 \text{ years}} = \underline{\$35,520,000}.$$

Operation and maintenance. Assumed to be 4 percent, the total cost of operation and maintenance would be:

$$\frac{\$1,065,600,000 \times 4}{100} = \underline{\$42,624,400}.$$

Total annual cost. Total annual cost of the plant includes total interest, amortization, and operation and maintenance. Therefore, the total annual cost of the plant would be:

$$\$106,560,000 + \$35,520,000 + \$42,624,000 = \underline{\$184,704,000}.$$

Total Energy Output

If efficiency of the power plant were 100 percent, then the total output of the plant would be 400,000 kw of electricity. However, efficiency is not 100 percent. Therefore, the plant factor must be used. The plant factor was given as 80 percent, so the net power production would be:

$$\frac{400,000 \text{ kw} \times 80}{100} = \underline{320,000 \text{ kw}}.$$

Total Cost per Kilowatt

The total cost of nuclear power per kilowatt of electricity would be:

$$\frac{\$184{,}704{,}000}{320{,}000 \text{ kw}} = \underline{\$577.20}.$$

Cost of Energy per Kilowatt Hour (kwh)

Operating 24 hours/day for 365 days, a plant would work 8,760 hours/year. However, a plant will not be able to work at peak efficiency each day of the year. Assuming a plant factor of 80 percent for the year, then the work hours per year would be:

$$\frac{8{,}760 \times 80}{100} = 7{,}008 \text{ work hours per year.}$$

The cost of electricity per kwh would be:

$$\$577.20 \times 100 \text{ cents/dollar} = 57{,}720 \text{ cents}$$

$$\frac{57{,}720 \text{ cents}}{7{,}008 \text{ hours}} = \underline{8.236 \text{ cents}}.$$

This compares with the cost per kilowatt hour of electricity from fossil fuel in New York City of 10.45 cents, for Buffalo of 7.54 cents, and for San Francisco-Oakland of 4.48 cents. These costs were for September 1976.[1]

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[1]U.S., Department of Labor, Retail Prices and Indexes of Fuels and Utilities Residential Usage, p. 4.

CHAPTER IV

ENERGY RESOURCES, RESERVES, AND CONSUMPTION IN IRAN

Geography

Iran is slightly smaller than Mexico and about one-fifth the size of the United States. It is approximately 636,294 square miles or 1,648,000 square kilometers in area, roughly the combined size of Nevada, New Mexico, Arizona, Utah, Colorado, and Wyoming. It is between 25 degrees and 40 degrees north latitude. The Iranian state today is bounded on the west by Iraq and Turkey, on the north by the Caspian Sea and the Soviet Union, and on the south by the Gulf of Oman and the Persian Gulf. Iran is in the western half of the Iranian Plateau, which is between three and five thousand feet above sea level.

Topographically, the country consists of a narrow stretch of plain bordering the Caspian Sea, flanked by the Alborz and Zagros mountain ranges, which extend in a southwesterly direction along the Persian Gulf. The southern portion of these ranges contains many salt domes which adversely affect the surface and underground water of the area.

Two great deserts, the Dashte-Lut and the Dashte Kavir, occupy a large part of the central plateau, and together account for one-half of the desert area and one-sixth of the total area of Iran. These deserts are the most arid in the world, and while an occasional oasis may be found in the Kavir, the Lut is totally barren, supporting no life whatsoever.

The climate of the southern Iranian coast is hot and arid, with only occasional rainfall. In many years, there is none at all. Snow in the higher elevations of the southern Zagros and Makran ranges about 4,000 ft. (1,220 meters) is the source of water for the irrigation systems in the plains.

Population

The first census indicated the population of Iran in 1956 was 20,380,000. The second census in 1966 determined the population to be 27,070,000.[1]

The latest estimate indicates the population of Iran to be 31.5 million (1973 estimate)[2] with a 3 percent annual growth, mainly concentrated in the north and west. Less

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[1]Government of Iran, Plan Organization Iranian Statistical Center, National Census of Population and Housing, vol. 168, November 1966 (Teheran: Government of Iran, 1966), p. 17.

[2]Overseas Business Report, OBR 74-34 (August 1974), p. 2.

than one-third of the population live in urban areas. Average population density per square mile is 24.

About 10 million people or 43 percent are in agriculture; followed by services with 25 percent; industries, mines, and handicrafts with 21 percent; and construction with 8 percent. Women comprise only 14.3 percent of the labor force.

The Iranian government hopes to lower the population growth rate to 2.4 percent by the end of the Fifth Five-Year Plan in 1978. In contrast to many of its Asian neighbors, Iran still has a low overall population density. As the population grows, it is becoming urbanized at the rate of about 7 percent annually, so that urban population doubles in only 11 years.

Energy and Economic Development in Iran

The process of urbanization in Iran has progressed rapidly and resulted in an unparalleled expansion of industry and subsidiary services. These developments have played a major role in the growth of direct and indirect demand for energy, especially for electricity. Since these developments in Iran have involved heavy investments of social capital per worker, the average productivity for all capital has declined.

Most investments in social capital, however, improve the general level of productivity over the long term, particularly after their indirect effects become manifest. This is true with energy. Facilities for providing new supplies of energy should, therefore, be provided before the demand for energy arises.

The availability of energy is of decisive importance for economic development. Before new investment in the remaining sectors can acquire any economic meaning, it is nearly always necessary to have a supply of energy. If, conversely, investment in the energy sector lags behind, many production sectors will remain partially idle. Therefore, one of the conditions for economic growth is the availability of reserve capacity in the energy sector.

The amount of energy consumed in the production process per worker can give a first indication of the degree of economic development in Iran.

The consumption of energy trends, as a factor of production, are growing at a relatively rapid rate in the intermediate stages of economic development in Iran. For example, the total energy generation by utilities and self-generating industries has maintained a steady growth from 7,139 million kwh in 1970 to 9,750 million kwh in

1972. This represents an average annual increase of 16.8 percent.[1]

Among the main causes of this greater demand for energy is the way in which techniques infiltrate the economy by the joint use of new and technically obsolete equipment, causing lower efficiency in the use of energy when compared with economies making use of more up-to-date and homogeneous techniques. The growth of industrialization involves the introduction of activities with a relatively greater consumption of energy per unit of product.

The oil revenues are the most spectacular, although not the only encouraging element in the favorable long-run economic prospects in Iran. However, experience shows that the rate at which oil revenues accrue is far greater than the rate at which some oil exporting countries can use them effectively for development. In some of the countries, the revenues even outstrip the total foreseeable potentialities of development.

Substantial revenues from oil in the form of direct payments by petroleum companies to the Iranian government are determined by the terms of the concessions, the volume of crude output and the prices of crude oil. The contribution of the oil industry to the economy of Iran goes

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[1]United Nations, Electric Power in Asia and the Pacific, 1971 and 1972, 1974, pp. 11-12.

beyond the direct payments received by the government of Iran and is in the form of revenues taxes and transit dues.

During 1973, Iran, for the first time, gained direct control over all petroleum production. The recent increase in world crude oil prices has increased Iranian foreign exchange earnings to well over a billion dollars a year. As a result, the pace of economic development has increased rapidly. Iran has one of the highest sustained economic growth rates in the world. Moreover, among the oil exporting countries, Iran has an economy sufficiently strong and diversified to put its oil wealth to work.

The real GNP growth rate in Iran, which averaged more than 11 percent a year between 1964-1972, jumped to 32.8 percent during 1973-1974 and is expected to exceed 40 percent in the current Iranian calendar year.[1] Iran's per capita income averaged $1,800 in 1975, which is very high for a developing country.[2]

Energy Consumption in Iran

In view of the outstanding role that has been played by energy in economic activity, the main purpose of this

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[1] "World Trade Outlook," Overseas Business Report, OBR 75-15, March, 1975, p. 4.

[2] U.S., Department of Commerce, Bureau of International Commerce, Foreign Economic Trends and Their Implications for the United States (Washington, D.C.: Government Printing Office, July 1975), p. 4.

chapter is to describe the characteristics of energy consumption in Iran, to outline future requirements and the method of satisfying them, as an indispensable first step toward an efficient program of new energy resource development, for economic development of the country.

The limitation of oil reserves in Iran is apparent in the long run. The discussion presented in the past chapter shows that research must continue on the various aspects of energy problems and on new forms of energy resources that can be used in the economic development of Iran.

With attention to the energy supplies in Iran, in spite of the relatively high rates of growth of per capita consumption particularly in view of the increasing influence of commercial fuels, consumption stands at lower levels than in more industrialized countries. In Iran, with respect to energy consumption, it is necessary to determine first what could be considered an adequate consumption for Iran in relation to the degree of development. The part of energy used by the population is fundamentally dependent on purchasing possibilities, that is, on average per capita income levels. It is, therefore, natural to first try to evaluate the relative position of energy supplies as a function of average per capita income levels, an index which accurately reflects the economic potential and degree of general development of Iran.

The present review of energy consumption in Iran covers only the main characteristics regarding the level and structure of consumption, in relation to the economic development and in comparison with similar cases in the past. The study is mainly concerned with the general structure and possible future requirements, in different forms of energy, with the probable demand for energy and the means to satisfy it.

In the first place, consideration is given to the development of gross consumption of all types of energy, whether or not derived directly from the natural resources. Only the so-called conventional forms of energy were considered, petroleum, natural gas, coal, and hydroelectric.

Iran has shown a rapid increase in consumption of energy in recent years. In 1957, the total energy consumption did not exceed 3.3 million tons of coal equivalent, it has since increased by 11.3 percent per year reaching 8.9 million tons of coal equivalent in 1966.[1]

In 1959, about 94.9 percent of the country's energy needs were derived from petroleum. The balance was supplied by coal and water.

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[1]United Nations, Proceedings of the Fourth Symposium on the Development of Petroleum Resources of Asia and the Far East, vol. 3, No. 41 (1973): 142.

In 1965, Iran's total energy use was 9,152 million tons coal equivalent. The share of solid fuels was 0.275; liquid fuels, 7.204; natural gas, 1.638; and 0.035 million tons of coal equivalent.[1] In the same year, the per capita energy consumption was 390 kilograms of coal equivalent. In 1966, the total energy consumption was 10.3 million tons coal equivalent, with a per capita consumption of 405 kilograms coal equivalent.[2]

With the utilization of natural gas as a source of new energy, however, the percentage produced from petroleum products has been declining. By 1977, it is expected to have dropped to 66.6 percent, whereas energy derived from natural gas would have increased from zero to 29.6 percent. Table 7 gives the consumption of various forms of energy with the percentage of consumption during 1966 and the projection for 1977.[3]

As indicated by a United Nations' publication,[4] the consumption of different forms of energy in Iran in 1973 was (all figures in million metric tons of coal equivalent): coal and lignite (solid fuels), 1.050;

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[1]Ibid., p. 24.

[2]Ibid., p. 59.

[3]Ibid., p. 142.

[4]United Nations, <u>World Energy Supplies, 1970-1973</u>, Statistical Paper Series J, No. 18, 1975, p. 25.

Table 7. Consumption of Various Energy Sources (1,000 tons Coal Equivalent and Percentage) in Iran, 1966, 1977

Years	Petroleum Products	Natural Gas	Water and Coal	Total
1966	8,507	160	269	8,936
	95.2%	1.8%	3.0%	100%
1977	20,803	9,250	1,195	31,248
	66.6%	29.6%	3.8%	100%

Source: United Nations, Proceedings of the Fourth Symposium on the Development of Petroleum Resources of Asia and the Far East, vol. 3, No. 41, 1973, p. 142.

crude petroleum (liquid fuels), 17.148; natural gas, 13.997; and hydro and nuclear power consumption of 0.676 million tons of coal equivalent.

The world energy consumption (all figures in million metric tons of coal equivalent) of coal and lignite was 2,484.613; crude petroleum, 3,592.976; natural gas, 1,617.856; and hydro and nuclear power, 189.072 million metric tons of coal equivalent. The Iranian per capita energy consumption indicated 1,050 kilograms of coal compared with 2,074 kilograms coal per capita for the world.[1]

Since 1957, the rapid growth in energy use has stimulated an even more rapid economic development in Iran. As figures show, during 19 years the population of Iran has

[1]Ibid., p. 13.

increased by about 50 percent but energy consumption has increased more than the population has.

Industrialization and industrial production has been another reason for the increase. A similar pattern of development is expected to continue. Energy use will increase more slowly than industrial development and both will grow somewhat more slowly than in the past decade. Thus, it can be seen that Iran will need considerable supplies of energy in the future. Considering the limited production life of its oil wells, thought should be given now to identifying and developing new and substitute sources of energy to meet its future requirements.

The latest primary energy consumption and projected electricity generation capacity in Iran has been shown in Tables 8 and 9.

Table 8. Primary Energy Consumption in Iran, 1973-1974 and 1978-1979

Source	1973-1974	1978-1979
Oil (thousand cubic meters)	12,584	31,912
Barrels	79,135,023.3	200,679,979.6
Natural gas (million cubic meters)	3,000	8,800
Cubic feet	105,930,000,000	310,728,000,000
Coal (thousand tons)	270	783
Hydroelectricity (million kwh)	3,460	7,500
Total	19,314	55,995

Table 9. Projected Electricity Generation Capacity (National Grid System or Major Production Centers) in Iran, 1973-1993

Source	1973-1978 (%)	1978-1983 (%)	1983-1988 (%)	1988-1993 (%)
Nuclear	--	20.0	40.8	52.1
Hydroelectricity	32.8	22.3	27.9	22.8
Steam	39.0	47.5	24.9	14.0
Gas turbine	25.6	9.9	4.9	3.3
Diesel	2.4	--	--	--
Other	--	--	1.3	7.5
Total (megawatts)	4,814	16,951	37,216	66,019

Source: Kayhan International, 28 February 1976, p. 5.

Energy Resources and Reserves in Iran

It is very important to appraise the energy resources of Iran as a basis for programming the development of new energy. However, before analyzing the figures showing the size of Iran's energy resources, it is necessary to note that the concept of energy reserves is changeable over time, since it depends on various technical and economic factors subject to continuous development. With respect to the former, the status of energy reserves is related to the current technological level of prospecting, exploitation, mining, etc., in Iran.

At the present time, information on Iran's reserves of minerals, fuels, and hydroelectric resources is irregular. But, it is to be expected that such information will be extended, added to, and improved upon as a consequence of the urgent need for using national energy resources as an instrument of economic development.

Since long experience in industrial production has contributed to the accumulation of a satisfactory compilation of data on potentials, petroleum reserves have been better surveyed. Iran is the oldest petroleum producing country of the Middle East. In this region, it is at present the second largest producer.

Iran's petroleum industry was nationalized in 1950 when the National Iranian Oil Company (NIOC) was established and granted proprietary rights over the country's hydrocarbon reserves.

Petroleum

Iran has been blessed by nature in having in its subsoil rich deposits of oil. For the first 30 years, Iran's oil production developed steadily but slowly. After 1945, the progress was rapid. By 1950, the production figures tripled as compared to the last pre-war year, and progress is moving ahead. Now, Iran is the second largest oil producing country in the world.

In January 1972, the estimated oil reserves of Iran were 55.5 billion barrels.[1] For the fields of the National Iranian Oil Company (NIOC), the Sarajeh structure's reserves are estimated at 70 billion barrels of light oil and vast quantities of natural gas. The remaining recoverable reserves of Nafte-Shah-Khanijin field are reported as 194 million barrels, of which 116 million barrels are in Iran.[2]

As indicated by the Statistical Yearbook of 1974 for the United Nations, the reserves of Iranian crude petroleum in 1973 have been estimated at 9,308 million metric tons. Production, at the same year, was 292,843 thousand metric tons.[3] Proven petroleum reserves in August 15, 1973 for Iran, were 62,202,200 (thousands of 42 gallon barrels), compared with 562,295,393 (thousands of 42 gallon barrels) total world reserves.[4]

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[1]Charles Issawi, Oil, the Middle East, and the World (New York: Library Press, 1972), p. 20.

[2]L. Nahai and C. L. Kimbell, "The Petroleum Industry of Iran," Bureau of Mines Information Circular, 1963, p. 5.

[3]United Nations, Department of Economic and Social Affairs, Statistical Office, Statistical Yearbook, 1974, 1975, p. 175.

[4]Joseph Barnea, The Energy Crisis and the Future (New York: UNITAR, 1975), pp. 76-80.

Iran's production of crude oil was 432.270 million metric tons of coal equivalent in 1973.[1] These figures clearly indicate that Iran's petroleum production increased in past years.

Natural Gas

Natural gas in Iran is mainly associated and exists partly in the form of gas caps and partly dissolved in the oil itself. About 8 percent of the total associated gas produced with the crude oil has been fully utilized.

For the future, the development of long distance natural gas transmission pipelines would be important to the utilization of natural gas. Technical developments aimed at the transportation gap between consumer and supplier separated by distance are also important. The main drawback of natural gas, at present, is its high transport cost, whether it be gas pipeline or the carrying of liquified natural gas by tanker.

Natural gas production, consumption, and reserves have been indicated by Energy Alternatives[2] as shown in Table 10.

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[1]United Nations, World Energy Supplies, 1970-1973, Statistical Papers Series J, No. 18, 1975, pp. 12-13.

[2]A Comparative Analysis (Norman: University of Oklahoma, 1975), pp. 4-11.

Table 10. Natural Gas Reserves, Production, Consumption in Iran, U.S.A., and the World in 1970 and 1971 (trillion cubic feet)

	Estimated Reserves 1971	Production 1970	Consumption 1970
Iran	197.0	1.1	0.4
U.S.A.	278.0	23.8	22.0
World	1,745.1	45.9	38.3

An estimate by Bernadette Michalski,[1] indicated that Iranian natural gas reserves rank behind the Soviet Union and the United States with 200 trillion feet and with production approaching 1.5 trillion cubic feet in 1972. Recent reserve discoveries near the Persian Gulf were estimated at between 180 and 200 billion cubic feet.

Coal

Among Iran's more significant known mineral resources are bituminous coal fields throughout the Alborz Range and vast deposits of cokable coal near Kerman.

Greater use of coal in the country's steel industry is being realized. The projected growth of Iran's steel output and its limited reserves of coal have forced the

[1] Bernadette Michalski, "The Mineral Industry of Iran," Minerals Yearbook, III (Washington, D.C.: Government Printing Office, 1972), pp. 411-420.

government to take immediate steps to economize on coal consumption. As indicated earlier, coal consumption will increase from 270 thousand tons between 1973-1974 to 783 thousand tons between 1978-1979. As indicated by the United Nations Statistical Yearbook,[1] the known economic reserves, in place, of Iran's coal in 1972 were 385 million metric tons, of which, 193 million metric tons is known recoverable.

Geothermal

With regard to the other nonconventional resources, it is recognized that there are valuable potential sources of geothermal energy in Iran. It will be some time before that geothermal energy can be expected to play an important role in the power development program of the country.

With geothermal energy reserves, it is theoretically possible to utilize the temperature difference between the surface and the interior of the earth at any point on the globe. However, in practice, it is only economically feasible in volcanic regions of Iran, where there is normally a natural source of steam and hot water. In theory, the power obtainable from this source is enormous, but technical difficulties and costs are usually prohibitive

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[1]United Nations, Department of Economic and Social Affairs, Statistical Office, Statistical Yearbook, 1974, 1975, p. 170.

in volcanic regions. In certain regions of the earth, much steeper temperature gradients occur--sometimes several times the normal.

It is the heat in these regions that is termed geothermal energy. Such thermal regions are usually, but not always, closely associated with volcanic activity and earthquakes.

The majority of the earthquakes occur in clearly defined belts or zones. The most important of these zones, which also contains a great number of active and extinct volcanoes, more or less follows the periphery of the Pacific Ocean. This zone is sometimes known as the belt of fire. Another important zone runs along the middle of the Atlantic Ocean with an easterly branch passing through the Mediterranean and the Middle East into Tibet.[1] Geothermal areas generally tend to lie within these earthquake belts, though not necessarily close to volcanoes.

With the geological pattern that Iran has, there is much possibility of having rich geothermal energy reserves, especially around the Alborz Range and the Zagros Mountains. In general, though, to obtain a geothermal power zone, it is necessary to survey the suitable area of appropriate size for an active area.

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[1]H. Christopher H. Armstead, ed., Geothermal Energy Review of Research and Development (Paris: UNESCO, 1973), p. 15.

Solar

Solar energy, as a new source of energy, is one of the alternative uses of energy in Iran. The ideal zone for the use of solar energy, as indicated earlier, is the zone with the maximum annual number of days of sunshine, where the daily duration of sunshine is constant, the conventional forms of energy scarce and, therefore, expensive.

According to Isao Oshida,

> the duration of sunshine will be a more quantitative reference in this connection. All the regions located between latitude 45° North and 45° South, and having over 2,000 hours of sunshine a year may be suitable for the use of solar water heaters.[1]

Iran lies on a latitude of 25° to 40° North and a longitude of 44° to 63° East. Iran, with almost nine months of sunny days a year, is a suitable place to use solar energy as a source of energy for many purposes.

A good development program is required to bring available technology and appropriate economic considerations on the problem of developing a practical solar heating and cooling system in Iran. Preparatory to effecting widespread use of solar energy house applications, one of the principal needs is to develop data oriented toward maximizing the use

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[1]Isao Oshida, "Use of Solar Energy for Heating Purposes," New Sources of Energy Proceedings of the Conference at Rome, 21-31 August 1961, vol. 5, Solar Energy No. II, (1964): 3.

of solar energy. In addition, with solar energy, water can be heated. Solar air heaters offer the opportunity for a heat supply to buildings and to air conditioning units. Their potential advantages are low cost, good efficiency, high durability, and efficiency at moderating temperatures. Solar water heating, house heating, and solar cooking developments appear to have reached a point where practical application may be imminent.

Storage has a great potential for solar energy. Water, because of its low cost, high heat capacity, low corrosibility, and excellent heat transfer characteristics can be used as heat storage. Water is the heat storage medium most conveniently applied to storage, using existing technology and practices. Water has been used for storage with success and appears to be the best all around choice as a heat storage medium.

Hydroelectric

The development of the hydroelectric potential is, for Iran, an unavailable necessity for the sound management of energy resources, since water is a renewable resource which can provide large amounts of energy without current expenditure on fuels. In addition, the installation of hydroelectric power stations does not usually demand more investment than that for a thermoelectric station. The development of water power has the added advantage that

multiple use can be made of water resources with the consequent economic benefits.

Hydroelectric power in Iran is limited with the number of dam sites. According to World Energy Supplies,[1] Iran's hydroelectric power production in 1973 has been 0.676 million metric tons of coal equivalent.

The hydroelectric energy consumption of Iran, as noted earlier, was 3,460 million kilowatt hours between 1973-1974. That would be 32.8 percent projected between 1973-1978. It is expected that this amount will decrease between 1988-1993, because of the use of nuclear power in the country for electricity generation.

Wind

Although wind has been recognized as a source of energy for several centuries, it has not as yet entered the field of power generation in a big way in Iran, in spite of sustained efforts. Wind energy can best be harnessed in rural areas of Iran, where its use is more localized. Before any development of this type is undertaken, areas with suitable wind conditions must be located and detailed meteorological records compiled of wind speeds, duration, etc.

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[1]United Nations, World Energy Supplies, 1970-1973, Statistical Papers J, No. 18, 1975, pp. 12-13.

Nuclear

Since the main technical difficulties in the way of using nuclear reaction for peaceful purposes have been overcome, the only problem now is to produce energy at competitive prices in Iran. Since, in the future, nuclear generation will probably reach the stage where it can compete regarding costs, atomic electric power stations may be considered as an alternative and supplementary to conventional hydro and thermoelectric power stations.

Iran is one of the first oil producing countries to seek an alternative source of energy. Iran is looking to solve its energy problems in the future by using nuclear power reactors. The Iranian governmental energy policy considers that petroleum is too valuable to be used for lighting and heating.

Choices Between Alternative Sources of Energy

Decision-making in the area of developing resources is usually based upon several criteria or factors. These factors may involve economic, sociological, political, and legal as well as resource availability considerations. Frequently, problems may arise in choosing between alternative resources to be developed. The problems may be the result of competing priorities either among the factors previously detailed or among elements of one factor.

Since this research has dealt with the economic aspect of new energy resource development, this section will be limited to a discussion of the economic problems of choosing between the three alternative sources. Factors to be discussed relative to each source include: location of raw materials, sites, and markets; transportation of power costs; relative costs of development; and, avoidance of pollution and safety hazards.

Iran's energy consumption has been increasing rapidly as a result of expanding industry and population. This increase has been mainly based on the use of petroleum and natural gas. As these are exhaustable, they cannot be treated as permanent sources for Iran. Fortunately, Iran has a high potential to develop nonconventional sources. However, choices must be made as to how development of the nonconventional sources should proceed. Each has specific problems associated with its development.

Utilization of geothermal energy in Iran is severely limited at present because little survey work has been done to delineate existing or potential fields. Second, the fields are probably located, because of required geological structures, in areas distant from primary centers. Ultimately, the use of geothermal energy in Iran depends not only upon the amount of reserves, but more importantly on technology and the complex problem of exploiting each geothermal field. The cost of transporting and transmitting electricity from this source makes it uneconomic in terms of providing a nationwide energy system. Within a local region, however, it is highly competitive with other sources. Thus, the location of the site away from markets is a constraint on developing this resource. However, the fact that power plants are being built provides important evidence that, given the correct geological and economic factors, geothermal energy sources have a high comparative advantage for development and probably should be viewed as the prime source for new energy supplies in some areas.

Solar energy is available everywhere, inexhaustible and clean. Technical difficulties involving conversion techniques and energy collection equipment have prevented it from being harnessed to any great extent. A central factor limiting the adoption of solar energy in Iran is the lack of a good technical and economic distribution system for use in all areas. Again, solar energy tends to be location-specific in its economies. That is, high costs of transmission, caused by low yields of electrical power associated with current solar power systems, make it uneconomical in terms of serving major centers. A positive factor is that this is the safest and least polluting of the energy alternatives evaluated here.

Decisions on development of nuclear energy involve more than just the cost of producing it in Iran. The most critical problems in developing this energy are the level of technology it requires, safety considerations, and waste disposal. In addition, developing countries are limited by a scarcity of uranium for fuel. Iran has only incomplete data on its reserves. Consequently, the possibility of Iran ultimately becoming dependent upon outside sources for nuclear fuel must be weighed in development decisions. Another major limitation in Iran is the need for large quantities of water in nuclear reactors. Limitations on the availability of water supplies means that there are constraints on where plants can be constructed. As transmission costs are not as great with nuclear power, this is not as severe a limitation as with the other energy sources. Because of this, nuclear energy does have a strong potential for supporting a nationwide energy system.

In summary, the primary problems associated with development of geothermal energy concern location: determining the fields and the distance of the sites relative to markets. Solar energy constraints are primarily those of technology and location. Nuclear power is limited by its technology (to include safety, waste, fuel needs).

Development planners must weigh all of these factors in arriving at decisions concerning power resource development. These factors are particularly relevant to the timing of development. Iran will continue to find it expedient to depend upon hydro, petroleum, and natural gas as sources of power as long as these resources can provide for the nation's needs at reasonable cost. As petroleum and natural gas supplies are depleted and as their prices rise, new sources of energy will be needed. These can logically be brought into use on a least cost first basis. Technological considerations and new technological developments will dictate which sources can be developed to provide power at the least cost. Many of the constraints on geothermal, solar, and nuclear energy are technological in nature. Predicting the rate of technological advancement is hazardous, at best.

Choices among these alternatives must be based on relative costs of development. The research methodology employed in this study was primarily designed to assist Iranian planners in establishing these relative costs.

The findings of this study can be used to develop general policy guidelines relevant to new energy resource development in Iran. The methodology employed in assessing energy costs can be used in preliminary feasibility studies for energy resource development in given regions of the country. The results obtained from the preliminary studies can be used as broad guidelines for directing energy programs for the country.

For example, this study has isolated the most significant cost determinants of the various sources. A planner can use the findings in this study to determine: (1) the cost components he must consider in arriving at relative costs; (2) the computational formulas to be employed; and (3) the approximate relative cost of each energy source. The relative costs so determined can be used as a basis for making public policies related to power.

Before establishing any program for energy development in the country, the factors and limitations of the new energy resources must be carefully considered. It should be stressed that this study was limited to economic aspects of energy resource development, but social development and human welfare also must be considered before any policy in regard to energy resource development is adopted.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Research and development are being directed towards the establishment of new economic uses of solar, geothermal, and nuclear energy. The main purposes of this research, by evaluating 14 different sources of energy, has been to analyze and determine current energy resources and reserves; to analyze and compare energy supply and demand; to discuss the development and improvement of some new sources of energy which can be substituted for petroleum, natural gas, and other exhaustible sources of energy, in order to provide for future needs of the country. The use of petroleum as a major source of energy at the present time for all purposes such as lighting, transportation, heating, fertilizer, medical products, and the petrochemical industry can't continue forever because of its increased costs and exhaustibility.

The advantages and disadvantages of alternative sources of energy for meeting future demand have been considered from the standpoint of availability of reserves, cost of production, utilization, renewability, avoidance of pollution, and volume of needed capital investment. Consideration of these factors will facilitate selection of the optimum alternative sources of energy.

Energy consumption in the world and, of course, in Iran is growing. A number of different trends in each energy use sector--residential, commercial, industrial, and transportation--have contributed to rapid growth in energy use rates in the last decade in the world and in Iran. Shortage of fuel is one of the most immediate and real problems for most people in the world.

Before taking up the specific economic and technical aspects of the new sources of energy (which are new not in origin but primarily because of newly developed methods for harnessing them), a general survey is appropriate. Some of the principal energy sources which the world now relies upon such as petroleum and natural gas are expected to decline in importance in the future. Energy needs after this time will have to be supplied from other sources.

Functional patterns of use have been emphasized in evaluating new sources and in planning energy development. Each of the new sources of energy has been studied systematically from various points such as technical facilities, economic advantages, and utilization problems. Altogether, fourteen different sources of energy that have been used in the world were described and evaluated. Each had advantages and disadvantages for fuller utilization.

Geothermal, solar, and nuclear energy were selected because they offer more advantages than the other sources of energy. The advantages influencing selection were that geothermal energy is supplied from the heat of the earth's interior hot springs and hot rocks. It is abundant in parts of Iran and can generate electricity and provide heat for domestic, agricultural, and industrial purposes. It also can be used to desalinate water. In relatively small power plant units, it can generate electricity economically. Geothermal heat can be produced at a very low cost. Environmental pollution is possible but is limited to small areas. Operation and maintenance is easy and practical.

Solar energy was selected as a second new source of future energy, because the supply of sunlight is inexhaustible. In addition, sunshine is not limited to specific areas around the world. It can be used for electricity, heating, and desalination. Solar energy is costly at present but with new technology and increasing oil prices, its cost may soon be comparable to oil. It is not a source of pollution.

Nuclear power, the third source of energy, needs uranium which is fairly widespread in nature. It is a powerful energy source and can provide unlimited energy resources through use in nuclear breeder reactors. Power plants can generate electricity. The heat can be used for the desalination of water. Nuclear fusion is virtually inexhaustible, likely to be safe, relatively pollution free, and involves no release of carbon dioxide. Installation of nuclear power plants requires much capital, and suitable sites are difficult to find. Control of the use of atomic energy raises complex political issues. Major weaknesses are waste control and uranium scarcity. Hopefully, these problems can be solved by new technology.

The economic evaluation of these three sources of energy has been based on assumptions that capital is available for investment and sufficient technology exists for harnessing them.

The size of the plant is the most important factor in energy production. Optimum size depends on availability of resources, needs, and technology. For comparison purposes, a medium sized 400 MW plant was assumed in the calculations for both the geothermal and nuclear power plants. Plants of this size can be used both in industrial countries and in nonindustrial nations for power production.

For solar energy, the cost of solar power plants, although the raw material (sunlight) is free, increases with the size of the power plant. The plant size must be large enough to insure demands and decrease the cost of

production. By evaluating these factors, the selected size for this research was 1,000 MW for the solar plant power.

A specific procedure was used in this research for the evaluation of these three forms of energy, to obtain the mean specific costs of each type of energy production and choose between alternatives which would result in lowest energy cost. To obtain the cost, it was necessary to know the probable capital outlays required for development of these three forms of energy and costs of operation and maintenance involved. These were estimated through analysis of cost data for each of the three forms of energy and by making adjustments for scale of development and improvements in operating use efficiency. The cost estimates were based on the capital investment and annual cost as related to the size and life of the plant. Total capital cost included land, construction, fuel, and equipment costs. Total plant production and cost of production were considered along with the plant factor, rate of interest, and operation and maintenance costs in obtaining the cost of producing electricity per kilowatt and per kilowatt hour.

Considering all of these factors, the capital investment of the plant in total and for each kilowatt, total annual cost of the plant, total energy output, total cost per kilowatt of power production, and cost of electricity from each source of energy per kilowatt hour were found.

Each estimate was compared to the cost of electricity from fossil fuel per kilowatt and kilowatt hour. It was found that the cost of electricity from geothermal, solar, and nuclear power is competitive with fossil fuel. The cost of electricity per kilowatt hour from nuclear power, at the present time, is higher than fossil fuel, but with further technology, this cost will probably decrease.

The cost data obtained in this study is summarized in Table 11. The data indicate that some of the alternative energy sources are cheaper than others for use in the future. However, it must be recalled that there are limitations on the use of each of these sources. Although solar energy is cheaper in most areas, as indicated earlier, the present technological level associated with solar energy is not sufficiently developed for the mass production of solar electricity. This is especially true for some countries like Iran. Geothermal is also less expensive than other sources. However, it is limited to use in certain areas because of geological conditions. Further, the transmission costs of geothermal generated electricity to far areas would make it uneconomical.

Nuclear power is still generally more expensive than other sources of energy. Even at a relatively high level of technological development, it is not presently at

Table 11. Cost of Plant per KW and Cost of Electricity per KWH in United States Dollars

Energy	Cost of Plant per KW (in U.S. $)	Cost of Electricity per KWH (in cents)
Solar	291.62	4.75 assuming 70% plant efficiency
Geothermal	30.10	0.43 assuming 80% plant efficiency
Nuclear power plant reactor (LWR)	577.20	8.236 assuming 80% plant efficiency
Oil fired station (United States)	350.00[a]	
New York (United States)		10.45
Buffalo (United States)		7.54
San Francisco (United States)		4.48
Hydroelectric power plant (Iran)	280.00[b]	6.50 to 10.5[c]

[a]Rurik Krymm, "A New Look at Nuclear Power Costs," International Atomic Energy Agency Bulletin 18(2), (1976): 4.

[b]United Nations, Economic Commission for Asia and the Far East, Electric Power in Asia and the Far East, 1970, 1970, p. 53.

[c]United Nations, Economic and Social Commission for Asia and the Pacific, Proceedings of the 12th Session of the Sub-Committee on Energy Resources Development at Bangkok, Thailand, 6-13 December 1972, Series No. 11, 1974, p. 268.

the stage where it can compete with other forms of energy, especially with fossil fuel.

The utilization of nuclear energy is limited by its technology. Currently, there remain complex difficulties concerning the building of nuclear power plants. A crucial limitation concerns uranium availability for fuel processing. Waste product disposal and controls stemming from environmental considerations and fears of nuclear accidents also pose important limitations at the present. Technology is improving rapidly but still is not sufficient to locate a fuel for nuclear power without waste hazards, that can be competitive with fossil fuel costs at the same time.

These elements all operate to hinder the rapid adoption and utilization of solar, geothermal, and nuclear power even though they offer economic and other advantages relative to the current use of conventional fuels. If these limitations can be overcome, the utilization of these forms will be more rapid.

There are limitations with all cost studies. Because of the nature of the research, it was not possible to obtain primary data. Obtaining primary data, in this research area, is extremely costly and requires long time periods for collection. Further, accurate primary data on nuclear installations is frequently classified. Due to political and business situations, project managers of nuclear, solar, or geothermal power plants are frequently reluctant to provide help or data for independent cost studies. Data collection for this research was based primarily on secondary data obtained from different sources. These data were integrated to establish new research data.

The use of secondary data in cost studies is a limiting factor. Frequently, the secondary data may itself be based on estimates rather than primary cost data. This makes specific comparison difficult. Instead, only orders of magnitude can be validly compared. In addition, the data on new energy resource development are frequently location-specific owing to particular geological structures, sunshine patterns, etc. Therefore, it cannot be automatically assumed that relationships which hold in one area will transfer to others. Large-scale cost studies, such as this, are useful in determining orders of magnitude and providing general policy guidelines on energy resource development. However, the results obtained may not always hold in small-scale studies or specific situations/areas.

Conclusion

The economic problems confronting a country, like Iran, do not differ fundamentally from those facing each nation in the world. The basic problem Iran is trying to solve may differ quantitatively from those of developed countries and qualitatively from those of other developing countries, but the nature of the problems cuts across national boundaries.

Iran is facing the following constraints: in the long run, shortages and, ultimately, depletion of nonrenewable energy resources; shortages of fertilizers; and, food shortages. These are, perhaps, the most immediate and real problems confronting people in all countries today.

Iran shares with other developing countries these concerns: an economy primarily based on one export; increasing demand for electricity as a result of rapid industrialization and urbanization; rural development; and, generally, inadequate human resources to meet the needs of development.

To meet the demands for increased electricity, the Iranian government is attempting to increase electric power generating capacity within a few years. Demand is exceeding supply and the shortage has been felt in homes and factories.

Iran is trying various projects in its efforts at rural development and to improve the quality of life in the villages. Industrialization is being taken to the villages in terms of small rural industries and limited manufacturing operations.

Human resources are a major concern. The need for qualified manpower is being felt. Educational and technical training programs have not been able to meet requirements. Iran's labor force is, generally, ill-equipped.

All of the constraints, problems, and concerns mentioned in the preceding paragraphs place limits on the amount of growth any country, or the world, can reasonably expect to achieve. One method to extend these limits on growth is to look for a basic cause, or a major bottleneck in overcoming these problems, to overcome it, and, thus, ease some of the constraints on growth.

Available energy is, obviously, one of the major constraints and bottlenecks in the process of development. The development of new energy resources certainly will lessen energy shortages in the future; slow down the depletion of nonrenewable energy resources; and, free quantities of conventional energy forms for use in processes in which other energy sources may not be substitutable such as lubrication, fertilizer production, etc.

Further, harnessing these new sources will allow electrical power generating capacity to increase more rapidly. New energy resource development, by making projects economical, which may not be so with conventional energy sources, speeds rural industrialization. The quality of rural life may also be more rapidly improved by electrification projects that become feasible when new energy resources are developed. In summary, Iran must consider developing other sources of energy to extend the limits of growth, to continue developing, and to make development as rapid as possible.

Present indications are that the role of oil and natural gas in Iran is going to substantially change from the current position. While no new oil discoveries have been made recently, some of the largest discoveries of natural gas fields in the world have been made in Iran. Total estimated gas reserves now place Iran at having one of the highest amounts of this type of energy in the world. From present trends, it can be expected that natural gas both as a consumption item in Iran and as an export will gradually reduce the importance of oil as an energy resource within the country and as a revenue earner.

Further, Iran has realized that its petroleum resources are scarce and are being depleted. Current energy plans include reduced dependence on crude oil as

a source of fuel, rechanneling it as a feedstock into petrochemical industries and increased dependence on natural gas. It is believed that hydrocarbons are too precious to be burned as fuel. Conservation measures are in evidence. Finally, Iran is rapidly increasing its nonoil exports to reduce its dependence on oil.

In summary, in the future, the importance of oil both for primary energy consumption in Iran and as a source of revenue can be expected to gradually decline due to conservation, increasing dependence on natural gas and other energy sources, and diversification of the export sector of the economy. Correspondingly, the role of natural gas will expand.

Of course, Iran should not plan to exchange dependence on one energy source for dependence on another. Rapid development of geothermal, solar, and other nonconventional sources must be planned. During the past decade, because of the use of various forms of cheap energy such as coal and oil, potential economic and technological developments in other sources of energy have not been growing as fast as domestic energy demand. These new sources of energy will have to be phased in or integrated with conventional energy resources.

Any timetable for new energy resource development must begin with the future world price of oil and reserves.

This will influence both the development and use of new energy resources for domestic use and export. The development of new sources of energy will ease the heavy dependence on fossil fuels and introduce flexibility into Iran's energy program.

For Iran, in the long run, there is no shortage of potential energy sources provided the necessary technologies can be developed and made economically competitive. Over the next 25 years, nuclear, solar, and geothermal energy combined, will become the prime sources of energy in Iran. The role of nuclear power is of great significance since Iran is already beginning to install nuclear power plants. The initial technical difficulties are being overcome and nuclear power technology is being introduced. Its increased application now depends only on economic conditions or on the extent to which its costs may compete with traditional forms. The outlook, in the long run over the next 25 years, is favorable since the traditional forms are increasing in costs and reserves are decreasing.

In the short term, over the next five to seven years, the basic status of Iran's energy program will be satisfied mainly by the same resources and technologies as exist today. Levels of oil exploration, development, and drilling activity will continue. Oil and gas will continue to play a major role in development.

In the short run, nuclear power should begin to be integrated into Iran's energy program. Its adoption is possible because available technology exists and can be integrated with the current technological level in Iran. In the short run, solar and geothermal energy will remain in research and development stages.

Integration of these energy resources will only occur once technological difficulties mentioned previously have been overcome. Overcoming these problems will make them competitive with nuclear and conventional energy. It can be projected that these forms should begin to be phased into Iran's energy program in the medium term.

Long run projections for the phasing in of new energy resources are, of course, difficult to make due to higher levels of uncertainty about technological advances, price levels, population growth, demand, etc. However, obviously, nonrenewable oil and gas will become increasingly scarce. Thus, in the long run, nuclear, solar and geothermal will increasingly replace these as energy sources. Utilization of solar and geothermal will increase over the levels of the medium term projection as technologies improve. It can be expected, though, that nuclear, in the long run, will become the predominant source of energy in Iran.

In the long run, solar energy can begin to make a contribution to the future for heat and power requirements. There are no technical barriers to wide application of solar energy during this time frame. In the short and medium terms, solar energy (because of the need for large and expensive collectors) cannot compete with oil and gas, where it is abundant. As these resources deplete in the long run, solar will become more and more competitive.

In the medium and long run, the adoption of geothermal energy may proceed at a faster rate in parts of Iran than that of solar energy. The economic advantages of exploiting a successful geothermal field are great, as shown in this research. However, investment in geothermal exploration is regarded as risk capital. The same is true of capital associated with petroleum exploration. However, if petroleum exploration is successful, it can be shipped and sold. Geothermal energy can only be used within a limited area. This will retard its integration into Iran's energy plan.

In summary, the timetable for integration of nuclear, solar, and geothermal is as follows: in the short run, Iran will continue to rely on oil and gas primarily, nuclear power will be considered as an alternative source, research and development of solar and geothermal energy will continue. In the medium term, solar and geothermal will come under consideration as alternative. Nuclear power will be phased into Iran's energy program. In the long run, it is possible that nuclear power will become the primary source for electrification and industry. During this time frame, it will become possible for geothermal and solar power to contribute to energy consumption.

The relative rates of adoption of these energy sources are primarily a function of economics and existing technologies. Iran already has a technological base for integrating nuclear power with existing energy forms. In addition, technologies associated with nuclear power are already developed and competitive with conventional energy forms. This is not so for geothermal and solar energy in Iran. Because of the abundance of oil and gas, there will be a delay in their becoming economically competitive with these forms. In addition, technologies associated with these forms are not so highly developed as nuclear power. Therefore, their adoption will be somewhat slowed pending solutions to technical problems.

As mentioned earlier, constraints on growth do exist. Other major factors slowing full integration of these energy resources are the lack of trained technicians and maintenance capability. These are problems requiring long term, complex solutions. The greatest need is for lower and middle level technicians to provide capability to operate and maintain the various types of plants associated with these energy sources. Whether in the short, medium, or long run the constraints associated with the quality of available human resources may prove to be the most significant in slowing the economic utilization of all these forms of energy.

To facilitate development, utilization, and integration of these energy forms, additional research is necessary. Initially, basic research and data collection must be done. In Iran, there is a need for exploration for geothermal fields. The most feasible areas for solar and nuclear power must be determined. Basic geological and meteorological data is inadequate in Iran. This must be corrected for fuller utilization of alternative energy resources to proceed. Next, similar cost studies to this one must actually be done in Iran to determine whether or not the same cost relationships exist between the three forms of energy. These cost studies can be the basis upon which a timetable for the use of these three forms is established. Lastly, manpower needs must be analyzed. Manpower studies must be done on the future needs of the energy sector for skilled lower and middle level technicians. The needs must then be incorporated into the educational development plans of Iran.

The problems surrounding the development of energy resources are highly complex and cut across many areas of study--economics, energy technology, and human resource development. Their solutions are equally complex and difficult to determine.

BIBLIOGRAPHY

BIBLIOGRAPHY

Books

Armstead, H. Christopher H., ed. Geothermal Energy Review of Research and Development. Paris: UNESCO, 1973.

Ayres, Eugene, and Scarlott, Charles A. Energy Sources, the Wealth of the World. New York: McGraw Hill, Inc., 1952.

Banquis, P. R.; Brasseur, R.; and Masseron, J. Bureau d'etudes Industrielles et de Cooperation. Paris: Institute Français du Petrole, 1970.

Barnea, Joseph. The Energy Crisis and the Future. New York: UNITAR, 1975.

Bowen, Richard, and Groh, Edward. "Geothermal--Earth's Primordial Energy." Energy Technology to the Year 2000. Cambridge: Massachusetts Institute of Technology, 1972.

A Comparative Analysis. Norman, Okla.: University of Oklahoma, 1975.

Fisher, Austin W., Jr. Proceedings of the World Symposium on Applied Solar Energy. Phoenix, Arizona, 1955.

Fisher, John C. Energy Crisis in Perspective. New York: John Wiles and Son, 1974.

Herwing, Laloyd. Workshop Proceedings: Solar Cooling for Buildings. Los Angeles, California, 1974.

Hottel, H. C., and Howard, J. B. New Energy Technology, Some Facts and Assessments. Cambridge: Massachusetts Institute of Technology, 1973.

Issawi, Charles. Oil, the Middle East, and the World. New York: Library Press, 1972.

Lof, O. G. "Solar Energy, An Infinite Source of Clean Energy." The Energy Crisis: Reality or Myth. Philadelphia: American Academy of Political and Social Science, 1973.

Michalski, Bernadette. "The Mineral Industry of Iran." Minerals Yearbook, III. Washington, D.C.: Government Printing Office, 1971, pp. 411-420.

Newspaper Enterprise Association. 1975 World Almanac and Book of Facts. New York: Newspaper Enterprise Association, 1975.

Organization for Economic Cooperation and Development. Energy R and D. Paris: Organization for Economic Cooperation and Development, 1975.

Oshida, Isao. "Use of Solar Energy for Heating Purposes." New Sources of Energy Proceedings of the Conference at Rome, 21-31 August 1961. Vol. 5, Solar Energy No. II, 1964.

Putnam, Palmer. Energy in the Future. New York: Van Nostrand, 1953.

Schramm, L. W. "Shale Oil." Mineral Facts and Problems. Washington, D.C.: Government Printing Office, 1970.

University of Maryland. Proceedings of the Solar Heating and Cooling for Buildings Workshop. Washington, D.C.: Government Printing Office, 1973.

Warner, Arthur J. "Natural Gas." Mineral Facts and Problems. Washington, D.C.: Government Printing Office, 1970.

Williams, J. Richard. Solar Energy Technology and Applications. Atlanta: Georgia Institute of Technology, 1974.

Government of Iran Publications

Government of Iran. Plan Organization. Iranian Statistical Center. National Census of Population and Housing. Vol. 168. Tehran: Government of Iran, 1966.

Kayhan International, 28 February 1976.

Journals

Ashraf, Hooshang. "The Relationship Between a Reservoir's Life and Sedimentation." Iranian Society of Engineers, October 1971, pp. 10-14.

Battelle Memorial Institute. Energy Perspectives 3 (October 1973).

________. Energy Perspectives 13 (August 1974).

________. Energy Perspectives 14 (September 1974).

Duffie, John A., and Beckman, William A. "Solar Heating and Cooling." Science 191 (16 January 1976): 143-149.

"Energy for America's Third Century." MOSAIC 5 (Spring 1974).

Fitts, R. B., and Fujii, H. "Fuel Cycle Demand, Supply and Cost Trends." International Atomic Energy Agency Bulletin, February 1976, pp. 19-24.

Hubbert, M. King. "The Energy Resources of the Earth." Scientific American, September 1971, pp. 60-88.

Krymm, Rurik. "A New Look at Nuclear Power Costs." International Atomic Energy Agency Bulletin 18(2), (1976): 2-11.

Nahai, L., and Kimbell, C. L. "The Petroleum Industry of Iran." Bureau of Mines Information Circular, 1963.

Newsweek, 24 February 1975, pp. 50-53.

Overseas Business Report, OBR 74-34, August 1974.

"Planning a Municipal Energy Future." MOSAIC, July/August 1975, pp. 24-29.

Polliart, Andre, and Goodman, Eli. "Prospects for Utilization of Nuclear Power in Africa." International Atomic Energy Agency Bulletin, February 1976, pp. 40-44.

"World Crude Oil Production Climbs 5.3%." Oil and Gas Journal, 19 February 1973, pp. 40-42.

"World Trade Outlook." Overseas Business Report, OBR 75-15, March 1975.

United Nations Publications

United Nations. Department of Economic and Social Affairs. Statistical Office. Statistical Yearbook, 1973, 1974.

________. Department of Economic and Social Affairs. Statistical Office. Statistical Yearbook, 1974, 1975.

________. Department of Economic and Social Affairs. "The Economics of Geothermal Power." Natural Resources Forum, 1971.

________. Economic Commission for Asia and the Far East. Electric Power in Asia and the Far East, 1970, 1970.

________. Economic and Social Commission for Asia and the Pacific. Proceedings of the 12th Session of the Sub-Committee on Energy Resources Development at Bangkok, Thailand, 6-13 December 1972. Series No. 11, 1974.

________. Electric Power in Asia and the Pacific, 1971 and 1972, 1974.

________. Proceedings of the Fourth Symposium on the Development of Petroleum Resources of Asia and the Far East. Vol. 3, No. 41 (1973).

________. Proceedings of the United Nations Conference on New Sources of Energy at Rome, 21-31 August 1961. Vols. 3, 5, 7 (1964).

________. Proceedings, Second United Nations Symposium on the Development and Use of Geothermal Resources. Vol. 1. San Francisco, California, 1975.

________. World Energy Supplies, 1961-1970. Statistical Paper. Series J, No. 15, 1972.

________. World Energy Supplies, 1969-1972. Statistical Paper. Series J, No. 17, 1974.

________. World Energy Supplies, 1970-1973. Statistical Paper. Series J, No. 18, 1975.

U.S. Government Publications

U.S., Atomic Energy Commission. Division of Production and Material Management. Nuclear Fuel Resources and Requirements. Washington, D.C.: Government Printing Office, 1973.

________. Division of Production and Material Management. Nuclear Fuel Supply. Washington, D.C.: Government Printing Office, 1973.

________. Division of Technical Information. Nuclear Energy for Desalination. Washington, D.C.: Government Printing Office, 1966.

________. The Growth of Nuclear Power, 1972-1985. Washington, D.C.: Government Printing Office, 1971.

________. Office of Planning and Analysis. Nuclear Power Growth 1974-2000. Washington, D.C.: Government Printing Office, 1974.

U.S., Congress. House. Subcommittee on Energy Research, Development, and Demonstration. Energy Facts II. Series H. Washington, D.C.: Government Printing Office, 1975.

________. House. Task Force on Energy. Energy, the Ultimate Resource. Washington, D.C.: Government Printing Office, 1971.

________. National Petroleum Council's Committee on U.S. Energy Outlook. U.S. Energy Outlook. An Initial Appraisal, 1971-1985. Vol. 2. Washington, D.C.: Government Printing Office, 1971.

________. The Nation's Energy Future. Report to Richard Nixon, President of the United States, 1 December 1973. Washington, D.C.: Government Printing Office, 1973.

U.S., Department of Commerce. Bureau of International Commerce. _Foreign Economic Trends and Their Implications for the United States_. Washington, D.C.: Government Printing Office, 1975.

U.S., Department of Interior. Bureau of Mines. "Coal Resources of the United States." _U.S. Geological Survey Bulletin_. No. 1275. Washington, D.C.: Government Printing Office, 1967.

________. Bureau of Mines. _Energy Perspectives_. Washington, D.C.: Government Printing Office, 1974.

________. Bureau of Mines. _Mineral Facts and Problems_. Washington, D.C.: Government Printing Office, 1965.

________. Bureau of Mines. _Mineral Industry Surveys_, 9 July 1976. Washington, D.C.: Government Printing Office, 1976.

________. Bureau of Mines. _Minerals Yearbook_. Vol. 1. Washington, D.C.: Government Printing Office, 1973.

________. Bureau of Mines. _United States Mineral Resources_. Geological Survey. Professional Paper No. 820. Washington, D.C.: Government Printing Office, 1973.

U.S., Department of Labor. Bureau of Labor Statistics. _Retail Prices and Indexes of Fuels and Utilities Residential Usage_. Washington, D.C.: Government Printing Office, 1976.

U.S., National Science Foundation. NSP/NASA Solar Energy Panel. _An Assessment of Solar Energy as a National Energy Resource_. Washington, D.C.: Government Printing Office, 1972.

________. _Proceedings of the Solar Heating and Cooling for the Public Workshop_. Part 1. Washington, D.C.: Government Printing Office, 1973.