Energy Self-Sufficiency for Hawaii

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Hawaii shares with many other isolated regions the problem of identifying a secure and affordable supply of energy. Through the middle half of this century, most of the energy-deficient regions, including Hawaii, have increasingly depended on cheap and abundant imported petroleum to satisfy their escalating energy demands. However, as imported oil has become progressively more expensive and less secure, greater effort has been directed in Hawaii to conserve energy and to develop indigenous energy resources.

Summary. Currently, Hawaii is almost totally dependent for energy on imported oil. The island state has a wide variety of renewable energy resources, however, and for the past decade has supported the development of these resources as substitutes for seaborne petroleum. Sufficient progress has been made to date in commercializing a number of these alternative energy sources to give cause for optimism that Hawaii will be able to achieve energy self-sufficiency with its indigenous renewable resources.

The benefits of energy self-sufficiency, as they are related to the future economic well-being of Hawaii, are recognized by its citizens. The vulnerability of this island state has been demonstrated by severe maritime strikes, which have tied up essentially all shipping from the mainland United States, as well as by the 1973 oil embargo and resulting energy shortfall. Each incident reinforces the resolve to strive toward greater independence from imported commodities. Although Hawaii's renewable energy alternatives in general are both capital-intensive and fairly expensive, a number of them already appear to be cost-effective by comparison with imported oil in a life-cycle analysis.

One obvious benefit of achieving full or near-total self-sufficiency with renewable energy resources is that a secured indigenous energy supply would provide protection from both short- and long-term fluctuations in the global energy market. This stability would have a positive effect on the general economy by assuring reliable, competitively priced energy to the local consumer and by helping to attract and retain energy-intensive industry, such as the refining of manganese nodules from the Central Pacific. In addition, Hawaii's renewable alternatives are less polluting than conventional energy supplies (oil, coal, and nuclear power) and are compatible with the state's concern for the quality of the environment. The development of an indigenous energy supply also represents a major potential growth industry for Hawaii—one that would help retain a portion of the $1 billion a year currently spent on oil imported into the state and would broaden the job and tax bases.

In recognition of the risks involved in continued dependence on imported oil and the benefits to be achieved from energy self-sufficiency, a major program for the development of renewable energy resources has been under way throughout the state during the past decade. This article describes the progress made to date in Hawaii in commercializing substitutes for imported oil.

Current Energy Demand and Supply Data

The state of Hawaii consists of the eight southernmost islands in the Hawaiian Archipelago, an island chain stretching across 600 kilometers of the Central Pacific and separated from the mainland United States by nearly 4000 kilometers of ocean. These islands are the tops of shield volcanoes rising from the ocean floor and are too recent in origin to have experienced the natural cycle necessary for the formation of fossil fuels. Hawaii has a resident population of about 965,000 and a de facto population of slightly over 1,100,000 when visitors to the islands are included (*1*). Nearly 80 percent of the resident population and most of the industrial and government infrastructure are concentrated on the island of Oahu, the site of the state capital, Honolulu. By contrast to this major metropolitan area with a high-density energy demand, most of the other islands have widely dispersed low-density energy requirements, similar to many of the less developed areas throughout the world.

The total civilian energy consumption for Hawaii in 1979 was 211 trillion Btu's, which is equivalent to about 37 million barrels of oil. Figure 1 compares energy utilization in Hawaii with that of the mainland United States (*2*). The energy consumption patterns for the state and the nation differ appreciably, largely because of (i) the absence of a space heating requirement in the subtropical climate of Hawaii and (ii) the huge amount of aviation fuel necessary to service the state's tourist industry. A significant point to consider in planning for Hawaii's energy future is that nearly 60 percent of the state's current energy demand is for liquid fuels to satisfy transportation requirements.

There is some variation in the cost of energy between the separate islands, particularly with respect to electricity, for which larger generating units are more economical. At present, the price of residential electricity varies from 11.4 cents per kilowatt-hour in Honolulu to more than 19 cents per kilowatt-hour on Molokai—one of the highest electricity rates in the United States. Regular gasoline costs about 41 cents per liter ($1.55 per gallon) on Oahu, including local and federal taxes, and about 5 cents a gallon more on the other islands. Although this is higher than mainland charges for gasoline, it is still a bargain in comparison to most worldwide figures.

Currently, Hawaii is probably the most vulnerable of the 50 states to dislocations in the global oil market. It has no known fossil fuel reserves on any of its islands and no offshore oil. There is no coal coming into the state by rail, no natural gas by pipeline. The energy demand on its utilities is too small to warrant nuclear power plants, and Hawaii is not tied into a regional grid so that it can share electric loads with adjacent states. As yet, its separate islands are not even connected by a common electric grid.

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0036-8075/82/0611-1193$01.00/0

More than 90 percent of Hawaii's existing energy supply is seaborne petroleum. This virtual dependence would be of somewhat less concern if most of this import originated within the United States. Unfortunately, the reverse is true: 62.5 percent arrives directly from foreign sources—Saudi Arabia, Oman, Indonesia, and Malaysia (*2*). Alaska supplies 13.5 percent and the mainland 24 percent. However, the last figure is misleading, since products from mainland refineries may also be of foreign origin. Therefore, as much as two-thirds of the petroleum imported into Hawaii today comes from foreign crude.

Bagasse, the fibrous residue remaining after sucrose is squeezed from sugarcane, is the second largest source of energy for Hawaii. Nearly 2.4 million metric tons of bagasse are burned each year in the boilers of the sugar companies, providing more than 7 percent of the total energy demand of the state. Other forms of biomass are also beginning to receive slight use for boiler fuel: cane trash (leaves and tops), pineapple waste, wood chips, macadamia nutshells, and hay. The final energy supply source for Hawaii—also developed entirely by the sugar industry—is hydroelectric power, which provides slightly less than 1 percent of the total energy demand.

Renewable Energy Resources

Hawaii's nearly total dependence on seaborne petroleum is a paradox, since the state has a variety and abundance of renewable energy resources. Research was initiated more than a decade ago on the utilization of these resources as alternatives or substitutes for imported oil (*3*), and the energy shortfall of 1973 added impetus to the effort. To date, the impact of renewable energy resources on Hawaii's oil imports has been slight, except for the existing 8 percent input from the bagasse and hydroelectric power plants. However, the great amount of research, development, and demonstration (RD&D) that has been directed to indigenous energy sources in recent years is beginning to have positive results. Table 1 shows the origin of the $65 million spent on renewable energy RD&D in Hawaii during the past decade and the general categories in which these funds were expended (*4*). In the following sections I will describe the progress that has been made in moving each of Hawaii's major energy alternatives toward commercialization.

Direct solar radiation. The principal Hawaiian Islands lie between 19° and 22°N. At Honolulu the midsummer sun is 3° north of vertical, while the winter low is 45° above the southern horizon. Therefore, Hawaii has both a higher average insolation rate and a smaller seasonal variation than the mainland United States. Average annual insolation values in excess of 500 langleys (calories per square centimeter) per day are not unusual (*5*). Consequently, Hawaii is well suited for the utilization of all types of direct solar radiation conversion systems.

Almost 40 percent of the residential energy consumed in the state is used for heating water. This represents a good target for solar water heaters, and at present there are about 19,000 flat-plate solar collectors installed in Hawaii, resulting in annual savings in imported oil of about $6 million. Depending on the hot water requirements of the family and insolation levels at the location of the dwelling, the investment for an average solar water heater can be amortized in 3 to 7 years at the current rate of state and federal tax incentives.

Where higher temperatures are required, solar thermal systems with concentrating collectors show excellent potential, both for process heat and for generating electricity. Three major design studies on solar thermal systems for utility and industrial applications in Hawaii, involving parabolic collectors with both dish and trough configurations, have been funded by the U.S. Department of Energy (DOE). Preliminary design studies have been conducted as well on solar ponds. The state is reviewing a proposal from Jet Propulsion Laboratory to design and construct a 500-kW salt-gradient solar pond to supply electricity to the Natural Energy Laboratory of Hawaii on the Kona Coast of the Big Island of Hawaii.

Photovoltaic power systems utilizing solid-state semiconductor devices to convert solar radiation directly into electricity are beginning to find limited application in Hawaii. A photovoltaic system that generates 35 kW of electricity for Wilcox General Hospital on Kauai was completed in December 1981. This concentrating dual system consists of a series of parabolic troughs that focus radiation on the solar cells. Water, which is warmed as it circulates through the system and cools the cells, provides much of the hospital's hot water.

Three small photovoltaic systems—2 to 3.5 kW—have also been installed on homes in Hawaii as demonstration projects of the DOE to provide operational data on the performance of photovoltaic units for meeting the requirements of three average families in Hawaii. These roof-mounted systems are metered into the utility grid, and records are kept of

Table 1. Funding of renewable energy RD&D in Hawaii: 1971 to 1980.

Program	Source of funding (thousands of dollars)			
	Federal	State/county	Private	Total
Ocean thermal	22,006	3,246	1,712	26,964
Geothermal	12,336	2,173	4,334	18,843
Insolation, wind, and hydro	9,437	1,494	423	11,354
Bioconversion	1,848	1,498	766	4,112
Other	1,026	2,674	256	3,956
Total	46,653	11,085	7,491	65,229

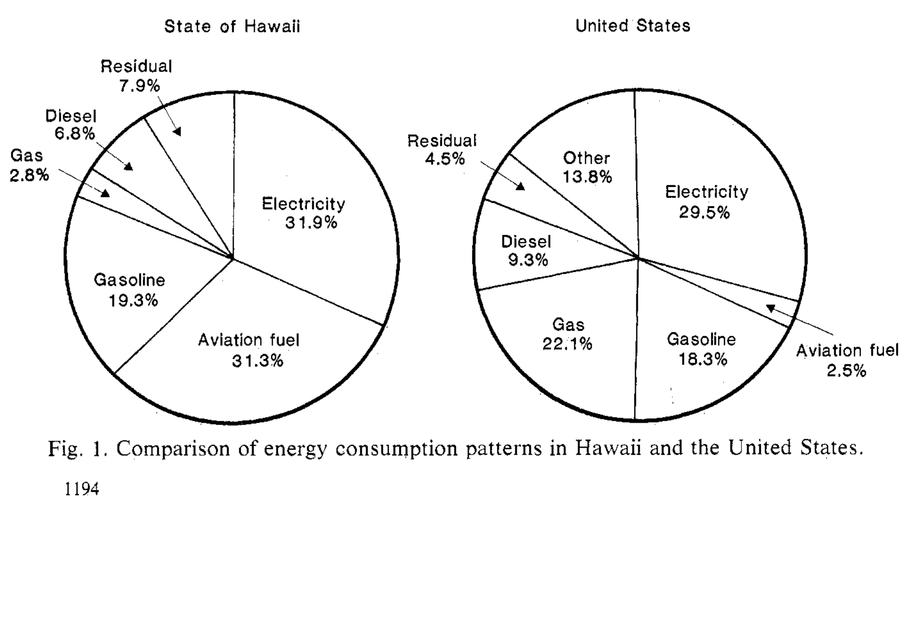

Fig. 1. Comparison of energy consumption patterns in Hawaii and the United States.

the amount of surplus electricity from the photovoltaic system that is fed back into the utility grid so that it can serve as a credit against utility electricity charges. In addition to these three demonstration projects, more than 250 homeowners in Hawaii have installed photovoltaic systems—both with and without storage—to help meet their electrical needs.

Ocean energy systems. The ocean is an excellent solar collector and storage system. A century ago, the French scientist Jacques d'Arsonval discovered that the temperature difference between the sun-warmed ocean surface and the cold deep-ocean water can be used to generate electricity. Unlike many other renewable resources, which provide energy intermittently, there is negligible cooling of the ocean at night, so that ocean thermal energy conversion (OTEC) could be utilized for 24-hour base-load power.

Figure 2 shows a preliminary inventory of locations throughout the state with some potential for OTEC systems, but additional bathymetric and ocean current studies are required to verify that these sites are suitable for OTEC plants. There is an economic advantage if a site is located near shore, since the umbilical cable for transmitting electricity from a floating OTEC power plant to a shore-based utility grid would be both shorter and simpler in design. There is also some interest in constructing shore-based OTEC plants, with the cold-water pipe running out through the surf zone. Hawaii has a number of sites that satisfy criteria for both nearshore floating and shore-based OTEC power plants.

In addition to OTEC power plants feeding electricity into an island utility grid, floating anchored platforms and untethered grazing OTEC plants could be utilized to produce ammonia or hydrogen as a synthetic fuel. Craven (*6*) estimated that within the 200-mile zone of the islands constituting the Hawaiian Archipelago, it is possible to produce 10 to 15 quads (1 quad = 10^{15} Btu's) per year of OTEC power—an amount of energy greater than that derived from the current annual import of oil by the United States.

Three significant saltwater OTEC projects have been located in Hawaii. Mini-OTEC was the first fully operational closed-cycle OTEC system to generate electricity from the ocean thermal gradient. It was a joint venture of the Lockheed Missile and Space Company, the Dillingham Corporation, and the state of Hawaii to demonstrate the technical feasibility of an OTEC power plant.

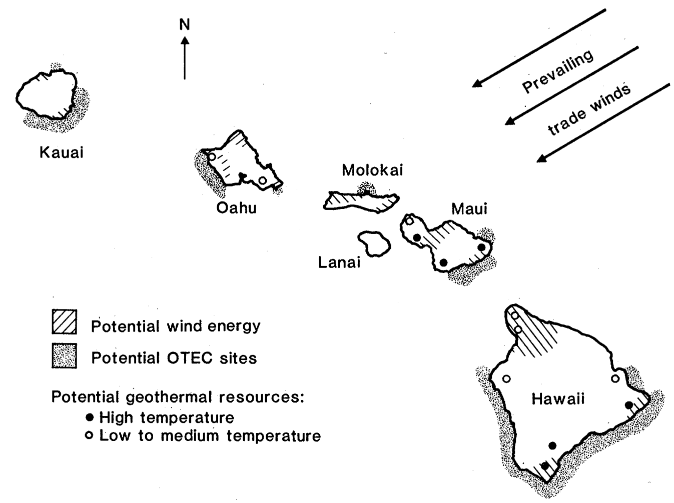

Fig. 2. Inventory of potential wind, OTEC, and geothermal resources in Hawaii.

The heat exchangers and other components of Mini-OTEC were located on a barge (Fig. 3), and a polyethylene pipe 61 centimeters in diameter suspended from a buoy was used to bring up cold water from a depth of 655 meters. During its 4-month deployment off Hawaii in late 1979, Mini-OTEC generated slightly over 50 kW of electricity, of which 35 to 40 kW was used internally to drive the system and 10 to 15 kW was net power.

The second project located in Hawaii was OTEC-1, which represented a major effort of the DOE to obtain operational data on the components of a 1-megawatt OTEC system. More than $50 million went into the project, most of which was spent in the mainland United States to convert a Navy tanker to accommodate the massive heat exchangers and other components for circulating deep-ocean water through the system at 246,000 liters per minute. The *Ocean Energy Converter* was deployed 25 km off the coast of Hawaii in early 1981, and 3 months of excellent operational data were obtained before budget limitations caused premature termination of the program.

The third major OTEC project is the Seacoast Test Facility (STF), located at the Natural Energy Laboratory on the Big Island of Hawaii. The STF was designed to provide a permanent shore-based facility from which to conduct reliable, economical, long-range test programs on biofouling, corrosion, and component performance. The advantage of this site is that the ocean floor drops off abruptly from the shoreline, so that a depth of 640 m can be reached by extending a pipeline 1860 m from the laboratory, through the surf zone, and along the ocean floor. Phase 1 of the STF has been completed and includes the installation of a 30-cm cold-water pipe with a

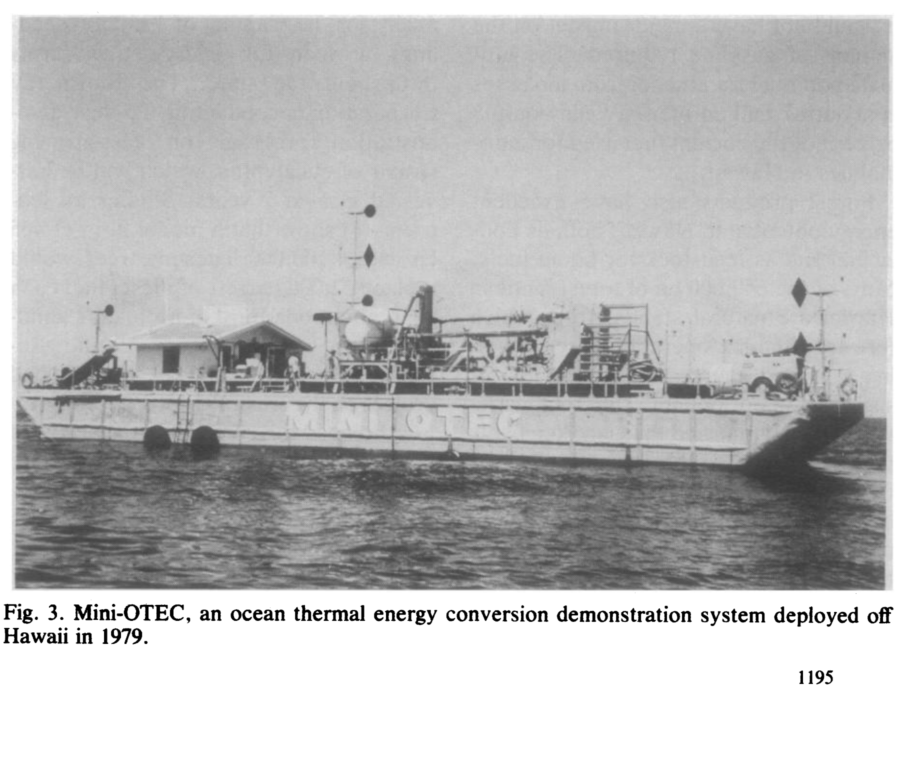

Fig. 3. Mini-OTEC, an ocean thermal energy conversion demonstration system deployed off Hawaii in 1979.

flow capacity of 5700 liters per minute. Current warm-water capability is 7600 liters per minute. It is likely that the warm- and cold-water capacities will be increased by a factor of 10 by the end of 1982.

Hawaii is interested in OTEC not only for base-load power but also for the probable spin-off in aquaculture and desalination from the cold, nutrient-rich, deep-ocean water. Since DOE funding for OTEC may be curtailed in the future, Hawaii is looking both to industry and to foreign governments as potential customers for conducting research with the unique cold-water capability of the STF. However, the immediate outlook for continuing OTEC activity in Hawaii was reinforced by the DOE announcement on 19 February 1982 that two of the nine proposals for conducting the conceptual design phase for a closed-cycle OTEC pilot plant had been approved for funding, each at $900,000. Both these proposals are based on OTEC sites located on Oahu.

Biomass resources. The major agricultural crop of Hawaii is sugarcane. Nearly 1 million metric tons of raw sugar are produced annually on 89,000 hectares of prime agricultural land (*2*). Major by-products are 2.4 million metric tons of bagasse and 280,000 metric tons of molasses. The moisture content of bagasse is about 48 percent, and it is an excellent boiler fuel, replacing nearly 2.5 million barrels of imported oil a year. Although molasses is a satisfactory feedstock for ethanol production, the economics of conversion still appear to be marginal, so that most of the molasses is used as cattle feed. Even if all of the molasses produced in the state were converted to ethanol and used as transportation fuel, it would not have a major impact on the amount of gasoline required. The ultimate potential for ethanol from molasses is about 87 million liters a year—only 8 percent of the current fuel used for automobiles in Hawaii.

Forest products also have excellent energy potential in Hawaii, both as boiler fuel and as feedstock for liquid fuels. Most of the 650,000 ha of forest lands in Hawaii are natural stands, from which forestry thinning operations are providing a limited source of wood chips for sugar company boilers. Different varieties of eucalyptus and the giant koa haole (leucaena) seem to show promise for tree farms in Hawaii, and an extensive study of the cultivation and harvesting requirements of several of these varieties has been conducted to determine the amount and location of land appropriate for tree farming with each of these strains (*7*).

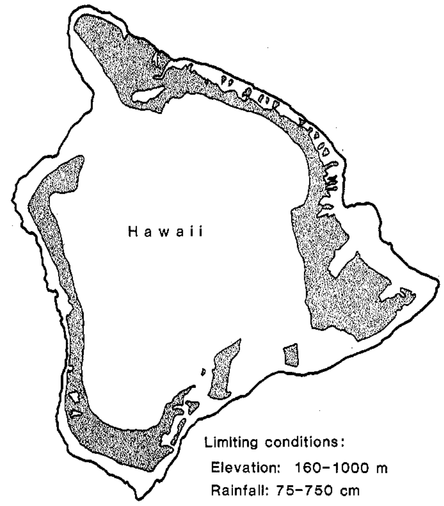

Fig. 4. Potential resource area for *Eucalyptus grandis*.

Figure 4 shows the potential growth area identified for *Eucalyptus grandis* on the Big Island of Hawaii. Similar figures have been completed on promising varieties of trees for each of the major islands, resulting in an overall inventory of land in the state with good potential for tree farming.

There are numerous projects and programs under way in Hawaii for expanding the energy role of biomass. The sugar industry has established a task force to investigate sugarcane as a total energy crop, with the sugar considered as either a by-product or a feedstock for liquid fuels. Row and stalk spacing; growth period; the use of irrigation, fertilizers, and desiccants; and genetic breeding to maximize bulk yield are under review.

Tree farming is also receiving a great deal of attention, with the Hawaii Division of Forestry providing $500,000 annually for the planting of 1 million seedlings a year for energy tree farms throughout the state. The BioEnergy Corporation is conducting a 5-year demonstration program on fast-growing strains of eucalyptus, which will be harvested in 5 to 7 years. Studies on leucaena (*8*) show that a model farm of 405 ha with 4,100,000 leucaena trees would replace 22,000 barrels of diesel fuel each year, about one-third of Molokai's annual electric energy need. Pacific Resources, Inc., is leading a DOE-funded project on the feasibility of a hydropyrolysis process for converting a variety of Hawaii's high-yield cellulosic crops to liquid fuels.

Other biomass projects are addressing (i) more effective use of pineapple waste for boiler fuel, particularly on Molokai, and (ii) growth in seawater of single-cell algae, which convert sunlight and nutrients to lipids rather than cellulose. The algae project is jointly funded by the state and the Solar Energy Research Institute and has achieved high mass densities in a 50-m^2 algal raceway (*9*), as shown in Fig. 5. The generation of both lipids and protein by this process looks sufficiently promising to justify increasing the project to a 40,500-m^2 system.

Wind energy. The northeast trade winds, which blow across Hawaii approximately three-quarters of the time, constitute one of the most consistent and reliable wind patterns in the world (*10*). This favorable wind regime is reinforced by the terrain of the islands and a fairly stable inversion layer at an altitude of around 1800 m. These factors combine to give a funneling effect: as the trade winds are forced up and over the mountain ranges and around the islands, their velocity is greatly increased—often more than doubled.

Each of the major islands in the state has good sites for wind development, as illustrated in Fig. 2. A refinement of the wind energy data for Molokai and Maui, both of which have excellent wind regimes, is shown in Fig. 6. In addition to the favorable wind patterns, there is no icing in Hawaii to contribute to overloading and vibration of windmill blades, while hurricanes and high-gusting winds are extremely rare in this area of the Pacific. Except for the corrosive effects of moist salt-laden air, which can be handled through proper design, Hawaii has an ideal combination of physical and climatic conditions for the introduction of wind power.

There are about 70 small wind generators—0.2 to 50 kW—dotting the Hawaiian landscape, most funded privately. To date, there is only one large windmill in Hawaii—a 200-kW wind turbine generator located at Kahuku on the north shore of Oahu (Fig. 7). The Hawaiian Electric Company (HECO) was one of four utilities selected by the Department of Energy to receive this MOD-OA wind generator for demonstration purposes. During its first year of operation, ending 3 July 1981, this windmill generated 870,970 kWh, far more electricity than any of the other MOD-OA's, located in New Mexico, Rhode Island, and Puerto Rico, have generated during any year.

HECO is optimistic about the future of wind power for Hawaii and has entered into a contract with Windfarms, Inc., for the purchase of 80 MW of electricity from wind turbine generators to be located near the 200-kW unit at Kahuku. Windfarms will finance these huge wind turbines at an estimated total cost of

$350 million, taking advantage of all available tax incentives and write-offs. HECO will not have to identify investment capital to purchase the generating equipment, but will buy the electricity from Windfarms for distribution through the utility grid. The system should be completed by the end of 1984, at which time it will provide nearly 10 percent of Oahu's electricity demand, saving about 600,000 barrels of imported oil a year.

Geothermal resources. Initial geological and geophysical explorations for geothermal resources were conducted in 1973 on the Big Island of Hawaii, which has two active volcanoes and a complex rift zone system. The first successful experimental well was drilled in Hawaii in 1976 to a depth of 1967 m. Preliminary flashing (Fig. 8) and flowing of the well were encouraging (*11*), and subsequent testing verified that this is one of the hottest geothermal wells in the world, with a 358°C downhole temperature. In addition, the quality of the fluid is excellent, with low levels of toxic materials and of components which precipitate out to clog the circulation and generation system.

A broader resource assessment program, consisting of the compilation and evaluation of readily accessible geological, geochemical, and geophysical data both on the island of Hawaii and throughout the island chain, identified 20 regions in 13 general areas with some potential for geothermal development (*12*). These areas are shown in Fig. 2, where the solid dots represent areas where temperatures are probably sufficiently high to generate electricity and the open dots represent lower temperature resources, which could be used to supply process heat for industrial applications. Unfortunately, there are no high-temperature geothermal resources on Oahu, where more than 80 percent of the state's population base and electricity market are located.

A 3-MW geothermal wellhead generator was installed at the well shown in Fig. 8, and when it first began generating electricity in August 1981, Hawaii became the second state to generate electricity from its geothermal resources. Compared to California's 900 MW of installed geothermal capacity, this 3-MW power plant is a very modest beginning. However, with 20 potential geothermal regions identified and the possibility of an interisland electric cable, geothermal power in Hawaii could approach the current capacity in California by the end of this century. Three drilling consortia have been established, and Hawaii's first successful geothermal well drilled entirely with private capital was flashed in October 1981. HECO has revised its plans to construct more fossil-fired power plants on the Big Island and has issued a request for proposal on a 25-MW geothermal power plant—to be the forerunner of commercial development for this major geothermal field.

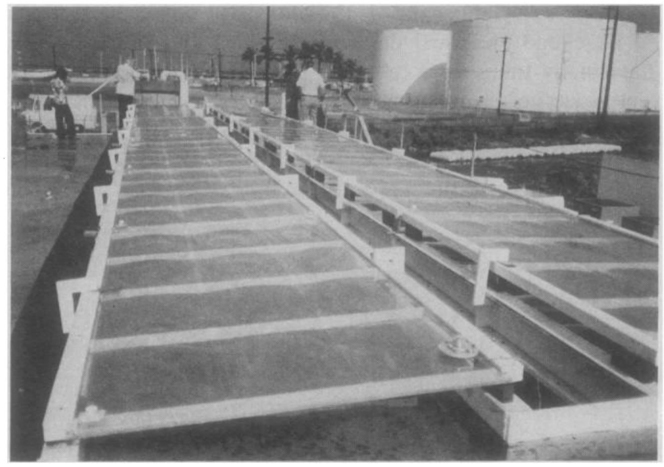

Fig. 5. Algal production raceway of the University of Hawaii.

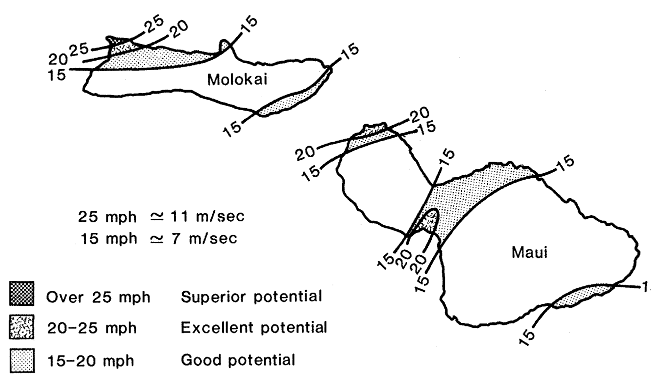

Fig. 6. Average annual wind speeds for Maui and Molokai.

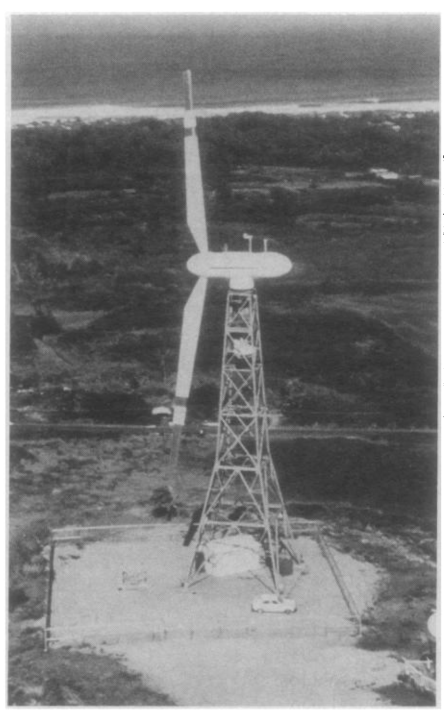

Fig. 7. Windmill at Kahuku, Oahu, operated by the Hawaiian Electric Company.

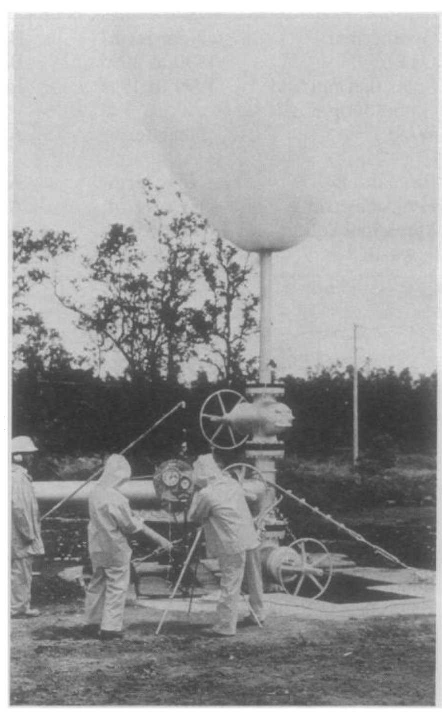

Fig. 8. Flow test of geothermal well at Puna, Hawaii.

Summary of Hawaii's renewable energy resources. The development of most of Hawaii's energy alternatives will in no way be limited by the magnitude of the resource base. The total capacity of all of the possible onshore and nearshore OTEC power plants exceeds the projected base-load electrical demands of the state many times over, as does the potential geothermal resource. It is estimated that the Puna area of the island of Hawaii alone may provide 3000 MW-centuries of generating capacity from its geothermal reservoirs (*2*). Similarly, during trade wind conditions, the potential wind energy in the state exceeds by a factor of 10 Hawaii's total electrical needs (*10*). Until and unless an economic method for storing wind energy is developed, the factor limiting commercialization of wind energy is the total amount of wind power that can be accommodated by the utility grid.

The availability of suitable land area could limit extensive utilization of both direct solar radiation systems and biomass growth for boiler fuel farms or liquid fuel feedstock. However, since the ultimate energy supply mix for Hawaii will probably include a variety of indigenous energy resources, each maximized to satisfy an end use of direct heat, electricity, or fuel, no single renewable resource is likely to be dominant. In fact, the other extreme will probably be the case. As cost-competitive energy systems are developed for the renewables, additional energy markets will be required to make effective use of these energy alternatives. Eventually, Hawaii should be able to reverse its role of near-total dependence on imported oil to one of energy self-sufficiency.

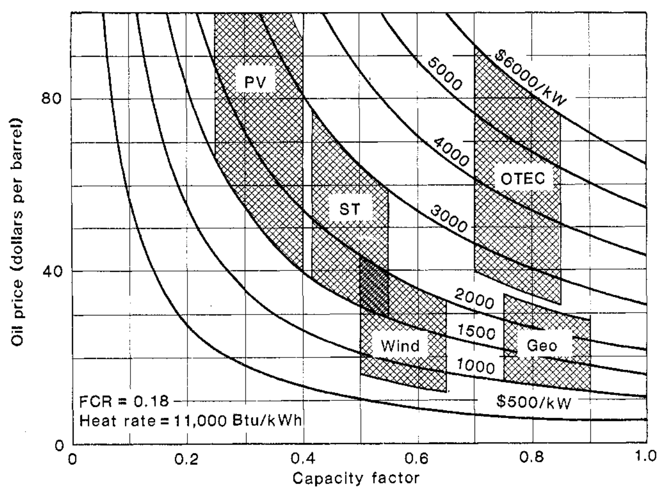

Fig. 9 Fuel displacement by renewable energy systems for capacity factors based on Hawaiian conditions.

Table 2. Electrical energy potential of renewable resources in Hawaii.

Technology	Commercialization	Base, intermediate, or peak load	Capital costs (1980 dollars per kilowatt-hour) 1985	2000	Resource potential by 2000 (MW)
Geothermal	Near term	Base	2000	1200	1000
OTEC	1990 to 1995	Base	8000	2600	1600
Solar thermal and photovoltaics	1990 to 1995	Intermediate (interrupted)	3000 8000	2000 2000	1800
Wind	Near term	All three (interrupted)	1500	700	450
Biomass	Near term	All three	1500	1500	160
Hydroelectric	Near term	All three	800	800	100
Municipal solid waste	1985	All three	2200	2200	45

Table 3. Electricity supply for Hawaii in 2005 based on three projected future cases.

Source	Amount (million kilowatt hours) Baseline case	Savings case	High oil cost case
Geothermal	5,684	5,339	5,306
OTEC	3,568	2,521	2,758
Wind	2,314	2,074	2,016
Solar thermal	1,120	974	1,967
Bagasse	860	860	860
Municipal waste	276	276	276
Hydroelectric	98	98	98
Photovoltaics	Negligible	Negligible	204
Oil	3,621	1,058	923
Total	17,541	13,200	14,408

Energy Future

Energy is a crucial element in planning for the state's economic future. However, it is difficult to predict with any degree of certainty what Hawaii's energy supply sources will be in the years ahead, since many of the key factors influencing the rate of penetration of the renewables into the energy market are independent of any actions and decisions that will take place within the state. Included among these factors are the continuing availability and the pricing of Middle East oil, the discovery and accessibility of new oil reserves throughout the world, the degree to which coal and nuclear power are developed in the future, the national energy policy on support and incentives for renewable energy, and improvements that may occur in alternative energy systems which will accelerate their acceptance in the energy market.

Extensive reviews and projections of Hawaii's energy supply and demand have been conducted throughout the past decade, both inside and outside the state. Easily the most comprehensive study was a 3-year, $550,000 joint effort by the DOE and the state to establish data bases and integrated energy analyses from which to develop scenarios for alternative energy futures. This was a collaborative effort of Lawrence Berkeley Laboratory and Hawaii's Department of Planning and Economic Development which resulted in the six-volume Hawaii Integrated Energy Assessment (HIEA) (*2*), covering the state's total energy picture. Table 2 is taken from the HIEA study and summarizes parameters related to the potential of the various renewable energy resources for satisfying a portion of Hawaii's electrical demand. Included are estimates of when commercialization of the technology is expected in Hawaii; whether the resource is suitable for base (24 hours), intermediate, or peak (2 to 3 hours) load; the capital cost range from 1985 to 2000, in 1980 dollars per installed kilowatt; and the maximum potential of the resource by the year 2000. It should be recognized that Table 2 summarizes electrical energy potential only. Although there may be a slight shift by the end of this century from liquid fuels to electricity, the major supply problem for Hawaii over the next two decades will be transportation fuel for both surface and air travel.

A convenient method for obtaining a rough estimate of how high the price of oil must go before the various renewable alternatives become cost competitive on the basis of fuel replacement alone has been developed by Weingart (*13*). Figure 9 illustrates the fuel replacement worth of five renewable resources: photovoltaics (PV), solar thermal (ST), wind, OTEC, and geothermal. Biomass would show up on Fig. 9 in about the same place as geothermal. The curves in Fig. 9 were computed on a fixed charge rate (FCR) of 18 percent and a heat conversion rate of 11,000 Btu's per kilowatt-hour. The capacity factor estimates are based on Hawaiian conditions, which explains the optimistic projection that windmills will generate power 50 to 65 percent of the time.

Even as a rough approximation, it is apparent from Fig. 9 that wind and geothermal (also biomass) are already cost-competitive as fuel replacements. If oil prices exceed $40 a barrel, the other alternatives also show economic benefit. In addition, for resources such as geothermal and OTEC, which can provide base-load power and satisfy capacity requirements of the utility, a greater allowance should be made for replacing new capacity at the margin.

Three scenarios for future energy demand in Hawaii are presented in the HIEA (*2*). All three are based on the state's "most likely" projection of population and personal income and on the assumption that the mandated automobile mileage standards will be implemented. All three of these demand forecasts are predicated on oil continuing to be the predominant energy supply. Therefore, these forecasts serve only as a starting point for an analysis of the role of renewables in Hawaii's energy future and how they will affect the projected demand, both for oil and for total energy.

In the first scenario, the baseline case, it is assumed that there will be a 3 percent per year escalation in the world oil price above the general inflation rate, starting with $30 a barrel in 1980. The second scenario, the savings case, is similar to the baseline case, but in addition to improved automobile mileage it is assumed that other conservation practices are instituted, mainly increased efficiency in appliances, lighting, water heating, and space conditioning. The third scenario, the high oil price case, is based on a 10 percent per year increase in oil price above the inflation rate, which could occur if there were major disruptions in global oil production. Table 3 lists forecasts for the contribution that the major energy supply sources will make in meeting total electricity demand for the state in 2005. Forecasts are presented for each of the three scenarios.

Table 3 projects a relatively high level of penetration of the renewables for electricity generation by 2005, with the baseline case showing 79 percent penetration and the high cost case 94 percent. However, since HIEA assumes that there will be very little replacement of liquid fuels by electricity during the next two decades and that jet fuel demand will increase by 68 percent over the next 25 years, the amount of the total energy provided by the renewables in 2005 is only 37 percent for the baseline case and 46 percent for the high cost case. These forecasts seem somewhat conservative. My own projections are that 50 percent electrical self-sufficiency by 1990 and 50 percent total energy self-sufficiency by 2000 represent an achievable goal for Hawaii.

There has been sufficient progress in Hawaii in laying the groundwork for converting from oil to renewable energy that the current reduction in federal support for renewable energy RD&D, while representing a severe setback, should not be fatal. Geothermal, wind, direct solar radiation, and various forms of biomass are already cost-competitive with imported oil in Hawaii, and other energy alternatives are fast approaching commercialization. The utilities, the sugar industry, the lending institutions, and other elements of the private sector have become active participants in the development of these alternatives to imported oil. An endowed chair in renewable energy resources was established recently at the University of Hawaii by an $800,000 grant from Coral Industries, Inc., of Honolulu. Both state and county governments are committed to the effort to commercialize renewables and will endeavor to provide a favorable political environment in which it can proceed. Therefore, the appreciable momentum that has been building over the past decade, in conjunction with the anticipated long-range price increases for conventional energy supplies, should assure continuing progress in the development of Hawaii's energy alternatives.

While an optimum energy program for any region must be unique and site-specific, the experience gained in Hawaii in the development of its renewable energy resources may have positive spinoff to other areas deficient in conventional energy supplies. The excellent physical resources and well-defined boundary conditions of an island state will facilitate rapid evaluation of the feasibility of these new technologies. The rate and level of penetration achieved by Hawaii with its renewable energy alternatives may help provide some insight to other regions on the potential of their indigenous resources for contributing to a rational energy future.

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