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Solar Thermal Power Systems
Point-Focusing
Thermal and Electric Applications Project

Small Solar Thermal Power System Market Overview

PRELIMINARY

April 30, 1979

Prepared for

U.S. Department of Energy

Through an agreement with

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R. Gurfield

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CONTENTS

SECTION I

U.S. UTILITY APPLICATIONS

This section reviews reports prepared by the Mitre Corporation, SRI, Aerospace Corporation, RPA, JPL, and Burns and McDonnell. A Mitre study[1] compares the National Energy Plan, as prepared in April 1977 with a "Recent Trends Scenario" in early 1978. In these scenarios, total energy consumption in the U.S. from 1990 to 2020 increases from 40 to 80 quads. Solar energy is expected to account for about 3 quads in 1990 with no further growth through 2020.

Under the NEP scenario, solar thermal electric energy output will increase from 0 in 1990 to 300 x 10^9 kWh/yr by 2020. According to the "Recent Trends Scenario," the solar thermal electric contribution will be less than half that estimate. The production of 150 x 10^9 kWh/yr by solar plants requires a capacity of 45,000 MW, operating 33% of the time.

Early in 1977, the Stanford Research Institute[5] suggested three alternative scenarios for the U.S. energy future: a low-demand scenario, a reference scenario, and a solar-emphasis scenario. The low-demand scenario assumed a national energy consumption growth of 40% from 1975 to 2020 to 105 quads; the reference scenario showed a 171% growth to 200 quads; and the solar emphasis showed 179% growth to 205 quads.

To achieve the reference scenario, the U.S. would have to acquire over one thousand nuclear plants of 1000 MW size, many located near population centers. It would require mining of western coal on a massive scale and construction of numerous gasification plants.

Under the solar-emphasis scenario the impact of coal and nuclear plants would be reduced by less than 10%, although solar energy would become the most rapidly growing energy resource in the first and second decades of the 21st Century.

The rationale for low-demand case was based on policies aimed at a minimum envionmental impact. Elements of both the solar scenario and the low-demand cases could occur only if a strong national commitment were made in the 1980's to establish results of these scenarios as future national goals. The major impact of implementing policies and regulations would be in the southwest U.S. where there are extensive coal and uranium resources, and where insolation is particularly high.

The SRI study concluded that solar electricity has potential for meeting the demand for intermediate load electricity. Assuming that solar intermediate power plants will cost $1600 kWe, synthetic high Btu gas from coal appears to be less expensive and may be solar energy's main competitor.[5]

An Aerospace Corporation study made several useful observations on the nature of U.S. small utilities, many of which are potential candidates for solar thermal technology.[25] The study enumerated the numbers of small diesel engines, steam turbines and gas turbines for electricity generation in the Western states, but did not make any estimates of market penetration by solar thermal systems for utility applications.

A companion Aerospace study[26] examined the potential market for solar total energy systems (electricity and process heat) in industry. The model assumed that industry would utilize a solar energy system if the total energy cost was less than that of the conventional alternatives. The inputs to the model included a conservative forecast of energy prices through the 1985-2015 period.

The Aerospace study concluded that pharmaceutical and paint manufacturers in California are expected to be the first industries in which solar total energy systems achieve an economic breakeven by 1990. By 1995, it will be economic for 114 industries in 15 states to convert to solar total energy systems displacing 0.8 quads per year of energy. By the year 2000, the penetration can increase to 521 industries in 44 states displacing 4.7 quads. Applications to industry in California and Texas resulted in the largest energy displacements.

A review paper by Resource Planning Associates[14] concluded that for small U.S. utility applications the potential solar thermal system penetration reaches 7000 MW in existing small generating units, 2700 MW of peaking units in the large utilities, and 1650 MW for distribution-only small utilities. No date was specified.

A contrary view of the market potential for small solar thermal electric systems has been articulated by Burns and McDonnell. They found that on the basis of independent estimates of costs for site preparation and balance of plant plus JPL's estimate of solar hardware costs, none of the solar thermal power systems would be competitive with conventional generation by small utilities in the Southwest[31] in the foreseeable future.

As a result of firsthand contacts with large utilities in the Southwest, JPL researchers[12] concluded that the utilities of Arizona and New Mexico have coal and nuclear plants under construction which are capable of doubling their capacity by the early 1990's. There is a possibility of reduced growth in the demand for power at that time. However, excess capacity may be sold to power-short areas over existing transmission lines. This factor does not mean these utilities will not be interested in solar power plants in the 1990's. They will have continuing needs for more efficient peaking plants, particularly nonfossil fuel units. To underline how the utilities can explore many technologies at the same time, note that Public Service of New Mexico, a utility with adequate nuclear and coal capacity, is conducting a project to study the repowering of existing oil steam power plants by central receiver solar thermal electric technology. Similarily, the El Paso Electric Co., which relies exclusively on coal and nuclear plants for its future growth has begun its first CdS photovoltaic test project in FY79. Several Southwestern utilities expressed interest in site selection competition for small solar thermal power system demonstration plants. The planning executives of these utilities indicated their willingness to accomodate such a project in their systems.

In California, utilities have been unable to gain state approval of proposed sites for new nuclear and coal plants since 1974. These utilities begun experimenting with alternative energy sources. With respect to solar electric technologies, the Southern California Edison Co. will install its own 3 MWe windmill in May 1979. It also plans to operate the 10 MWe central receiver at Barstow, California, in cooperation with the Los Angeles Department of Water and Power and the U.S. Department of Energy. In the Spring of 1978, the San Diego Gas and Electric Company expressed interest in being considered as a site for a small power system. If the costs of solar powered intermediate plants decrease, the utility replacement market of several hundred MW/yr may develop more rapidly than previously estimated.

According to the Western Systems Coordinating Council,[18] the southwestern utilities are summer-peaking with baseloads about 60% of the summer peak. To estimate the potential market size, consider the total projected installed capacity of 27,000 MW by 1995;[12] of this total 11,000 MW consists of peaking and intermediate units. If each unit is replaced every 30 years, and the system as a whole continues to grow at 2% per year, then the average market will be 580 MW or more per year. Small solar thermal systems must compete in this market with intermediate and peaking units powered by wind, geothermal, oil, synthetic gas, biomass, and small hydroelectric devices.

High summer peak demand in the Southwest results from heavy use of residential and commercial air conditioning. The development of an economical solar air conditioner could contribute toward meeting the high summer electricity demand. Moreover, the utilities are receptive to becoming participants in the distribution and servicing of such air conditioners.

SECTION II

IRRIGATION PUMPING IN THE U.S.

The possibility of replacing irrigation pumps by solar-powered machines has intrigued men since the 17th century. An excellent review article by Pytlinski traces the history of these machines.[19] It may be of particular interest to members of the Caltech family to note that A. Eneas erected a 10.2 meter diameter conical two-axis tracking machine at the Pasadena Ostrich Farm in 1901. In 1919, Robert H. Goddard described a point-focusing, two-axis tracking parabolic dish Rankine system to power large farms.

Few papers provide in-depth analyses of the market potential for solar powered irrigation machines. This section reviews studies by Iowa State University, RPA, Battelle Institute, Brookhaven National Laboratory, Sandia Laboratory, Lincoln Laboratory and the University of Oklahoma.

Energy requirements for Western U.S. irrigation pumping may be as high as 261 x 10^{12} Btu/yr.[20] To provide this energy by solar powered machines requires on the order of 10,000 MWe peak power.

In a survey of energy sources for irrigation pumping in the United States during 1974 utilities supplied 19 x 10^6 MWh of electricity. Farmers consumed fossil fuels at the following rates: diesel fuel 177 x 10^6 gal, gasoline 71 x 10^6 gal, natural gas 132 x 10^9 ft^3 in all states except Washington, Oregon and Hawaii. Diesel fuel was used in all states except Arizona, Washington, California, and Hawaii.[39] One can infer that, in the Southwest, solar irrigation must compete against grid-supplied electricity, and, in Texas and New Mexico, a declining supply of natural gas.

The five states leading the U.S. in energy consumption for irrigation are Texas, Nebraska, Arizona, New Mexico, and California. Table 1 shows the energy consumption and cost in 1974 by electricity, natural gas, and liquid fuels consumed.

The ability of solar power to penetrate the irrigation markets depends on farm economics.

The highest priced crops per acre, vegetables and fruits, also have the highest energy consumption. Perhaps some of these farms may become early penetration candidates for solar pumping systems.[30] According to University of Arizona researchers[39] the highest pumping energy costs per acre of cropland occur in Hawaii and Arizona (up to $10/acre/yr). On a per crop basis, the groundwater pumping requirements exceed 2000 kWh/acre/yr for cotton, alfalfa, winter wheat and sorghum in Arizona, and sugarcane, pineapple, vegetables and papaya in Hawaii (1975$).

Rising prices for electricity, fossil fuels and reduced availability of natural gas do not necessarily mean that farmers will switch to solar-powered machines when the energy costs become

Table 1. Irrigation Energy Characteristics of Major States, 1974[42]

	Energy Consumed		Cost of Energy Consumed		Quantity of Electric Energy Used		Quantity of Natural Gas Energy Used		Quantity of Diesel & Gasoline Energy Used	
	Trillion BTUs	National Rank	Million $	National Rank	% of U.S. Total	National Rank	% of U.S. Total	National Rank	% of U.S. Total	National Rank
Texas	72.6	1	87.2	2	8.9	3	46.9	1	5.4	5
Nebraska	30.8	2	78.9	3	6.5	4	4.8	5	40.0	1
Arizona	22.2	3	52.5	4	14.6	2	11.2	4	—	—
New Mexico	21.2	4	31.2	5	2.8	9	11.8	3	7.9	2
California	16.3	5	89.4	1	31.1	1	0.9	8	—	—
TOTAL (% of U.S.)	70%		65%		64%		76%		53.3%	

equivalent. Rather, market prices may not yield sufficient margins to make these energy intensive crops profitable, so that the amount of irrigation pumping actually decreases.

Faced with higher real energy costs, the farmer is likely to invest in energy systems only when the price of his crops rises to pay for it. As an alternative to making large investments in water pumping capital equipment, he may convert to dryland crops which require less water. In west Texas, for example, farmers have begun substituting other crops requiring less water for the cotton traditionally grown in the region.

Two sources indicate that the peak solar pumping power requirements of western agriculture is 6000 MW.[14, 15] Neither of these papers presents a market penetration schedule. One could assume that replacements of diesels must be made periodically and that if solar energy becomes economic, a portion of the diesel use will be converted to solar power. Using a scheme developed by Marchetti to estimate the rate of technology substitution, analysts at Battelle Institute have estimated that the market may be 1% in 1990, 1.6% in 1995, and 24% in 2000 (which amounts to 250 MW/yr in 2000).[22]

In an economic analysis, Matlin and Katzman[42] estimated the time at which photovoltaic water pumping becomes profitable. If the cost of solar arrays follows DOE projections, solar energy for irrigation purposes will become profitable in the early to middle eighties in the Southwest and in the Midwest.

Under both conservative and optimistic assumptions, solar energy for irrigation becomes profitable in Arizona, California, and Texas around the same time, which is one to three years earlier than in Nebraska. Reducing the fuel inflation rate from four percent to two percent postpones the viability of solar irrigation by about one or two years in the Southwest, and by somewhat longer in Nebraska.

The optimal time of investment is approximately seven years after solar photovoltaics become commercially profitable. Under the optimistic scenarios, the optimal year of investment in arrays is 1996 in California and Arizona, 1997 in Texas, and after 2000 in Nebraska. Under the conservative scenario, the optimal year of investment is after the year 2000 in all four states.

An economic analysis of water pumping indicates that a solar electric system in the western U.S. becomes competitive when it is used in year-around service. Power for water pumping assumes priority but electricity production for other farm needs during remaining hours of insolation must be included in the system design for it to achieve economic breakeven. This system suggests that extensive work in requirements definition must be undertaken in order to match solar power availability with a variety of loads around the year such as irrigation, crop drying and livestock production. In addition to engineering compatibility of end uses, new organizations may be needed to manage and schedule users with the solar and other sources of energy supply.[16]

SECTION III

REMOTE U.S. LANDS

In the U.S., where there is an extensive rural electrification network, the number of communities not supplied by electricity is small. Most of these are on Indian lands, in remote parts of Alaska, and some mountain areas. Remote areas of U.S. island possessions also lack electricity.

A number of Federal agencies operate facilities in remote areas. These include the National Park Service, Bureau of Indian Affairs, Bureau of Outdoor Recreation, Indian Health Service, Public Health Service, Forest Service, Community Services Administration and others.

As an example, the total population of Indians on reservations is about 486,000. Information on the number of Indian villages presently without power and the number of Indians in these villages is not readily available. However, it has been reported that a minimum of 40,000 Navajo and 5,000 Hopi Indians are presently living in areas with no utility power. The Papagos have about 30 villages in their reservation without power. The Papagos have about 30 villages in their reservation without electricity. Assuming a value of 24 watts peak per person, supplying energy to these 45,000 Indians will result in a potential demand for 1.1 MW.[13]

SECTION IV

NATIONAL PARKS

The U.S. National Park Services (NPS) maintains facilities at remote sites throughout the country for visitor centers, residences, and maintenance complexes, ranger stations, water and sewage pumping, comfort stations, special buildings, facilities, and applications. According to a Lincoln Laboratory study,[33] the NPS has a diesel generating capacity of almost 3 MW at the present time.

The Lincoln Laboratory researchers identified 63 sites as suitable candidates for a demonstration of photovoltaic power plants with a total peak power requirement of 2765 kW. The most suitable site, according to the ten criteria listed in Table 2, is Natural Bridges National Monument, Utah, where a 100 kW demonstration power plant is presently under construction.

The ten most suitable NPS sites are:

(1) Bullfrog Basin, Glen Canyon National Recreational Area, Utah.

(2) Halls Crossing, Glen Canyon National Recreational Area, Utah.

(3) Natural Bridges National Monument, Canyonlands National Park, Utah.

(4) Mesa Verde National Park, Colorado.

(5) West Side Development, Pinnacles National Monument, California.

(6) Cottonwood Complex, Joshua Tree Monument, California

(7) Boulder City Administration Building, Lake Mead Recreational Area, Nevada.

(8) Lake Mead Visitor Center, Lake Mead Recreational Area, Nevada.

(9) Emigrant Ranger Station, Death Valley National Monument, California

(10) Hite Marina, Glen Canyon National Recreational Area, Utah.

Table 2 indicates how they scored with respect to the site selection criteria used in the Lincoln Laboratory study.

SECTION V

U.S. MILITARY

The military services of the U.S. employ large quantities of electric power for fixed bases, remote sites, and transportable land-based applications. According to a BDM Corporation report[4], the typical peacetime requirement for large bases requiring power sources over 1 MW in 1975-76 is as follows:

68 Army bases use 4×10^6 MWhrs/yr
224 Navy installations use 7×10^6 MWhrs/yr
17 Marine Corps bases use $.95 \times 10^6$ MWhrs/yr
113 Air Force bases use 9×10^6 MWhrs/yr

Tactical generator sets of the 100 to 750 kW size number 10,900 with an aggregate capacity of 1823 MW.

The smallest generators of the .5 to 60 RW size number 264,000 with a capacity of 2600 MW (Ref. 4).

The fraction of this capacity for which small thermal power systems might provide an early substitute is difficult to determine. One approach is to enumerate the power requirements at remote sites not served by major utilities. Islands, interiors of desert bases, and special cases where utility supplied power is not appropriate, represent the types of applications suitable for early use of small solar thermal electric power systems.

Military bases located in the Bahamas, Guantanamo Bay, Puerto Rico, elsewhere in the Caribbean; Maye, Seychelles, and North Cape, Australia in the Indian Ocean; and Okinawa, Iwo Jima, Wake and Midway Islands in the Pacific appear to be among the most viable solar thermal electric plant sites. Because it competes favorably with conventional sources presently employed, the military have an additional reason that might induce them to pay a premium for that energy. During peacetime, fuel can be trans-shipped directly from the continental U.S, or purchased through normal commercial outlets. However, during periods of international emergency, many bases located on islands or at coastal locations in foreign countries may be isolated from their usual source of supply. If they have to obtain their fuel directly from the U.S., the delays and consequent effects on the mission of the base could be considerable. The effect of a cutoff of normal fuel supplies to remote bases could be minimized by the capacity for independent generation.

The RPA study reported that the potential small solar thermal power system applications for the entire U.S. military establishment amounts to 1600 MW for large bases and 40 MW for remote sites. No date indicating when this penetration could be achieved was provided.[14]

Numerous independent studies have been made by the major services. The Navy has 75 bases out of the total 300 designated as potential solar energy sites because of geographical location and suitable insolation. The on-base solar electric potential is 4 x 10^6 MWh/yr total base load. It was estimated that the goal for solar electric is 0.25 x 10 MWh/yr with no storage, and .075 - 1.50 x 10^6 MWh/yr with storage.[8] Fuel costs for remote Navy sites tend to be underestimated. The services purchase fuel at an average price for delivery at all its bases. Seventeen island sites have been identified by the Naval Civil Engineering Laboratory as being potential candidates for solar thermal electric installations. These total 100 MW and are shown in Table 3.

Table 3. Prime Naval Diesel-Electric Power Plants at Remote Sites

	Activity	Estimated Peak Load (MW)
1.	NS, Subic Bay, Philippines	18.48
2.	NRS, North West Cape, Australia	15.40
3.	NRS, Cutler, ME	10.33
4.	PWC, Tarlac, Philippines	7.00
5.	NS, Adak, Alaska	6.30
6.	NAS, Bermuda	5.23
7.	PWC, Guantanamo Bay, Cuba	5.25
8.	PWC, Orote, Guam	4.90
9.	PWC, Agana, Guam	4.83
10.	NW, Diego Garcia	4.20
11.	PWC, Midway Island	3.78
12.	NS, Rota, Spain	3.50
13.	PWC, Yokosuka, Japan	3.50
14.	Andros Island, Bahamas	2.59
15.	PWC, San Miguel, Philippines	2.36
16.	PMTC, San Nicolas Island, CA	1.68
17.	San Clemente Island, CA	1.30
	TOTAL	100.65 MW

The Army has reviewed requirements for photovoltaics at remote sites on military bases of all services. Examination of remote military facilities, particularly those of military test sites, has indicated that the power for such operations ranges well into hundreds of megawatts. The power is used for instrumentation; e.g., radar, relays, communications, remote camera sites for missile range measurement and tracking. The optical sensor equipment consists of cinetheodolites, tracking telescopes and ballistic cameras. The electric sensor equipment consists of electronic sky screen devices, radar, real-time azimuth, elevation and slant range determination, angle measuring requirements and characteristics for these equipments. Twenty-six military bases that participate in missile test site experiments are listed below:

White Sands Missile Range	Jefferson Proving Ground	Air Defense Weapon Center
Pacific Missile Range	Aberdeen Proving Ground	Kwajalein Missile Range
Eastern Test Range		National Parachute Test Range
Space and Missile Test Center	Naval Air Test Center	Tropic Test Center
Satellite Control Facility	Naval Weapons Center	Electronic Proving Ground
Arnold Engineering Development Center	Air Force Special Weapons Center	Naval Air Propulsion Test Center
Dugway Proving Ground	Tactical Fighter Weapons Center	Naval Air Test Facility
Arctic Test Center	Air Force Flight Test Center	Atlantic Fleet Weapons Range
Yuma Proving Ground	Armament Development and Test Center	Atlantic Under-Water Test and Evaluation Center

The Army may follow the practice of developing standard solar electric generator sets with batteries for different capacities and allow the field organizations to select the most appropriate power sources. This is the present practice which is used with diesel generator sets.[6]

The U.S. Air Force has numerous remote sites. These include Kwajalein and Johnston Islands in the Pacific, installations in the Canary Islands and Azores in the Atlantic, and remote sites elsewhere. It also maintains remote sites at desert bases in the Western states, such as Horse Ridge at Nellis AFB near Las Vagas. On site power is required where instrumentation may be located twenty or more miles from the nearest utility drop. Typically, the smallest stand-alone power unit in the Air Force is 10 kW.

A recent study was published by the Air Force indicating the present and future energy conversion systems expected to meet future ground power requirements. The electric power requirements ranged from 10 kW to 50 MW. No site-specific requirements were presented, but 21 types of systems (conventional as well as advanced) were considered.[3]

The Air Force report recognized the potential contributions of alternative energy technologies. They would provide up to half the total USAF terrestrial energy needed by the year 2010. Total energy needs are estimated at 0.2 quads/yr.

Table 2. Site Selection Criteria of the National Park Service for a 100 kW Demonstration Photovoltaic Solar Plant[33]

CRITERIA	NBNM	CRS	Lake Mead Visitor Center-Boulder, NE.	Mesa Verde National Park	Boulder City Admin. Building	Emigrant Ranger Station, Death Valley, CA	Bullfrog Basin Glen Canyon NRA	Halls Crossing Glen Canyon NRA	*Hite Marina	**West Side Pinnacles, CA
1. 10 - 100 kW-pk	1.0	1.0	–	–	–	1.0	–	–		
2. Geographically Located in Southwest	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
3. Small Load Center	1.0	1.0	–	1.0	–	1.0	–	–		
4. Remote and Electrically Independent Community	1.0	0.5	–	–	–	–	1.0	1.0		
5. Good Visitation and Accessibility	1.0	1.0	1.0	1.0	–	1.0	1.0	1.0		
6. Relatively Modern Facilities	1.0	0.5	1.0	1.0	1.0	–	–	–		
7. On-Site NPS Personnel Not Opposed to PV Application	1.0	1.0	1.0	1.0	–	1.0	1.0	1.0		
8. Permanence and/or Growth of Site	1.0	1.0	1.0	1.0	1.0	1.0	–	–		
9. Year Round Use	1.0	1.0	1.0	–	1.0	1.0	1.0	1.0		
10. Application Representative of a Substantial Sector of NPS Needs	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
TOTAL	10.0	9.0	7.0	7.0	5.0	8.0	6.0	6.0		

*Hite Marina was not scored because it is presently being developed (three-year maturity).

**Fire hazard and lack of sunlight eliminates this site from consideration.

At the present time, the Air Force is determining the energy requirements of its remote sites. It is expected that this information will be available in the next few months. The work is being performed at Tyndall AFB in Florida.

SECTION VI

U.S. COAST GUARD

The Coast Guard currently operates navigation aids at over 100 sites in U.S. waterways. Many are unmanned, diesel-powered, 24 hours-per-day lighthouses in the 5 to 10 kW range. A remote Loran station requires 300 kW.

The Coast Guard applications present major challenges for engineering of small solar thermal power stations. In addition to the sea water environment and 24 hour-a-day operation, some are located on rocks which present only a few square feet of surface above the water. Most power stations are located along the Alaskan and North Atlantic Coasts of the U.S., although there are stations in more benign environments off Southern California, Hawaii, and the Gulf of Mexico. These include a Loran station at Kure Island and a facility at French Frigate Shoals, both west of Kauai. The Coast Guard has not been able to develop a complete list of remote sites yet, but the organization is highly energy conscious and interested in utilizing proven solar technology to the maximum extent.[34]

SECTION VII

U.S. ISLANDS

U.S. Islands present many interesting possibilities as sites for early penetration of solar thermal power systems. Most remote islands have evolved special purpose functions, and the requirements for establishing a power plant on each candidate island may have to be considered on an individual basis. The islands used by the military and Coast Guard, have been discussed. In addition, civilian power needs may exist on an island that is only partially under military control such as Guam.

Islands with large populations, like Oahu and Puerto Rico, have utilities with electric grids powered by several hundred megawatts of fossil steam generation. Many of these units are old and have poor heat rates. Smaller islands have diesel power stations and grids to the population centers.

As an example, about 4% of the population of Puerto Rico are presently without electric power. The main island, which is about 100 miles by 30 miles in size, has a central electrical utility grid system. It is estimated[13] that there are about 125,000 people living in remote farm areas inland and on off-shore islands who do not have access to the grid network.

The U.S. Virgin Islands comprise an unincorporated territory administered by the U.S. Department of the Interior. There are over 50 islands, with a total population of about 100,000. Most of the population lives on the three largest islands, St. Thomas, St. Croix, and St. John. Of the total population living in the Virgin Islands, it is estimated that about 2,000 people live in remote villages without electricity.[13]

Remote sites exist on many of these islands ten or more miles from the population centers. Most of the Hawaiian Islands and the U.S. Caribbean possessions have such remote sites. These remote sites may be sparsely inhabited and have low requirements for power. Lack of power is not the primary reason they remain undeveloped. Microclimate, terrain, or legal protection may preclude development. Therefore, the potential for supplying solar thermal power must be consistent with the pattern of local development.

Some islands have agricultural industries that utilize cogeneration; e.g., sugar plantations. Private islands used as farms, hotels or primitive areas have diesel power stations; in such cases, the owners must be approached individually. The State of Hawaii Planning Department is working with Molokai Electric Co. on ways to employ solar technologies for heating water and providing electricity. Molokai Electric operates 5 MW of diesel generators at a busbar cost of over 7¢/kWhr[37].

The Southern California Edison Company provides power to inhabitants of Catalina Island. They employ diesel generator sets with a total capacity of 6.2 MW. The rate is more than 10¢/kWhr for electricity. Edison plans to encourage solar applications for space and water heating as well as for electricity, on Catalina [38]. Possibilities exist for conducting small power system experiments at these island sites.

The U.S. Trust Territories of the Pacific have a primitive diesel-powered electric system serving a population of 120,000. The Trust Territory spans approximately 2000 islands, of which a few dozen are inhabited. Table 4 presents the power generation capacity on 17 islands. There are 78 diesel generator units ranging in size from less than 100 kW to over 1 MW. Total installed capacity is 37 MW.

Pacific Islands are developing rapidly and may offer opportunities for early penetration of solar electric systems in environments that differ from the U.S. mainland.

American Samoa, the size of the District of Columbia, is the only U.S. territory south of the equator. It is a part of Polynesia and so related to Hawaii. Its 29,000 people, who for the first time recently elected their own governor, Peter Coleman, depend largely on subsistence agriculture, tuna canneries and U.S. government payrolls. Many Samoans have moved to Hawaii and the West Coast.

In Micronesia, the U.S. plans to end the last United Nations Trusteeship by 1981. The future of one of the Trust Territory's districts -- the Northern Marianas -- has been determined. That island group (including Saipan and Tinian) north of the separate U.S. territory of Guam, early this year became an American commonwealth.

The Commonwealth of the Northern Marianas was hailed in January 1978 as the first new territory added to the U.S. since 1917. Its constitution gives its people special land-owning and job privileges denied to persons not born there, including other Micronesians. Its economy depends on considerable U.S. spending and Japanese tourism.

An agreement between the U.S. and the six remaining Trust Territory districts was reached in Hilo in April 1978. The eight-point statement covered the basic relationship the U.S. will have with the districts, but not the relationship between the district.

Influenced by the Northern Marianas, two other districts, the Marshalls and Palau have started separate negotiations with Washington. They could emerge as separate political entities, although not as closely tied to the U.S. as the Northern Marianas. The other four districts (Truk, Ponape, Kosrae and Yap) are still united under the banner of the Congress of Micronesia. The trend toward increasing self-government is also present in these districts.

The above trends indicate that there may be three separate governments with whom the U.S. will negotiate.

Economically, the islands of the Trust Territory are likely to remain heavily dependent on the U.S. as client states. Their assets include strategic location, fishing rights and resources, and some tourism.

The U.S. territory of Guam, will remain strategic because of its important naval and air base, despite economic problems. A new emphasis on agriculture and culture may relieve economic stagnation.

The interaction between the U.S. mainland and the American areas of the Pacific has intensified since WW II. The assets of these island groups, including strategic location, fishing rights, natural resources and tourism, continue to increase in value to the U.S. and other nations. Energy resource development will be an important aspect of their future. Solar technology is one alternative that may be able to replace significant portions of their oil dependent power systems.

Table 4. Electric Power Generating Capacity in the Trust Territory 1977
(Number of units by size and total capacity)

District Center	Number of Units with Capacity of: Less than 100 kW	100-249 kW	250-499 kW	500-999 kW	1000 kW and over	Total No.	kW Total Firm Capacity: Op. Units	Non-Op. Units*
Kosrae Island**	1	2	1	0	0	4	425	600
Marshall:								
Majuro	0	0	3	2	1	6	3,150	0
Ebeye	0	0	3	2	0	5	2,350	0
Jaluit	2	2	0	0	0	4	500	0
Palau:								
Koror	0	0	0	5	1	6	4,900	0
Angaur	1	0	0	0	0	1	50	0
Peleliu	0	2	0	0	0	2	210	0
Ngiwal	2	0	0	0	0	2	100	0
Ponape Island**	0	0	0	6	0	6	1,500	2400***
Truk:								
Moen	0	1	0	5	0	6	3,405	1000
Dublon	0	2	0	0	0	2	0	350
Tol	0	2	0	0	0	2	0	350
Yap:								
Yap Island	0	0	4	3	0	7	3,500	0
Ulithi	1	3	0	0	0	4	360	0
Northern Marianas:								
Rota	2	2	0	0	0	4	800	500
Tinian	0	2	0	0	0	2	480	285
Saipan	0	0	9	4	2	15	15,000	9034
TOTALS	9	18	20	27	4	78		

*Not yet installed. Bad condition or standby power.
**District and Island both.
***New hospital not opened.

SOURCE: 1977 Annual Report of High Commission Trust Territory of Pacific (to Secretary of State for review and transmittal to United Nations).

SECTION VIII

CALIFORNIA WATER TRANSPORT SYSTEMS

A recent JPL study was performed to determine the application of solar thermal electric technology to water transport systems, e.g., Aqueduct systems, in California (11). The study included the Los Angeles Owens River Aqueduct, Colorado River Aqueduct, and the State Water Project (California Aqueduct).

The Los Angeles Owens River Aqueduct (operated by the Los Angeles Department of Water and Power) extends 338 miles north of Los Angeles. The system does not require pumping to keep water flowing through the aqueduct and is a net producer of electricity.

The Colorado River Aqueduct is operated by the Metropolitan Water District of Southern California and serves 27 water districts. There are five pumping plants on the aqueduct system with a total plant requirement of 1988 million kW/hr (1977). Electric energy is available from Hoover, Parker, and Davis Dams to pump the water over the aqueduct.

The California Aqueduct, part of the State Water Project, is a 684-mile long system operated by California Department of Water Resources. Energy requirements, energy generated by the system's hydroelectric power plants and net energy requirements were determined for 1998-2000. The results are shown below.

State Water Project Annual Requirements

	1978	1980	1985	1990	1995	2000
Net Energy Required kWh x 10^6	4205	4984	5336	6920	7574	8228

At the present time, the Department of Water Resources purchases power from utilities on long-term contracts. The last set of 15-year contracts expires in 1983, at which time the cost of purchased energy will be significantly increased. A portion of the net energy required may be a possible market area for the application of solar thermal electric systems. A number of alternatives are being considered by the DWR to meet the net demand: wind, geothermal, hydroelectric, construction of additional generating facilities, and the purchase of energy from electric utilities or other sources.

However, the DWR requires hundreds of megawatts of baseload, low-cost electric power. As a result, solar thermal technology probably will not be a serious candidate to meet these requirements during its early penetration years.

SECTION IX

DEVELOPING COUNTRIES

The potential market in developing countries for small solar thermal power systems depends on conditions in the individual countries. Countries with large populations remote from electrical grids, as well as some indigenous means to support and pay for this technology may be the best early markets. Experts and extensive data on foreign countries' energy plans is available to the project. For example, organizations prominent in this field include:

Group	Organization	Contact
Energy Systems Group	Brookhaven National Laboratory	P. Palmedo
Energy and Natural Resources Group	East-West Center	H. Brown
Energy Systems Group	International Institute for Applied for Applied Systems Analysis	W. Hafele

Private firms with experience in non-U.S. energy studies include:

Harbridge House	Los Angeles	S. Schorr
Arthur D. Little, Inc.	Cambridge, Mass.	W. A. W. Krebs

Many developing countries are under great domestic political pressure to provide rural electrification throughout the country before the end of the century. The purpose is to alleviate population pressures on the urban areas. Moreover, Asian, Latin American, and African nations currently are among those shopping in Europe, Japan and in North America for central power systems, despite their high energy costs. These countries are implementing power systems for cities and remote areas. Some may have interest in large quantities of small power systems for deployment in the next decade.

The market for small solar thermal power systems in the developing countries is difficult to estimate because most countries have not published analyses of their requirements. One study puts the market at 33 MW in Africa, 61 MW in Asia, and 4 MW in Latin America before 1985.[14] Other studies put the non-U.S. market for photovoltaics at between 19 and 268 MW per year[29]. Many countries will face large increases in energy demand as the upwardly mobile groups seek to emulate living standards of the wealthy. Palmedo and colleagues [10] believe per capita electricity demand grows faster than personal income. They have developed national energy plans for various countries such as Peru, Egypt, Turkey, and Indonesia under sponsorship of DOE and AID. In these plans, solar technology accounts for a small fraction of the new resources to be added before the end of this century.

The utilization of diesel engines and gas turbines varies considerably with each country. Table 5 presents a comparison of installed generating capacity, electrical generation, and per capita generation for a number of selected developing countries. In the more advanced countries like Brazil, Taiwan, Korea, India and Singapore solar power will initially be used for industrial electric power needs. The non-OPEC less developed countries (LDC) are a varied group of countries that have a wide range of per capita income levels, income distribution, economic and social institutions, states of development, and political systems. In 1974, the annual per capita generation for these countries ranged from 94 kWh/person in Nepal to 1742 kWh/person in Singapore.[40]

The information indicates the initial potential market, i.e., diesel and gas turbine electric generation. The specific market penetration of solar thermal electric systems will be a function of specific local energy prices, currency, inflation rate, energy supply, and a number of other variables which need to be studied in greater depth for each developing country.

All the countries are experiencing a crisis in petroleum supply. Fossil fuel resources are very unevenly distributed among the countries. Even assuming success in discovering and exploiting new reserves, most of the LDC's will have to rely on imports for most or all of their oil. Even if world-wide supplies remain available, the cost of oil imports will impose a serious financial burden on all but a few of the non-OPEC LDC's. This could significantly impair their economic development. Unable to afford oil or electricity, the majority of the population in most LDC's will continue to use more and more noncommercial fuel.

Without a large increase in the management of these resources and in the efficiency of use, it is expected that there will be severe shortages. Palmedo [10] has grouped 88 non-OPEC countries in terms of their potential for energy development as shown in Table 6. The percent urbanization for the categories of LDC's are[10]:

		% Urbanization*
I.	Industrialized	60
II.	Oil Exporters	51
III.	Balanced Economies	25
IV.	Primary Exporters	29
V.	Agricultural Exporters	23
VI.	Other Agricultural	15

*Urbanization rate indicates the increase in per capita energy consumption.

The potential growth of population and per capita consumption points to rapid energy demand increases in the developing countries. Between the years 1975 and 2020, forecasters at Brookhaven National Laboratory indicate population growth ranging from 3 to 5 percent and per capita energy consumption increases from 1.2 to 2.0. Total energy demand in some countries may multiply by a factor of 10 over the 1975 estimate.

Table 5. Installed Generating Capacity in Pacific Basin and Asian Countries[32]

Country	Year	Installed Generating Capacity (MW)		Generation (million kWh)		Per Capita Generation (kWh)
		Diesel	Gas Turbines	Diesel	Gas Turbines	
Afghanistan	1974	12.4	36.0	15.5	–	25.8
Australia	1974	242.4	313.6	443.5	81.4	4763.0
Bangladesh	1974	236.3	154.0	75.4	90.7	18.1
Brunei	1974	11.4	63.0	2.2	209.2	1412.3
Cook Islands	1974	2.5	–	6.7	–	702.6
Hong Kong	1974	6.8	73.0	0.3	2.6	158.3
India	1974	503.0	178.0	401.0	466.0	130.3
Indonesia	1974	264.0	126.0	531.9	151.3	25.1
Iran	1974	516.0	410.0	615.0	688.0	425.0
Japan	1974	987.0	1029.0	4817.0	942.0	4137.4
Malaysia						
East: Sabah	1974	65.1	–	187.9	–	238.1
Sarawak	1974	70.8	4.8	–	153.2	139.3
West	1974	39.8	–	153.0	–	479.0
Nauru	1974	8.2	–	24.7	–	3363.0
Nepal	1974	20.8	–	9.8	–	9.4
New Zealand	1974	4.3	186.0	–	162.1	5996.0
Papua New Guinea	1974	64.8	–	96.7	–	344.6
Philippines	1974	569.0	–	2971.5	–	315.0
Republic of Korea	1974	509.0	150.0	1113.3	125.7	533.0
Republic of South Vietnam	1973	389.1	61.5	674.5	5.6	81.7
Singapore	1974	–	94.0	–	28.4	1742.3
Thailand	1974	232.8	165.0	314.3	7.1	178.6
Western Samoa	1974	5.9	–	12.3	–	142.6

Table 6. Groups of Developing Countries[10]

I. Industrialized

- Argentina
- Brazil
- Chile
- South Korea
- Singapore
- Spain
- Taiwan
- Uruguay
- Yugoslavia

II. Oil Exporters

- Angola
- Boliva
- Congo
- Egypt
- Malaysia
- Mexico
- Oman
- Syrian Arab Republic
- Trinidad and Tobago
- Tunisia

III. Balanced Growth Economies

- Colombia
- Greece
- India
- Pakistan
- Panama
- Peru
- Philippines
- Turkey

IV. Primary Exporters

- Botswana
- Guinea
- Guyana
- Jamaica
- Liberia
- Mauritania
- Morocco
- Sierra Leone
- Surinam
- Togo
- Zaire
- Zambia

V-a. Agricultural Exporters

- Costa Rica
- Dominican Republic
- Gambia
- Guatemala
- Honduras
- Ivory Coast
- Senegal
- Sri Lanka

V-b. Other Agricultural

- Afghanistan
- Bangladesh
- Benin
- Burma
- Burundi
- Cameroon
- Central Agrican Empire

V-b. Other Agricultural (contd)

- Chad
- Cyprus
- El Salvador
- Eq. Guinea
- Ethopia
- Fiji
- Ghana
- Haiti
- Jordan
- Kenya
- Lebanon
- Lesotho
- Madagascar
- Malawi
- Mali

VI. Other Agricultural

- Mauritius
- Mozambique
- Nepal
- Nicaragua
- Niger
- Papua N. Guinea
- Paraguay
- Rwanda
- Somalia
- Swaziland
- Sudan
- Tunisia
- Uganda
- Upper Volta
- Yemen A. Rep.

OPEC

- Algeria
- Ecuador
- Gabon
- Indonesia
- Iran
- Iraq
- Kuwait
- Libya
- Nigeria
- Qatar
- Saudi Arabia
- United Arab Emirates
- Venezuela

Other analysts also point to the increasing demand for energy in urban areas of developing countries. Large increases in population are forecast for urban cities in the LDCs. Table 7 indicates the projection for 1995 for the world's largest metropolitan areas. The increases in these cities will be reflected in increasing demands for electricity.

Table 7. Population Projection of the World's Largest Metropolitan Growth Areas[27]

Urban Regions	1978 Population in millions	Expected 1995 Population in millions
Paulo-Janeiro (Sao Paulo, Rio de Janeiro)	21	45
Nile Delta (Cairo, Alexandria)	20	40
Mexico City	13	28
Calcutta (Kharaqpur, Haldia)	10	22
Shanghai	9	20
Bombay	8	19
Jakarta	7	18
Delhi	6	16
Manila	7	17
Karachi	4	13
Bangkok	4	13

In developing countries, the largest share of electricity is used by industry. Electricity is consumed principally in urban areas in upper income houses and commercial buildings for air conditioning. In seeking strategies which reduce dependence on petroleum in the oil-importing LDCs, electricity produced by nonpetroleum resources can play an important role. In the agricultural sector, electricity can be used to increase irrigation pumping and to produce fertilizer.

Many developing countries encounter difficulties in expanding their electric generating plants, either large scale hydro or nuclear power, because of size and long delays in construction. Small and medium on-site electric generating stations (0.1 to 1 MW) may offer more appropriate, less costly solutions. These would involve less delay, if standardized, modular designs could be developed.[9] These appropriate technologies include wind, biomass, small hydroelectric, diesels, and solar thermal electric generation. Solar energy technology has considerable potential for widely decentralized use patterns provided high capital costs can be reduced, standardized designs developed, reliability of systems improved, and institutional difficulties overcome. The small power systems can be fabricated, installed and serviced locally. Hence, the country can anticipate independence of foreign suppliers for the machines as well as for the fuel.

The needs for power in the developing countries appear to be large and growing rapidly. There is an obvious need for central power systems in the cities. Some of these cities are extensively served by hydropower. During dry months when the water level behind the dams is low, power should be rationed among users by such devices as voltage reductions and scheduled outages. Even though the cost of power is low, sometimes it is unavailable. Thus, its social cost far exceeds its price.

The well-managed utilities in urban areas of developing countries produce power at costs comparable with U.S. utilities using central generation plants. Many countries have remote villages not connected to the central grid system. Requirements for solar power in these areas need to be studied more carefully. Some of these villages are wealthy with literate populations. Many are very poor. A study of photovoltaics in several poor remote agricultural villages concluded that the peak demand is for water pumping for a cotton/wheat cropping system.[28] Power during off-peak periods may be employed for other applications, such as water pumping for a fodder crop, powering sewing machines, lights, TV, and drinking water pumps. The studies considered villages in Bangladesh, Lake Chad, India and Pakistan. The important differences among these villages were insolation and the price of diesel fuel. This affected the economic size applications even in the small villages. However, at about $1300/kW peak, the solar pumps compete favorably with diesel pumps in Lake Chad. However, the array cost must be about $1000/kW to compete in Pakistan and India. (A solar array for a 5 hp pump occupies 600 ft^2, and therefore removes from cultivation an area which could yield 13 lb of rice per year in Bangladesh.) Small solar thermal power systems would have to be available at similar costs ($1000-$1500/kW) in order to reach this market of poor farmers in developing countries.

Representatives of Brazil, Italy, Mexico, New Guinea, Nigeria, Sri Lanka, Sudan, and United Nations agencies in both New York and Vienna have made inquiries as to the availability of small power systems for non-U.S. applications. It has been suggested by representatives of the U.S. Agency for International Development that some funding for demonstration projects in Egypt might be available. Also, a joint U.S.-Saudi Arabian agreement for solar energy development might provide support for small solar thermal electric demonstrations. The Solar Energy Research Institute has the responsibility for coordination of the Saudi program.

Expressions of interest in small solar thermal power systems have been received from several sources in Mexico, including the National Academy of Engineering, the Office of Saline Water Management of the Department of Public Works, and several universities.

SECTION X

PACIFIC ISLANDS

The independent Pacific Island nations comprise special subset of the developing countries that are characterized by high fuel costs, long distances from supply sources, high insolation and many instances where large central power systems are inappropriate. They may offer potential markets for solar thermal electric systems. Many of the islands are sparsely inhabited. However, a number of the island chains have a considerable population with significant and growing energy needs. Most of these islands enjoy favorable insolation. In addition, many produce agricultural wastes that could provide a significant portion of their energy requirements either as boiler fuel or as methane from anerobic digestion. Table 8 is a listing of a number of representative Pacific Island groups, population data, and estimated energy requirements (assuming a value of installed capacity of 24 watts/person), a value also adopted in other studies.[13]

Several of these Pacific Island groups have representation in Honolulu. The East West Cenyer's Energy and Natural Resources Group is particularly concerned with introducing technology that meets local needs in this region.

Table 8. Estimated Energy Requirements for Representative Pacific Island Groups[32]

Island Groups	Population	Estimated Energy Requirements kW	Notes
Fiji	589,000 (1975)	14,136	a
French Polynesia	134,100 (1974)	3,218	b
Gilbert Island	54,400 (1975)	1,306	c
Irian Jaya	923,000 (1976)	22,152	d
New Caledonia	135,000 (1975)	3,240	e
New Hebrides	96,532 (1975)	2,317	f
Papua New Guinea	2,756,000 (1975)	66,144	g
Solomon Islands	179,000 (1975)	4,296	h
Tonga	97,000 (1976)	2,328	i
Western Samoa	155,000 (1976)	3,720	j

Notes to Table 8[21]

a. Independent dominion within British Commonwealth; 300 islands, $10 million power plant being built at Vudu Pt. near Nadi to serve most of Western Viti Levu. In mid-1975, Fiji Electric Authority had 9000 customers; Fiji Government planning a major hydroelectric plant in central Viti Levu at a cost of $76 million. Extensive agricultural wastes from sugar and copra plantations offer a source of biomass fuel.

b. Overseas territory of France; capital is Papeete on Island of Tahiti; Papeete population on Tahiti is over 80,000 people.

c. Self-governing colony of Great Britain; colony consists of four main groups of islands; administrative center is Bairiki on Tarawa.

d. Province of Republic of Indonesia; generation of electric power in Irian Jaya was approximately 16,500 MW in 1971. The power was provided to 7,377 registered customers.

e. Overseas territory of French Republic; capital is Noumea on New Caledonia. Hydroelectric stations and diesel operated generators in Noumea provide electric energy; island electricity supplies come from municipal and private generators. Nickel mine is principal industry.

f. Self-governing condominium, administered jointly by Britain and France; a private company, Union Electrique d'Outre Mer has a 40-year agreement (since 1939) to generate and supply electricity. Information on the nature of arrangements to succeed this agreement were not available at the time this report was prepared.

g. Independent state, member of British Commonwealth; Papua New Guinea Electricity Commission operates generating stations in main centers and maintains numerous small stations.

h. Self-governing British Protectorate; electricity supply is operated by Solomon Islands Electricity Authority. Potential for agricultural wastes to be used as fuel source.

i. Independent kingdom; member of British Commonwealth; electrical generation by diesel engines.

j. Independent state, member of British Commonwealth; group consists of two large islands and several smaller ones.

Between Australia and New Zealand in the south and Hawaii in the north lie the 10,000 islands of the Pacific. The aggregate population is a modest four million -- less than half of New York or Tokyo or Shanghai. And the actual land area, although spread across one-third of the globe, is also small, under a half-million square miles (less than the size of Iran or Libya), and most of that is in Papua/New Guinea. Despite their small area and sparse population these islands have great importance to the larger nations of the world. These nations include the former European colonial powers as well as the Russians, Germans, Australians, Japanese, Chinese, and Indonesians. Hence, the area is one of increasing strategic importance. These nations could become benefactors of U.S. solar technology and thereby represent a potential advantage for U.S. relations in this area.[35] Other island nations in the Pacific such as Indonesia and the Philippines may also benefit from solar applications that have been proven in island environments. A similar agrument may be made for tropical islands in the Caribbean and Atlantic Ocean.

SECTION XI

CONCLUSIONS

In summary, numerous economic sectors suggest themselves as candidates for early market penetration by small solar thermal electric systems. Most analysts of technology replacement assume an S-shaped logistic curve over time, with slow penetration initially as a few industries experiment with novel systems. This introductory phase is followed by a rapid increase in penetration as many industries convert to new technology and as new industries employing this technology come into existence. The mature phase shows slow growth again, but a high level of replacement sustains a highly productive industry. Table 9 summarizes the market penetration potential for the sectors covered in this report. The potential market size in Table 9 represents the replacement market achievable by 2020 according to the data in the references cited. The largest potential market is the non-U.S. market outside the U.S. Each country has only a small market. Only a few of these countries represent practical markets for early penetration due to their size, ability to absorb technology, and import policies.

The earliest U.S. markets appear to be the military, followed by the remote sites such as islands. Each of these ultimately may be served by a standard solar product, as they are currently served by standard diesels. However, the first few should be custom tailored to local needs in order to make solar technology preferable to the conventional alternative. This is especially true if the purchaser pays a premium for the solar system over the cost of conventional energy sources.

The U.S. industrial and cogeneration market may become very large if the price of fossil and fission energy rises very rapidly or becomes unavailable to meet demand. The industrial and utility sectors are more sensitive to energy cost than many of the specialized remote site applications where ease of maintenance and freedom from fuel oil supply may be worth large extra cost to the user.

Competition to small solar thermal power systems technology is based on locally available alternatives. Few expect solar thermal electric systems to compete in an area where the user has access to less costly energy systems such as existing central generation, hydro or wind power. However, where these are in limited supply or unavailable, solar thermal electric must compete against new systems such as new dams, steam plants, or diesels, or photovoltaic plants, which may have high life-cycle costs of the same magnitude as advanced, mass-produced small solar thermal electric systems.

This report has evaluated ten economic sectors in which early penetration of small power systems shows promise. The evaluation has been conducted on the basis of published reports on these sectors; where there has been a divergence of opinion with respect to market potential, this has been noted.

The references employed are too general in scope to provide a definite set of requirements for operational hardware or a confirmation of cost goals for the application. Further study would be required to analyze requirements and competing energy costs for representative applications in each sector.

Table 9. Market Penetration for Small Power Systems, 1985 - 2000

Market	Potential Market Size (Annual Replacement Rate)	Competition	Remarks	Source
U.S. Utilities	1500 MW/yr	Conventional Interm. Plants Wind Oil Biomass HiBtu Syn. Gas Photovoltaics Geothermal Advanced Coal Systems	By 2020 U.S. utilities will have twice the capacity in WECS machines as in solar thermal, and ocean thermal will equal solar thermal capacity[1]. Syn fuels will be the strongest competitor to solar[5]. Typical size - 10 MW and up.	(1), (2), (5), (25), (31)
9 SW Utilities	>500 MW/yr	Same as Above	Intermediate and peaking load during summer comprises 40% of total capacity. By 1993 intermediate and peaking capacity will grow to 11,000 MW. If units have an average 30 year life and 2% annual growth continues, then the expected market exceeds 500 MW/yr.	(12)
U.S. Industry Total Energy Systems	7 MW/yr	Diesels Conventional Sys. & Util. Geothermal Process Heat from Combustion	Early markets for solar thermal total energy systems will be in Calif. and Texas especially pharmaceutical and paint manufacturers by 1995. (Aerospace)	(15), (26)
Military ● Navy ● Army ● Air Force ● Coast Guard	50 MW/yr 10 MW/yr 29 MW/yr 10 MW/yr 1 MW/yr	Diesel Photovoltaics Wind OTEC	Peace time power requirement for bases and mobile generator units, island, and Coast Guard facilities. Typical size 10 kW and up by 1985.	(3), (4), (6), (8), (17), (24)
California Aqueduct	Up to several MW/yr	Conventional Wind Hydroelectric Geothermal	California Department of Water Resources (DWR) is actively seeking new sources of energy to replace contracts expiring in 1983; typical size - 100 MW and up.	(11)
Non U.S. Countries ● OPEC Countries ● Non OPEC Countries – Industrialized – Oil Exporters – Balance Growth Economies – Primary Exporters – Agricultural Exporters – Other Agricultural	0.1-50 MW/yr	Biomass Wind Photovoltaics Diesel Small Hydroelectric Central Grid Systems Foreign Vendors Geothermal	PFTEA is attractive in developing countries because local industry can supply systems; U.N. estimates 3 million villages of up to 1000 inhabitants without electric power in need of electrification, cooling, refrigeration, and pumping; reliable data on energy requirements sketchy. Applications include village power systems, agricultural pumping, on-site industry power, island power systems, and augmentation of central power systems serving cities. Typical size - 10 kW and up by 1980.	(9), (10), (13), (14), (27), (21), (28), (29), (40)

Table 9. Market Penetration for Small Power Systems, 1985 - 2000 (Contd)

Market	Potential Market Size (Annual Replacement Rate)	Competition	Remarks	Source
U.S. Islands, Remote Villages	17-50 MW	Photovoltaics Diesel Geothermal Wind Biomass OTEC Small Hydroelectric	Puerto Rico, Virgin Is. American Samoa, Guam, U.S. Trust Terr. Catalina, Hawaiian Is., etc. 1979 electricity cost >$0.10/kW hr. Typical size -01-10 MW. Requirements: agricultural waste fuels, power desalination, pumps, refrigeration and electricity.	(13), (36)
Government Agencies ● Department of Interior – National Park Service – Bureau of Indian Affairs – Office of Territorial Affairs – Bureau of Outdoor Recreation ● Department of HEW – Indian Health Service – Public Health Service ● Department of Agriculture – Forest Service ● Community Services Administration ● State and Local Agencies	<1 MW/yr	Wind Photovoltaics Geothermal Diesel	Estimate 40,000 Navajo and 5,000 Hopi Indians presently living in areas without electric power. The Papagos reported 30 villages on their Arizona reservation have no electric power. Presently most of the 320,000 campsites at 5500 public parklands throughout the U.S. do not have power available. The U.S. Forest Service estimates over 1500 towers and camps in the U.S. without grid power. Typical size 10 - 1000 kW. Early penetration in 1990s. National Park Service uses 3 MW of diesel power.	(13), (14), (33), (34)
Non-Industrial ● Remote Recreational Operations – Hunting and Fishing Lodges – Construction and Surveying Camps – Logging Camps – Ranches	1 MW/yr	Diesel Photovoltaics Wind	Typical size 10 kW - 10 MW. Early penetration in 1990s.	(13)
Agricultural Pumping	1-200 MW/yr	Diesel Windmills Electric Utility	Pumps located in Hawaii and S.W. states. As energy costs rise farmers may switch to dry-land crops thereby reducing pumping needs. Early penetration in 1990s.	(16), (20), (22), (39), (41), (42), (43)

SECTION XII

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