An Overview of Hawaii's Photovoltaic Experience

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Introduction

This paper provides a brief overview of Hawaii's experiences with photovoltaic (PV) technology, Hawaii's energy usage and the distinctive features of the state's isolated island electrical grids, including statistics on both conventional and renewable electrical generation capacities. The state's solar resources are reviewed, followed by a presentation of the major PV projects that have been fostered by the state government. Two major issues associated with Hawaii's PV usage are discussed; the development and growth of a local residential PV market (especially on the Big Island of Hawaii), and the trend in costs of PV systems in this state, for both utility and residential sized systems. Finally, cooperative working groups are introduced which are dedicated to promoting the cost effective application of PV technology in Hawaii.

Overview of Hawaii Energy Use

Hawaii is without indigenous fossil fuel resources and depends on imported oil for 92 percent of its energy. This makes Hawaii the most vulnerable state in the United States to the disruption of its economy in the event of a disturbance of the world oil market or rapid oil price increases. Currently 40 percent of Hawaii's oil comes from Alaska with the remainder from the Asia-Pacific region. The export capacities of these sources of supply are projected to decline significantly approximately 50 percent by the year 2000. This will likely increase Hawaii's dependence on the oil reserves of the politically unstable Middle East.

Like the United States as a whole, Hawaii consumes over 60 percent of its oil for transportation purposes. However, in contrast to the rest of the nation, over 37 percent of Hawaii's oil consumption goes to air transportation, as compared to only 9.5 percent nationally. Approximately 31 percent of Hawaii's oil is burned for electricity generation, which is a much higher percentage than the 4 percent which the nation as a whole uses for the same purpose.

Hawaii is distinctive in its electrical power usage since it is an island chain with isolated grid systems with capacities that range in size from less than 10 megawatts to over 1,600 megawatts (a range that spans four orders of magnitude). The state also has many off grid dwellings and at least one isolated village system. Three quarters of the electricity sold in 1992 by Hawaii's utilities (totaling to approximately 6,678 GWh) was purchased by customers on the island of Oahu. The islands of Maui and Hawaii (the Big Island) consumed approximately 9 percent each of the state's electricity, and Kauai used about 5 percent. Molokai and Lanai usage accounted for less than 1 percent of the state's electrical consumption.

The bulk of the state's renewable capacity is attributable to the Hawaii sugar industry which burns bagasse to provide factory process heat as well as electricity that is regularly sold to the islands' electric grids. In fact, approximately 20 percent of Hawaii's generating capacity is owned by non utility generators (NUGs). These NUGs include the sugar companies as well as various cogenerators and other independent power producers.

Hawaii is considered one of the leading states in the country in the availability of alternate energy resources and in the development of their use in producing electricity and other forms of energy. Some alternative resources, such as biomass, geothermal, wind, hydropower, biogas, photovoltaics and solar thermal have been used in Hawaii for some time.

Hawaii's Solar Resource

Data on solar insolation has been recorded in Hawaii from as early as 1932. The majority of these data were collected by the sugar industry, which has had approximately 145 observation stations over various periods of time. This activity was managed by the Hawaii Sugar Planters' Association for the evaluation of the amount of solar energy available for photosynthesis by sugar cane.

In the 1970s and mid 1980s, the University of Hawaii Department of Meteorology and Hawaii Natural Energy Institute (HNEI) conducted a state-wide assessment of the solar energy resource. This program was sponsored by the state and county governments, as well as the National Science Foundation. Approximately 20 stations throughout the state were monitored in 1976, and three remained operational until 1986.

A number of other reports on the solar insolation data at specific sites throughout the state have been published over the past two decades. These involve data recorded as part of several photovoltaic projects over this period, as well as that gathered by the Natural Energy Laboratory of Hawaii, the National Weather Service, and the National Oceanic and Atmospheric Administration. Additionally, the Hawaiian Electric Company monitors solar data for air quality purposes at the locations of existing power stations throughout the islands, although generally this information is not published. Finally, an assessment of Hawaii's renewable energy resources has recently been completed as part of the state's comprehensive Hawaii Energy Strategy Project.

Hawaii's Photovoltaic Experience

The first photovoltaic demonstration project in Hawaii was a remote weather station at South Point on the Big Island of Hawaii which started operation in 1977. Several experimental navigation aids were also placed in Hawaii waters, and the U.S. Geological Survey employed PV powered sensors to monitor seismic activity at the Mauna Loa and Kilauea volcanoes.

Throughout the 1980s, Hawaii participated in numerous other PV demonstrations. The first occupied residences in the U.S. to be retrofitted with PV power interconnected with utility power were in Hawaii. Three PV systems on houses that broadly represent typical housing in Hawaii (a downtown duplex in Honolulu, a public housing quadroplex in

Oahu, and a 40 year old ranch house on Hawaiian Homestead land on the island of Molokai) were installed in 1981.

An experimental 35 Kw (electrical) PV-solar thermal hybrid system was also installed on the Wilcox Memorial Hospital on Kauai in 1981. This system consisted of 10 parabolic collectors which tracked the sun and concentrated sunlight on PV cells mounted on hollow pipes at the focal point of the collectors. Water passing through these pipes was used to cool the PV cells and to supply heat to the hospital's hot water system. This system was later disassembled and transferred in 1984 to the U.S. Navy's Barking Sands Test Range on the western, sunny side of the island of Kauai. The system's PV circuits were disconnected and it was devoted to water heating service for selected buildings on the base.

In 1984, the state installed a 148 panel, 5 Kw PV system at the Hawaii Institute of Marine Biology on Coconut Island in Oahu's Kaneohe Bay. This system, which operated for more than two years, was designed to provide most of the daytime primary load in the main office area of this facility. In 1985, the state also installed two PV powered lights to provide night time lighting at Oahu's Moanalua Bay public boat ramp. State funding was also involved in the 1988 installation of a 3 Kw stand alone residential PV system in a Honolulu neighborhood. On the Big Island of Hawaii, the village of Milolii received fifty 700 w PV residential power units in 1992 via a joint state and county effort. This village is located in a remote area and has no access to utility transmission lines.

The most recent activities in Hawaii involve the utilization of PVs as the least cost alternative to a remote power need. In 1993, two solar powered 2.5 Kw lamps were selected by the state Department of Transportation as the option with the lowest life cycle cost for lighting portions of Oahu's Deep Water Harbor at Barbers Point. On the island of Kauai, replacement of hurricane damaged rural street lamps with seventy PV powered lamps was found to be the least cost alternative. The installation of the solar lamps was estimated to be $100,000 less than replacement of the original lines and poles.

The state of Hawaii has also become involved with the nationwide Photovoltaics for Utility Scale Application (PVUSA) Project. This project was launched in 1986 with the primary goals of assessing photovoltaic technologies in a utility setting and to transfer photovoltaic technology knowledge to the U.S. utilities. The Hawaii system was installed near Kihei, Maui inside the U.S. Air Force Satellite Tracking compound, also known as the Antenna Farm located above the Maui Research and Technology Park.

The system installation, completed in October of 1989, consists of 1,210 tandem-junction (two-layer) thin-film amorphous silicon modules (total area of 497 m2) interconnected to the utility via a line-commutated inverter and has no storage facilities. The rated capacity of the system is 17.6 Kw (ac), but it has achieved a maximum power output of 21.3 Kw. The system produces power that is being used by the island's electric utility.

The state has also been active in promoting the concept of PV in area high schools by assisting in the development of Ka'ahele La (Tour of the Sun) Inter-Scholastic PV Powered Vehicle Competition. This program, the first of its kind at the high school level had students at selected intermediate and high schools design, construct, and operate PV

powered vehicles. Hawaii's program won the 1989 Best-In-All Categories award for the best energy educational promotion project from the U.S. DOE.

Issues:

Domestic Use of PV Systems

Survey work performed in 1981 indicated that there were at least 200 households on the Big Island of Hawaii which used some form of PV devices. More recent numbers on the precise penetration of small photovoltaics systems in the state are not available. Definitive data are lacking, but there is general agreement that the bulk of the photovoltaic systems in the state are located on the Big Island of Hawaii. Photovoltaic equipment dealers on the Big Island of Hawaii provide estimates that there are from 1,000 to over 10,000 households using some form of photovoltaic systems. However, estimates from energy officials in the state and county governments place the number between 1,000 and 2,000 households. The largest wholesale distributor of photovoltaic equipment in the state estimates that between 25 to 50 percent of the photovoltaic equipment in Hawaii was purchased via mail order. Therefore, there is no central depository of information on exactly how many systems are operating in the state.

The fact that there are very large subdivisions on the Big Island of Hawaii which are not completely serviced by the island's electric utility is another one of the reasons for uncertainty about the number of photovoltaic powered homes. Some of these subdivisions have in excess of 15,000 lots, and it is difficult to assess building permit data to ascertain which of the lots have houses on them, and which use photovoltaic equipment.

For those people living in areas of Hawaii not serviced by the island's electrical grid, the cost of a residential grid extension can be expensive. A rough estimate of $66,000 per mile for grid extension costs has been made by HELCO engineering department for the Big Island of Hawaii. Such estimated grid extension costs provide strong motivation for the consideration of PV as a form of residential power in some parts of the state. (Note that there estimate were obtained by specifying a simple one mile straight flat terrain extension to an average residential customer (a load representing 1.5 to 3 KW). Estimated line cost for a grid extension involves the actual design of the extension, and depends on many factors, including the terrain, the number of poles required, the route of the extension considering property easements, the number of turns in the line, etc. Only the actual survey of the site can render enough information for a design that can be used to establish true line extension cost.)

Costs

Throughout the 1980s, costs have been identified as the single most important factor in the development of PV applications in Hawaii. Although there have been some dramatic price drops over the past 20 years, it is still generally held that PV produced electricity is more expensive than the power supplied by utilities.

Information from the reports prepared by the state's electric utilities for the on going Integrated Resource Planning (IRP) process provides an insight as to what these utilities believe the costs of photovoltaic systems are. The utilities owned by the Hawaiian Electric Industries, Inc. (Hawaiian Electric Company, Maui Electric Company, and Hawaii Electric Light Company), submitted documents that concluded that photovoltaic power stations are not currently cost-competitive as an option for a multi megawatt utility power station. For a smaller one megawatt plant, these three Hawaiian utilities expect that the total plant cost will equal $8,000 per Kw, with a fixed operation and maintenance cost of $15 per Kw-year. Citizens Utilities Company on Kauai priced photovoltaic power stations at about $7,200 per Kw in its IRP submitted to the Public Utilities Commission. Alternatively, the installed capital cost of new Stork-Wortsilla medium speed diesels (the brand currently used on Kauai) is reported to be $1,267 per Kw in the Kauai IRP. On the Big Island, Hawaii Electric Light Company's IRP indicates that a 15.2 megawatt diesel could be installed for $1,981 per Kw.

Land cost and availability are also critical to the economic competitiveness of large photovoltaic generating systems. A recent assessment of potential sites for a large solar thermal electric generation station in Hawaii contained estimates of land costs for potential solar thermal power sites which should be reasonably applicable to PV facilities. However, it must be noted that there are a limited number of land owners in Hawaii that possess tracts of land suitable for a large solar electric facility and that the willingness of these owners to make land available for such a project has not been assessed. Additional data is also available from the Supply-Side Reports submitted by the state's utilities to the Public Utilities Commission as part of the ongoing IRP process. In these reports, the utilities owned by Hawaiian Electric Industries, Inc. estimated land costs to develop a new power station on property previously zoned for industrial development. These various land cost estimates, categorized by island, are summarized in Table 1.

Table 1
1992 Estimated Land Cost Ranges of Potential Hawaii Solar Power Station Sites
Source: HEI Supply Side Reports and SEGS Assessment for Hawaii

Island	($/acre)
Oahu	40,000 to 1,000,000
Hawaii	10,000 to 330,000
Maui	15,000 to 40,000
Kauai	7,000
Molokai	5,000 to 7,000

Recent survey work commissioned by the state of Hawaii Energy Division has collected information that provides an indication of typical costs of residential PV systems that have been installed on the Big Island of Hawaii. A small sample of owners of residential PV systems were asked what they believe it would cost to replace their system if it were damaged or destroyed. Responses to this inquiry indicated that the average replacement cost of just the PV systems on Big Island homes is $5,683, a price that includes as a

minimum the panels and batteries, and in most cases an inverter and a back up generator. (Note that 76 percent of the systems had inverters to convert D.C. power to A.C., and 85 percent had a back up power supply.) However, this replacement cost does not include any energy efficient appliances (e.g. D.C. powered refrigerators, etc.). Most (69 percent) of the owners surveyed originally purchased systems piecemeal as personal finances allowed.

Complete residential systems tailored to a specific household are also marketed in Hawaii. These "upscale" systems normally run between $20,000 and $30,000 to install. A typical system design would include 1,000 watts in panels, a 700 amp hour battery bank, a 4.5 Kw back up fossil fueled generator, and a high efficiency refrigerator.

Future Projected Developments

Future developments in photovoltaics will be impacted by the rate at which cost effective applications of the technology are identified. To this end, Photovoltaics for Utilities (PV4U) working groups are being established around the country to provide a platform for the key energy stakeholders in a state to come together and participate in a collaborative process to commercialize photovoltaics. Members of the working groups are drawn from state government, consumer advocate organizations, the utility industry, the research community, and the photovoltaic industry. The focus of the state working groups is to facilitate the implementation of photovoltaics in the utility sector through a collaborative process.

Hawaii's own PV4U working group was organized in February, 1993. Principles that underlie the direction of the Hawaii PV4U working group include the idea that state action will be based on collaborative-based consensus to create a sustainable market for photovoltaics that will capture the confidence of the investment community. State activities will begin with efforts to exploit current cost effective photovoltaic applications, but also concentrate on advancing the competitiveness of emerging applications in the utility market. This has been demonstrated this past year in Hawaii by two area lighting projects in which PV powered lamps were selected as the most cost effective source of illumination. (These were the Barbers Point Deep Harbor Lighting Project, December 1993 and the Camp Kamakaui repair of Hurricane Iniki damaged lights in March 1994.)

The utility company of the Big Island of Hawaii (HELCO) is an active member of the PV4U group and has recently launched its own Hawaii Remote Photovoltaic (PV) Program. This effort will evaluate the utility's ability to provide electrical PV services to residents on the Big Island of Hawaii who do not live near the grid. HELCO-maintained residential PV systems will be designed, constructed, and monitored as part of this program.

Summary

The number of installed PV systems is small primarily due to the high cost of PV components. Further, Hawaii's high land prices must be factored into any economic analysis for commercial viability of any proposed large PV power station.

High utility grid connection costs have encouraged the market for residential PV systems in the state. On the Big Island of Hawaii, the development of housing in remote locations distant from the island's electrical grid has generated a demand for off grid power systems. Given the very high connection costs on this island, residents have investigated the relative benefits of PV systems versus other home powering options, and the result has been a growth in the number of residences using PV as a primary electrical power source. In fact, if the number of the PV households exceeds 5,000 (a value within the range of estimates provided by PV professionals in the state) then Hawaii may have the greatest number of off grid PV households in the United States.

Future growth in the application of PV in Hawaii is expected to be encouraged by efforts of such organizations as PV4U, which are aggressively seeking out existing cost effective applications. PV4U group cooperation and evaluation of similar efforts on the U.S. mainland have proved valuable to the promotion of PV utilization.