N73 22748

NASA TECHNICAL MEMORANDUM

NASA TM X- 68230

NASA TM X-68230

THE UTILIZATION OF SOLAR ENERGY TO HELP MEET OUR NATION'S ENERGY NEEDS

by Ronald L. Thomas
Lewis Research Center
Cleveland, Ohio 44135

TECHNICAL PAPER proposed for presentation at
Energy Crisis Symposium sponsored by the National
Professional Societies of New Mexico
Albuquerque, New Mexico, May 3-4, 1973

E-7439

THE UTILIZATION OF SOLAR ENERGY TO HELP MEET OUR NATION'S ENERGY NEEDS

Ronald L. Thomas

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

SUMMARY

There is a national need for abundant clean supplies of energy. Our present fossil fuels are being depleted at an ever-increasing rate. Nuclear energy and coal can supply our needs but each has environmental and safety problems to overcome. This paper discusses the potential of solar energy as a major source of energy to meet our nation's energy needs. Solar energy is a clean, nondepleting resource that is available and has the potential to meet our expected needs. The optional solar energy systems presently under evaluation are briefly discussed. These options include systems for meeting our needs for generation of electricity, for heating and cooling of buildings and for production of clean fuel for transportation and industrial uses. The key technology requirements, estimated system costs, and potential of meeting our national energy needs are presented for each of the solar energy options. And, finally, the present national solar energy plans and programs and their possible impact on our energy needs are briefly discussed.

INTRODUCTION

There is a national need for abundant domestic supplies of clean energy. At the present time this need is often referred to as the "Energy Crisis". As a nation our energy needs are increasing rapidly and are expected to double by the year 2000. In addition to our increasing energy needs, some of our energy resources are being rapidly depleted (refs. 1, 2, 3). As if these problems are not enough, we also have environmental problems and balance-of-payments problems due to our energy needs.

The nation's energy needs, domestic energy resources, and possible future energy resources are briefly discussed in this paper. Three potential solutions, coal, nuclear and solar are compared as to benefits and problems. The paper primarily discusses the options available in using solar energy as a natural energy resource. These options are discussed under the generation of electricity, heating and cooling of buildings, and the production of clean fuel.

Discussed under the generation of electricity from solar energy are such systems as photovoltaics in space and on Earth, thermal energy collected from sunlight to operate conventional powerplants, solar-derived energy in the winds to obtain power from wind turbines, and a heat-engine that operates from the temperature difference available in the ocean.

The heating/cooling section discusses the principle of operation utilizing flat-plate collectors, thermal storage and heating and cooling equipment. Several examples of solar heated residences are described and the key technologies required to make the systems practical and economical.

Solar energy also offers ways of producing clean fuel: solid, gas and oil from crops. Several possible methods of producing fuel are discussed and the key technologies identified.

This paper then discusses current funding levels and programs for the development of solar energy. Also identified are projected milestones and possible impact of solar energy on our nation's future energy needs.

U.S. ENERGY: DEMAND AND PROBLEMS

Demand

The U. S. presently uses about 70×10^{15} BTU/yr of energy. These energy sources are primarily oil, natural gas and coal. A small amount of our energy is supplied by hydroelectric systems and an even smaller amount by nuclear reactors. Figure 1 shows the U. S. energy demand projected through the year 2020. This projection was made by the Associated Universities for the Office of Science and Technology (ref. 1). It can be seen from figure 1 that our needs are forecasted to increase rapidly, with four times the total energy predicted to be required by the year 2020. The increases are predicted to be met by a very large increase in the use of nuclear energy and increases in the use of oil and coal. Natural gas consumption is not projected to increase because of the depletion of gas reserves.

Energy Problems

Depletion

The forecast increase in energy use in the U. S. will result in a rapid depletion of some fuels as shown in figure 2. The Associated Universities, the Brookhaven study (ref. 1) and the AEC forecasts show that if present trends in energy consumption continue, oil, gas and uranium-235 (used in present power reactors) will be exhausted in

40 to 50 years. There are, however, abundant supplies of coal and uranium-238 (used in the fast breeder reactors now being developed by the AEC).

Pollution

Another impact of increased energy consumption is increased pollution. Figure 3 shows the possible output of several key pollutants over the next 50 years. As can be seen in figure 3, there is a temporary reduction of pollutants like NO_x and SO_2 by 1980 because of present government restrictions on emissions from automobiles and powerplants. However, the projected increase in energy consumption will override the present controls and cause the rate of pollution to double by 2020 unless new controls or new technology are introduced. Not shown in the figure are environmental impacts of strip mining operations and the generation of large quantities of radioactive wastes. An important fraction of these radioactive wastes must be stored for many thousands of years before they could be safely released. This latter is a crucial problem to which the AEC is giving very serious consideration.

Balance-of-payments

One of the major impacts of the depleting oil and gas reserves is dependence on foreign purchase of those convenient-to-use fuels. The value of oil and gas imports from 1968 to 1971 is shown to vary in figure 4 from 1.5 to 2.2 billion dollars. By 1985 the National Petroleum Council predicts a cash outflow for oil and gas of 20 billion dollars (ref. 4). This is to be compared to the net outward flow of cash of 10 to 30 billion in the years 1970 and 1971. Obviously, our dependence on fuel imports will have a major adverse impact on the net balance of payments in addition to making us dependent for more than half of our fuel on the policies of foreign countries.

DOMESTIC SOLUTIONS TO NATION'S ENERGY NEEDS

There are three major potential solutions to the shortage of oil and gas that can be considered seriously because they are technically feasible. These solutions are summarized in Table I. They are the gasification and liquefaction of coal, the use of nuclear energy to produce electricity, and the use of solar energy. The reserves of coal and nuclear energy (assuming the commercial success of the fast breeder) are measured in terms of centuries but even so are limited. Solar energy is unlimited. Another fossil fuel is shale oil. It is estimated that the U. S. has an order of magnitude more energy in shale oil than in coal (ref. 5), but at the present time it is not economical to utilize this source of energy. For this paper, solar is compared with only nuclear and coal, both of which are expected to provide much of our energy in the near future.

The use of coal involves solution of the SO_2, NO_x, and particulate pollution problem. In addition the added burden on the environment of unprecedented strip mining operations will create further problems already considered serious in several locations in the U. S.

The use of nuclear energy to solve the energy problem introduces safety questions and management of the large amounts of radioactive waste products that are generated by the fission of uranium.

There are no major environmental problems introduced by utilization of solar energy. Solar energy continuously falls on the Earth whether or not we use it. Solar energy therefore does not add any new thermal burden on the Earth's atmosphere as does the combustion of fuel and fission of uranium.

The technology that is needed to use coal involves the successful development of large-scale economical and efficient processes to convert coal to oil and gas. In addition, work needs to be done to economically extract coal in a socially acceptable way.

The technology required for the use of nuclear energy to solve the energy problem requires the successful development of an economical and safe breeder reactor. Also required is an acceptable and safe means for handling the vast amount of radioactive waste products that will be generated and that require storage or disposal with positive assurance of no release for 300 centuries.

The solution to the technical and environmental problems associated with the use of coal and nuclear fuel is expected to substantially increase the cost of energy. Estimates are that energy costs may triple in the next ten years because of the dependence on foreign sources, the cost of replacing oil and gas sources with nuclear and coal, and the cost of eliminating pollution and environmental problems.

It appears timely now to consider the use of solar energy. The chief problem in the past has been achieving cost-competitive systems. There is no question that technically solar energy is feasible. What is needed now is technology that will reduce the cost of solar energy systems. Innovative approaches, good simple efficient designs, proper selection of concepts, optimized systems approach and sound management of technology development programs are required to make solar energy an economical solution to the energy shortage problem. It is the only energy source that is unlimited, everywhere available, and offers a clean solution to the energy shortage.

SOLAR ENERGY CAN PROVIDE ALL OUR ENERGY NEEDS

Solar energy is diffuse and variable but abundant. In space at the Earth's distance from the Sun, the solar radiation available is approximately 130 watts/ft^2. Considering day-night and seasonal variation of solar flux and attenuation due to atmospheric conditions (clouds, dust and smog), the average energy falling on the U. S. on a year-round basis is 17 watts/ft^2 or 1410 BTU/ft^2 per average day (ref. 6). Figure 5 shows that the daily solar flux in the U. S. varies from 1000 to 2000 BTU/ft^2. As shown in figure 5, the solar energy falling on the continental U. S. is 300 times the total projected 1985 energy needs of the U. S. At an average efficiency conversion of 5%, it would take less than 7% of the U.S. land area to supply all our 1985 forecasted energy needs.

Figure 7 shows percentage of land area required versus efficiency of conversion of solar energy for both total U. S. energy consumption and energy required to produce electrical power. From figure 7 it can be seen that solar cells at 10% efficiency could meet all our 1985 electrical power needs by covering less than 1% of our total land area. Solar energy is diffuse but its abundance makes it possible to be a major energy resource for the U. S. and for the world.

The U. S. uses energy to generate electricity, heat and cool buildings, and to provide fuel for transportation systems and industrial processes. At the present time, approximately 22% of our total energy consumption is used for generating electricity, 25% for providing thermal energy for buildings, 23% for transportation and 30% for industrial processes. As shown in figure 8, solar energy can provide all forms of our energy needs.

ELECTRICITY FROM SOLAR ENERGY

Several methods of generating electricity from solar energy have been identified. Briefly these methods are:

1. Direct conversion of solar energy to electricity using solar cells.

2. Collection of solar energy by collectors to heat fluids that can be used to operate heat engines. These heat engines are then used to drive generators to produce electricity.

3. Using the solar-heated upper layers of the ocean water and the cold lower depths of the ocean to operate a low ΔT heat engine. This heat engine is then used to drive a generator to produce electricity.

4. Using the solar-derived wind power directly to operate a wind turbine. The wind turbine then drives a generator to generate electricity.

5. Using solar energy to grow crops that can be converted to fuel. The fuel is then used to operate heat engines that are used to generate electricity.

A brief description of each of these methods is discussed in the following sections along with their potential, technology needs and estimated costs.

Electricity from solar cells in space

The SERT II solar array is shown in the upper photo of figure 10. This array is approximately 150 ft^2 and generates $1\frac{1}{2}$ kW, and is currently operating in space. This array demonstrates that reliable electric power can be provided in space with solar cells.

The lower photo in figure 10 is a proposed concept for using solar cells in synchronous orbit to make power for use on the ground. This is the Satellite Solar Power System (SSPS) concept proposed by Glaser (ref. 6). The solar cells convert the solar energy to dc electrical power; this electrical power is converted to microwaves and beamed to the Earth. On the Earth, a receiving station converts the microwaves back to electrical power through a combined antenna and rectifier, called a rectenna.

The SSPS concept shown is proposed to generate 5000 MWe on the ground. The solar array panels total nearly 21 mi^2 with a total system weight of about 25 million pounds.

Because of the availability of nearly limitless solar energy in synchronous orbit, the deployment of SSPS's could provide all the Earth's energy needs. For example, 80 SSPS's could supply all our projected 1985 electrical needs of 400,000 MWe.

The technologies required to make the SSPS a viable system are: low-cost high-efficiency solar cells; light-weight structures that can be assembled in space; a low-cost synchronous-orbit transportation system, and a reliable, safe microwave system.

At the present time the costs of such a system are prohibitive. For example, present space solar arrays cost $200,000/kW or more. Such a high cost would result in a power cost of 4800 mills/kW-hr for electricity compared to conventional electricity costs of about 7 mills/kW-hr. The goal for the SSPS concept is to reduce the costs so the total system is of the order of $1000/kW.

Electricity from solar cells on Earth

The possibility of placing large solar arrays on the ground in prime areas of the U. S. has also been looked at by Cherry (ref. 8) and by Spakowski and Shure (ref. 9), (figure 11). Several advantages over the space system are immediately obvious, such as elimination of the need for a microwave system and for a space transportation system. However, on the ground the average solar radiation is much less, being less than 25 watts/ft^2 even in our prime southwest desert areas compared to 130 watts/ft^2 in orbit. Also, because of the day-night cycles and inclement weather, energy storage is required for the ground-based system.

Even with the above limitations, the ground system offers the potential of supplying all our 1985 electrical needs by using an area 100 by 100 miles of our southwest deserts covered with presently available solar cells of 7% efficiency. In addition to the solar cells, however, energy storage must be provided for the day/night cycle.

The technologies required for the ground-based system are low-cost solar arrays and low-cost energy storage.

It is now possible to purchase solar arrays for ground usage at about $100,000/kW (significantly lower than space arrays). This cost must be lowered to $1000/kW or less if solar cells are ever to compete with conventional means of generating electricity.

Electricity from Solar Thermal Energy

This concept uses solar energy in the form of thermal energy and has recently been suggested for re-evaluation by the Meinels (ref.10) and by the University of Minnesota and Honeywell, Inc. (ref 11). Very simply, solar energy is collected and focused on pipes carrying a heat transport fluid. The fluid is heated to a high enough temperature for operation of a conventional steam power Rankine system, figure 12.

The major system components are the focusing collector, absorber, heat transport loops, energy storage and the powerplant. The key technologies are both in the component and the systems area. Focusing-type collectors are needed to obtain the required temperature range of $600^{o}F$ to $1000^{o}F$ for efficient powerplant operation. The collectors must also be able to withstand periodic cleaning and problems associated with wind, desert, and rain storms. Stable absorber coatings of α/ϵ of 10 or greater are required. The heat transport loops collect energy from square miles of desert and must be efficient. Pumped loop and heat pipe systems using H_2O, air, and liquid metals are being investigated. Energy storage is a major problem. Energy storage may be limited to supplying requirements for daily periods of darkness, for longer periods of inclement weather, or for averaging summer peak radiation with the low winter radiation.

Because of the higher efficiencies possible with this system, it is estimated 60 x 60 miles of our southwest desert could supply all our 1985 electrical needs.

Preliminary cost estimates have been made by advocates of this system. Their estimates range from $1000/kW to $3000/kW resulting in a 15-50 mills/kW-hr cost for the electricity.

This system appears to have potential, but what is needed is innovative component and system approaches to develop low-cost competitive systems.

Electric Power from Ocean Temperature Difference

An interesting system for generating electricity that has been demonstrated by Claude (ref. 12) is the ocean Δ T system that uses the warm and cold ocean water to operate a heat engine (figure 13). It is proposed by the Andersons (ref. 13) that such a system would float in the Gulf Stream off the sourthern cost of Florida and generate electricity economically. The upper ocean layers are warmed to about 80^{O}F by the Sun and are used to boil a fluid to drive a turbine. The turbine operates a generator for making electricity. The fluid is condensed by a cold water supply of 40^{O}F at depths of about 2000 feet. The cold water is the result of melting of the polar ice caps and this cold water is flowing toward the Equator.

Systems using the ocean ΔT have been demonstrated: Claude demonstrated a 22 kW system in Cuba in 1929 and the French built two 3500-kW systems in the 1950's. The major advantages of such a system are that no collectors or storage are required. The ocean both collects and stores the solar energy for day/night cycles and inclement weather.

The ocean Δ T system has the potential to make a major contribution to our energy needs. For example, it has been estimated that less than a 0.3^{O}F drop in Gulf Stream would supply all our 1985 electrical needs (400,000 MWe). It is also interesting that the ocean Δ T system reduces the thermal pollution of oceans instead of increasing it as most other systems do.

The oceanΔT does have some key technology needs that must be solved before this system can contribute to our needs. The technologies identified are:

1. The long large-diameter cold-water duct. The duct will be about 30 feet in diameter and 2000 feet in length. A major problem is how to support and anchor such a duct with the lateral forces exerted on it by the ocean currents flowing in opposite directions at different depths.

2. The large low-cost heat exchangers. Because of the low ΔT available, large heat exchanger surfaces are required to extract large amounts of power. New methods for fabricating large, low-leakage heat exchangers at low costs must be determined.

3. Seawater compatibility. The ocean ΔT system must be compatible with the ocean. It must withstand corrosion, hurricanes, and the possibility of debris, fish, etc., from clogging up the boiler passages. The methods for operating and maintaining a sea-plant and delivering its energy to shore must also be determined.

Preliminary cost estimates by advocates of the ocean ΔT system range from $300 to $500/kW. Such capital costs indicate that the ocean ΔT system may provide very competitively priced electricity. However, these estimates depend on solving the key technology problems.

Electric Power from the Wind

Solar-derived wind power can and has been used to generate electricity. A large 1.25 MWe wind-generator was built in Vermont (ref. 14) in the early 1940's and delivered electricity directly into the local power grid. Wind-generators are currently being used to generate small amounts of power around the world. A 200 kW wind-generator was constructed in Denmark (ref. 15) in 1957, figure 14.

There is no question about the technical feasibility of generating electricity from wind-generators as evidenced by the many demonstrations. The only question is can electricity be generated continuously and competitively by wind power and is there enough wind power available to make a significant impact on our energy needs? Besides electricity, the wind-generators could be used to produce fuel (H_2) by electrolysis to be used for transportation or other purposes.

Estimates by advocates of wind power in this country, such as Heronemus (ref. 16), claim there is enough wind power to supply all our electrical needs and that winds in the Great Plains alone could supply 50% of our 1985 electrical needs (400,000 MWe).

The question that comes up most often when discussing wind power is that of energy storage. What happens when the wind stops? Energy storage would certainly make it possible to use wind-generators for individual or small-scale applications such as homes or small communities. However, wind-generators could be added to any system that has storage such as pumped-storage or a conventional hydroelectric plant. In addition, wind-generators could supply power to any grid and the storage could be considered to be the fuel that runs the conventional generating plant. What needs to be done is to determine applications for large-scale use of wind-generators. This includes wind analysis and economic analysis. Also, storage should be worked on but is not essential for all applications. Analysis of wind data may show that netowrking of large generators without storage may make sense.

Costs of previous demonstrations and estimates by present-day advocates range from \$200 to \$650 per installed kWe with a cost of electricity from 7-15 mills/kW-hr. Electricity from wind appears attractive and should be looked at seriously.

SOLAR ENERGY FOR HEATING AND COOLING BUILDINGS

Approximately 25% of our present energy consumption is used for heating and cooling buildings. This energy demand is met by the use of gas and oil. Supplying this thermal energy for buildings by solar energy would save our dwindling supplies of gas and oil for other uses.

As shown in figure 15, solar energy can be utilized for heating and cooling of buildings by putting flat-plate collectors on the roof. These collectors are fairly simple in construction. A black surface is used to absorb the sunlight, this surface is covered with one or several panes of glass which reduce re-radiation. The collector is insulated on the sides and back to prevent conduction and convection losses.

Water, air or some other fluid is passed through the collector and can reach temperatures from 140°F to greater than 200°F. The thermal energy from the fluid is then stored in a heat storage container to provide energy for the day/night cycle. The thermal storage can be sensible heat of water or rocks or the latent heat-of-fusion of special salts.

Coupled to the heat storage system are a heating loop and a cooling loop. The heating loop takes heat from the thermal storage system to heat the building. The cooling loop takes heat from the thermal storage to operate an absorption or mechanical airconditioning system. Also connected to the heat storage loop is an auxiliary heater. The purpose of this heater is to supply thermal energy to the system during periods of inclement weather using conventional fuel.

Twenty buildings are presently heated with solar energy in the United States. The upper photograph in figure 16 is of a home in Dover, Massachusetts. Solar energy provided 90% of the heat load during the month of February. The bottom picture shows an office building in Albuquerque, New Mexido. Solar energy provides 75% of the heating load for this building.

None of the solar-heated homes has solar-supplied airconditioning. The addition of airconditioning could make the solar energy systems for buildings much more competitive. Systems could then be utilized nearly 12 months of the year. Solar supplied airconditioning will also help reduce our peak-load requirements on our electrical systems.

The Federal Council on Science and Technology (FCST) solar energy report estimates that by 2020 40 to 50% of the thermal energy for buildings in the U. S. could be supplied by solar energy. In areas and buildings where solar energy is used, it is estimated that solar energy can supply up to 75% of the buildings' thermal energy needs.

The technology needs include efficient low-cost flat-plate collectors. To operate airconditioning systems, temperatures equal to or greater than 200°F are needed. Collectors must be developed that can be manufactured for about $\$2/ft^2$ compared to present costs of about $\$4/ft^2$. Also needed is low-cost efficient thermal storage. Present methods use water or rocks and the latent heat of fusion of some salts. As mentioned above, a critical need is to develop low ΔT airconditioning systems. Absorption and mechanical systems are being considered.

Economic studies by Lof and Tybout (ref. 17) have indicated that solar heating is less expensive than electrical heating anywhere in the U. S., but is not competitive with gas or oil in most places. If solar airconditioning systems can be developed, however, the picture should change. For example, it is estimated that it costs $312/yr for fuel to heat and cool the average house. These fuel costs could pay for a $3000 solar heating/cooling system mortgaged over 15 years. With the increase in fuel costs, the solar systems will become even more economical.

CLEAN RENEWABLE FUEL FROM SOLAR ENERGY

At the present time gas and oil supply nearly 75% of all the nation's energy sources. The U. S. is rapidly running out of domestic supplies of gas and oil. Figure 17 shows several processes for producing fuel from solar energy:

Electrolysis. - Hydrogen can be produced from electrolysis powered from solar-generated electricity.

Direct Burn. - Land and water plants can be grown, dried and processed to provide fuel for use in present powerplants in place of coal dust as proposed in the Energy Plantation Concept by Szego (ref. 18).

Conversion Systems. - There are several systems for converting organics to gas or oil. These systems include pyrolysis, chemical, and biochemical conversion.

Pyrolysis is a destructive distillation process that heats organics in the absence of air. Pyrolysis has been investigated as a way to convert refuse to oil by Sonner (ref. 19). A present demonstration plant produces two barrels of oil (12,000 BTU/lb) from each ton of dried organics at a breakeven cost of about 75 cents/10^6 BTU.

In the chemical process organics are heated under pressure in the presence of water and a cover gas of CO. A small pilot plant demonstration of this system indicates that two barrels of oil per ton of dried organics can be produced (15,000 BTU/lb) at a breakeven cost of about 87 cents/10^6 BTU.

Several biochemical or fermentation processes have been in the U. S. over the past 20 years as sanitary plants. These systems produce methane which is used in the process for fuel; however, the plants have not been optimized to produce fuel.

Photolysis

A process currently being funded by the NSF for laboratory research is the photolysis of water. This is a proposed method for getting H_2 and O_2 from water and sunlight using blue-green algae and micro-organisms. This process is fundamentally possible but must be developed to determine technical feasibility.

As shown in figure 18, approximately 15% or 470,000 mi^2 of U. S. land is presently used to produce food, and another 3% or 95,000 mi^2 is kept in reserve as surplus land. We presently pay farmers nearly $2.6 billion not to grow crops on this surplus land. If this surplus land could be used to grow crops for fuel at the present efficiency rates of 1%, enough fuel could be produced to meet 10% of our predicted 1985 total energy needs. If this efficiency could be increased to 5%, then 7% of our land area could supply all our 1985 energy needs.

To make fuel from crops economically feasible, crops with the highest BUT's per acre per year must be identified or developed. Also, low-cost processing methods such as harvesting, preparation, and transportation must be identified. And finally, low-cost conversion systems for converting crops to gas and/or oil must be developed.

Assuming an average of 1500 BTU/ft^2 per day, it can be shown that one acre of farm land growing crops at 1% conversion efficiency will produce 230x10^6 BTU/yr. At \$1/10^6 BTU one acre of land then yields $230 worth of energy. Conversion efficiencies must be pushed higher and harvesting and processing costs must be kept low if clean fuel from solar energy is going to be economical.

Several preliminary costs estimates for producing fuel from organics indicate that such processes are close to being economically competitive today. Present-day costs for natural gas and oil range from \$.50/10^6BTU to \$1.20/10^6 BTU respectively.

NATIONAL SOLAR ENERGY PROGRAM

As shown in Table II, the National Science Foundation Solar Energy Program was begun in 1971 with a total of 1.2 million dollars. This effort has grown over the last 4 years to an expected value of 12.2 million dollars for 1974. The effort is divided between the three major areas of electric power generation, heating and cooling of buildings and clean fuel production. The National Aeronautics and Space Administration's program invested about $1 million in 1973 and has about 15 scientists working in this area.

During the year 1972 a joint NASA/NSF solar energy panel was formed to assess the potential of solar energy as a national resource. Experts in all areas of solar energy were pulled together to come up with recommended development plans for the selected solar energy systems. The panel report was published in late 1972.

The objective of the present NASA and NSF solar energy programs is to develop practical, economical and socially acceptable systems utilizing solar energy for the generation of electricity, heating and cooling of buildings, and the production of clean fuels.

Figure 19 shows the possible milestones that could result from the solar energy program. The upper arrows indicate the systems developed under government funds while those at the bottom show potential industry takeover. As indicated in the NASA/NSF Solar Energy Report, it is estimated that solar energy, if developed vigorously, could supply up to 50% of the total U. S. energy required in 2020.

The total U. S. energy research and technology funding as shown in Figure 20 has increased from about $300 million in 1970 to just over $500 million in 1973. This funding has been divided mainly between nuclear and coal, with nuclear receiving the most, followed by coal, and with a small amount for solar. It is interesting to note the U. S. spends about $100 billion a year for energy and that $500 million for research and technology represents only 0.5% of our total energy bill. With as little as a 0.5% increase in our energy costs, we could double over nation's research efforts on energy. This would allow adequate investigation and development of alternate sources with potential, such as solar.

CONCLUDING REMARKS

1. Solar energy is a nondepleting energy source that is abundant, clean and safe.

2. Solar energy can be used to supply all our energy needs such as generation of electricity, heating and cooling of buildings, and production of clean fuel.

3. Development of technology and systems utilizing solar energy will make us less dependent on foreign nations. It will also help our balance of payments by reducing fuel imports and providing an exportable technology that can help other countries.

4. Solar energy appears to offer much potential as a major energy source to help meet our nation's energy needs. It is an area that has been inadequately funded and should receive increased support.

References

1. Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies, April 1972, submitted to the Office of Science and Technology, Associated Universities, Inc.

2. National Gas Supply and Demand, 1971-1990, Staff Report No. 2, Bureau of Natural Gas, Washington, D. C., Feb. 1972.

3. The U. S. Energy Problem, Vols. 1, 2, and 3, by InterTechnology Corporation, Nov. 1971, to National Science Foundation.

4. U. S. Energy Outlook: An Initial Appraisal, 1971-1985, Vol. I.

5. Duncan, Donald C., and Swanson, Vernon E.: Organic-Rich Shale of the United States and World Land Areas; Geological Survey Circular 523, U. S. Department of the Interior, 1965.

6. Solar Energy as a National Energy Resource; NSF/NASA Solar Energy Panel, Dec. 1972.

7. Glaser, Peter E.: The Use of the Space Shuttle to Support Large Power Generation Systems - paper presented at meeting of American Astronautical Society, Dec. 26-31, 1972, Washington, D. C.

8. Cherry, William R.: Generation of Pollution-Free Electrical Power from Solar Energy. Goddard Space Flight Center, March, 1971, X-760-71-135.

9. Spakowski, A. E., and Shure, L. I.: Large-Scale Terrestrial Solar Cell Power Generation Cost - A Preliminary Assessment, Lewis Research Center, March 1972, NASA TMX-2520.

10. Meinel, A. B. and Meinel, M. P.: Solar Power Farms, A Briefing

to the Task Force on Energy of the House of Representatives Committee on Science and Astronautics, Washington, D. C., March 6, 1972.

11. Research Applied to Solar-Thermal Systems - Prepared for NSF by University of Minnesota and Honeywell, Semi-Annual Program Report, NSF Grant GI-34871. Period 7-1-72 to 12-31-72.

12. Claude, G.: Power from the Tropical Seas, Mechanical Engineering, December 1930.

13. Anderson, J. Hilbert and Anderson, James H.: Large-Scale Sea Thermal Power, ASME Paper 65-WA/Sol-6, Dec. 1965.

14. Putnam, Palmer C.: Power from the Wind, D. VanNostrand Co., Inc. New York, 1948.

15. Juul, J.: Design of Wind Powerplants in Denmark, Proc. of UN Conf. on New Sources of Energy, Rome, Aug. 21-31, 1951, p. 229, Vol. 7.

16. Heronemus, Wm.: The United States Energy Crisis: Some Proposed Gentle Solutions, Joint Meeting of the local sections of the ASME and IEEE, West Springfield, Mass., Jan. 12, 1972.

17. Tybout, R. A. and Lof, G. O. G.: Solar House Heating, Natural Resources Journal, 10, (2) p. 268-326, April, 1970.

18. Szego, G. C., Fox, J. A., Eaton, D. R., The Energy Plantation, Paper No. 729168, IECEC, Sept. 1972.

19. Sonner, W. S., et al:: Conversion of Municipal and Industrial Refuse into Useful Materials by Pyrolysis, U. S. Department of Interior, Bureau of Mines Report, No. RI-7428, August 1970.

TABLE I. - DOMESTIC SOLUTIONS TO NATION'S ENERGY NEEDS.

SOLUTIONS	RESERVES	MAJOR ENVIRONMENTAL PROBLEMS	TECHNOLOGY NEED
COAL	~500 YR	POLLUTION STRIPMINING	COAL GASIFICATION LOW COST EXTRACTION
NUCLEAR	~10 000 YR	SAFETY QUESTIONS NUCLEAR WASTE	FAST BREEDER WASTE HANDLING
SOLAR	UNLIMITED	NONE	LOW COST SYSTEMS

E-7439

TABLE II. - NSF SOLAR ENERGY PROGRAM

	FY 71	FY 72	FY 73	FY 74
ELECTRIC POWER	1 2 M	1. 1 M	1.5 M	6 0 M
HEATING AND COOLING	0	0. 1 M	1.0 M	3 3 M
RENEWABLE FUEL SOURCES	0	0. 4 M	1. 5 M	2 9 M
TOTAL	1. 2 M	1. 6 M	4 M	12. 2 M

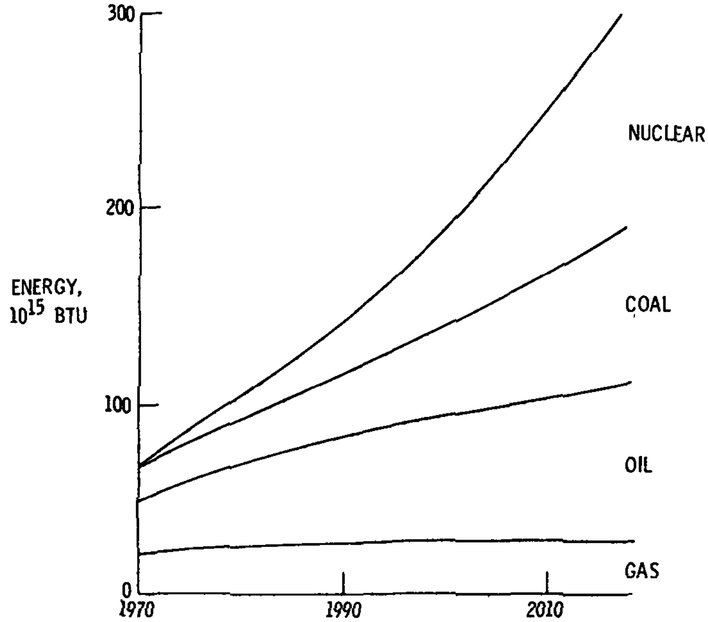


Figure 1. - U. S. energy demand.

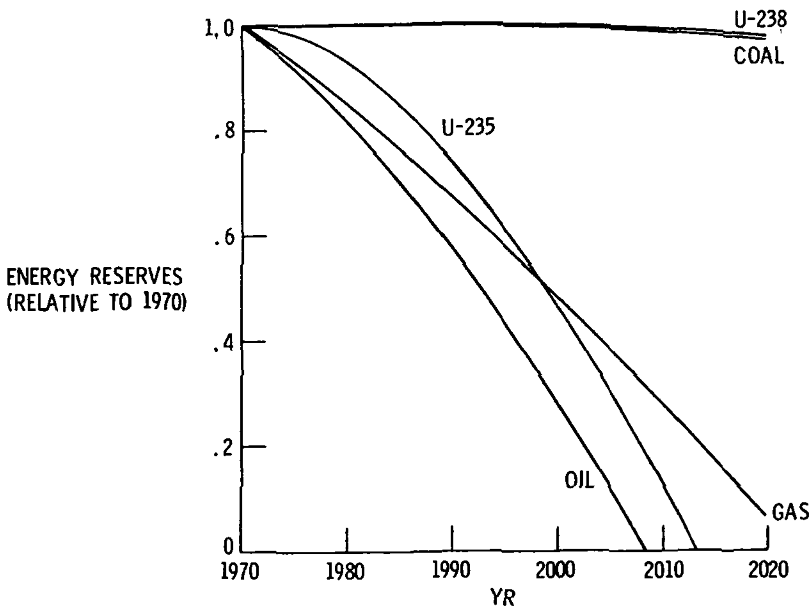


Figure 2. - Depletion of domestic energy reserves.

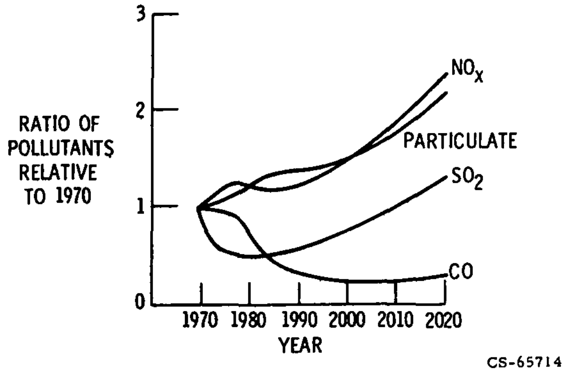


Figure 3. - Relative annual production of pollutants.

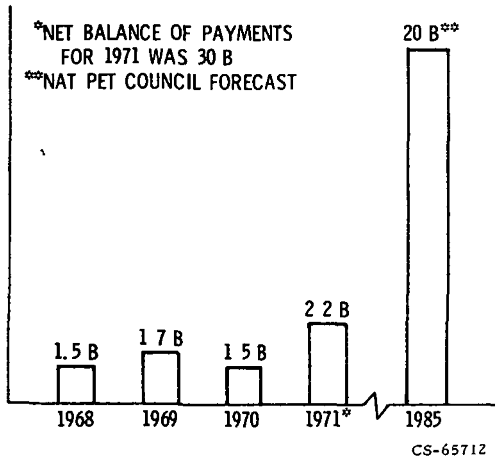


Figure 4. - U. S. net cash outflow for fuel imports.

E-7439

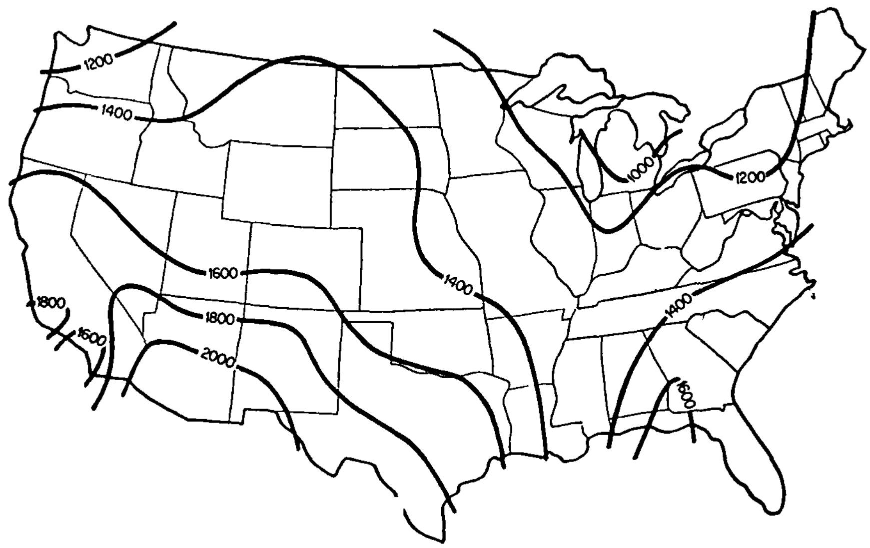


Figure 5 - Solar heat, btu/ft^2/average day.

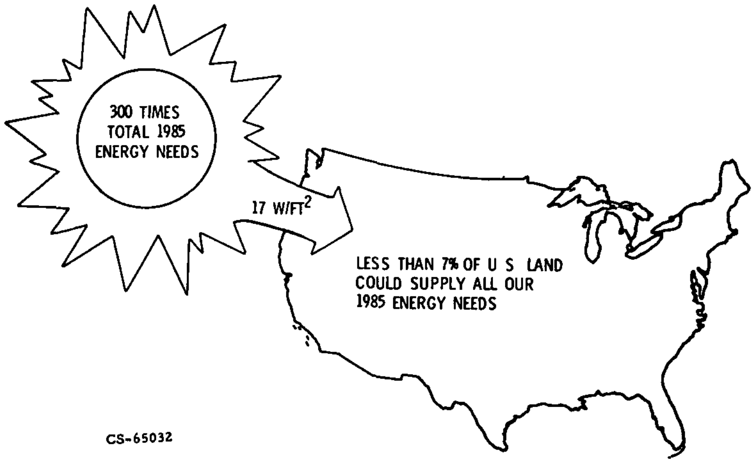


Figure 6. - Solar energy is diffuse but abundant.

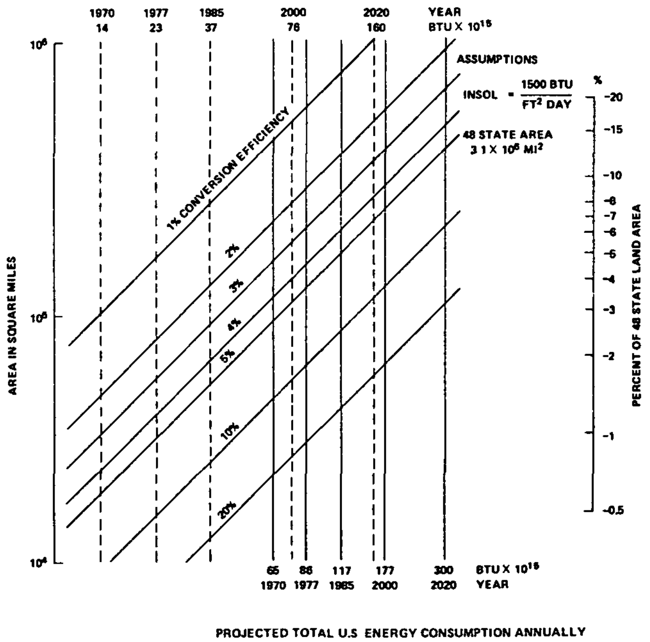


Figure 7. - Percent U S. land area required to meet U. S. energy needs as a function of conversion efficiency. (1) From the NSF/NASA solar energy report (ref. 6).

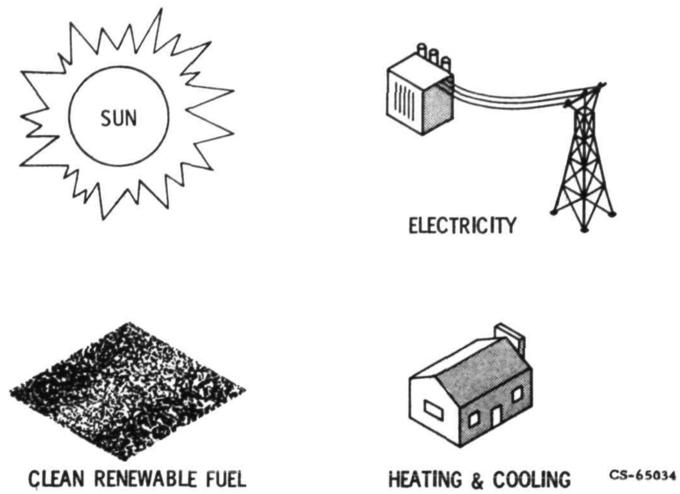


Figure 8. - Solar energy can provide all energy needs.

E-7439

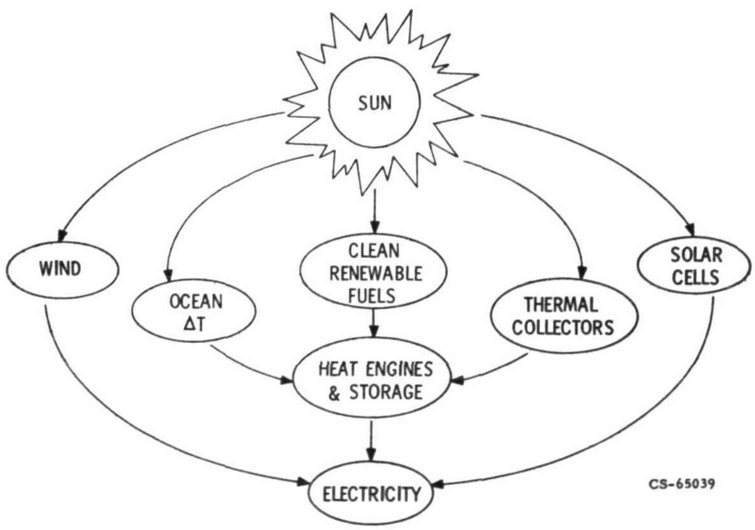


Figure 9. - Electricity from the sun.

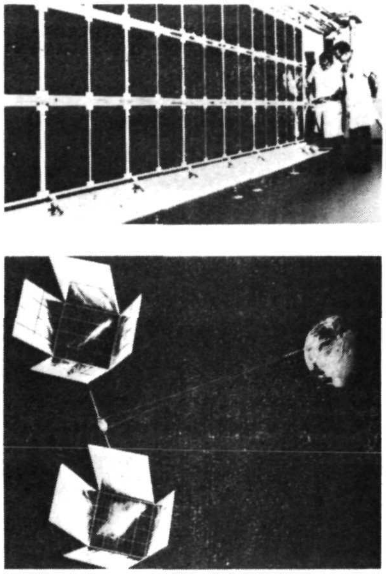


Figure 10. - Electricity from solar cells in space.

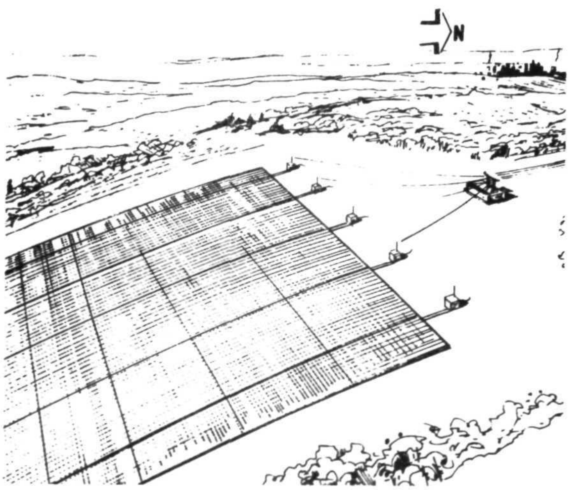


Figure 11. - Electricity from solar cells on the earth.

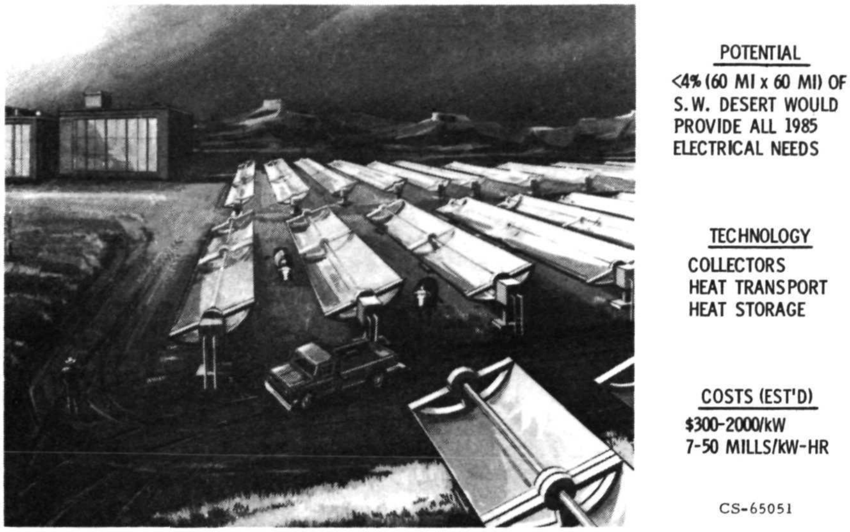


Figure 12. - Electric power from solar thermal energy.

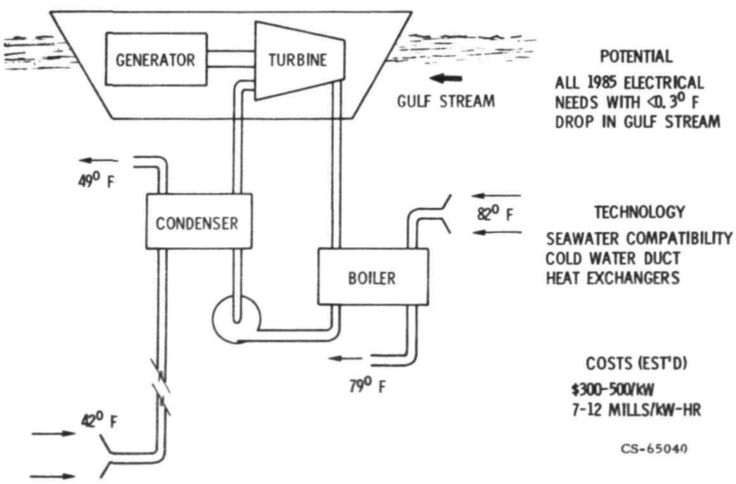


Figure 13. - Electric power from ocean ΔT.

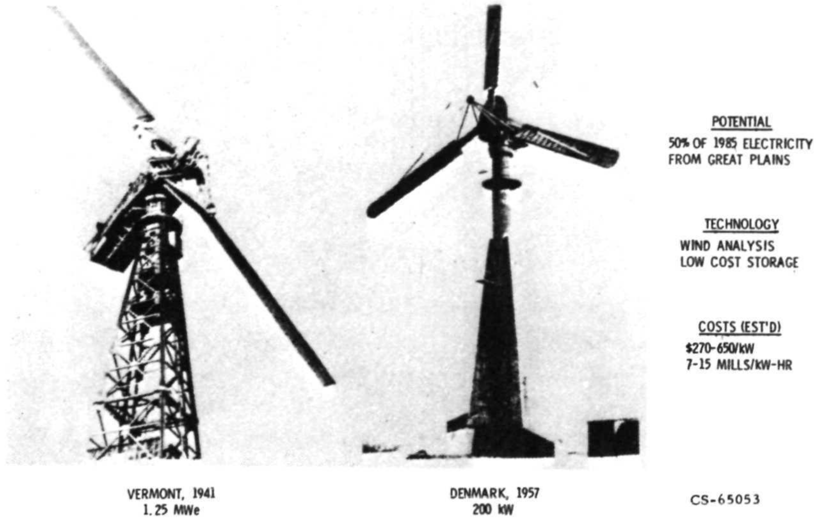


Figure 14. - Electric power from wind.

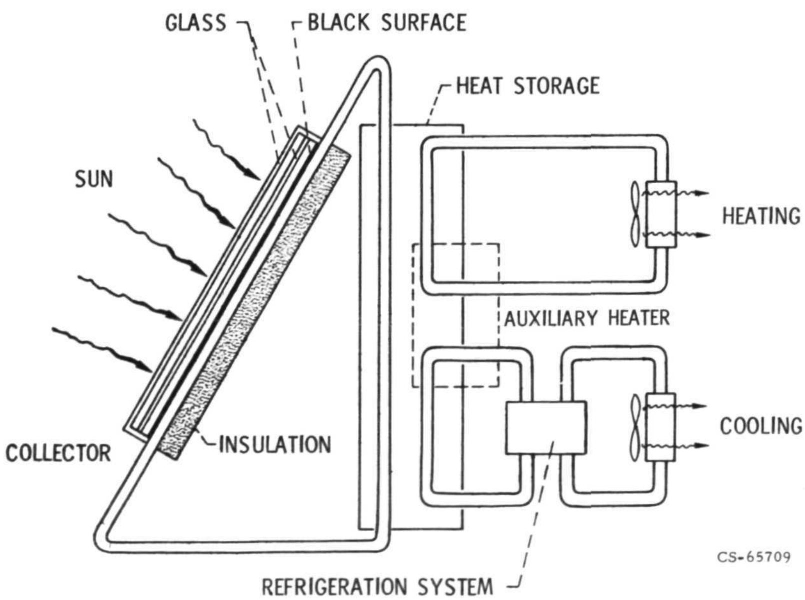
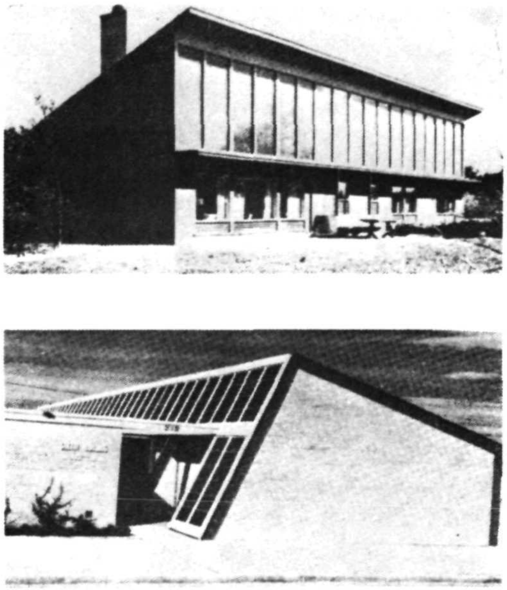


Figure 15. - Solar energy for heating and cooling buildings.



POTENTIAL

CAN PROVIDE 75% OF THERMAL ENERGY FOR BUILDINGS

TECHNOLOGY

COLLECTORS
HEAT STORAGE
AIR CONDITIONING

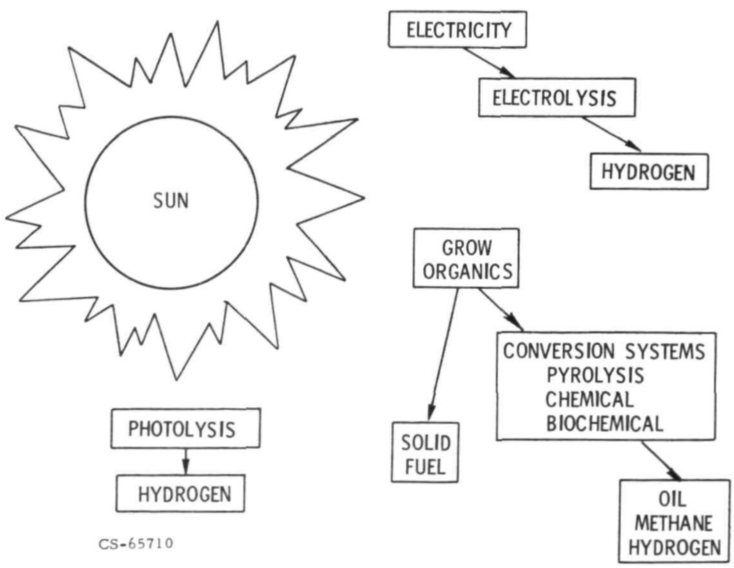
COSTS (EST'D)

$312/YR FOR HEATING & AIR CONDITIONING

CS-65050

Figure 16. - Solar energy for heating and cooling buildings.

E-7439



CS-65710

Figure 17. - Clean renewable fuel from solar energy.

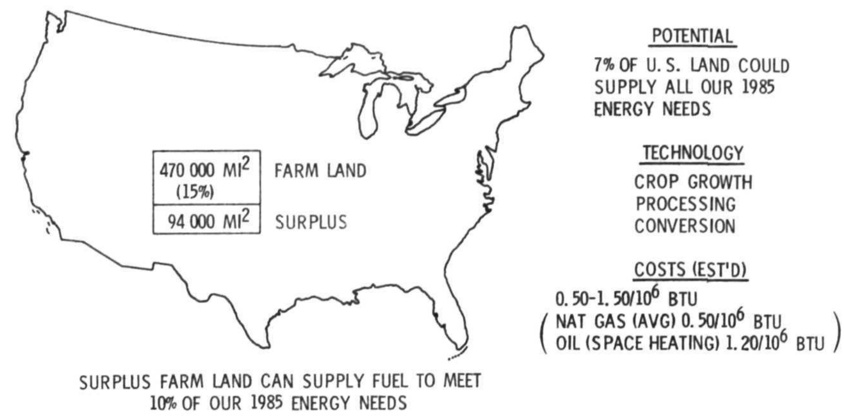


Figure 18. - Clean renewable fuel from solar energy.

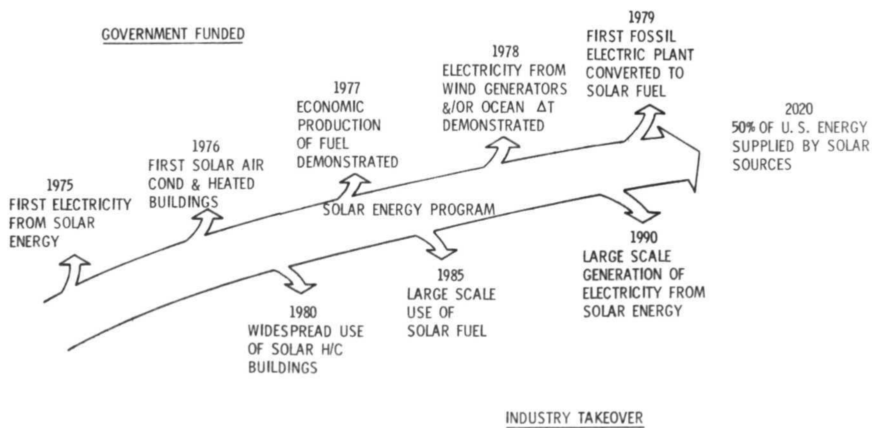


Figure 19. - Solar energy program milestones.

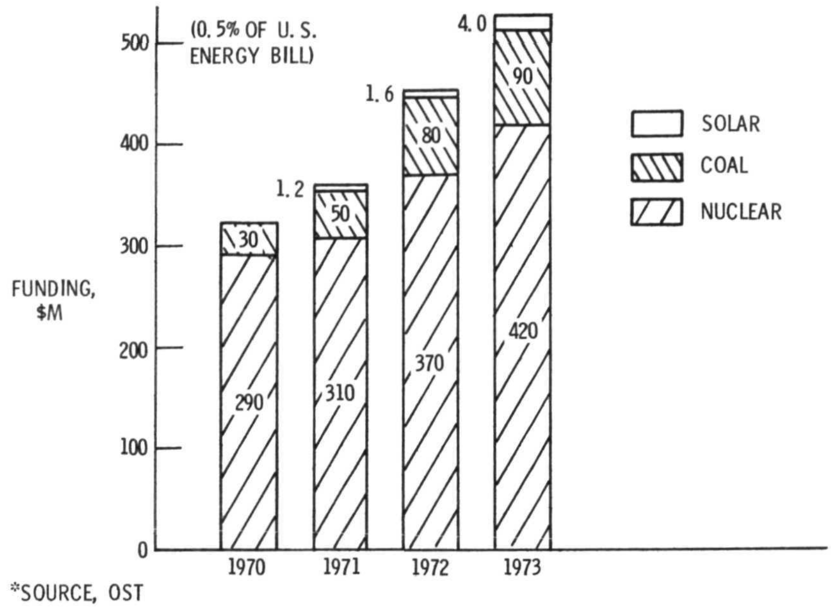


Figure 20. - U. S. energy research and technology funding*.

E-7439

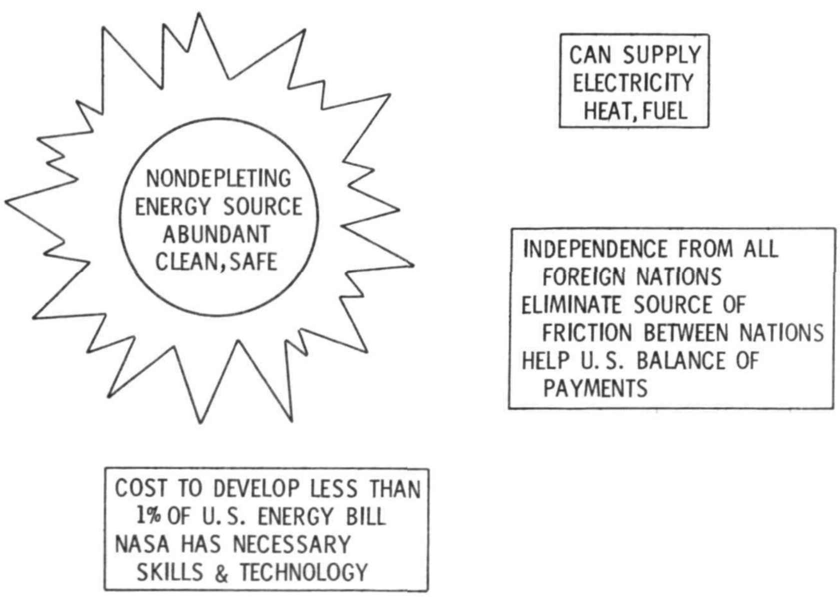


Figure 21. - Solar energy program summary.