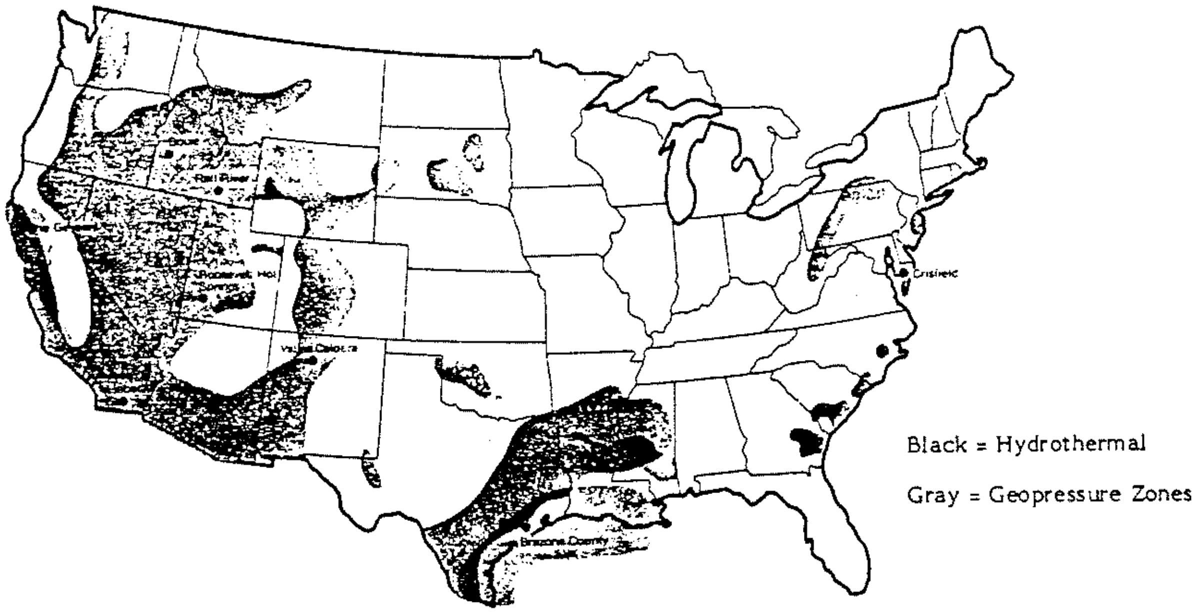
Figure 3.12-1[233]

REPRESENTATIVE U.S. GEOTHERMAL PROJECTS



Location	Purpose	Technology	Capacity (MW)	Starting Date	Sponsors
The Geysers, California	Electricity, commercial	Natural steam cycle	800	1960-1980	Pacific Gas and Electric Co.; Union Oil Co. of California
Heber, California	Electricity, demonstration	Binary cycle	45	1984	DOE; EPRI; San Diego Gas & Electric Co.; Chevron Resources Co.
East Mesa, California	Electricity, pilot	Binary cycle	11	1974	Magma Power Co.
Raft River, Idaho	Electricity, experiment	Binary cycle	5	1980	DOE
Valles Caldera, New Mexico	Electricity, demonstration	Direct-flash steam cycle	50	1982	DOE; Public Service Co. or New Mexico; Union Oil Co. of California
Northern Nevada (site to be selected)	Electricity, commercial	Direct-flash steam cycle	50	1984	Sierra Pacific Power Co. and other utilities
Heber, California	Electricity, commercial	Direct-flash steam cycle	41	1982	Southern California Edison Co.; Chevron Resources Co.
Roosevelt Hot Springs, Utah	Electricity, commercial	Direct-flash steam cycle	20	(pending)	Utah Power & Light Co.; Phillips Petroleum Co.
Brawley, California	Electricity, pilot	Direct-flash steam cycle	10	1980	Southern California Edison Co.; Union Oil Co. of California
Boise, Idaho	District heat, commerical	NA	NA	1981	DOE; State of Idaho; City of Boise
Crisfield, Maryland	Hydrothermal exploration	NA	NA	1979 (reached 60°C water)	DOE
Brazoria County, Texas	Geopressure, exploration	NA	NA	1979 (well complete)	DOE

The different types of geothermal resources have necessitated three different types of generating technology: the dry-steam process, the flashsteam process, and the binary process. The only dry-steam reservoir now in production in the United States is at The Geysers in Northern California. Dry steam from deep wells is brought directly to electrical generating turbines at about 100 psi pressure. Cool water from previously condensed steam condenses the steam from the turbine exhaust in cooling towers. The several plants at The Geyers, ranging in size up to 135 MW, have been operated since 1960 by Pacific Gas and Electric Company, a California utility. There are now 660 MW of capacity on-line at The Geysers, with 1,400 additional MW expected by 1987.[234]

The main problem associated with dry-steam geothermal generation is hydrogen sulfide (H_2S) emissions. The steam at The Geysers contains H_2S at varying levels; average concentration is around 200 parts per million.[235] Emissions there often exceed California air quality standards.[236] The condenser and the cooling tower are the main points at which H_2S is released. A supplemental catalyst process and the Stretford process, a widely used industrial pollutant control technology, are now being tested for removing H_2S from the noncondensible gases.

The dry steam process using surface condensers and the dry steam cycle processes are provided schematically in Figures 3.12-2 and 3.12-3 respectively. Note that the various emission points for hydrogen sulfide are illustrated in Figure 3.12-3.

Figure 3.12-2[237]

DRY STEAM PROCESS USING SURFACE CONDENSERS

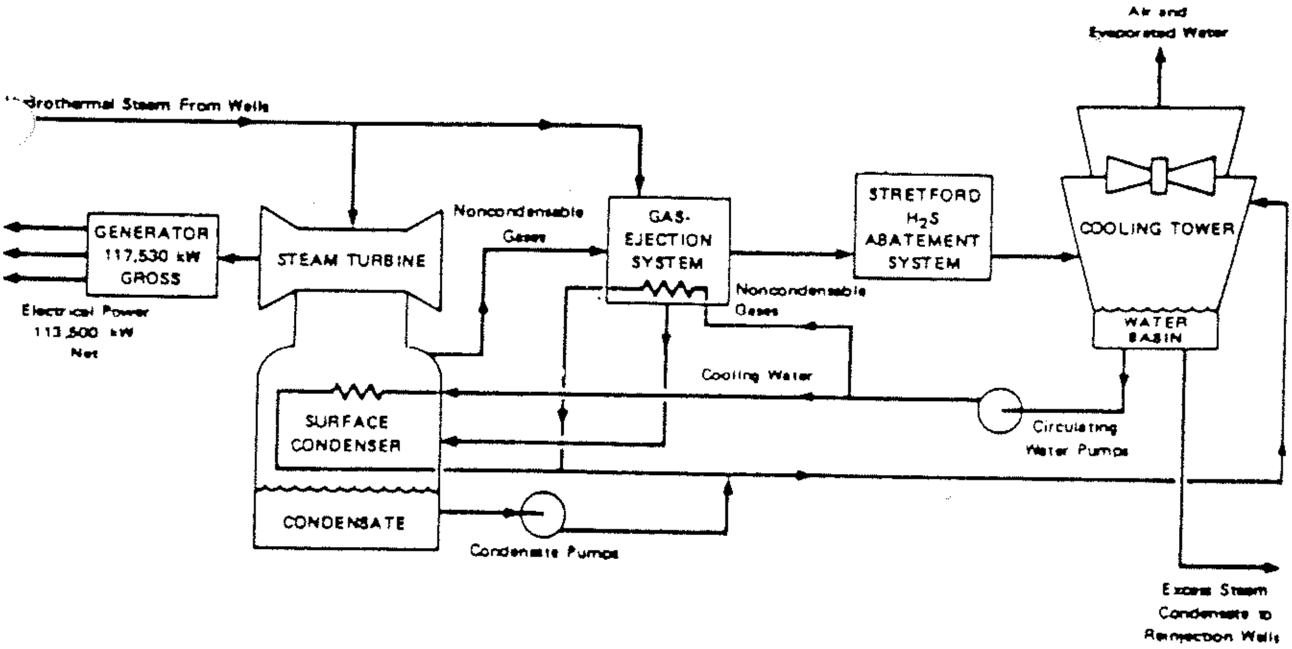
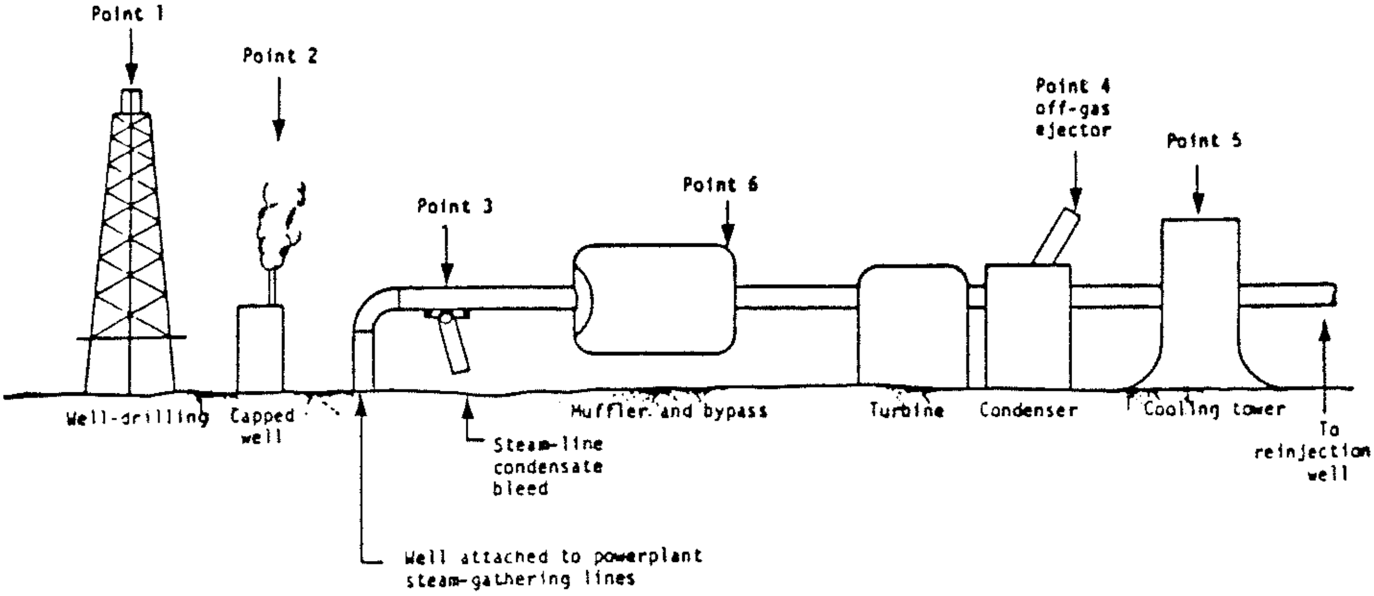


Figure 3.12-3[238]

GEOTHERMAL DRY STEAM CYCLE AND EMISSIONS POINTS



The flash-steam process is used for liquid-dominated geothermal reservoirs. None are currently in production, but two plants are planned. One plant is in California's Imperial Valley, and one is in New Mexico.

Liquid-dominated geothermal conversion begins by bringing hot brine to the surface by means of wells. Depending on the depth of its origin, the brine may be at pressures of hundreds of pounds per square inch. The flash process vaporizes (flashes) some of the brine's water to steam and directs it through a conventional steam turbine.

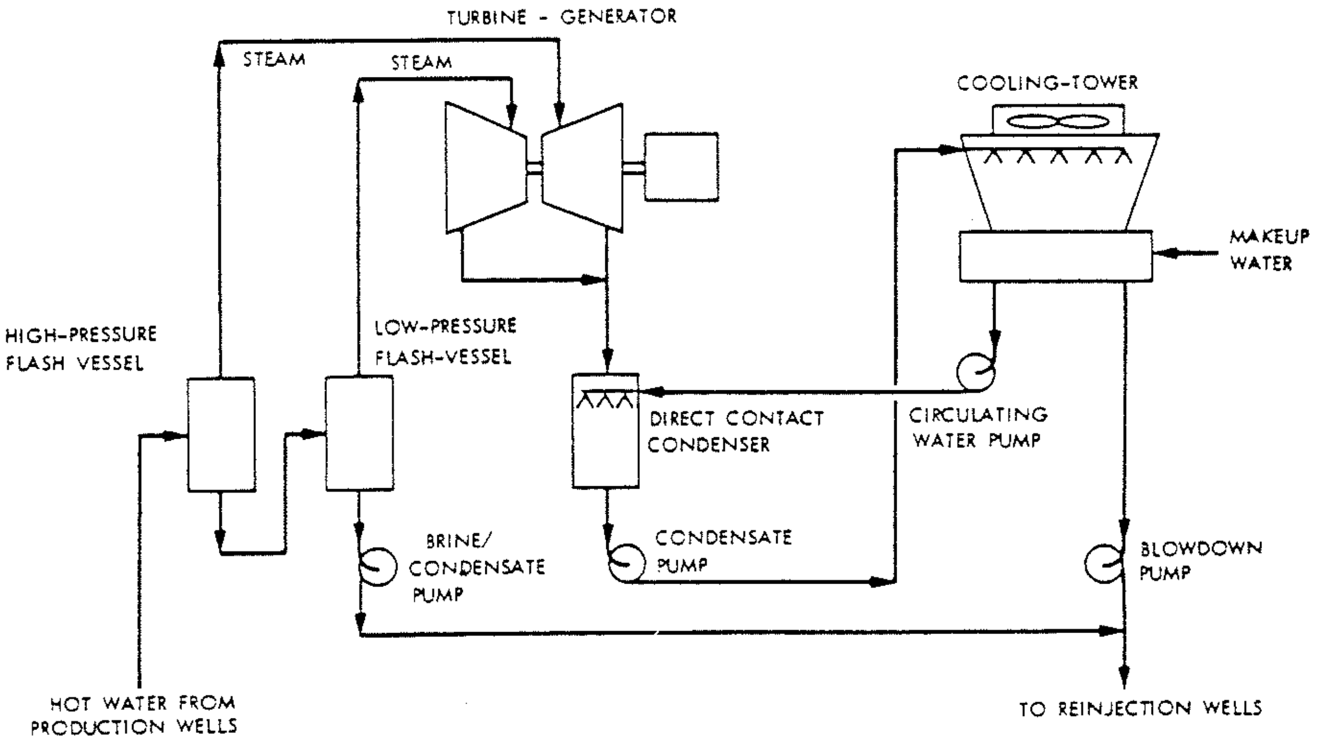
Chevron Resources Company and Southern California Edison Company have contracted to build a 50 MW double-flash plant near Heber, California. The plant will provide electricity for about 45,000 people, and is scheduled for completion in 1982.

Figure 3.12-4 illustrates a two-stage (high pressure and low pressure) flash-steam electricity generation process. One associated problem with this process is the salinity content of the brine brought to the surface from the wells. The Heber Plant at the Imperial Valley KGRA has been slow to come on-line due to environmental regulations and technological resolution of the salt residue problem.

The binary process, like the flash-steam process, is applicable to liquid-dominated reservoirs. In this process, the brine from the wells passes through a heat exchanger to transfer heat to a working fluid, such as isobutane. The working fluid operates in a closed-loop cycle. The fluid vaporizes in the heat exchangers then expands through the turbines and returns to the heat exchanger after being condensed. The brine, after passing through the heat exchanger, is reinjected into the ground.

Figure 3.12-4[239]

TWO STAGE, FLASHED STEAM POWER GENERATION PROCESS



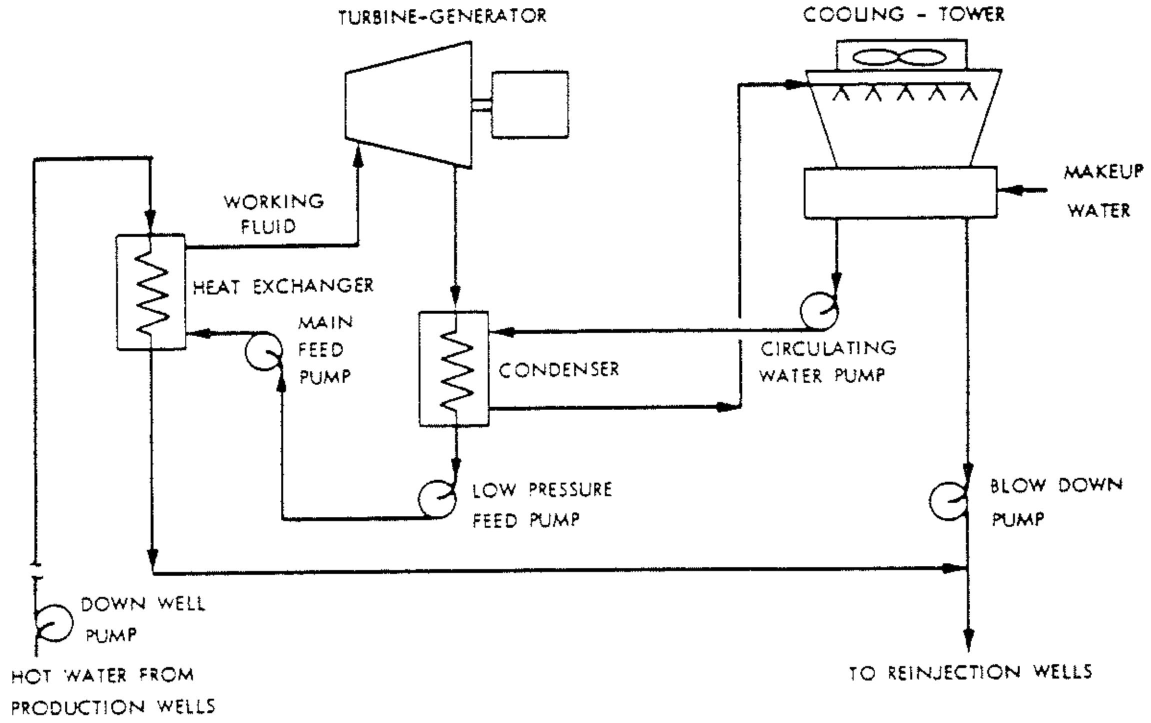
The binary process is less developed than the flash-steam process. For example, the large turbines that will be used in conjunction with the hydrocarbon working fluid have not been operated in the sizes being considered for use in commercial binary plants.

An advantage of the binary process is that it releases no H_2S. Figure 3.12-5 illustrates the binary process for converting geothermal energy to electricity.

A U.S. government task force has concluded that with an expanded federal program, the U.S. could develop 20-30,000 MW of geothermally generated electrical power by 1985, and as much as 100,000 by 1990.[241] An early federal effort to expand geothermal production was the Geothermal Leasing Act of 1970. The U.S. Department of Energy is involved in many geothermal research programs and demonstrations, including project grants and a loan guarantee program.

Figure 3.12-5[240]

BINARY POWER GENERATION PROCESS



Recently the Department of Energy granted funds to the California Department of Water Resources to study the feasibility of a geothermal-wood waste cogeneration plant near Susanville, California.[242] The DOE is testing wellhead generators in Hawaii.[243] In addition, DOE funds general research in resource exploration and assessment, drilling and utilization technology, and environmental control. It now costs about three times as much to drill a geothermal well as it does a petroleum well. The technology is the same as that for oil wells, but much higher temperatures and harder rock surround geothermal deposits. An impediment to geothermal development is the difficulty in assessing resources. According to DOE, "Early statistics indicate that only one of every ten to fifteen sites identified as prospects may ultimately be confirmed as an economic reservoir."[244]

Environmental impacts which must be addressed for successful geothermal development include subsidence of reservoirs after brine is pumped out, H_2S emissions, disposal of spent brine, seismicity induced by drilling and general geologic disruption, groundwater contamination, and water requirements for cooling. Reinjection of spent brine into the reservoir seems to mitigate several of these problems.

Despite the problems, geothermal electrical generation is a cost-effective technology. Levelized 1980 generation costs for steam geothermal are estimated to be about 5.6 cents per kilowatt hour, compared to about 7.0 cents per kilowatt hour for coal-fired plants.[245]

In addition to the "indirect" applications of geothermal energy (conversion to electricity via steam turbines), there are a variety of direct uses. Direct utilization of geothermal energy for space and process heating, for the most part, uses known technology. The utilization of geothermal energy requires only conventional engineering techniques rather than revolutionary advances or major scientific discoveries. The technology, reliability, economics and environmental acceptability have been demonstrated throughout the world.

Each geothermal resource has unique physical characteristics and conversion systems must be designed accordingly. There can be some problems with corrosion and scaling (generally confined to higher temperature resources), but most of these problems can be surmounted by proper materials selection and engineering designs. For some resources, standard materials can be used if particular attention is given to the removal of atmospheric and geothermally-generated gases. For others, system designs are possible which limit geothermal water to a small portion of the overall system by utilizing highly efficient heat exchangers and corrosion resistent materials in the primary side of the system.

Today, the equivalent of over 7,000 megawatts thermal (MWt) of geothermal resources are utilized worldwide for space heating and cooling (space conditioning), agriculture and aquaculture production and for industrial processes.[246] Table 3.12-1 indicates the variety of potential direct heat end-uses and the required temperatures for each application.

Generally, the agriculturally-related applications utilize the lowest temperatures, with typical values from 80°-180°F (27°-82°C). The amount and types of chemicals and dissolved gases in the resource such as boron, arsenic and hydrogen sulfide, can be a major problem. However, use of heat exchangers and proper venting of gases can solve this problem. Almost all of the agriculturally-related energy utilization is in the Soviet Union where over 5,000 MWt are reportedly being used.

Space heating generally utilizes temperatures in the range of 150°-212°F (66°-100°C), with 100°F (38°C) being used in some cases. Use of groundwater heat pumps can extend this range down to 55°F (13°C). The leading user of geothermal energy for space heating is Iceland, where over 50 percent of the country is provided with geothermal heat. The only geothermal cooling application currently on-line is Rotorua, New Zealand, at the International Hotel. However, many other cooling and refrigeration applications are presently being considered.[248]

Industrial process heat typically requires the highest temperatures, using both steam and super-heated water. Temperatures up to 300°F (150°C) are normally required. However, lower temperatures can be used in some cases, especially for drying of various agricultural products. Though there are relatively few examples of industrial processing using geothermal energy, they represent a wide range of applications from drying of wool, fish, earth, and lumber, to pulp and paper processing and chemical extraction. The two largest industrial uses are the diatomaceous earth drying plant in Iceland and the paper and wood processing plant in New Zealand. Table 3.12-2 indicates the extent of worldwide use of geothermal energy in direct-heat applications.

Table 3.12-1[247]

TEMPERATURES REQUIRED FOR COMMERCIAL, INDUSTRIAL, AND AGRICULTURAL PROCESS HEAT FROM GEOTHERMAL SOURCES

DEGREES CENTRIGRADE		
200		
190		
180	Evaporation of highly concentrated solutions Refrigeration by ammonia absorption Digestion in paper pulp, Kraft	Temp. range of conventional power production
170	Heavy water via hydrogen sulphide process Drying of diatomaceous earth	
160	Drying of fish meal Drying of timber	
150	Alumina via Bayers process	
140	Drying farm products at high rates Canning of food	
130	Evaporation in sugar refining Extraction of salts by evaporation and crystalization	
120	Fresh water by distillation Most multiple effect evaporations, concentrations of saline solution Refrigeration by medium temperatures	
110	Drying and curing of light aggregate cement slabs	
100	Drying of organic materials, seaweeds, grass, vegetables, etc. Washing and drying of wool	
90	Drying of stock fish Intense de-icing operations	
80	Space heating Greenhouses by space heating	
70	Refrigeration by low temperature	
60	Animal husbandry Greenhouses by combined space and hotbed heating	
50	Mushroom growing Balneological baths	
40	Soil warming	
30	Swimming pools, biodegradation, fermentations Warm water for mining in cold climates De-icing	
20	Hatching of fish; fish farming	

Table 3.12-2[249]

WORLDWIDE DIRECT USE OF GEOTHERMAL ENERGY

County	Space Heating/ Cooling (MWt)	Agriculture/ Aquaculture (MWt)	Industrial Processes (MWt)
Iceland	680	40	50
New Zealand	50	10	150
Japan	10	30	5
U.S.S.R.	120	5,100	—
Hungary	300	370	—
Italy	50	5	20
France	10	—	—
Others	10	10	5
USA	75	5	5
TOTAL	1,245	5,570	235

Benefits of Direct Application

The main advantages of direct utilization of geothermal energy are:

- High conversion efficiency (80-90 percent).
- The use of low-temperature resources, which are numerous and readily available.
- The use of many off-the-shelf hardware items (pumps, controls, pipe, etc.).
- Short development time as compared to electrical energy development.
- Lower-temperature resources require less expensive well development (the wells are shallower in some cases), can be drilled with conventional drilling equipment, and the water can technically be transported 20-40 miles (32-64 km) without major heat losses.[250]

At current fuel prices, geothermal energy for direct-heat applications should cost about the same or less than the corresponding fossil fuel applications. Due to the expected escalation of fossil fuel prices, the relative costs of geothermal systems should decline. Most geothermal direct-use systems should pay for themselves in five to ten years due to savings over conventional fuel use applications.[251]

Reservoir characteristics dominate geothermal energy costs because they determine the cost of the equipment required to produce and reinject the geothermal fluid used, and this equipment is by far the most costly factor in a geothermal system.[252]

The degree to which available geothermal energy is utilized by a commercial, industrial, or agricultural process is the most important element in determining the cost of energy in that process. Under conditions of high energy utilization, geothermal energy is at present competitive with fossil energy, and this competitive position is likely to improve.[253]

Wind Energy (3.13)

Introduction (3.13-1)

Wind power is a renewable energy technology with the potential to contribute substantially in the near term to reducing our dependence on nonrenewable energy resources. Thousands of years ago in Persia windmills were used to grind grain. Hundreds of years ago in Europe windmills were used to pump water. In recent times windmills were used on American farms to pump water and to produce small amounts of electricity. Today new designs involving the latest advances in materials, aerodynamics, electronics, structural engineering, and control theory are being developed both by government funded programs and by the private sector.

Wind energy systems are currently under development in the United States and in a number of other countries including Sweden, West Germany, Denmark, the Netherlands, Great Britain, Japan, and the Peoples' Republic of China. Through this diversity of development, many new concepts and designs are evolving.

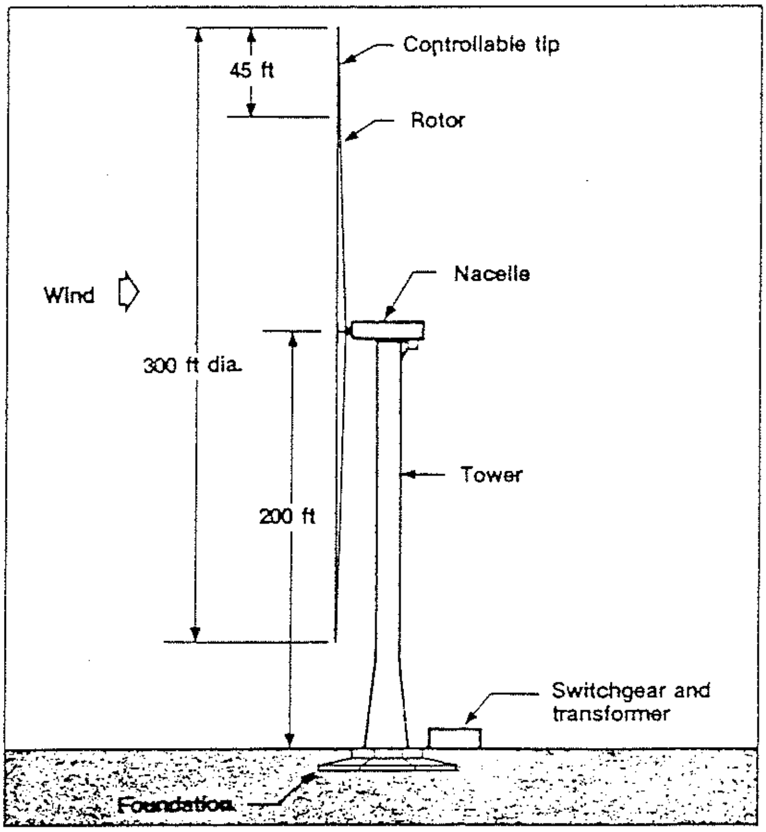
System Description (3.13-2)

Modern windmills are more appropriately described as wind energy conversion systems or "WECS." Those WECS which convert wind energy to electricity are called wind turbine generators, since the wind is actually powering a turbine consisting of a set of rotating propellers or blades which in turn are connected to an electrical generator by means of a shaft. As Figure 3.13-1 illustrates, the basic components of a wind turbine generator are relatively simple. The blades which collect the wind turbine generator are relatively simple. The blades which collect the wind's energy are usually connected to the electrical generator via a set of gears or speed increasers which convert the speed of the shaft rotating at 30 to 120 rpm to 1,800 rpm on the generator side of the gear box. The wind system depicted here is the 2.5 MW MOD-2 horizontal axis system developed by Boeing for DOE and NASA in which a two or three bladed propeller rotates on an axis which is horizontal to the wind direction. The rotor is mounted on top of a tall tower to take advantage of the fact that wind speed generally increases with height above ground.

The horizontal axis wind system depicted in Figure 3.13-1 is the most thoroughly developed system currently being used to produce electricity, although vertical axis systems are also being developed and tested. The most successful vertical axis design developed to date is the Darrieus concept, in which two or three slender blades resembling airfoils are attached to the top and bottom of a vertical shaft or torque tube. This unit is one of a family of designs currently being developed by Alcoa. Although less efficient than a horizontal-axis WECS of similar sweep area, vertical axis machines have the advantage of accepting winds from any direction without the need for the rotor turning or yawing to face the wind. Another advantage of vertical axis machines is the ability to locate all the machinery and controls at or near ground level, thus providing much easier access for maintenance, as well as reducing the load carrying requirements of the tower.

Figure 3.13-1 254

MOD-2 WIND TURBINE CONFIGURATION
DIAMETER: 91m, RATED POWER: 2.5 MW

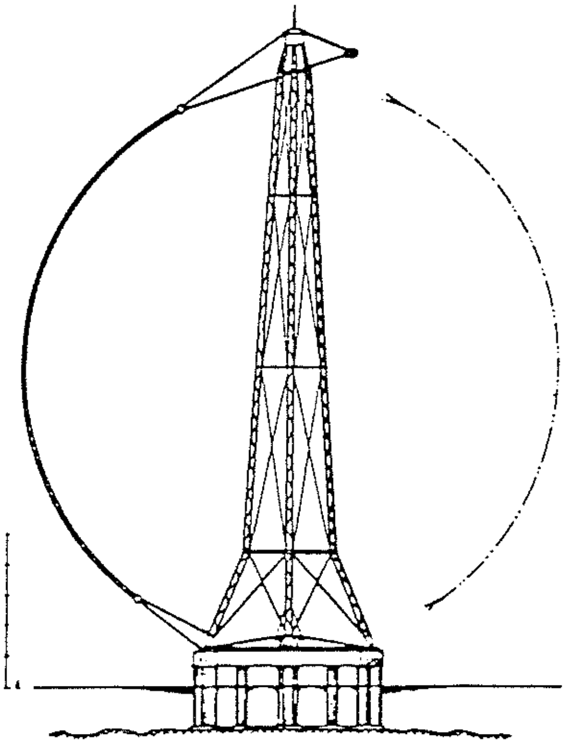


The Alcoa vertical axis systems range in size from eight kilowatts to 500 kilowatts. The Canadian National Research Council and DAF-Indal have developed and tested 50 and 224 kilowatt vertical axis systems. Perhaps the most ambitious vertical axis design still in the conceptual design stage is the twenty megawatt "Poseidon L-180" vertical axis system proposed by Olle Ljungstrom of the Swedish Aeronautical Research Institute. The Poseidon system dimensions are 180 meter rotor diameter by 210 meter tower height. Ljungstrom's proposed design is shown in Figure 3.13-2.

Wind systems can be classified according to physical scale or power rating at a reference windspeed. Systems rated at less than 100 kilowatts at twenty miles per hour (32.2 kilometers per hour) wind speed are classified by the DOE as "small-scale," while systems larger than 100 kilowatts are classified as "large-scale." Actually there is a "medium-scale" that overlaps these two scales, and the distinction is rather imprecise. For the purpose of discussion we can arbitrarily select 50-100 kilowatts as the lower end of "medium-scale," while 500-1,000 kilowatts might be the upper end of the "medium-scale" range.

Figure 3.13-2 [255]

"POSEIDON L-180" TYPE DESIGN
DIAMETER: 180m, RATED POWER: 20 MW

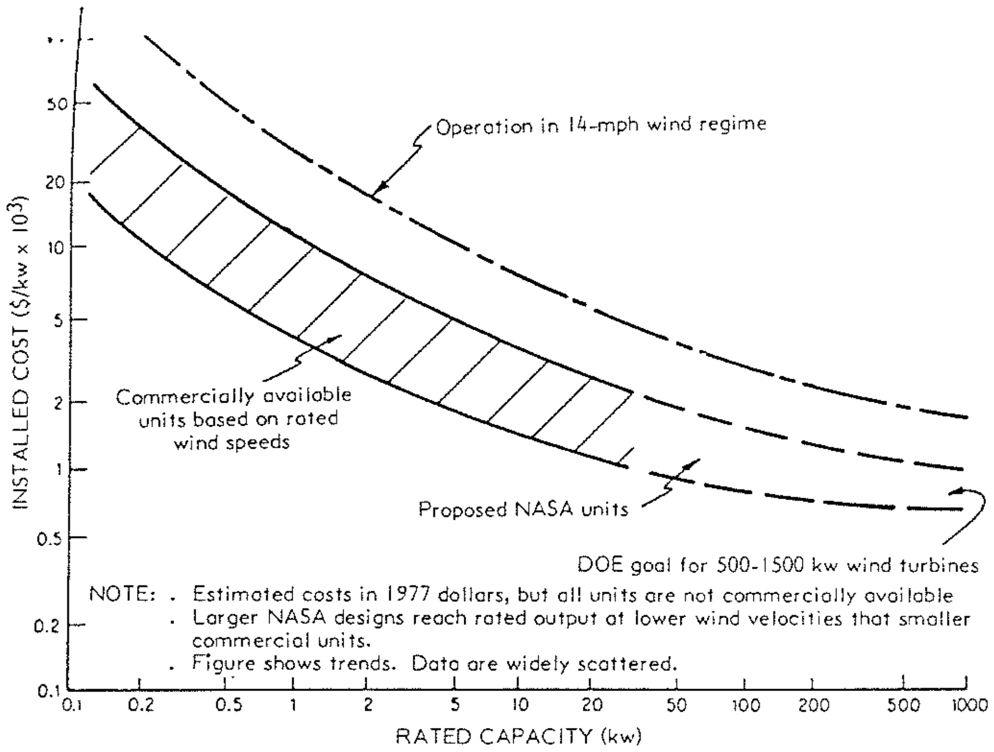


Large-Scale Systems

Large-scale wind turbine systems in the megawatt class sited in clusters of 25 or more units (wind farms) appear to offer the greatest promise for producing large quantities of electricity at the lowest cost. Total system costs per installed kilowatt of capacity tend to decrease with increasing capacity up to a certain point. Above a certain capacity the weight and cost of the rotor increase faster than the power output increases, with the result that very large-scale machines appear to undergo diminishing economies of scale. Generally speaking, the optimum cost machines appear to be in the range of one to five megawatts. Figure 3.13-3 illustrates the trend of anticipated cost decrease with increasing size. This should be interpreted as a general anticipated trend rather than observed fact. As more experience is gained in the development and testing of machines in various sizes, the costs will be clarified. Structural optimization, particularly for blades, tower, and gears will be useful in reducing the costs of the large machines. As indicated previously, the availability of higher windspeeds at greater heights above the ground permit more energy capture per unit rotor area. This tends to reduce the cost of electricity for the larger machines by providing greater energy capture per unit swept rotor area.

Figure 3.13-3 [256]

COST OF WIND GENERATORS



Large-scale wind systems are being developed in this country by the federal government wind program under the management of the Department of Energy (DOE) and the NASA Lewis Research Center. The DOE/NASA program goal is to develop reliable and economical systems which ultimately can be commercialized. The first generation machines developed by NASA and its contractors were primarily research tools from which engineering and operational experience could be gained. Machines of various sizes operating under different loads, environments, and in different utility grids were tested.

The basic first generation NASA design was the MOD-O series. This unit is the DC-3 "workhorse" model from which valuable operational and maintenance data are being obtained. The MOD-OA system has an aluminum rotor of 125 foot diameter mounted on a 100 foot (30.5 meter) tower and produces 200 kw at 21.7 miles per hour (31.9 kilometers per hour).

The unit at Clayton, New Mexico, installed at the end of 1977 logged more than 5,000 hours of operation during its first two years, and the basic system design has been verified.[257]

Another first generation machine, the MOD-1, is basically a scaled-up version of the MOD-O series. This system is designed to produce two megawatts of power at a rated wind speed of 32.6 miles per hour (52.5 kilometers per hour) measured at 140 foot (42.7 meter) hub height. The rotor is made from welded steel and has a diameter of 200 feet (61 meters). This machine was developed by the General Electric Company and was dedicated in July 1979. The unit is located atop Howard's Knob at Boone, North Carolina. According to recent results reported by NASA the unit's measured performance data is very close to the anticipated design output.[258]

A second generation design being developed for NASA by Boeing, is the MOD-2 which is designed to produce 2.5 megawatts at 27.7 miles per hour (44.6 kilometers per hour) measured at 200 foot (61 meter) hub height. The welded steel rotor is 300 feet (91.4 meters) in diameter. This system has been developed specifically for the electric utility market with a 100th unit cost goal of four cents per kilowatt hour (1977 dollars) when located at a site with moderate wind speed (fourteen miles per hour or 22.5 kilometers per hour average measured at 30 feet or 9.1 meters). A cluster of three MOD-2 units will be constructed at Goodnoe Hills near Goldendale, Washington. Start-up of the first machine is planned for December 1980.

Advanced systems planned for development under NASA sponsorship are the MOD-5 and MOD-6 systems. MOD-5 will be an advanced multimegawatt scale design under parallel development contracts to Boeing and General Electric. MOD-6 will be a second generation design in the 100 kilowatt class with parallel contracts for horizontal axis and vertical axis designs. Start-up of both of these prototype systems will not begin until the end of 1983.

In addition to these government-funded development programs, a number of privately-funded large wind turbine programs are being developed. The Hamilton-Standard Division of United Technologies Corporation is working under a joint arrangement with a Swedish shipbuilding concern to develop a three megawatt, 255 foot (77.7 meter) diameter horizontal axis system for the Swedish National Board for Energy Resource Development. The WTS-3 design incorporates many advanced concepts including the use of a teetered rotor to reduce loads, a "soft" tower to provide acceptable structural resonance characteristics at minimum cost, fiberglass blades for improved fatigue life, and the use of "free" or uncontrolled yaw, which eliminates the need for power to drive the rotor to face the wind.

The prototype WTS-3 unit will begin testing in Sweden in late 1981. An uprated, four megawatt system verification unit, the WTS-4 has been ordered by the U.S. Department of the Interior for tests at Medicine Bow, Wyoming starting in late 1981. If successful, quantities of large-scale units will be ordered by the Interior Department for wind farm operation.

Another large system being developed privately is the three megawatt Bendix/Wind Power Products system which features a three-bladed, 165 foot (50.3 meter) diameter rotor that will develop its rated power at 40 miles per hour (64.4 kilometers per hour). A prototype unit has been ordered for testing by the Southern California Edison Company starting in late 1980. The unit is sited in the San Gorgonio Pass near Palm Springs, California. The machine is estimated to produce about six million kilowatt hours per year and would save about 10,000 barrels of oil annually.

Small-Scale Systems

Small-scale systems are being developed, tested, and sold by a developing industry which currently numbers about 40 companies. The federal government is funding the development and testing of small-scale prototype systems in the range of 1-40 kilowatts, as well as testing commercially available systems developed by the industry. These systems would be used in a variety of applications for farm, residential, and rural applications. The DOE operates a national test center at Rocky Flats, Colorado for small wind energy conversion systems (SWECS) under contract to Rockwell International.

The SWECS under development by the DOE are summarized in Table 3.13-1. The one to two kilowatt high-reliability systems are for remote locations where conventional power costs are high. The four to eight kilowatt systems are for home or farm use. The fifteen to eighteen kilowatt systems are for small community, industry, or farm applications. The 40 kilowatt systems are for deep well irrigation, farm/ranch application, and for small isolated communities or industries. Some of these systems are shown in Figure 3.13-4.

Table 3.13-1 [259]

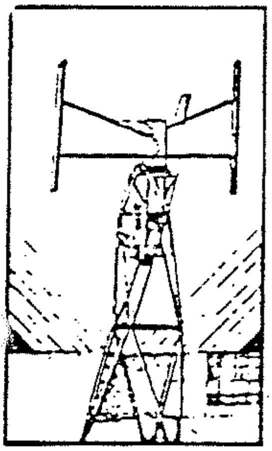
SPECIFICATIONS OF SWECS UNDER DEVELOPMENT BY DOE/ROCKY FLATS

Contractor	Rated Power, kw @ 20 mph.	Rotor Size*, feet
1-2 kw (High Reliability) Systems		
Enertech	2.3	16.4
Northwind	2.0	16.4
Aerospace Systems, Inc. (VA)	1.0	15 x 8
4-6 kw Systems		
Northwind	4.0	32.8
Structural Composit 5.7		31.2
Tumac (VA)	6.2	21 x 32
8 kw Systems		
Windworks	8.0	31
United Technologies Research Center	9.0	31
Grumman	11.0	33.25
15-18 kw Systems		
Enertech	15.0	44
United Technologies Research Center	18.0	47.9
40 kw Systems		
Kaman Aerospace	40	64
McDonnell Douglas	40	32.5 x 65

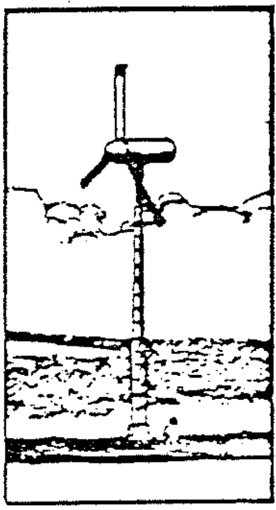
*For Vertical axis systems (VA) first figure is rotor diameter, second figure is rotor height.

Figure 3.13-4 [260]

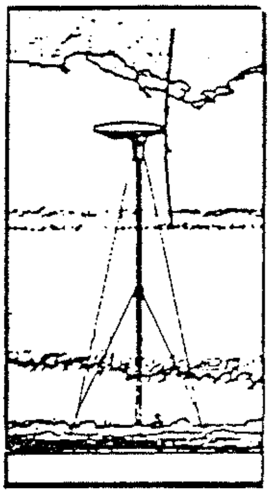
ADVANCED SWECS UNDER DEVELOPMENT
(1-2 kw and 8 kw)



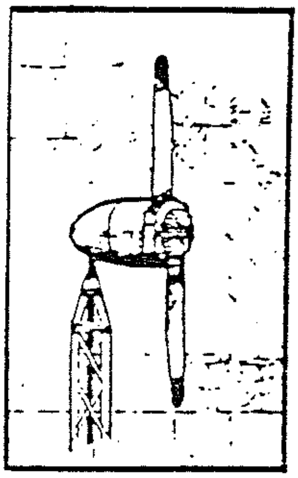
Aerospace Systems, Inc.
1 kw - High Reliability



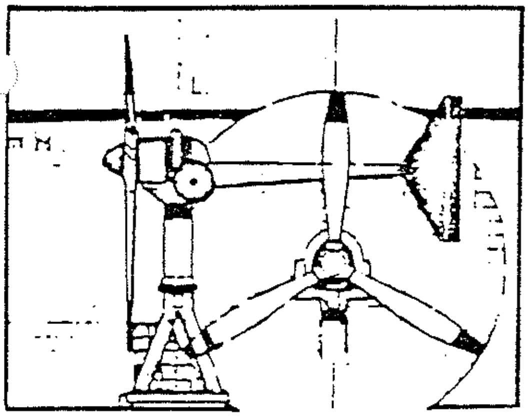
Grumman
8 kw



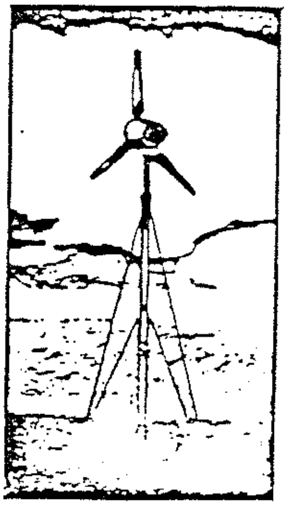
United Technologies
Research Center
8 kw



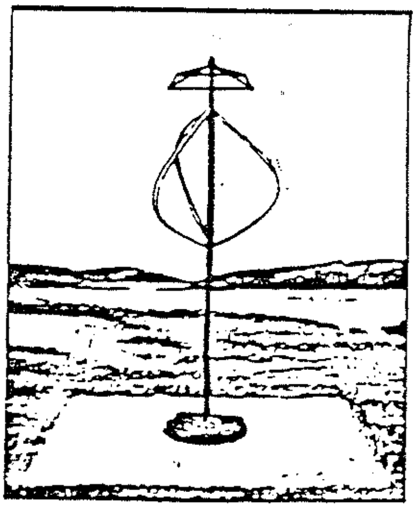
Enertech
1 kw - High Reliability



North Wind
1 kw - High Reliability



Windworks
8 kw



Alcoa
8 kw

A number of privately developed, commercially available machines are currently being evaluated at Rocky Flats. These systems include the one kilowatt systems manufactured by Sencenbaugh and Aeropower, the ten kilowatt Millville unit, the 25 kilowatt Jay Carter Enterprises system, and the 40 kilowatt system of Mehrkam Energy Development Company. The Jay Carter machine, capable of producing 25 kilowatts at 25 miles per hour (40.2 kilometers per hour), is illustrative of what can be accomplished by the private sector. The Carter design, which is highly innovative, incorporates molded fiberglass blades, passive aerodynamic overspeed control, and flexible blades for load reduction during operation in high wind speeds. Currently the unit is selling for $16,000 with site prepartion, delivery, and installation costs dependent of the specifics of the site. Total turnkey installed cost of around $25,000 are typical for this model.

Since production lines have not yet been established for the DOE-developed machines, actual production costs are not yet available; however, DOE-sponsored field evaluation tests using privately-developed systems are being conducted during 1980 and 1981 to learn more about actual costs and to gain operational experience.

Wind Energy Potential (3.13-3)

Wind Energy potential involves both the power available in the wind and the efficiency of a WECS to convert this power to useful electrical or mechanical energy. The theoretical maximum efficiency of a horizontal axis wind turbine is 59.3 percent. Practically speaking, a well designed wind turbine should have a overall efficiency around 40 to 45 percent at rated wind speed and lower for other wind speeds below or above the rated wind speed.

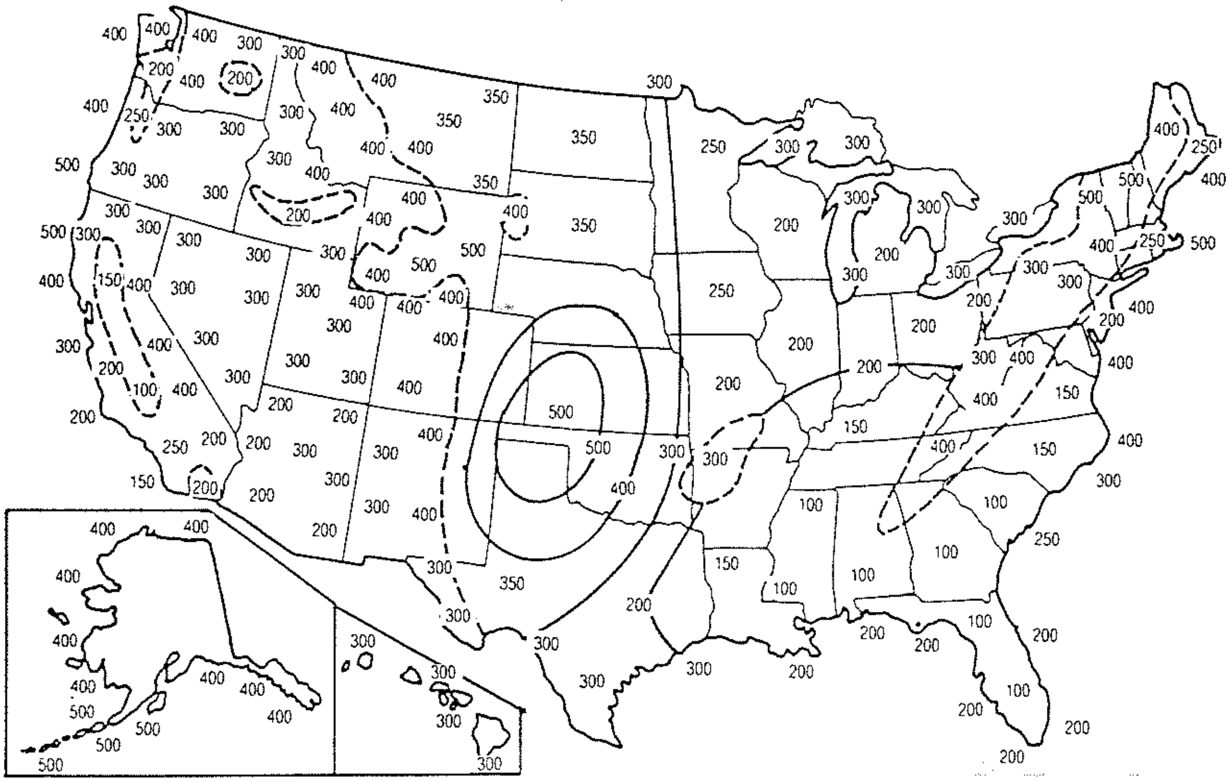
Since the power output is so sensitive to the wind speed, and since the average wind speed at a site is generally considerably less than the rated wind speed, the average power produced by a turbine will always be less than the rated output. For example, for a turbine rated at 32 miles per hour (51.5 kilometers per hour) wind speed, the power at sixteen miles per hour (25.7 kilometers per hour) will be one eighth of the rated output. The average power produced by a wind turbine at a given site is perhaps more indicative of performance. The capacity factor is a measure of the average power of the wind turbine. A unit that runs at 100 percent of its rated power over a year's time has a capacity factor equal to 100 percent. Depending on site location and wind turbine generator characteristics, the capacity factor can vary from 25 percent to as high as 45 percent for a typical moderately windy site, although higher capacity factors are possible for certain very windy sites such as the Hawaiian Islands.

Resource Base

Estimates of the total wind resource base for the U.S. vary considerbly. An assessment of the nation's wind resources has been initiated by the Battelle Pacific Northwest Laboratories under the direction of the DOE. Figure 3.13-5 is an estimate made by Battelle of the annual mean wind power in the U.S. at 50 meters above exposed areas. Vast areas of the U.S. including the Northeast, the Appalachian Mountains, the Great Plains, the western states, and the Pacific Coast states appear to have consistently strong winds.

Figure 3.13-5[261]

ANNUAL AVERAGE WIND POWER (WATTS/M^2) AT 50M

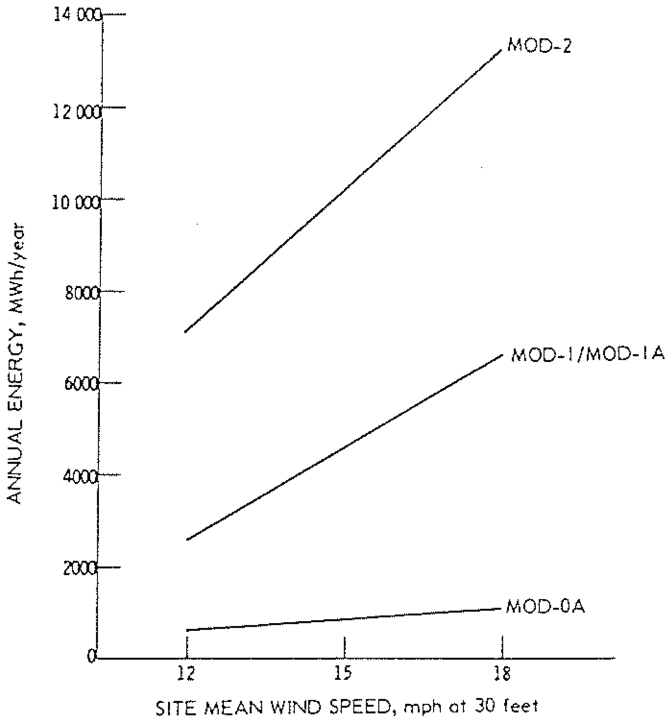


Although average wind speed is an unreliable indicator of the strength of a given site, it is a commonly used indicator. Generally speaking, a site with an annual average wind speed of fourteen miles per hour measured at a 30 foot or ten meter height is considered a "moderately windy" site. Sites with mean wind speed around twelve miles per hour would be marginal, while sites with sixteen miles per hour (25.7 kilometers per hour) or greater mean wind speed would be considered highly energetic. Figure 3.13-6 provides an indication of the annual energy output of the NASA MOD series of wind turbines as a function of site mean wind speed.

Wind characteristics tend to be highly variable from one site to another or from one day to another at a given site. This requires an on-site measurement program of one to two year's duration collecting hourly wind speed and direction data in order to ascertain the viability of a given site. Site winds tend to be highly seasonal with different diurnal (daily) wind patterns from one season to another. A number of states, most notably, California, Hawaii, and Oregon, have initiated wind prospecting programs to systematically search out sites that have the best wind characteristics. Owing to the fact that wind power varies as the cube of the wind speed, a one or two mile per hour difference in mean annual wind speed between sites can have a significant bearing on the economic viability of a given site.

Figure 3.13-6 262

ANNUAL ENERGY OUTPUT



Energy Production (3.13-4)

The total potential annual energy production for the U.S. from wind turbines is probably in excess of $2x10^{12}$ kilowatt hours ($2x10^9$ MW hours) the approximate magnitude of the current annual electricity production for the U.S. This amount of electricity could be produced from approximately 200,000 megawatt-scale wind turbines rated at four megawatts each. These machines would save the equivalent of three million barrels of oil daily, which is greater than the current level of oil imports to the U.S. Assuming the units are spaced at ten diameters apart to avoid aerodynamic interference, the machines would require 67,000 square miles (173,529.2 square kilometers) of involved land, roughly two percent of the land area of the U.S. Approximately ten acres of land would be required for each machine and its associated roads, maintenance facilities and transmission lines; thus, a little more than 3,000 square miles (7,700 square kilometers) of land would be exclusively dedicated to the machines (about five percent of the 67,000 square miles or 173,529.2 square kilometers of "involved" terrain).

It is important to note that either a utility back-up or energy storage system is required with wind systems owing to the difficulty of matching the demand for power with the availability of the wind. If wind machines are deployed and interconnected with a common utility grid over a large geographical area, the diversity of the wind characteristics at the various sites will result in a fraction of the installed capacity which can be earmarked as firm; thus, a capacity "credit" can be attributed to the wind system. For a ten to twenty percent penetration of wind systems perhaps 20 to 30 percent or more of the installed capacity could be counted as firm. The actual amount of wind capacity that can be integrated with a given utility system and the capacity credit which can be attributed to these sytems depends on the particular demand profile of the network, the mix of conventional generation systems, the local, site-specific wind characteristics, and the wind turbine operational characteristics. A utility-specific simulation using hourly wind data is required to analyze the situation in order to estimate the maximum amount of wind energy penetration that can be sustained.

Development and Production Issues (3.13-5)

The constraints to wind system deployment are economic rather than strictly technical issues. The development and test programs of the past several years sponsored by the federal government and by private industry have proven the technical viability of the basic design concepts for wind turbines as large as 200 feet (61 meters) in diameter. The key issue is that of cost to generate electricity. This cost is a function of system performance, reliability, and service life. The experience gained to date with the NASA MOD-OA 200 kilowatt prototype wind system which has been operating at Clayton, New Mexico since November 1977, has been very useful in delineating all three of these major potential problem areas. While the predicted power levels have actually been achieved, the annual energy production during the first year was about half of the predicted value.[263]

Improvement in performance is being examined by studies that compare various design choices on the basis of improved energy capture for a given cost. Both the MOD-2 and the WTS-3 were designed after very detailed trade-off studies. Various new design concepts will be employed in the design and development of advanced second generation designs such as the Westinghouse MOD-OW 500 to 900 kw system and the NASA MOD-5 multimegawatt systems to be developed in parallel by Boeing and General Electric. Use of variable speed rotors and advanced high performance airfoils offer the means to increase energy capture.[264,265] NASA is attempting to obtain approximately 25 percent improvement in cost of electricity for the MOD-5 compared to the MOD-2 design.[266] The cost of electricity for the 100th unit would be three cents per kilowatt hour (1977 dollars) or approximately four cents per kilowatt hour (current 1980 dollars). Even if this goal is not achieved, the fact that current fuel oil costs are in excess of five cents per kilowatt hour, and increasing more rapidly than the general rate of inflation, indicates that by the mid-1980s the cost of electricity from mass-produced large wind turbines could be well below the cost of oil-fired electricity.

By mid-1982 both the MOD-2 and WTS-3 megawatt-scale designs will have undergone sufficient test experience to verify the basic designs. Barring any unforseen proglems these units could be in mass production at that time. The smaller 500 kw MOD-OW systems could be in mass production before that date. The small and medium scale units should also have had sufficient test experience by mid-1982 to be considered ready for mass production.

Resource Issues

There appears to be a very large resource base capable of supplying perhaps as much as 2×10^{12} kwh per year. This would be equal to 6.82 Quads of primary energy displacement or about twenty percent of the total U.S. energy requirement projected for the 1990s. Achievement of a target of ten to twenty percent of the U.S. electricity production, an equivalent of 50,00 to 100,000 megawatts of installed wind system capacity and two to four Quads of primary energy displacement, would require the location and verification of 5,000 to 10,000 square miles (25,899.9 square kilometers) of sites swept by winds of fourteen miles per hour or greater mean annual wind speed. A massive site prospecting and verification program will be required to locate and verify this many sites. Owing to the fact that many sites will not prove viable due to poor quality resource or siting difficulties, perhaps 50 times as many sites will have to be surveyed as are ultimately developed. The cost to survey and validate 100,000 megawatts of wind resource would be between one and three billion dollars. This is based on an estimate made by Ginosar[267] of the cost to develop sites for approximately 100 large wind farms in California totaling 10,000 megawatts of installed capacity and an estimate by Lindley and Melton[268] of the costs to validate a 450 MW wind farm for Hawaii.

There are some unresolved questions concerning how much wind measurement is ultimately required to validate a site prior to erecting a large number of wind turbines. A case in point is an 80 megawatt wind farm project planned for the Hawaiian Electric Company under the direction of Windfarms, Ltd., a California-based wind farm developed. Although a number of site surveys and measurements have already been performed over the past five years on the island of Oahu, and a great deal of useful wind data have been collected, more detailed site-specific measurements costing about $600,000 will be required prior to siting approximately 20 to 32 large turbines. Tall meteorological towers for collecting one minute averages of wind speed at several heights will be installed in order to accurately predict the turbines' performance. Similar measurement programs are already underway in California at candidate wind farm sites under the sponsorship of the California Energy Commission and the two largest investor-owned utility companies, Southern California Edison and Pacific Gas and Electric Company. These pioneering resource validation programs and subsequent wind turbine tests at the Hawaii and California sites will resolve most of the technical uncertainties.

Fortunately, in the case of large wind farms, the cost of wind resource validation is only about one percent of the total cost of installing a wind farm. The importance of this activity is overriding owing to the sensitivity of the economics to site resource magnitude. A one mile per hour (1.6 kilometers per hour) decrease of site mean annual wind speed from the nominal design of fourteen miles per hour will result in a fifteen percent increase in the cost of electricity for the MOD-2.

For single-unit installation of small wind systems the need for accurate site resource data is perhaps even more critical for economic success since a few miles per hour difference in mean annual wind speed can spell the difference between a marginally economic installation and an uneconomic one. The reasons for this are primarily that the SWECS unit installed cost per rated kw tend to be higher than for the medium scale or large scale systems, thus site wind energy availability is even more important for success. Compounding this is the fact that a SWECS unit will probably be installed at the user's site, rather than at some remote, more energetic site. The user then, must have accurate information on his site wind resource. Data from nearby measurement stations are generally not indicative of the local site wind resource; thus onsite wind measurements are required. The cost of performing these measurements is going to be a much greater fraction of the total cost than for the larger machines. The site analysis work for example might cost on the order of ten to fifteen percent of the total cost of installing a small wind system. For example, for siting an eight kw system costing $15,000 installed, a one year meteorlogical onsite measurement program might cost on the order of $1,500 for equipment leasing, data collection, data analysis, and economical analysis. This problem has not been adequately addressed by the DOE. The recently-issued revised SWECS siting handbook by Wegley, et al addresses the major issues.[269]

Environmental Issues

Although a number of potential environmental issues have been identified which could possibly limit the development of the technology, most of these potential problems can be mitigated by careful site-specific evaluation prior to siting. The major issues are electromagnetic interference, noise, construction impacts, bird strikes, land use, aesthetics or public acceptance, and safety.

Electromagnetic interference of radio, TV, and microwave signals does not appear to be a significant problem. The ability of a wind turbine to scatter electronic signals depends on the rotor swept area and on the blade material. Large wind turbines with all-metal blades offer the greatest potential for scattering signals but remote siting will alleviate most problems. Non-metallic blades will further reduce the severity of the problem. TV and microwave interference could be a problem in rural areas where reception is weak, if the turbine is located in close proximity to a TV receiver or a microwave link. The TV interference can be solved by installing cable TV, and the microwave interference problem can be solved by installing the wind turbine outside the narrow zone where signals will be affected.

Noise in the audible range and infrasound do not appear to be a problem, except perhaps for certain types of large-scale systems located near populated areas or for small scale systems located in urban and suburban areas. Experimental measurements of sound levels near the 125 foot (38.1 meter) diameter, 100 kilowatt MOD-O indicated that no significant problems exist; however, recently, noise problems have been encountered in connection with the 200 foot (61 meter) diameter, 2,000 kilowatt MOD-1 at Boone, North Carolina. The machine is a two bladed, downwind turbine with a truss tower. Residents have complained about the noise, and NASA is currently investigating the situation. The problem appears to result from the fact that a blade passes behind the tower at a frequency of about one cycle per second. Each time this occurs a blade passes through the turbulent wake caused by the wind flow around the tower legs, and the resulting interference produces sound pressure fluctuations. These disturbances are focused and amplified by the terrain with the result that some of the nearby inhabitants are disturbed. NASA has curtailed operations and is installing a lower-speed generator. The problem can be corrected by design changes (changing the tower shape, changing the rotor rpm, or mounting the rotor in an upwind configuration) or by siting wind farms using large machines a sufficient distance from populated areas.

Construction impacts associated with land leveling and tower foundation appear to be minimal, although siting in forest areas or fragile ecological areas could produce some problems.

Bird strikes do not appear to be a problem. Observation with the MOD-O indicated that birds tend to take evasive action to avoid hitting the blades. Further test experience will provide more information for this question.

Land use could be a problem in the event that the potential site conflicts with other uses. Residential wind systems in densely populated urban and suburban areas appear to offer substantial problems owing to the relatively large blades and tall towers, although this may be more a question of safety and aesthetics. In the case of remotely sited wind farms, the wind machines and associated roads and service facilities would occupy a very small percentage of the land area (less than five percent) so that wind farms could coexist with other land uses such as cattle grazing. Only in the case of conflict with a wilderness area, park, or other scenic or valuable resource would there be a potential problem. Wind farms may be excluded from these areas and from sites in close proximity to densely populated residential areas.

A large portion of the U.S. wind resource is located on federal lands with wilderness potential. Many of these lands administered by the Bureau of Land Management (BLM) and the U.S. Forest Service will soon be classified by Congress according to land use designation. If detailed wind resource assessment surveys are not conducted prior to this land use designation, vast wind resources could be inadvertantly locked up and forever precluded from development. Congress should appropriate adequate funding to make a preliminary resource assessment on federal lands. The task would cost about $100 million over a period of two to three years and could result in the discovery of vast wind resources. Informed decisions could then be made regarding the ultimate designation of these federal lands. The California Energy Commission is currently working cooperatively with the BLM to begin to assess the wind resources in the 25,000 square mile (64,749.7 square kilometer) California desert. The BLM has agreed to permit wind resource measurements on all California desert lands which it administers. Federal funds will be required to continue to job initiated by the Commission. This project could be a pilot project that could pave the way for similar projects on all of the vast lands managed by BLM and the Forest Service.

Safety is of concern owing chiefly to the possibility of accidental structural failure of blade or tower elements. Large wind turbines are being designed to survive 125 mile per hour (201.2 kilometer per hour), hurricane force winds. In the even of a tower collapse a distance equal to the tower height plus rotor diameter would be affected, hence public access should be restricted from this area. Blade failure resulting in a thrown blade could thrust a large blade approximately 550 feet (167.6 meters) according to NASA analysis.[270] Rigorous design requirements, testing, and preventive maintenance could reduce the failure rate so as to pose a very small risk to human life. Remote siting and the fact that these failures would likely occur during extreme environmental conditions would further reduce the likelihood of any risk. Some certification and licensing of systems should be required to prevent unsafe designs from being sold. The DOE Rocky Flats SWECS test center in Colorado is an excellent location to test survival of small wind systems owing to the annual occurrence of 100 plus mile per hour (160.9 plus kilometer per hour) winds during winter storms.

Legal and Institutional Issues

There are a variety of legal and institutional issues confronting full-scale development of wind energy, and the problems vary for large and small scale wind systems. A question arises over the issue of "wind rights." Upwind obstructions, such as buildings or other wind turbines, could seriously impede the airflow and limit the amount of energy available. Existing statutes do not cover this area, and as matters now stand, potential wind system owners would have to purchase preclusionary interest or "easements" in the surrounding land to assure adequate availability of wind energy for their turbine(s). This impediment will be of primary concern in urban or suburban areas. For the wind farm application and the land requirement for adequate spacing between turbines forces the wind farm developers to obtain wind rights for large parcels of land, although the ownership and use of the land are between the turbines could remain as it was prior to the wind farm development.

For the small-scale systems there are a number of institutional issues that may severely limit system implementation. Zoning restrictions such as limitations on height, setback, use, and aesthetics could severly restrict residential and commercial wind systems in urban and suburban areas.[271] Building, safety, and housing codes, although not likely to totally preclude wind turbine use, could impose substantial burdens on the user.[272] It is unlikely that utility applications are subject to these regulations and codes, since the utilities are regulated by state public service or utility commissions or are covered by state power plant siting statutes.

There are a number of utility interface issues that directly and substantially affect the small-scale system user. For utility-connected systems the chief issues are interconnection requirements and utility rates for purchase of unused power. The utility will require the user to install and maintain control and protective devices to permit the safe operation of the SWECS in parallel with the utility's generation facilities. Utility conservatism in this area may initilly place a heavy burden on the SWECS user. As more experience is gained, these requirements will be less costly and cumbersome. The issue of buyback rates is another very important consideration for interconnected systems. The Federal Public Utilities Regulartory Policies Act of 1978 (PURPA) requires utilities to purchase power from small producers unless the purchase would result in a net loss to the utility. Each state public utility commission must issue regulations regarding these rates. The producer is to be guaranteed a rate equal to the utility's avoided cost which translates to the marginal cost to generate an additional kilowatt hour of electricity. The utility will be required to revise the buyback rate each quarter to reflect changes in the marginal cost of energy.

Another issue that could have a strong influence on the economic viability of SWECS is the cost of insurance premiums to cover destructive loss of the wind turbine by acts by God, vandalism, or misuse. The annual cost to obtain this coverage could be a significant factor contributing to the cost of the electricity produced.

Finally, the lack of a well developed, sophisticated, and adequately financed manufacturing, distribution, installation, and servicing infrastructure for the wind industry is a very serious impediment to the expansion of this technology.

Trends (3.13-6)

At the present time the price that either a utility or a residential owner could pay for wind systems and break even over the system lifetime are off by approximately a factor of 1.5 to 2.0.[273] Under the present economic situation and assuming that oil prices escalate at three percent above the rate of inflation, the market for both utility and residential wind systems should emerge by the mid 1980s. Assuming that the technical performance and reliability of these systems is demonstrated, the value of electricity produced from these systems will be equal to or less than the value or cost of the fuel oil displaced. The market is not yet developing owing to currently high capital cost of these systems and the uncertainty of the potential buyer about system performance and reliability. Potential buyers of these systems are waiting until the cost comes down and performance is proven, while the manufacturers are not tooling up for mass production because the orders are not yet sufficient to warrant it. Various incentive measures can help to remove this barrier by reducing the risks to both the buyer and the manufacturer.

Currently there are several federal incentive measures recently passed in the U.S. Congress. The 1980 Crude Oil Windfall Profits Tax Act provides for a 40 percent tax credit for the first $10,000 of a residential wind turbine system. For business investments in wind systems, a fifteen percent tax credit is available in addition to the existing ten percent investment tax credit for a total credit of twenty-five percent. In addition to this legislation the Congress recently passed the Wind Systems Act of 1980 which sets a national goal of 800 megawatts of installed wind system capacity by 1988. The Act provides incentives in the form of subsidies and loans to encourage the purchase and testing of wind systems.

The Act specifies subsidies initially equal to 50 percent of the capital cost for large-scale wind systems and low-interest loans for 320 megawatts of wind farm projects. The Act calls for a program to procure and install wind systems at federal facilities, and establishes a three year wind resource program funded at ten million dollars during the first year. The Act authorizes $100 million; however, Congress has not yet appropriated this level of funding for Fiscal Year 1981. The direct federal purchase of wind systems could be very helpful in stimulating an early market, particularly demonstrations of large wind systems by the Water and Power Resources Service (formerly the Bureau of Reclamation) and the federal power marketing agencies such as the Bonneville Power Administration.

Various regulatory actions such as PURPA are also a stimulus to commercialization. PURPA is a vehicle by which small power producers can deliver up to 80 MW of power to a utility and avoid regulation by state public utility commissions while at the same time receiving the utility's avoided cost for the energy delivered. State utility commissions can do a great deal more to stimulate utility investment in wind systems by allowing an increased rate of return on investment for wind farm systems or by artificially increasing the cost of oil fired generation and plowing the increased revenues into wind farm deployment. The California Public Utilities Commission offers for example, an extra one half percent to one percent return on investment for renewable energy systems. This trend should be increased in the future by as much as five to seven percent to stimulate more rapid investment by utilities. The ratepayers would benefit from secure electricity prices from wind systems.

Accelerated depreciation is another incentive that is beneficial to utilities and businesses that invest in wind energy property. The trend will probably be to allow for much faster tax write-offs, for example, three years as opposed to seven years to depreciate an item of wind energy property, although the actual system lifetime is anticipated to be 20 to 30 years. Recently California enacted a law which allows a twelve to sixty month amortization for alternative energy equipment, including wind energy systems (Chapter 1327, Revenue and Taxation Code, 1980 Statutes).

Sizing (3.13-7)

The issue of sizing is most appropriately discussed in terms of the application. Utility wind farms employing clusters of medium- or large-scale WECS could be considered a "centralized" application, while residential and other applications employing single units or clusters of several units in unit sizes from several kw to large-scale systems in the megawatt class could be considered a "decentralized" application. The "centralized" category does not fit the traditional definition since the wind farm may be quite small in comparison to a large, centralized nuclear, coal-, or oil-burning plant ranging in capacity from 500 to 2,000 megawatts. In comparison, a small wind farm might consist initially of ten MOD-2 units rated at 2.5 megawatts each, totaling 25 megawatts. Later, as more experience is gained the farm might consist of 32 MOD-2 units or 20 WTS-4 units totaling 80 megawatts. The land area requirements for an 80 MW wind farm are summarized in Table 3.13-2.

Table 3.13-2[274]

80 MW WIND FARM LAND AREA REQUIREMENT AND NUMBER OF UNITS

Model	Unit Rating Kilowatts	Rotor Diameter (feet)	Farm Area*	Number of Units
Hamilton-Standard WTS - 4	4000	225	4.7	20
Westinghouse MOD-OW	500	125	7.3	160
Jay Carter 125	125	64	9.4	640
Jay Carter 25	25	32	11.75	3200

*assumes ten diameter spacing between units

Table 3.13-2 also illustrates the fact that increasing the rotor diameter not only decreases the number of machines required for a given number of megawatts of total capacity, but decreases the land area required. For these reasons the large units appear to be more attractive assuming the cost per installed kilowatt is approximately equal for all these systems. Since the wind farm covers a much larger land area than a conventional power plant of comparable size, or alternately, the same land area as a conventional plant of ten times the capacity, this "centralized" application can be considered less centralized than conventional large central station fossil or nuclear plants.

Another way to explain this distinction is the following example: Consider two alternative means to satisfy the total U.S. electrical demand of 2×10^{12} kwh (two trillion kwh). Alternative 1 specifies 1,000 megawatt coal or nuclear stations operating at an average capacity factor of .60. Alternative 2 calls for 80 megawatt wind farms operating at an average capacity factor of .25. Table 3.13-3 illustrates the fact that over 30 times as many wind farms would be required to satisfy the U.S. electrical demand as compared to large centralized fossil or nuclear plants.

Table 3.13-3[275]

NUMBER OF PLANTS REQUIRED TO SATISFY U.S. ELECTRICAL DEMAND

Alternative	Plant Size, MW	Capacity Factor	Number of Plants	Land Area Square Miles
Alternative 1: Centralized Conventional	1,000 MW	.60	380	1,900
Alternative 2: "Centralized" Windfarm	80 MW	.25	11,428	53,712 (1) 3,571 (2)

Notes:
(1) Total Farm Area assuming four MW units, ten diameter spacing
(2) Land dedicated exclusively to wind machines, roads, and facilities assuming ten acres per four MW unit

In terms of vulnerability, wind farms would be less vulnerable to attack or sabotage owing to the fact that there would be 30 times as many plants and the individual units would be dispersed over a larger area. Since the individual wind turbines would be separated by about one-half mile, each of these would represent a separate target. Thus, for a conventional (non-nuclear) attack, the wind farms would pose over 228,000 individual targets as opposed to the 380 targets offered by the conventional plants. As the individual unit size decreases, the number of individual targets increases. This is summarized in Table 3.13-4. At some point it no longer becomes "cost-effective" for a potential aggressor or saboteur to destroy this many targets.

Table 3.13-4[276]

WIND SYSTEMS AS POTENTIAL TARGETS

Targets	Unit Size, MW	Number of Individual
Alternative 1	1000 MW	380
Alternative 2	4 MW	228,560
Alternative 3	500 kw	1,828,480
Alternative 4	125 kw	7,313,920
Alternative 5	25 kw	36,569,600

The "decentralized" on-site applications involving single units appear to be less cost-effective than the wind farm application owing to the fact that site selection and preparation, operation and maintenance will be more expensive, the site resource may not be as energetic, and the institutional barriers may be more prohibitive. For a scenario in which wind systems capture fifteen percent of U.S. electrical demand (1.02 Quads primary energy displacement, 300 billion kilowatt hours per year) the contribution from "decentralized" wind systems will be at most about ten percent of this amount or 1.5 percent of U.S. electrical energy demand (.1 Quads, 30 billion kwh per year). This amount of energy could be supplied by 600,000 machines rated at 25 kw each, or 1,500,000 units rated at ten kw each. Assuming a total year 2000 U.S. energy demand of 100 Quads, "centralized" wind applications would supply for this scenario about 2.4 percent, while "decentralized" wind would supply less than .3 percent of the total energy.

Potential for Decentralization and Community Self-Sufficiency (3.13-8)

There are numerous non-grid applications of wind systems for the remote or isolated energy consumers. Since many of these isolated users currently pay more than ten cents per kilowatt hour for electrical energy, this is a ready market for WECS. Non-grid-interconnected applications include telecommunications, isolated utilities, offshore oil and gas platforms, onshore oil and gas pipelines, defense installations, navigational aids, rural residences, and farms—all totaling perhaps more than two million wind systems of various sizes.[277] However, each application is constrained by the need to provide energy storage systems. Many types of energy storage systems have been proposed for use with wind power systems; however, many of these options, such as hydrogen, thermal, flywheel, and compressed air storage systems, are in the conceptual or early experimental stage and their associated energy storage costs are not well defined.[278] Assuming the average size of wind systems in this market sector is eight kw and capable of supplying 15,000 kw annually in a wind regime of twelve miles per hour (19.3 kilometers per hour) annual average wind speed, then two million individual applications would supply approximately 30 billion kilowatt hours annually, or about 1.5 percent of the U.S. electrical demand.

The key to maximum utilization of wind energy and maximum oil savings rests with the use of grid-integrated wind systems. Without some form of energy storage system, these WECS will probably bw limited to ten to twenty percent penetration of the electric supply as fuel savers. One very promising approach for avoiding the temporal, seasonal, and geographic limitations of more extensive deployment of wind technology is through the use of hybrid or integrated systems of renewables technologies which incorporate WECS with other renewables such as wind/hydro, wind/biomass, or wind/solar/hydro.[279] The wind-hydro integration combination appears to be particularly attractive. Two alternates are possible: 1) use of wind for peaking, by conserving water during periods when the wind is blowing for controlled release later through the hydroelectric turbines during peak demand periods, and 2) using wind to pump water to a higher reservoir during base demand time and release of the water to generate power during peak demand.

Community self-sufficiency becomes a distinct possibility for certain locales that possess the "correct" blend of renewable energy resources. Wind, or any single solar or renewable resource, taken alone, cannot provide self-sufficiency; however, a hybrid combination of two or three renewables does offer this possibility. A community must first identify its renewable energy resource potential, then consider scaling and compatibility of various renewable technologies, examine engineering feasibility, consider load management, costs, financing, institutional and legal factors, and community access and acceptance. Wind energy used in conjunction with hydro, biomass, geothermal, and possibly solar photovoltaic (when this alternative becomes less expensive) offers some promise for community self-sufficiency.

In New Hampshire, a feasibility study is underway to investigate the use of wind in conjunction with an upgraded 750 kw hydro site to provide for reliable year-round cost-effective operation. In the absence of wind, the hydro facility can operate only for about eight months of the year. The wind turbine would probably be used in the pumped storage mode to stabilize peak energy requirements needed during the winter nights. The wind turbine will be interfaced with the utility for backup in the event of a drastic lack of water or wind availability. Even for a "self-sufficient" application such as this, there is still a need to inter-face with the utility both to assure reliable power at all times and to provide for a means to sell unused power. There are approximately 9,600 potential small hydro sites in New England with an estimated total capacity of nearly 1,800 MW where wind/hydro integration could possibly be undertaken. Other regions in the U.S. are similarly endowed.

Another example of community self-sufficiency is Cuttyhunk Island, Massachusetts where a 200 kw wind turbine prototype developed by WTG Energy Systems, Inc., is operating in conjunction with the island's independent utility grid system. The island's municipal utility is diesel-electric with an installed capacity of 465 kw. Currently the island consumes 330,000 kwh per year. The wind turbine will provide most of the electricity except during the summer months when the diesel will be required to meet demand. WTG Energy Systems estimates that 500 small diesel utilities in the U.S. are located in high wind areas.[280]

Other examples of island installations of single large wind turbines are the DOE/NASA MOD-OA 200 kw systems located at Block Island, Rhode Island; Culebra, Puerto Rico; and Oahu, Hawaii.

A community that pays high fuel costs for electricity and is located near a windy area could develop its own wind farm either through its municipal utility or through a wind farm development company. The electricity could be "wheeled" to the community or sold to a regulated utility. The community would still be interconnected with the utility network and would require the utility to supply firm power when the wind farm was not generating power. Although not an example of self-sufficiency in the strict sense, this application would eventually provide a reduction in utility bills when oil costs escalate beyond the cost of wind electricity.

Wave Energy (3.14)

Ocean waves possess tremendous energy, and finding ways to capture this energy for man's benefit have occupied inventors for many years. Numerous concepts have been designed and tested but only recently has significant technical progress resulted. Unfortunately, the few operating devises that have been built have provided only about a kilowatt of power.

It has been estimated that the total wave energy contained in the oceans equals about 300 trillion kilowatt-hours.[281] Because of its diffuse nature, its low or highly variable magnitude and its remote locations, only a fraction of that energy is available for conversion. For these reasons, large-scale wave energy power plants do not currently exist. However, in those countries where wave energy potential exists, there has been some effort to develop large-scale converters. The most ambitious programs to date have been undertaken by the British and Japanese. Other countries such as the United States, France, Germany and Canada have programs but these are not as extensive.[282]

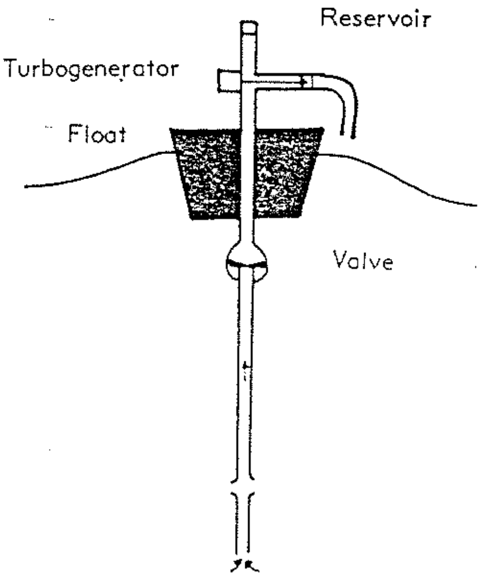
The extraction of energy from ocean waves is not a new concept. Many designs have been proposed, built and tested ranging in size and complexity from so-called wave motors that power buoys, to large installations that are intended to power cities. In a recent British study, it was reported that the development of wave power is technically feasible and could be achieved by the use of existing technology.[283]

Wave energy converters can be divided into five categories: wave pumps, pneumatic devices, motion devices, underwater pressure field devices, and facilities operated by the mass transport of water from breaking waves.

The wave pump is a simple device designed at Scripps Institute in La Jolla, California. Figure 3.14-1 illustrates this device.

Figure 3.14-1 [284]

SCRIPPS WAVE GENERATOR



It consists of a long tube attached vertically to a float. The tube and float sink with passing wave troughs, causing water to be forced upward into the tube. A oneway check valve prevents water from flowing back on the crest of the wave. After repeated wave cycles, the water is raised to a level where the pressure is suitable for power generation. Models of the device have yielded an estimated power of 60 watts at an efficiency of fifteen percent.[285]

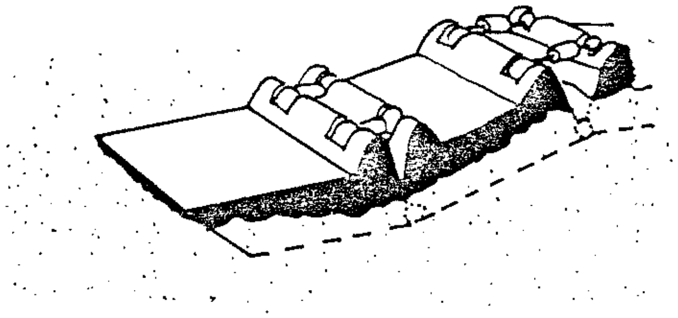
The most notable effort in pneumatic conversion devices has been made by the Japanese with the Masuda design. It is presently employed in over 300 navigation buoys and lighthouses in Japan. The British Oscillating Water Column (OWC) is a slight modification of the Japanese model. Basically it is an upturned cannister with an air bubble above the water line and a hole in the side or on the top. As the waves rise and fall, air inside the canister is pushed out and sucked in through the hole. This drives an air turbine which is linked to a generator. The overall efficiency is estimated at about 50 percent.[286] The U.S. Coast Guard has tested the wave-powered buoys and found that they would be suitable for the use of Coast Guard floating aid devices.

With the development of the Salter Nodding Duck and the Cockerell Raft, England may some day utilize its hugh wave energy resources. The Nodding Duck design is so-called because the beaks bob up and down with the waves. It consists of a row of cone-shaped vanes strung sequentially in a line. This axis displaces very little water and is thus very efficient. It is able to extract as much as 90 percent of the available energy.[287]

The Cockerell Raft utilizes a chain of floats or rafts, hinged together (Figure 3.14-2).

Figure 3.14-2 [288]

THE COCKERELL RAFT



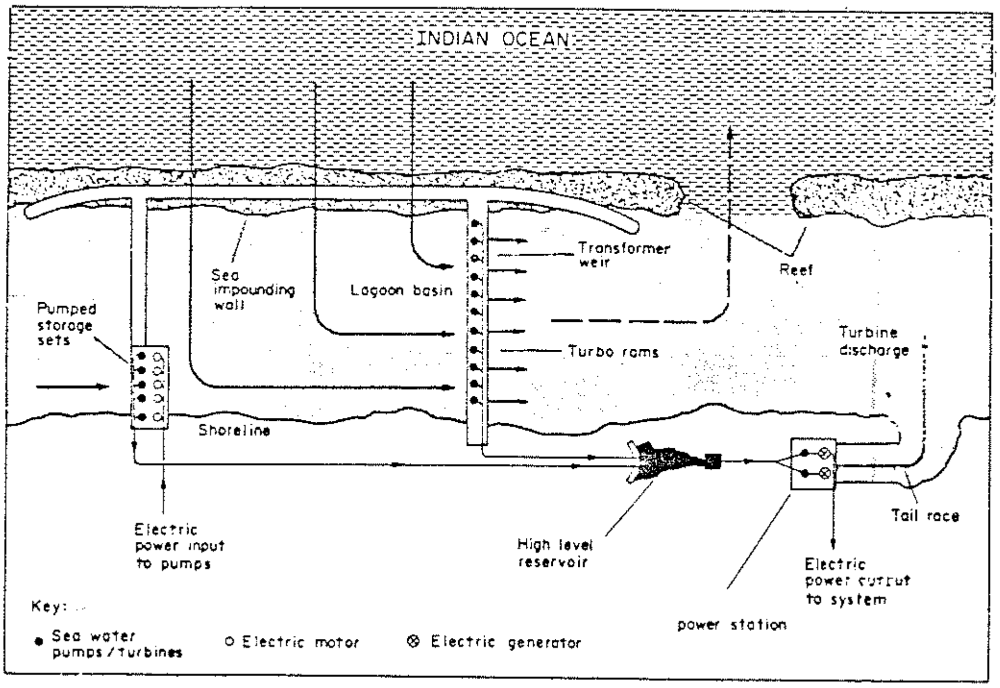
These oscillate up and down successively with the changing slope of the passing waves. Pumps on the hinges absorb the power of the oscillations and convert the energy into fluid pressure which drives a turbine. Tests have yielded efficiencies of about 90 percent.[289]

Underwater pressure field devices have been built and designed for buoys both in the United States and Germany. Such devices convert wave energy through transformation of hydrostatic pressure changes. The changes in pressure are sensed by the sub-surface or bottom-mounted converters as the waves pass overhead.

Wave energy devices utilizing the mass transportation of water were among the earliest wave power schemes developed. Figure 3.14-3 illustrates a design for a system in the Indian Ocean.

Figure 3.14-3[290]

A WAVE ENERGY SYSTEM



Onrushing water from breaking and shoaling waves is channeled into storage basins. The head of water thus developed is used to operate a low head turbine as it returns to the level of the sea. At present, only one facility has been proposed. This facility would be located on the island of Mauritius, where swells arrive uniformly throughout the year. The design of this facility, however, is slightly different. The head developed in the storage basin is only a few feet and a hydraulic ram is used in place of a turbine. Water from the ram is pumped to a higher reservoir. There a turbine utilizes the higher head to generate power and returns the water to the ocean.[291]

The United States shoreline is buffeted by waves which vary considerably with the season and geographic location. The shores of the Pacific Northwest demonstrate on the average, the most consistent wave conditions along the continental U.S., thus the Oregon-Washington coast offers the greatest potential for wave energy in the U.S. Estimates of power production range from a high of sixteen megawatts per kilometer of coastline during December, to a low of five megawatts per kilometer during August, with a yearly average of 11.5 megawatts per year. This can be compared to the conditions on the Gulf of Mexico with .8 megawatts per kilometer in April to .2 megawatts per kilometer in August and a yearly average of about .5 megawatts per kilometer. When multiplied by the respective coastline length, these averages yield a total potential wave power ranging from over 87,000 megawatts on the Washington-Oregon coastline to about 10,000 megawatts on the Gulf of Mexico coastline.[292]

In terms of wave energy potential, Britain is much more fortunate, with a stretch of ocean between 600 to 1,400 miles (965.6-2,253.1 kilometers) long capable of providing almost half of its total energy requirements.[293]

The slow development of wave energy technology stems from technical and economic problems. A major technical problem relates to the difficulties of mooring the devices. Wave power facilities must be very large and durable enough to withstand the constant pounding of the waves. Experience with offshore oil platforms may be helpful in designing a suitable type and size mooring, but the costs of a suitable mooring system may still be prohibitive for some time. Only when a safe, reliable and cheap method for mooring is developed will wave power be able to compete with conventional energy sources.[294]

Underwater transmission lines also contribute to the high costs of wave power facilities, although most estimates place a plant only four or five miles (6.4 or 8 kilometers) from shore and therefor transmission costs may pose less of a problem then mooring.

A lack of funding has impeded development of a wave energy program in the United States. For the first time, the funding for government-sponsored research is above $1 million. If it is to be a part of the national energy program, wave power must receive a substantial increase in government funding.[295]

In the United States, a wave power program exists under the Division of the Ocean Energy Systems of the Department of Energy and is administered by the Solar Energy Research Institute (SERI). The program consists of providing technical expertise and cooperation with Japan, Britain and other countries for the advancement of wave power. Development of wave focusing devices and an air turbine for the Oscillating Water Column is also slated under the United States program. At present, funding for 1980 stands at about $1.1 million; this may double by 1985. A working model generating between one and five megawatts is also planned to be put into operation by 1985. Beyond this, however, there are no large scale development plans for the future.[296]

There are environmental issues that must be addressed with wave energy production. The altering of local wave conditions could reduce wave action on the shore although it is difficult to assess the effects this might have since little research has been done in the area. Also, with increased commercialization, the oceans and thus the shorelines would be subject to increased industrialization. The effects of these impacts must be examined before any development is undertaken.[297]

Conclusions (3.15)

Increasing the nation's energy security through accelerated conservation efforts and approaches designed to increase self-sufficiency through the use of alternative energy technologies has been outlined in Section 3. Solar and renewable energy technologies cannot be expected to meet national needs immediately, but through a phased program, the nation's national security can be enhanced and goals for energy self-sufficiency reached.

Moving towards a less centralized energy and resource system would require both a national will to do so (expressed politically and economically), and a mechanism for funding. The Battelle Memorial Institute has conducted a substantial research effort for the Department of Energy aimed at understanding the present U.S. system and the history of providing incentives to stimulate energy production from conventional sources. Table 3.15-1 summarizes this research, which has tabulated $252 billion in subsidies and incentives for coal, oil, hydro, nuclear, gas and electricity. The study concludes:

> ...That a precedent exists for utilizing Federal incentives to increase energy production. Design of national energy policy which considers the results of Federal investment in incentives to increase energy production could be an efficient basis upon which to integrate current and impending technology, existing energy stocks, and consumer requirements and preferences. The conclusion of micro-economic solar energy feasibility studies could be inconsequential without a comprehensive understanding of the costs and results of incentives to increase energy production. This is so because of the disparity in rationale between the Federal Government and the private sector. The Federal Government need not predicate national policy on short-term micro-economic analysis. As confirmed by this study, Federal justification is predicated on long-term goals met with the aid of new technology and supported by social values of the nation. If it is socially desirable and technologically feasible to increase solar energy's share in the national energy budget, the paramount policy question is one of selecting an incentive strategy and determining the government's level of investment in it.[298]

Table 3.15-1[299]

AN ESTIMATE OF THE COST INCENTIVES USED TO STIMULATE ENERGY PRODUCTION (IN BILLIONS OF 1978 DOLLARS)

	Nuclear	Hydro	Coal	Oil	Gas	Electricity	Total	Percent of Total Incentives
Taxation	—	2.0	4.74	55.48	14.92	38.83	115.97	46.0
Disbursements	—	—	—	1.30	—	—	1.30	0.5
Requirements	1.7	0.04	0.80	57.49	-0.80	—	59.23	23.5
Traditional Services	—	—	2.57	6.92	—	0.52	10.01	4.0
Nontraditional Services	17.2	—	3.55	1.88	0.30	—	22.93	9.1
Market Activity	2.1	14.86[(a)]		0.02	0.50	0.15	25.17[(a)]	42.80
Totals	21.0	16.90	11.68	123.57	14.57	64.52	252.24	100
Percent of Total Incentives	8.3	6.7	4.6	49.0	5.8	25.6	100	

(a)This Value based on incentive definition 1 (Federal money outstanding).

As has been noted in prior sections of this report, numerous studies have suggested varying levels of funding for alternative energy sources, conservation, dispersed power plants, etc. Former Joint Economic Committee Energy Director, Jerry Brady, suggests a modest beginning:

> If we took one-half (of the national $20 billion per year in various conventional energy subsidies), or $10 billlion, and redirected it for just ten years at a total cost of $100 billion, we could provide interest-free loans sufficient to insulate half the homes in America. According to Rosenfeld, (of the Lawrence Berkeley Laboratory) the savings would amount to approximately 10 Quads a year, or roughly 75 percent of the heat content of oil now imported to the U.S. This should be compared to the $88 billion synfuels program, which will produce no more than 15 percent of the oil we now import by the year 1990.[300]

This study concludes that the strategic viewpoint on decentralization of energy sources must take into account two major time frames if the issue of energy and national security is to be appropriately addressed:

1. The Short-range Strategy (current to twenty years)

During this period, acceleration of government programs and incentives can result in the increase of community self-reliance by incorporating a range of dispersed and renewable energy sources with increasing decentralization of electrical grids and fuel transportation systems. Some methods to increase this process and utilize civil defense and emergency planning programs are discussed later in this section.

2. The Long-range Strategy (twenty to seventy years)

The activities and programs undertaken by communities in the short-range to increase community self-reliance and accelerate the use of renewable and dispersed energy sources can pave the way towards a more comprehensive re-orientation of the society's energy organization over a longer time-frame. Whereas during the short-range implementation period the greatest gains are in replacing and substituting conventional and centralized resource supplies, the long-range strategy allows for the development of major new systems which can operate largely on renewable sources of energy (solar, wind, hydro, biomass, etc.).

One recent study conducted by the Union of Concerned Scientists addressed this question and the results of their scenario for energy supply and demand in the year 2050 (70 years hence) are provided in Table 3.15-2.

Table 3.15-2[301]

ENERGY SUPPLY AND DEMAND IN THE YEAR 2050 *

ENERGY-USE ENERGY FORM	ENERGY SOURCE TECHNOLOGY	APPROPRIATE ENERGY SUPPLY	PERCENT	ENERGY REQUIREMENTS (in quads) HIGH EFFICIENCY/HIGH POPULATION SCENARIOS		
				Current Standard of Living	Intermediate Standard of Living	High Standard of Living
Low-temperature thermal energy (100°C)	Direct solar energy	Passive and active solar heating and cooling, district heating systems	25	13	17	20
Intermediate to high-temperature thermal energy (100°C)		Flat-plate collectors stationary and tracking solar concentrators	25	14	17	21
Electricity	Direct solar energy	Photovoltaic, solar-thermal, and cogeneration systems	30-40	8-10	10-13	12-20
	Wind	Wind generators		8-11	10-14	12-20
		Subtotal		16-21	20-27	32
Liquid fuels	Biomass	Organic residues and wastes		3-5	3-7	3-5
Carbon feedstocks methane		Energy "plantations"	10-20	2-5	3-6	3-5
		Subtotal		5-10	6-13	8
		TOTAL	100	53	67	81

*All demand estimates assume that we would use energy twice as efficiently on the average in 2050 as we do now. The "Current" standard of living case assumes that effective average per capita energy use remains unchanged while the "Intermediate" and "High" standard of living cases represent increases in effective per capita consumption of an average of 28% and 55%, respectively. The latter increase is equivalent to raising the average energy use of all U.S. citizens to levels now characteristic of only the upper 20 percentile income group.

Table 3.15-3[302]

A PROPOSED LONG-TERM SOLAR ENERGY ECONOMY

DEMAND SECTOR	END-USE ENERGY FORM	APPLICATION	PERCENTAGE OF OVERALL ENERGY USE	APPROPRIATE ENERGY SUPPLY TECHNOLOGY
Residential and Commercial	Low-temperature thermal energy (100°C)	Space heating, water heating, air conditioning	20-25%	Passive and active solar system, district heating systems
	Intermediate-temperature energy (100-300°C)	Cooking and drying	5%	Active solar heating with concentrating solar collectors
	Hydrogen			Solar thermal, thermochemical, or electrolytic generation
	Methane			Biomass
	Electricity	Lighting, appliances, refrigeration	10%	Photovoltaic, wind, solar thermal, total energy systems
		Subtotal	35%	
Industrial	Intermediate-temperature thermal energy (300°C)	Industrial and agricultural process heat and steam	7.5%	Active solar heating with flat-plate collectors, and tracking solar concentrator
	High-temperature thermal energy (300°C)	Industrial process heat and steam	17.5%	Tracking, concentrating solar collector systems
	Hydrogen			Solar thermal, thermochemical, or electrolytic generation
	Electricity	Cogeneration; electric drive, electrolytic, and electrochemical process	10%	Solar thermal, photovoltaic, cogeneration, wind systems
	Feedstocks	Supply carbon sources to chemical industries	5%	Biomass residues and wastes or plantations
		Subtotal	40%	
Transportation	Electricity	Electric vehicles, electric rail	10-20%	Photovoltaic, wind and solar thermal-electric
	Hydrogen	Aircraft fuel, land and water, transportation vehicles		Solar thermal, thermochemical, or electrolytic generation
	Liquid fuels methanol, ethanol gasoline	Long-distance land and water transportation vehicles	5-15%	Biomass residues and wastes or plantations
		Subtotal	25%	
		Total	100%	

The UCS study concludes that the U.S. could complete a transition to a solar economy by 2050 and with proper incentives, could gain the equivalent of 12-28 Quads of energy by the year 2000. By 2050, renewable sources, ranging from passive and active solar heating, district heating, thermochemical, biomass, photovoltaic, wind and total energy systems would supply all energy needs in the residential, commercial, and industrial sectors. The end-use demands are shown in Table 3.15-3.

Given the dispersed nature of many renewable resources, the UCS study discounts the possibility of total system decentralization:

> (S)ome degree of transmission will be absolutely necessary to provide energy for certain urban and industrial concentrations (such as Manhattan) where the density of energy use exceeds locally available solar and wind power. Furthermore the establishment of an integrated, nationwide electricity grid system could provide substantive benefits for a solar energy future by contributing to greater overall system reliability, minimizing requisite peaking power capacity, and reducing energy storage requirements.[303]

This study is an example of a complete synthesis of known renewable technologies, with a fair explication of their future potential. An essential feature of the study is an attempt to set a rational time frame for implementation of the system-wide changes to implement a fully renewable energy economy. Many current efforts assume that a renewable energy economy can be developed within a few years. These efforts do not take into account the substantial industrial, economic infrastructure, and social changes required.

The final section of this document is concerned with the important first steps to be taken to categorize the strategic energy technologies and resources required to increase energy security on a regional and local level.