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SOLAR ENERGY RESEARCH AND UTILIZATION

WILLIAM R. CHERRY

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SOLAR ENERGY RESEARCH AND UTILIZATION

by
William R. Cherry

ABSTRACT

The gas and oil shortages of the 1970's are forewarnings of more serious energy deficiencies to come near the turn of the century. Solar energy processes are on the verge of commercial readiness to help the nation utilize this enormous, renewable clean source for many of our future energy needs. The paper describes what role solar energy will play in the heating and cooling of buildings, the production of renewable gaseous, liquid and solid fuels, and the production of electric power over the next 45 years. Potential impacts on the various energy markets and estimated costs of such systems are discussed along with illustrations of some of the processes to accomplish the goals. The conclusions of the NSF/NASA Solar Energy Panel (1972) are given along with the estimated costs to accomplish the 15 year recommended program and also the recent and near future budget appropriations and recommendations are included.

Introduction

The energy "crisis" of 1973–1974 is mostly associated with the production of useable fuels and their distribution and not because the world has run out of natural gas and crude oil. Further, since a great deal of our energy is wasted in overheated, overcooled and poorly designed structures and oversized, overpowered vehicles the demand for energy has become disproportionate to our true needs. Even with some moderation on these demands the world's energy consumption is expected to continue to increase for the foreseeable future creating major problems world wide in the extraction, refinement and distribution of our fossil fuels in the next few decades.

The shortages of the 1970's have brought into focus the necessity for man to look at renewable sources of energy which are abundantly available yet, when used, have minimal effect on the environment. One of the few energy sources that meets these criteria is Solar Energy. Numerous times in history the use of solar energy has been tried and discarded because it was not cost competitive with existing energy sources. However, the true costs of the conventional sources of energy have rarely been taken into consideration especially when the costs of destroyed land, disposal of useless or hazardous wastes and the degradation of the atmosphere, health, structures, flora and fauna are considered. Now with the cost of fossil fuels increasing substantially and the problem of future availability questionable, solar energy is finding applications which are competitive with conventional sources of energy.

Availability of Solar Energy

Solar energy arrives on the surface of the 48 contiguous states at the average rate of 4000Kcal/M^2day (1500Btu/ft^2/day), more in the southern U.S. and less in the north. Figure 1 shows the anticipated consumption (Ref. 1) of energy in the U.S. for all purposes for the years 1970, 1977, 1985, 2000, and 2020 amounting to 16, 21, 29, 44, and 75 x 10^{15} Kcal/yr (65, 86, 117, 177, and 300 x 10^{15} Btu/yr), respectively. To produce the equivalent of the total expected energy requirement for the U.S. in the year 2000 by converting solar energy arriving at the ground at 10% efficiency it would require about 4% of the U.S. 48 state land area or about 322,500km^2 (124,000 square miles). This is slightly larger than the state of Arizona. To put it in another perspective, the major metropolitan areas of the U.S. cover 1½% of the U.S., the Great Lakes occupy about 3% and U.S. farms cultivate greater than 15% of our land area to produce about 1% of our energy – food. Therefore, setting aside various regions in the U.S. as energy farms shouldn't create major problems; in fact, a lot of nonproductive land would suddenly become useful.

In the Solar Energy Panel's report (Ref. 2) of December 1972 three applications were identified in which solar energy could have a major usage impact. These are:

Thermal Energy for Buildings
Production of Renewable Clean Fuels
Electric Power Generation

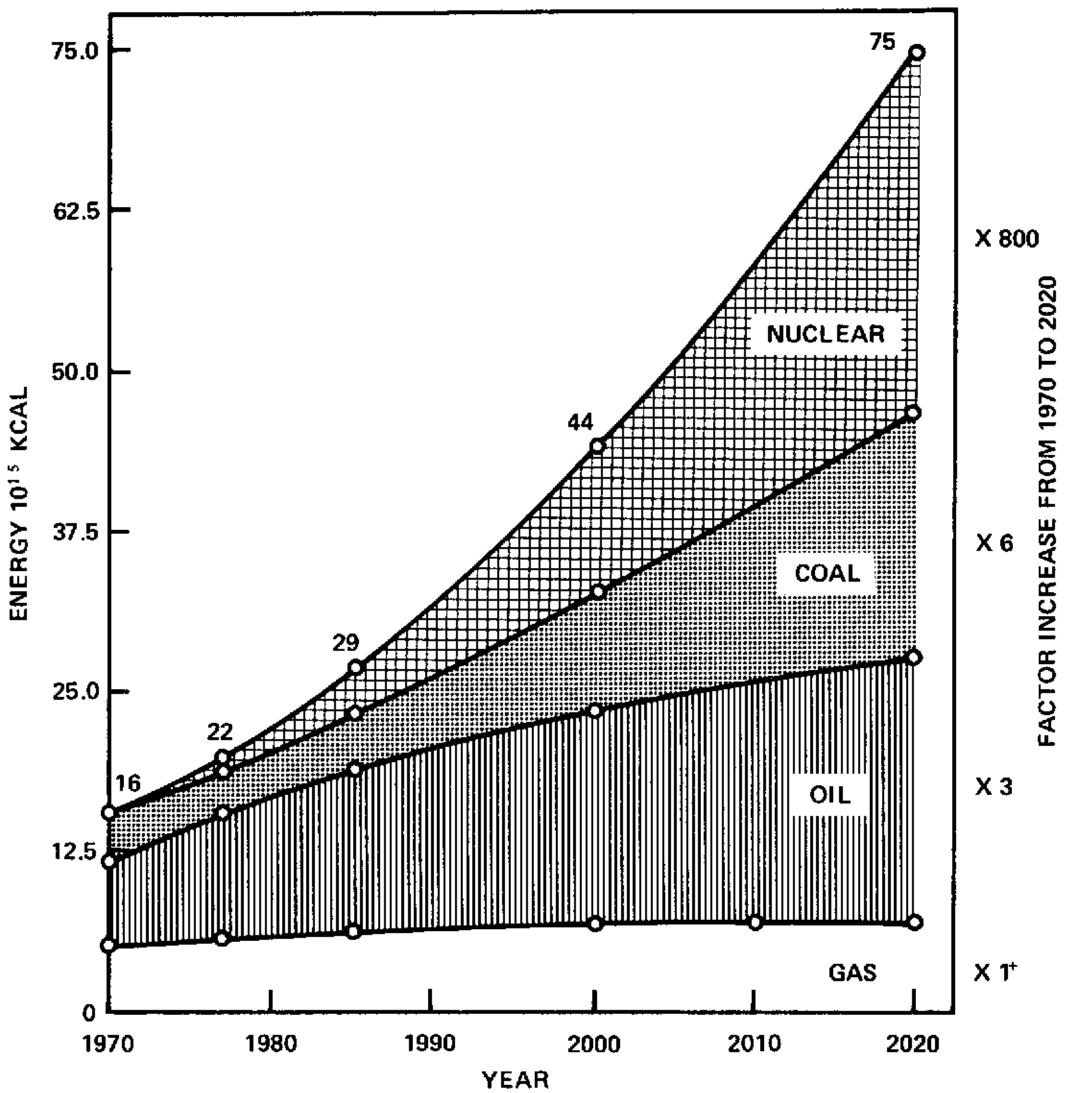


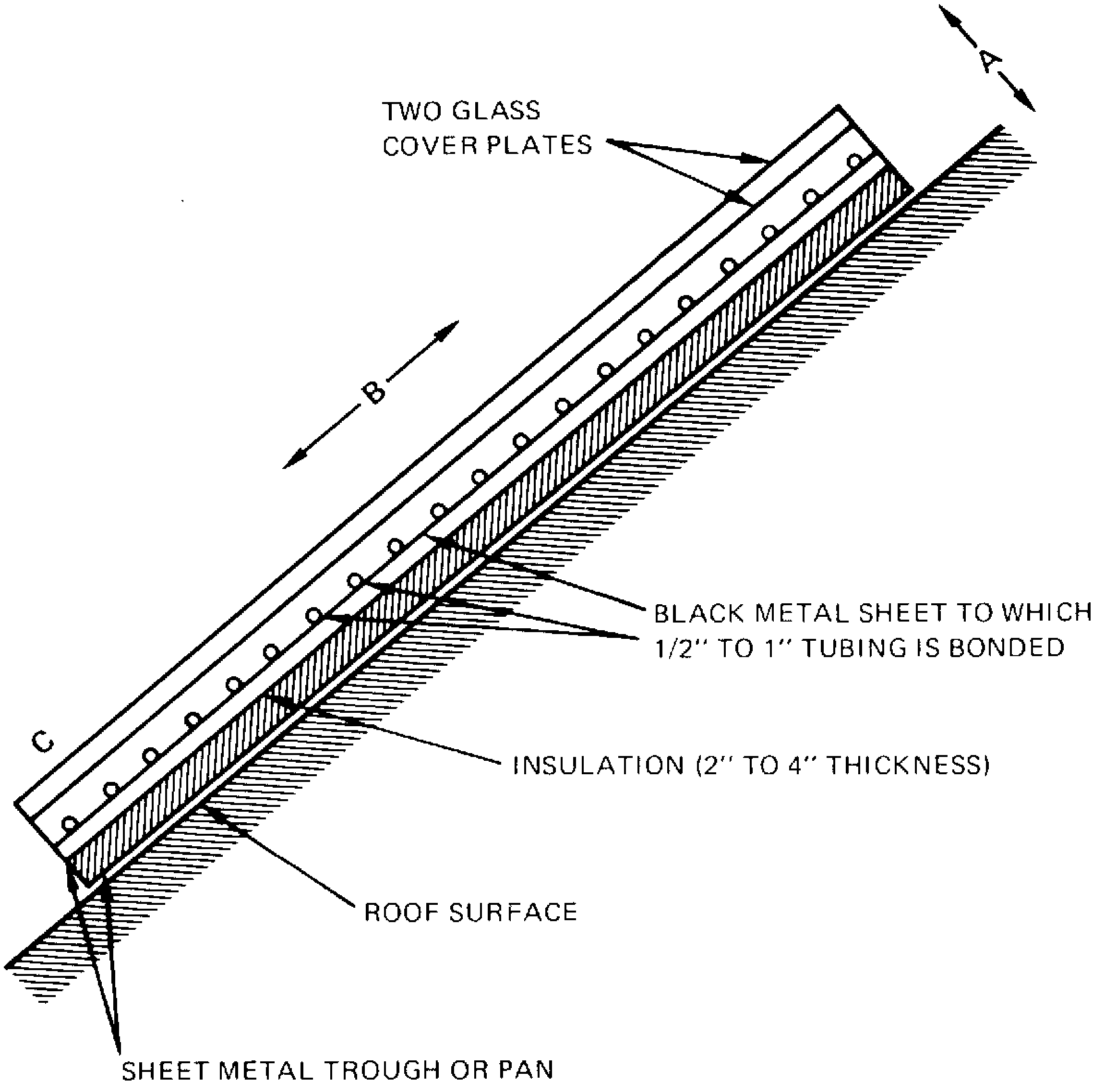
Figure 1. Projected U.S. Energy Demand by Source

Thermal Energy for Buildings

By the year 2000 about 5.25 x 10^{15} Kcal (21 x 10^{15} Btu) or 12% of the U.S. energy consumption will be used for heating and cooling buildings. If only 10% of this load is derived from solar energy it would represent a savings of over 0.5 x 10^{15} Kcal (2 x 10^{15} Btu) of fossil fuels which at \$8/10^6 Kcal (\$2/10^6 Btu) would represent an annual savings of over \$4 billion! Over 30 buildings in the U.S. have been equipped with solar heating systems which derived various amounts of their heating needs but none attaining 100%. The houses have been built in Massachusetts, Maryland, Florida, Delaware, New Mexico, Arizona, California, Oregon, Colorado and other areas. Only a very few structures have been built to provide a significant amount of the cooling needs of a house but great progress is now promised. The major capital investment in a solar house is the collector which must be large enough to absorb sufficient thermal energy to provide adequate instant heat and allow for storage of heat during the night or for inclement weather. The black flat plate collector covered with one or more layers of glass, illustrated in Figure 2 is typical of many systems so far developed. Some systems do use water cascading down the hot collectors rather than the closed tubes illustrated, while some systems circulate air over the collectors and store thermal energy in rock beds. Water temperatures range up to the boiling point under good sunny conditions and precautions must be taken about excessive collector temperatures if the system is shut down during the summer. In regions with favorable night sky radiation in summer, bags of water built into the roof have been used for cooling of dwellings. During the day the bags are shielded from the sun and absorb heat from within the structure. At night the shields are removed and the heat radiated to the night sky thus cooling the water mass for the next day's cooling process. In winter, the process is reversed, exposing the water bags to the sun in the daytime to absorb thermal energy, then shielded from the sky at night to prevent radiation loss and provide warmth to the dwelling.

An experimental house in Delaware is equipped with a combination of cadmium sulphide photovoltaic arrays and flat plate collectors as illustrated in Figure 3. Air is circulated behind the solar arrays and the latent heat is stored in tubes containing fused salts which have melting points of about 10°C (50°F), 24°C (75°F) and 50°C (120°F). During the heating season the house air is circulated over the 50°C (120°F) salts while during the summer it passes by the 10°C (50°F) salts. A small heat pump allows the shifting of the thermal energy from one fused salt to another depending on the need. The electric power generated by the solar arrays is passed to an electrochemical storage system where it is held in reserve until needed or directly used in the house. While dwellings in the U.S. have used combinations of solar thermal collectors and wind generators to provide heating and electric power this is the first structure which has combined photovoltaics and thermal systems.

A 1970 study (Ref. 3) of costs of residential space heating showed that in a number of places in the U.S. solar energy was competitive with fossil fuels at that time. With the recent dramatic increases in natural gas and oil fuels, many more regions of the U.S. will find the use of solar energy very competitive. When solar cooling can be used in conjunction with heating then solar energy for space conditioning becomes very attractive. An industry must be started so that the cost advantages of mass production can be brought to bear on the present high cost of collectors. These present \$64 - \$107/m^2 (\$6 - \$10/ft^2) must approach \$32 - \$42/m^2 (\$3 - \$4/ft^2) and the public must have the benefits of a service industry before wide spread use will take place. Government funding will probably be necessary for "pump priming" of the industry and incentives given for installing capital intensive equipment which must be amortized over the life of the dwelling. Operating and maintenance costs should be low while fuel costs are zero. In regions where solar heating cannot handle the entire load, an auxiliary fossil fuel must be integrated with the solar system.



NOTES: ENDS OF TUBES MANIFOLDED TOGETHER
ONE TO THREE GLASS COVERS DEPENDING
ON CONDITIONS

DIMENSIONS: THICKNESS (A DIRECTION) 3 INCHES TO 6 INCHES
LENGTH (B DIRECTION) 4 FEET TO 20 FEET
WIDTH (C DIRECTION) 10 FEET TO 50 FEET
SLOPE DEPENDENT ON LOCATION AND ON
WINTER-SUMMER LOAD COMPARISON

Figure 2. Solar Collector for Residential Heating and Cooling

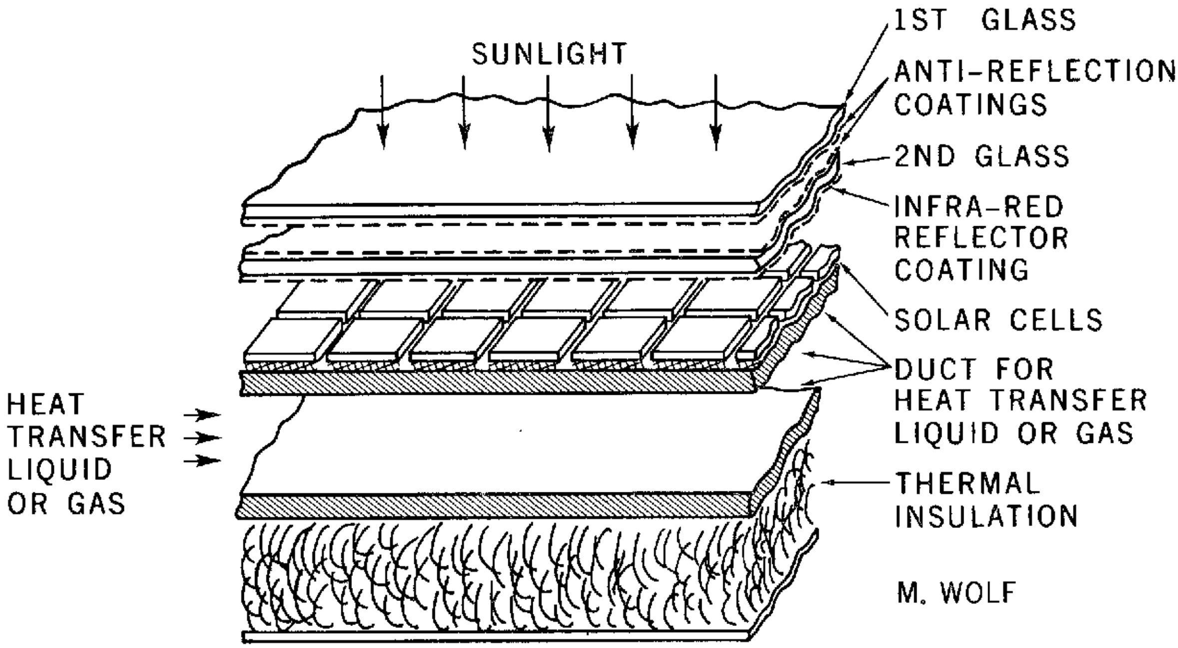


Figure 3. Structure of Combination Thermal-Photovoltaic Solar Collector

Production of Renewable Clean Fuels

Over 95% of the U.S. total energy is derived from fossil fuels. Until the last few years, much of the industry and central power plants were attempting to use natural gas for firing boilers in an attempt to comply with NEPA emission standards. When natural gas became difficult to obtain, especially for new installations, oil was selected as the fuel because of cost and ease of use. This, plus the addition of millions of new vehicles to the economy each year, placed an unprecedented demand on oil refinery capacity causing short falls to appear in various locations in the U.S. Because foreign crude oil was available at costs below domestic stock, the U.S. became more and more dependent upon imports, reaching somewhere near 35% of our total demands by 1973. About half of these imports were from the middle east and when that supply became seriously reduced in late 1973 the availability of petroleum products reached a critical stage. President Nixon's late 1973 proclamation to become independent of outside sources for energy is indeed a desirable one but will require a great deal of exploitation of our natural deposits of gas, oil and coal. In addition, solar energy can be used to produce a line of renewable, clean gaseous, liquid and solid fuels which can supplement the Nation's growing demand for fuel yet have a minimal impact on the environment and even help dispose of our wastes.

Gaseous Fuels

In general about 285 m^3 (10^4 ft^3) of methane gas can be produced from 900 kgm (one ton of dry organic material (Ref. 4) which corresponds to about 2.5 x 10^6 Kcal (10^7 Btu) of heating value. The U.S. presently uses about 0.57 x 10^{12} m^3 (20 x 10^{12} ft^3) of natural gas per year.

Under advanced growth conditions, 2% conversion efficiency, about 4.5 x 10^6 kgm/km^2 (20 Tons/acre) of organic material can be produced per year and even more might become available through plant research. Therefore, each km^2 (acre) could produce enough organic material to yield 1.4 x 10^6 m^3/km^2 (2 x 10^5 ft^3) of methane gas. Thus 0.57 x 10^{12} m^3/yr (20 x 10^{12} ft^3/yr) divided by 1.4 x 10^6 m^3/km^2 (2 x 10^5 ft^3/acre) yields 4 x 10^5 km^2 (10^8 acres) of the U.S. to produce all the current natural gas consumption. This is equivalent to about 5% of the U.S. 48 state land area or less than 1/3 of the area used for farming. This crop being renewable year after year could continue to supply a large amount of the nation's gaseous fuel needs for years to come. Costs of natural gas during 1971 ranged from about $1.00 to $4.00 per million Kcal compared with estimated costs of $2.00 to $8.00 per million Kcal for solar produced methane.

Liquid Fuels

The pyrolysis of organic materials under an atmosphere devoid of oxygen at temperatures greater than 500°C will produce both combustible gases and a good quality oil suitable for use in power plants. (Ref. 5) Research on 17,600 kgm (4 Ton) per day plant showed that about 2 barrels of oil can be derived from a 900 kgm (ton) of dry organic material. Enough gas was also produced to provide the fuel to heat the reactor to produce the oil. If the 4 x 10^5 km^2 (10^8 acres) mentioned in the previous paragraph were devoted to oil production at 4.5 x 10^6 kgm/km^2 (20 tons per acre) per year about 4 x 10^9 barrels of oil could be produced each year from this land. This is equivalent to about 2/3 of the present total U.S. petroleum consumption. Major developments in farming and harvesting enormous crops at low cost must be achieved before such a system will compete with natural crude oil prices but the recent upswing in costs and the eventual nonavailability of natural crude oil will make the pyrolysis process more attractive. Natural crude ranged from about $2.00 to $4.00 per million Kcal in 1971 compared to estimated costs of $3.00 to $6.00 per million Kcal by the solar/pyrolysis process. Already this process is being used for the disposal of urban wastes and because there is a credit earned for the cost to dispose of garbage this helps to make the liquid fuels produced by these plants competitive with natural fuels. If the total U.S. solid urban waste of about 4.5 x 10^{10} kgm/yr (5 x 10^7 tons/yr) were subjected to pyrolysis, about 10^8 barrels of oil could be obtained. This is about 1½% of our annual petroleum consumption.

Solid Fuels

With the drive to convert the gas and oil burning boilers of industry and the electric utilities to coal perhaps some could be converted to wood burning. Until about 1971 more energy in the U.S. was derived from wood burning than from controlled nuclear fission. A recent study (Ref. 6) showed that in certain regions of the U.S. conditions exist which would permit the production of clean, renewable wood fuels at a competitive price with fuel oil. Assuming a 1% solar energy capture efficiency and an average annual insolation 4000 Kcal/m^2/day (1500 Btu/ft^2/day) an area of about 1000 km^2 (400 square miles) would produce enough wood on a continuous basis to power a 1000 MW steam electric plant operating at 35% efficiency with a load factor of 75%. This energy plantation would have the power plant located near its center and would emit a minimum of pollutants because of complete combustion processes and controlled nutrients in the plantation soil from which the fuel is derived. Improved photosynthetic processes could reduce the land area needs. Also, they would be attractive and useful for recreation and ecological purposes. Modern growing, harvesting chipping and drying processes would have to be utilized and developed. Estimates of the price of fuel derived from pulpwood and chips ranged from about $4.60 to $5.40 per million Kcal in 1971. Coal and oil costs ranged from about $2.00 to $4.00 at that time.

Electric Power Generation

In 1970 about 22% of our total energy consumption was devoted to the generation of electric power including the use of gas, oil, coal and nuclear energy. Only electric power produced from hydroelectric plants, amounting to about 3% of our total energy demand, did not consume some unrenewable resource for its production. Unfortunately most of the choice sites for hydro power plants in the U.S. have been built up and it appears that it is unlikely to ever double the production of electricity by this method on the U.S. mainland. Projections (Ref. 1) indicate that more and more of our increasing total energy consumption will be used to produce electric power amounting to 27% in 1977, 32% in 1985, 43% in 2000 and greater than 50% by 2020.

Nuclear energy has been the bright hope of the future to pick up the electric power generation load from the fossil fuels. With the many problems the world is facing in harnessing the atom ranging from sociological, ecological to technological it is clear that alternate methods for producing electricity should be explored now so that they will be ready for wide scale application in the next 15 to 30 years. Following are some indications of the potential of solar energy related methods which could provide significant quantities of electric power to the U.S.

Wind Power

Kung's (Ref. 7) studies indicate that between 1% and 1½% of the 1 kw/m^2 of energy reaching the earth's surface in the U.S. is converted into the kinetic energy of the atmosphere thus amounting to some 10 to 15 watts/m^2. Certain regions of the U.S. have reliably continuous winds particularly along the New England and Middle Atlantic East Coasts, along the Great Lakes, through the Great Plains, along the Gulf Coast, through the Rockies and Cascades and along the Aleutian Chain of islands. It is estimated (Ref. 2) that there is over 10″ kilowatts of generating capacity in the winds over these regions. If only 0.1 of 1% of this energy were converted to electric power it would be equivalent to one quarter of the total electric generating capacity of the U.S. today. Due to friction and deflection by buildings and natural features of the terrain the aeroturbines should be placed from 30 to 350 meters (100 to 1000 feet) above the ground and in those locations where winds persist at 4.5 to 6.5 m/sec (10 to 15 mph) or greater. A comprehensive study (Ref. 8) shows how the total electric power requirements for all of New England could be derived from floating wind stations located off shore. Hydrogen can be produced as a clean fuel from such an installation, stored in underwater pressure vessels and shipped to the mainland as a clean fuel in place of the diminishing natural gas. Table 1 indicates the electric power generation

Table 1

Electrical Energy Production from Wind Power by 2000 AD

Site	Annual Power Production	Possible by Year
Offshore, New England	318×10^9 kWh	2000
Offshore, Eastern Seaboard, along the 100 meter contour, Ambrose shipping channel south to Charleston, S.C.	283×10^9 kWh	2000
Along the E-W Axis, Lake Superior (320 m)	35×10^9 kWh	2000
Along the N-S Axis, Lake Michigan (220 m)	29×10^9 kWh	2000
Along the N-S Axis, Lake Huron (160 m)	23×10^9 kWh	2000
Along the W-E Axis, Lake Erie (200 m)	23×10^9 kWh	2000
Along the W-E Axis, Lake Ontario (160 m)	23×10^9 kWh	2000
Through the Great Plains from Dallas, Texas, North in a path 300 miles wide W-E, and 1300 miles long, S to N. Wind Stations to be clustered in groups of 165, at least 60 miles between groups (sparse coverage)	210×10^9 kWh	2000
Offshore the Texas Gulf Coast, along a length of 400 miles from the Mexican border, eastward, along the 100 meter contour.	190×10^9 kWh	2000
Along the Aleutian Chain, 1260 miles, on transects each 35 miles long, spaced at 60-mile inervals, between 100 meter contours. Hydrogen is to be liquified and transported to California by tanker.	402×10^9 kWh	2000

Estimated Total Production Possible: 1.536×10^{12} kWh by year 2000

possible by the year 2000 if steps are taken now to mass produce this significant energy source. Costs of plant installations are expected to range from about $300 to $600 per kilowatt and electric power costs ranging from 16 to 21 mills per kWh. One of the largest aeroturbines built in the U.S. was located at Grandpa's Knob near Rutland, Vermont. In a 9 m/sec (20 mph) wind this unit developed 1.25 mw from the 53 meter (175 ft) tip to tip blades. An ice storm during the early 1940's caused a blade fracture and the whole system fell into disuse when low cost electric power was strung through New England by the Rural Electrification Administration shortly after World War II.

Ocean Thermal Power

Enormous amounts of solar energy is absorbed by the tropical oceans increasing their surface waters to temperatures above 27°C (80°F). The melting of polar ice caps and glaciers causes a large source of cold dense water at about 4°C (40°F) to flow along the ocean bottoms toward the equator eventually warming and rising to the surface and then heading North in the Northern hemisphere. In regions where the warm and cold water overlay each other, such as in the Gulf Stream, the potential exists for the conversion of this energy into electricity using Carnot cycle engines. Figure 4 illustrates a possible floating station (Ref. 9) with dimensions of 120 meters (360ft) long by 100 meters (300ft) deep located in the Gulf Stream

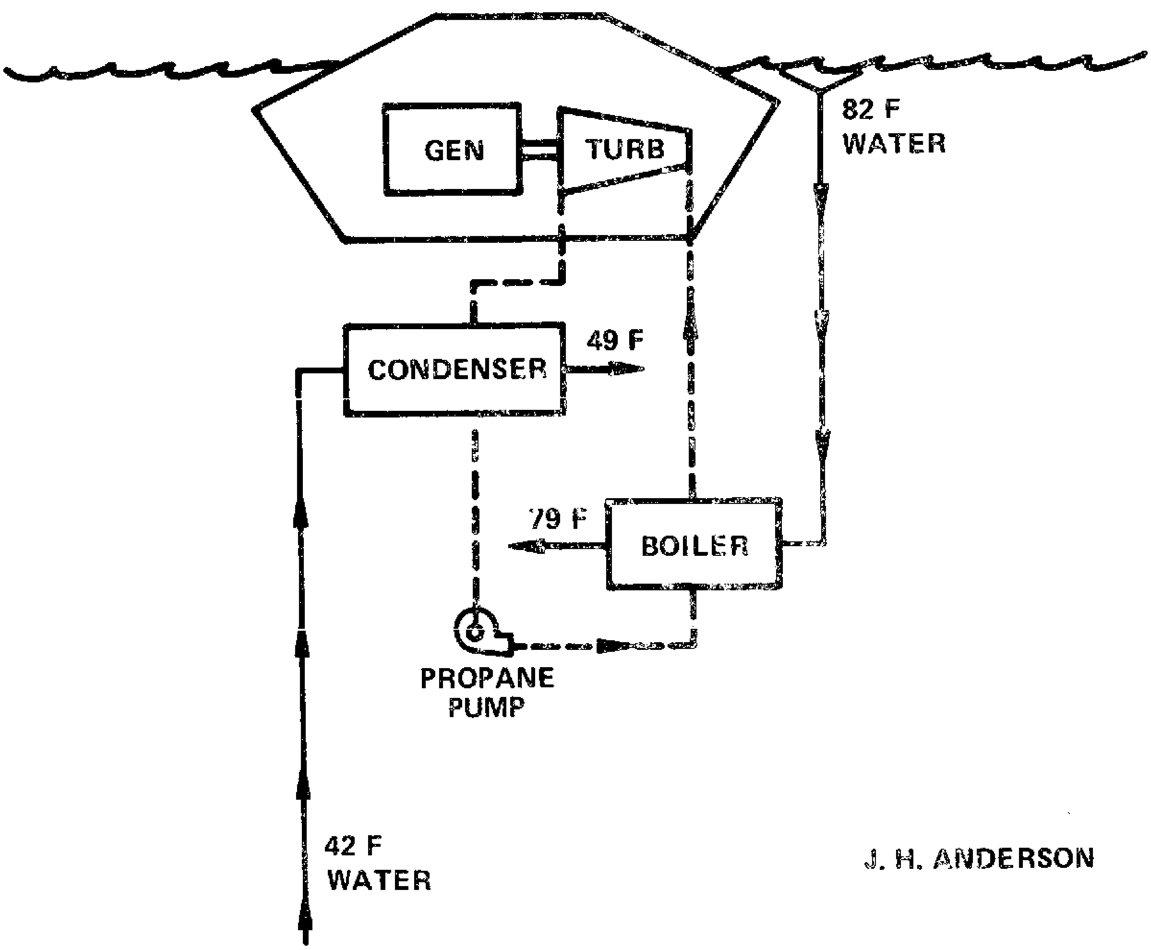


Figure 4. Sea Solar Power Plant

and drawing warm water from the surface and the cooling water from depths of 600 to 900 meters (2000 to 3000 feet). Assuming a 3% efficient system, a power plant of 100 mw would require the passage of about 1.8 million m^3 (64 million cubic feet) of warm water per hour for the boiler. With a 1.5 x 100 meter (5 foot high by 300 foot long) intake it would need to capture water at the rate of 3.5 m/sec (8 miles per hour), just about the speed of the Gulf Stream. Cooling water for the condensers would be drawn through a pipe about 10.5 meters (35 feet) in diameter from near the bottom of the ocean. The propane would be contained in a closed system and is the medium which powers the turbogenerator producing the electricity.

Since ocean thermal power plants are closely allied to the ship building industry some reasonable estimates can be derived for the power station costs. Installation costs are estimated to be between $300 to $500 per kw and because of very favorable load factors of 90% the cost of power is expected to range from 5 to 10 mills per kWh. Ocean thermal power stations obviously require the special conditions of warm surface waters and cool underlying currents. This occurs only on the Gulf and lower Atlantic coasts of the U.S. but could be developed as a major electric power source for those regions of the U.S.

Concentrated Solar Thermal Electric Power Plant

Vast regions in the SW portion of the U.S. are endowed with direct sunshine between 80% and 90% of the possible sunlight time. By focussing the solar radiation on tubular collectors under a concentration factor of about 10, temperatures of 425°C (800°F) or more can be obtained. The general scheme of such a system is shown in Figure 5. Several studies (Ref. 10) are underway to better identify the problems of large scale solar thermal systems and components. If systems of 20% efficiency evolve which are economically competitive with conventional electric power generation methods, then a 1 million Kilowatt power station would occupy about 26 sq. km (10 sq. mi) of desert in the U.S. SW. Much new technology and materials developed for the space program will be brought to bear on the solar thermal

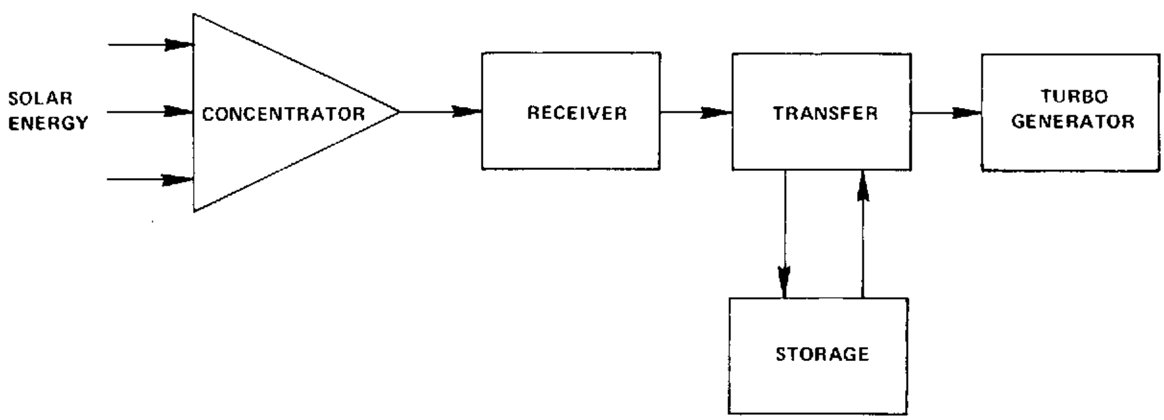


Figure 5. Thermal Conversion Concept

collection, transmission, storage and conversion problems to see how such systems fit into the Nations' future. Plant installation cost estimates range from about $900 to $2000 per installed kilowatt. This is considerably more than fossil fuel plants but nuclear installation costs are now rising above $500 per kilowatt. When fuel and disposal costs for the life of these plants are considered there could be some major trade-offs by the 1990's.

Photovoltaic Electric Power Generation

Photovoltaic type phenomena have been known since first reported by E. Becquerel in 1839. It wasn't until 1954 when the Bell Telephone Laboratories announced the silicon solar cell that practical conversion efficiencies approaching 10% became available. Since that time, about a dozen substances have been researched for their potential as practical photovoltaic materials. Silicon solar cells have been used almost exclusively for powering long life satellites since the launching of Vanguard I March 17, 1958. Gallium arsenide was developed to a space flight quality but didn't replace silicon because of its significantly higher cost. Thin film cadmium sulphide cells in 7½ x 7½cm (3 x 3inch) sizes have not as yet proven themselves suitable for space flight but are striving for acceptance in terrestrial applications. The greatest problem in adopting photovoltaics for ground applications is their cost, primarily caused by the very limited production needed in the space program and the rather sophisticated materials and processes required in their production. Typical performance characteristics of the three main solar cell materials are shown in Table 2.

Table 2

Solar Cell Efficiencies

Material	Air Mass Zero (Space)	Air Mass One (Ground)
Silicon	11–12%	13–14%
Gallium Arsenide	10–11%	12–13%
Cadmium Sulphide	3–4%	5–7%

Some recent developments (Ref. 11) in the silicon solar cell fabrication methods are showing individual cells with air mass zero efficiencies greater than 14% and ground performance approaching 18% with the expectations of attaining 20% in the next year or two. While space quality silicon solar arrays cost anywhere from $300 per watt to over $1000 per watt, terrestrial systems are now selling for around $50 a peak watt in small orders and as low as $20 a peak watt in kilowatt quantities. Improved manufacturing processes and an expanding market for remote and unattended navigation aids and data relay stations should reduce these costs to something around $10 per peak watt. A peak watt is defined as the maximum power output of an array at normal incidence to the sun in the zenith at sea level on a clear day (approximately $100 mw/cm^2$).

Before extensive use of photovoltaic arrays will come about, such as wide application on buildings, auxiliary power plants and massive central station installations, large scale automated methods of producing long life arrays at costs in the tens of cents per peak watt will have to be developed. Steps in this direction are being made in the research of single crystal silicon dendritic growth (Ref. 12) and the Edge Defined, Film-Fed Growth (EFG) process (Ref. 13) which will permit the continuous growth of ribbons suitable for making solar arrays. Cadmium sulphide lends itself particularly well to mass productions since the base material is deposited upon thin substrates by a vapor deposition process. (Ref. 14) Other investigations (Ref. 15) are underway in methods of depositing silicon films by chemical vapor deposition (CVD) so as to reduce array fabrication costs and reduce the amount of semiconductor needed in an array. The ultimate method will probably closely resemble the process and technology used in the manufacture of photographic film which is produced in millions of square meters per year at costs less than $10.00 per square meter. This concept is illustrated in Figure 6 which represents a continuous operation with efficient use of manpower, materials, and energy.

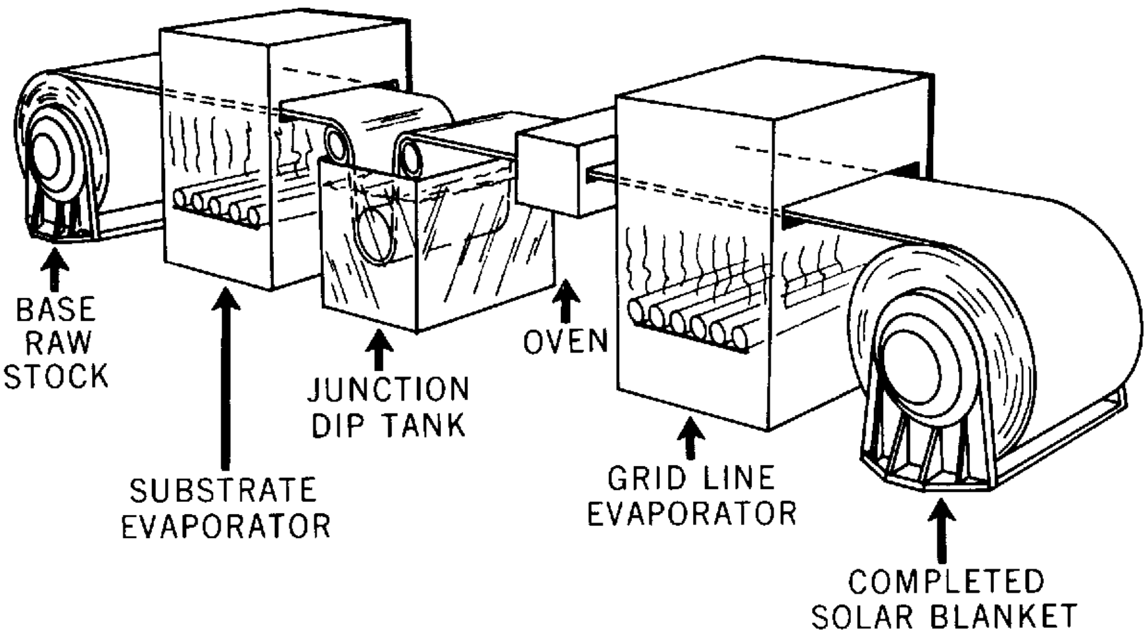


Figure 6. Solar Array Manufacturing

When low cost photovoltaic arrays become available in large quantities one of the early applications will be for providing electric power on buildings and at remote sites. Experiments using solar arrays in conjunction with flat plate thermal collectors were studied at the University of Pennsylvania and now being done at the University of Delaware's "Solar One" house where cadmium sulphide is employed. Figure 3 illustrates the general principle showing the collection of sunlight on the solar array where electricity is produced and the cooling of the array being done by the passage of a fluid behind the cells. The thermal energy is then stored in either rocks, a liquid or in fused salts until needed for space conditioning.

As very large amounts of solar array become available then considerations will be made for their use in terrestrial central power stations. (Ref. 17) This is illustrated in Figure 7 showing the conversion of underutilized land into productive regions. For such stations to become self-sufficient for around the clock service, inexpensive high capacity electric storage systems will have to be developed to work in conjunction with them. These are in research now. Another concept (Ref. 18) explores the potential of floating power stations on huge helium filled mattresses at elevations in excess of 50,000 feet to get above the weather. A "mattress" 2.6 sq. km (1 sq. mile) and 30 meters (100 feet) thick could support over 9.1×10^6 kgm (10,000 Tons) at 0.1 atmosphere elevation, sufficient to provide 250,000 KW of electric generating capacity.

The ultimate method for collecting solar energy is described in a concept of a synchronous space station (Ref. 19) converting the sun's rays to electricity by solar arrays, inverting to microwaves which are beamed to a terrestrial station which then converts the energy back to 60 hertz current. All of these schemes would require considerable research and development of components and systems which are not yet available and especially the development of very low cost solar arrays.

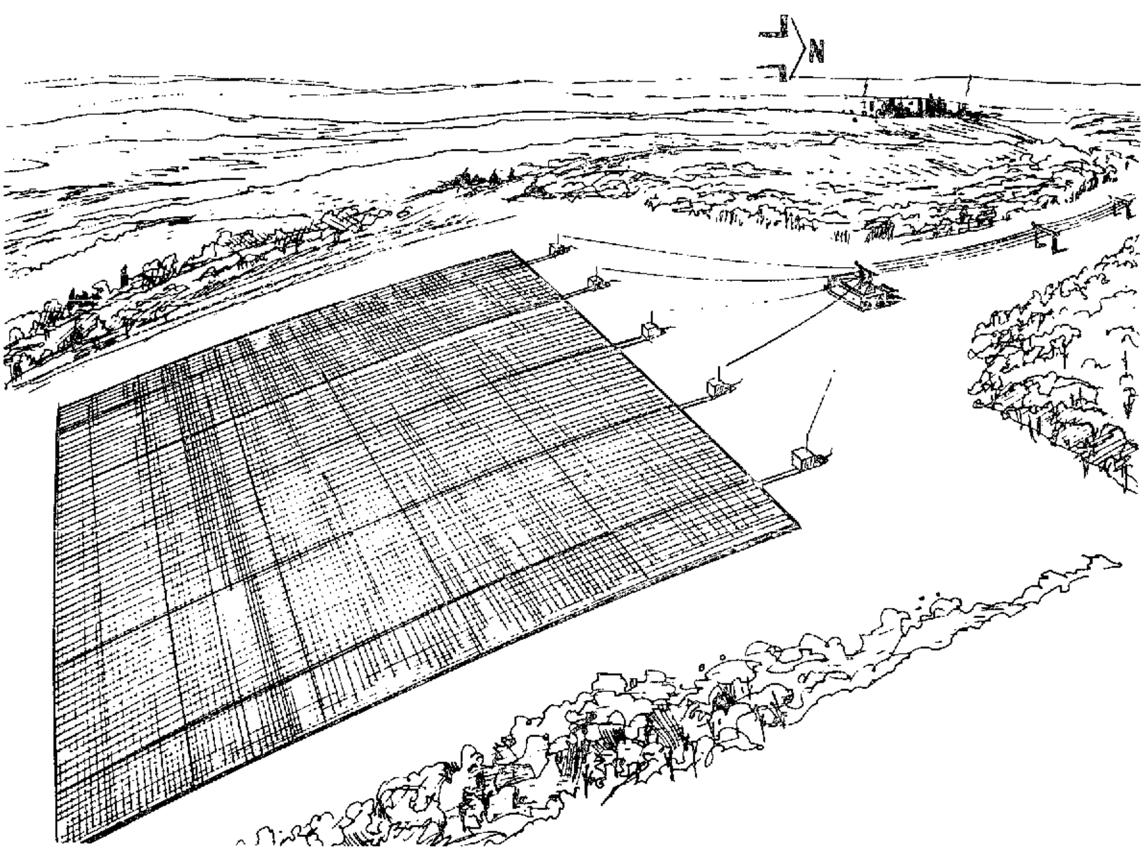


Figure 7. One Square Mile Terrestrial Solar Power Plant

Electric Power Plant Costs

The comparative costs for the construction for various types of electric power plants are shown in Figure 8. The costs for gas, oil and coal plants are well known; however, due to nonavailability of fuel no new gas and oil fired plants are being built in the U.S. Some oil plants are being converted to coal and there are about 50 new nuclear plants in planning or under construction which will add to the 37 or so now on line. Costs for all these plants are increasing dramatically as are the fuels they consume. The construction costs of breeder plants are projected to range from $500 to $1000 per installed kilowatt but the first full scale plant is not expected "on line" until the early or mid 1980's. Since no commercial power plants using solar derived energy or fuels have been built, the construction cost varies widely depending upon the source. Best estimates seem to fall near the $1000 per kw price which is high in the 1970 market but will be competitive in the near future. Obviously, no operating experience has been gained for solar plants, thus these costs can only be estimated but are thought to be modest. Fuel costs are zero. Wood burning plants would be similar to coal fired plants since the only difference in their operation would be the fuel.

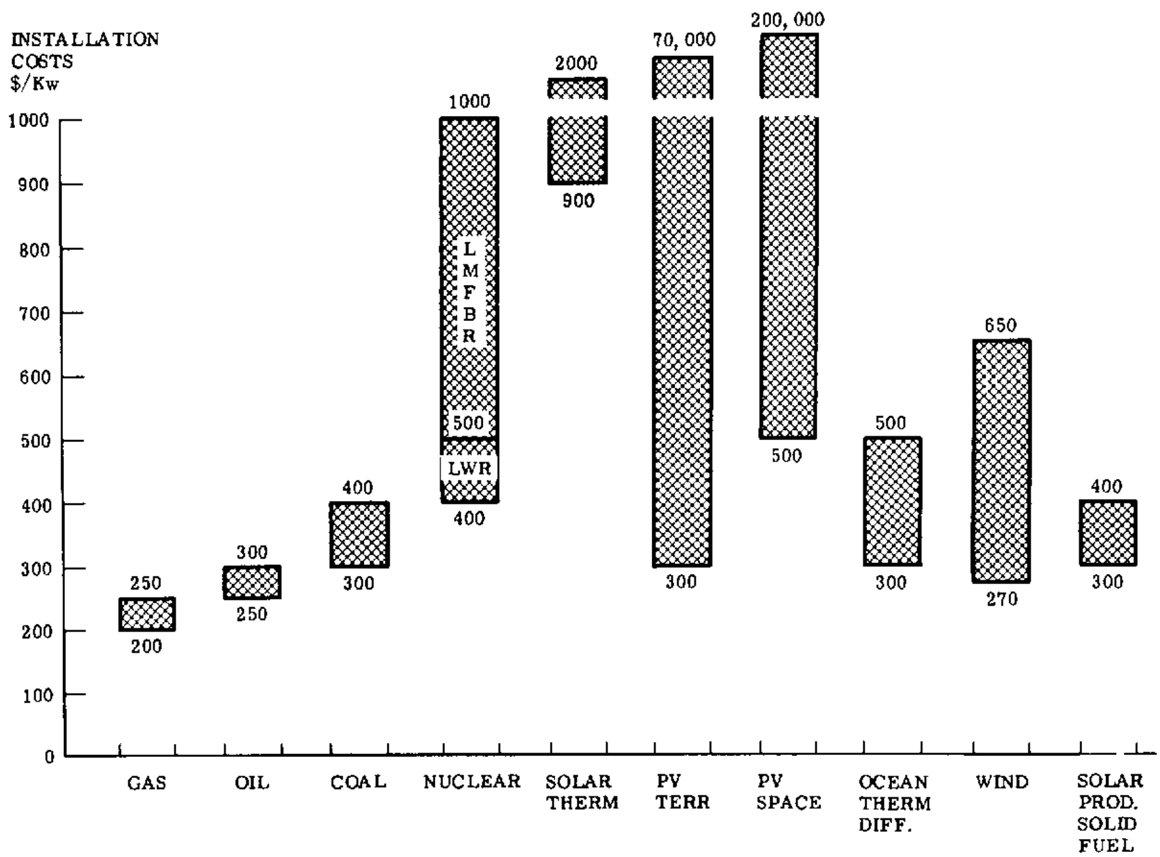


Figure 8. Estimated Installation Costs for Electric Generating Plants

Status of Solar Energy Research

Table 3 shows the general state of the art in the various solar energy application areas mentioned in this paper. Only solar hot water heaters are in a commercial readiness status at this time. Building heating systems are expected to be available in mass quantities during 1974 or 1975 as should large scale pyrolysis systems especially for the disposal of urban solid wastes. While many small power plants have burned wood in the past no planned energy plantation type of system has been developed.

Recommended Program and Budget

The NSF/NASA Solar Energy Panel (Ref. 2) recommended a research and development program spanning a period of 15 years for the total expenditures shown in Table 4. The actual funded program for Fiscal years 1973 and 1974 along with the funding recommended by the Chairman of the AEC on December 1, 1973 in response to the President's request for an energy R&D program is shown in Table 5. Some adjustments in the AEC's recommendations

Table 3

Status of Solar Utilization Techniques

Application	Research	Development	Systems Test	Full Scale Demonstration	Model Plant	Commercial Ready
Thermal Energy for Buildings:						
Water Heating	X	X	X	X	X	X
Building Heating	X	X	X	X	X	
Building Cooling	X	X	X			
Combined H/C Systems	X	X	X			
Production of Fuels:						
Gaseous Fuels	X	X	X	X		
Liquid Fuels	X	X	X	X	X	
Solid Fuels	X	X	X	X		
Electric Power Generation:						
Wind Power	X	X	X	X		
Ocean Thermal Power	X	X	X			
Solar Thermal Power	X	X				
Photovoltaic Power	X	X				

Table 4

NSF/NASA Solar Energy Panel Recommended 15 Year Program

Application	Funding in $Millions
Thermal Energy for Buildings	$100
Production of Fuels	$370
Electric Power Generation:	
Wind Power	$610
Ocean Thermal Power	$530
Solar Thermal Power	$1,130
Photovoltaic Power	$780
Total	$3,520

Table 5

U.S. Terrestrial Solar Energy R&D Program
(in millions of dollars)

Application	Actual		Proposed	
	FY73	FY74	FY75	FY75–79 Total
Thermal Energy for Buildings	0.9	5.6	12.8	50.0
Production of Fuels	0.7	1.1	2.4	20.4
Electric Power Generation:				
Wind Power	0.1	0.2	6.2	31.7
Ocean Thermal Power	0.2	0.8	1.9	26.6
Solar Thermal Power	1.4	2.7	5.0	35.5
Photovoltaic Power	0.9	2.8	4.2	35.8
Totals	4.2	13.2	32.5	200.0

are expected during the second session of the 93rd Congress meeting during 1974 which should place even more emphasis on accelerating the application of solar energy to our National energy needs.

Solar Energy Impacts & Conclusions

With funding support from both Government and private sources at the levels recommended by the NSF/NASA Solar Energy Panel the impact on the Nation's energy demands can be

Table 6

Impact of Solar Energy Applications on the Nation's Energy Demand

System	Year	Annual consumption[2] (10^{15} BTU)	Percent of total energy consumption in USA	Estimated percent of market captured	\$$10^6$ Annual savings in fossil fuel @\$1.00/ 10^6 BTU	Significance[6] on impact on reference energy system by 2020
Thermal energy for buildings	1985	[3]17	15	<1		Major on building industry
	2000	[3]21	12	10	2,100	Minor on total energy
	2020	[3]30	10	35	10,500	consumption
Conversion of organic materials to fuels or energy						
Combustion of organic matter	1985	37	32			Major on electric utility
	2000	76	43	1	760	Modest on total energy
	2020	160	53	10	16,000	consumption
Bioconversion to methane	1985	[4]27	23	1	270	Major on gas consumption
	2000	[4]31	18	10	3,100	Minor on total energy
	2020	[4]41	14	30	12,300	consumption
Pyrolysis to liquid fuels	1985	[5]50	44			Major on oil consumption
	2000	[5]63	36	1	630	Minor on total energy
	2020	[5]80	27	10	8,000	consumption
Chemical reduction to liquid fuels	1985	[5]50	43			Major on oil consumption
	2000	[5]63	36	1	630	Minor on total energy
	2020	[5]80	27	10	8,000	consumption
Electric power generation						
Thermal conversion	1985	37	32			Modest on electric utility industry
	2000	76	43	1	760	Modest on total energy
	2020	160	52	5	8,000	consumption
Photovoltaic						
Systems on buildings	1985	[3]9	9			Major on building industry
	2000	[3]15	9	5	750	Minor on total energy
	2020	[3]21	6	50	10,500	consumption
Ground stations	1985	37	32			Major on electric utility industry
	2000	76	43	1		Modest on total energy
	2020	160	52	10	16,000	consumption
Space stations	1985	37	32			Major on electric utility industry
	2000	76	43	1	760	Modest on total energy
	2020	160	52	10	16,000	consumption
Wind energy conversion	1985	37	32			Major on electric utility industry
	2000	76	43	1	760	Modest on total energy
	2020	160	52	10	16,000	consumption
Ocean thermal difference	1985	37	32			Major on electric utility industry
	2000	76	43	1	760	Modest on total energy
	2020	160	52	10	16,000	consumption

Notes: (1) Each of the above impact estimates assumes the successful development of practical economically competitive systems. However in each case a judgement has been made resulting in estimates that are less than the maximum possible. The estimates are not necessarily additive since not all systems will be carried to commercial readiness.

(2) Nonrenewable fuel consumed to generate the electric power as projected in the energy reference system and resource data report, AET-8, Associated Universities, Inc., April 1972 [1].

(3) Nonrenewable fuel consumed to generate the projected electric power requirements for buildings, AET-8 [1].

(4) Methane consumed to meet projected energy needs, AET-8 [1].

(5) Oil consumed to meet projected energy needs, AET-8 [1].

(6) Minor, 0.5%; Modest, 5-10%; Major, >10%.

expected as shown in Table 6. As can be seen from the table the savings in fossil fuel consumption in one year at the turn of the century would more than pay for the R&D expenditures to develop solar energy applications.

In conclusion, it is expected that at least 20% of the U.S. total energy requirements by 2020 will be derived from solar energy. This is nearly equivalent to the total energy consumed by the U.S. in 1970. From this harnessed solar energy, at least 35% of the building heating and cooling requirement at least 30% of the Nation's gaseous fuel requirement, (more if wanted) 10% of the liquid fuel requirement (more if wanted) and at least 20% of the Nation's electrical power demand can be obtained. All this may be accomplished with a minimal impact on the environment, producing little atmospheric thermal or particulate pollutants, no unusable solid residues and no harmful conditions or wastes.

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