Advances in Hawaii's Ocean Energy RD&D

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Abstract

The wave energy resource in the Pacific Ocean surrounding Hawaii is abundant enough to, in theory, supply most of the state's electricity. In addition, the Hawaiian Islands are situated perfectly for Ocean Thermal Energy Conversion (OTEC). Tidal and ocean current resources, however, are less promising.

The State of Hawaii is proposing that an aggressive 40% of its electricity come from renewable resources by the year 2030, a significant increase over the currently legislated 20% by 2020 Renewable Portfolio Standard. Ocean energy is anticipated to play a role in achieving that goal. Recognizing that obtaining permits for renewable energy projects is a major barrier to their implementation, the state has hired a renewable energy facilitator to coordinate permits for large-scale projects. The Department of Business, Economic Development and Tourism has also been assigned the responsibility for designing a streamlined permitting process.

A number of ocean energy developers are pursuing RD&D projects in Hawaii. In 2008, a 2.7-MW project by Oceanlinx off the northern coast of Maui was announced. Later that year, OPT deployed its third PowerBuoy in Kaneohe Bay, an effort supported by the US Navy. A demonstration of CIIIS/SG2's wind-wave buoy was also completed in Kaneohe Bay. Other wave energy companies have expressed interest in pursuing projects in Hawaii.

The University of Hawaii's Hawaii Natural Energy Institute (HNEI) has received one of two US Department of Energy awards establishing a National Marine Renewable Energy Center. HNEI anticipates implementing projects to test components, devices, and interconnection systems for wave energy at three sites on the islands of Oahu and Maui, and to pursue OTEC R&D at the existing Natural Energy Laboratory of Hawaii Authority (NELHA) facility on the island of Hawaii.

A 2008 agreement between Lockheed Martin Corporation and the Taiwan Industrial Technology Research Institute will support the development of a 10 megawatt pilot OTEC plant in Hawaii.

Keywords: Hawaii, OTEC, policy, research and development, wave energy

1 Hawaii Clean Energy Initiative

On January 31, 2008, Hawaii embraced the aggressive goal of achieving 70% clean energy by 2030, converting a community now nearly 90% dependent on fossil fuels to one which relies instead on efficiency and indigenous renewable energy resources within a single generation. [1]

The Hawaii Clean Energy Initiative (HCEI) is an unprecedented partnership between the State of Hawaii and the U.S. Department of Energy (USDOE). A number of partnership projects have been initiated, including studies of linking several islands with an undersea transmission cable; currently, each island is served by an isolated utility grid. Several islands' grids have been characterized, and analyses are underway which will determine how best to integrate intermittent renewable resources. Smart grid upgrades, feed-in tariffs and demand response programs are pending.

Expertise from USDOE and its national laboratories has been dedicated to the achievement of the goal, as have staff from the State of Hawaii Department of Business, Economic Development and Tourism (DBEDT).

A DBEDT staff member has been designated as the state's energy permitting facilitator and is working to streamline state and county permitting procedures for renewable energy. In addition, as part of HCEI, DBEDT staff and other stakeholders will be developing recommendations for Renewable Energy Zones with the intention of simplifying infrastructure requirements and clarifying permitting needs.

Among the major findings of HCEI analyses are that Hawaii can, in theory, generate 150% of the electricity it now consumes from locally-available renewables, including ocean waves, ocean thermal resources, wind, solar, geothermal, hydroelectricity and biomass.

A number of renewable energy resources, including photovoltaics, wind, geothermal, run-of-the-river hydroelectricity, and biomass from agricultural wastes, already generate electricity at costs which are competitive with utility power. Due to Hawaii's overdependence on oil for electricity, electric rates within the state are significantly higher than the national average. During 2008, when oil prices soared, some islands' retail electricity rates approached US$0.50/kWh.

Although Hawaii does presently have a Renewable Portfolio Standard (RPS), there are no specific set-asides, obligations or specific tariffs applicable to ocean energy development or designed to explicitly encourage any other renewable. By law, the RPS calls for 20% renewable energy in Hawaii by 2020. HCEI proposes a 40% renewable electricity RPS, along with an efficiency portfolio standard, to achieve its more aggressive goals.

As a result of HCEI agreements, the state Public Utilities Commission (PUC) is considering feed-in tariffs which would simplify power purchase agreements with the local utilities. The PUC is expected to conclude its deliberations in mid-2009. Although the first set of renewables which are expected to be eligible for feed-in tariffs does not include ocean energy, future expansions of the tariffs are expected to address additional technologies such as wave and OTEC.

2 Hawaii's ocean energy resources

Hawaii's average wave resource has been estimated to be 10-15 kW/m at the 80 m (262 ft) depth contour in exposed northeastern coasts [2]. However, these figures should be confirmed with actual on-site data. Preliminary calculations performed by Sea Engineering, Inc. for the proposed Oceanlinx installation off the northern coast of Maui show more wave energy available than was predicted by the 1992 assessment—in excess of 20 kW/m at that location.

Most of the wave energy available to Hawaii is the result of tradewind-driven swells. Tradewind waves have dominant periods of 6-8 sec and significant heights of 1-2 m. The tradewinds blow year-round from the northeast, though they are more frequently interrupted during the winter months.

Hawaii's ocean thermal resources are well documented as the state's Natural Energy Laboratory of Hawaii Authority (NELHA), located at Keahole Point on the island of Hawaii, was one of the world's premier sites for OTEC research from the mid-1970s into the 1990s. With annual warm surface waters typically in excess of 25º C (77º F) and deep, cold water available less than 1.6 km (1 mile) offshore providing the rule-of-thumb 20ºC temperature differential, Hawaii is an ideal site for OTEC research, development and commercial deployment.

There is less potential, however, for ocean current and tidal energy. Hawaii's tidal flux is generally less than one meter, and utility-sponsored surveys of deep ocean currents as well as published data on surface currents indicate that maximum current speeds are less than 1 mps, well below the minimum 2 mps desired by technologies presently under development.

The State of Hawaii has a general coastline of over 1206 km (750 mi), the fourth longest in the U.S., and an exclusive economic zone of about 2.4 million km².

3 National Marine Renewable Energy Center established at the University of Hawaii

In September 2008, the University of Hawaii (UH) Hawaii Natural Energy Institute (HNEI) was named by USDOE as one of two National Marine Renewable Energy Centers in the United States; the other will be managed by Oregon State University and the University of Washington. Approximately US$5 million in USDOE funding, plus significant matching, is expected for HNEI's Center over five years.

This award was the result of a nationwide competitive solicitation for Advanced Water Power Projects. The goal of the solicitation was to advance commercial viability, cost-competitiveness, and market acceptance of new technologies that can harness renewable energy from oceans and rivers.

HNEI's work plan is strongly industry-driven and additional partnerships with ocean energy development companies wishing to test devices or components are welcome. A number of private partners—local, national and international—are already participating.

Present partners include technology developers, the local electric utility companies, engineering companies, planners, and the State of Hawaii. International partners include groups from Norway, France and the United Kingdom; additional partners from Asia are anticipated.

Specific partners include:

- State of Hawaii
- Maui Electric Company, Ltd.
- AGS/AECOM
- CIIIS/SG2
- Lockheed Martin
- Ocean Power Technologies
- Oceanlinx
- Planning Solutions, Inc.
- Sea Engineering, Inc.
- SwellGen
- Le Club des Argonautes (France)
- Norwegian Institute for Water Research
- Runde Environmental Center (Norway)
- The University of Edinburgh

HNEI envisions supporting its partners by assisting with the completion of necessary environmental studies, helping to acquire required permits, providing engineering support, assisting with monitoring the performance of deployed systems, and coordinating information exchange.

Field Test Facility Sites

Three field test facility sites have been identified for wave energy development and one for OTEC research, offering a range of opportunities for component optimization as well as for testing complete systems.

Figure 1: Hawaii's National Marine Renewable Energy Center activities will be focused at four sites.

One test site, at Pauwela Point on Maui, is also the proposed location of Oceanlinx' 2.7 MW plant. Center investment at Pauwela Point will leverage and expand the Oceanlinx permitting efforts as well as the undersea power and instrumentation cabling to be provided by the utility. This will allow testing by other power providers. The Center will also conduct testing and obtain oceanographic data that would benefit wave power system development.

At a second site offshore of the Kaneohe Marine Corps Base Hawaii on the windward coast of the island of Oahu, Ocean Power Technologies (OPT) has been testing single buoys in 30 m (100 ft) deep water.

Testing larger devices in deeper water will require additional permitting, new buoy development, and the deployment of additional infrastructure. The Center proposes to help by conducting oceanographic and environmental studies and by directly supporting permitting efforts for the deep water experiments. Sea Engineering, Inc., a Hawaii-based ocean engineering contractor that installed the OPT buoy and conducted much of the environmental field work, is also a Center partner.

The third field test facility will be at the Makai Research Pier at Makapuu, on the eastern tip of Oahu. This site will obtain long term data on the wave energy resource and other environmental parameters. Also, Makai Pier will be the site for research on corrosion and innovative materials, and offers an easily accessible location for the deployment and testing of small wave energy conversion devices and components.

Two of the Center's partner organizations, the UH Hawaii Undersea Research Laboratory and Sea Engineering, Inc., are primary tenants of the Makai Research Pier.

In addition, there is one site for long-term testing of an OTEC plant of at least 5 MW capacity, intended to move OTEC technologies to pre-commercialization. The technical role of the Center will be to focus on system and component engineering and local and global environmental studies. This work is likely to be performed in part at NELHA.

NELHA was established in 1974 by the State of Hawaii to pursue OTEC and other ventures utilizing deep ocean water. Numerous sea water intake systems have been installed at the laboratory, including a recently-completed 3.1 km (1.9 mi) long, 1.4 m (4.6 ft) diameter, high density polyethylene (HDPE) pipe that extends to a depth of 915 m (3000 ft) to supply cold seawater at 6ºC at rates up to 1.8 m^3/s (27,000 gpm). Another 1.4-meter diameter HDPE pipe is used to supply 2.56 m^3/s (40,500 gpm) of warm seawater from a depth of 24 m (79 ft).

Testing and demonstration might also be performed at facilities operated by HNEI's international partners.

A key objective of the Center is to have one or more of the wave energy systems deployed at one of the Center's sites to be supplying power to the local gird at more than 50% availability before the end of the five-year program.

Regarding OTEC, the Center's objective at the end of five years is to be in the process of completing, or to have completed, the final design of an OTEC plant. In addition, major permits are to be secured, environmental documents prepared, and a power purchase agreement with a utility will be in place.

Another major goal of HNEI's National Marine Renewable Energy Center is to facilitate international exchange of information such as test data and modeling results through a web-based virtual Center.

Advanced Forecasting Research

HNEI will conduct research on advanced wave forecasting technologies with the intent of identifying locations and periods of time around the Hawaiian Islands which are most favorable for the operation of wave power systems. Researchers will identify and develop effective forecasting protocols and methods with the goal of improving the accuracy of wave forecasts and resulting hindcasts.

These tasks will be based on current work being performed by the UH Department of Oceanography and the UH Department of Ocean and Resources Engineering (ORE).

ORE has been operating a model system to provide 7.5-day experimental forecasts of wave conditions around the Hawaiian Islands at regional and island scales. The system includes the spectral wave models WaveWatch3 (WW3) and Simulation Wave Nearshore (SWAN), as well as the Coastal and Estuarine Circulation (ECOM) model. These models provide forecast runs every 6 hours for the main Hawaiian chain at 6-km resolution, and for individual islands at 600-m resolution.

In each forecast run, the NOAA Global WaveWatch3 model and TPXO.6 global tidal database provide the wave and tide boundary conditions. High-resolution atmospheric models (MM5/WRF) with proper depiction of terrain and land surface conditions operated by the UH Department of Meteorology provide the wind forcing that accounts for the modification of large-scale flow by the Hawaiian Islands, which are as high as 4205 m (13,796 ft).

The Center will improve the accuracy of the wave forecast and use the resulting system in hindcast mode to develop a wave atlas of the Hawaiian Islands. Improved wave forecasting accuracy will aid the deployment and operation of test devices, while the wave atlas will offer detailed information which will be of significant value for planning commercial wave power systems as well as for related environmental studies.

A key component of the proposed work is to enhance the Hawaii regional MM5/WRF model by assimilating satellite observations of ocean surface winds. Both WW3 and SWAN consider wave propagation, refraction, shoaling, and breaking under the influence of specified wind and current fields. Addition of diffraction will greatly enhance the spectral wave models in describing the wave conditions on the leeward side of islands.

Experimental and Numerical Modeling

HNEI will also conduct experimental and numerical modeling for optimization of marine energy conversion devices and arrays. These models will support field testing and complement laboratory studies. Researchers hope to refine numerical simulation packages to predict dynamic loads on floating and submerged structures, and assess the performance of both single wave devices and interacting arrays. Another objective is to conduct tank tests of prototype devices being investigated at the Center's field sites.

Existing facilities at the University of Hawaii include a 15.2 m (l) x 1.2 m (w) x 0.9 m (d) wave tank/wave generator equipped with a towing carriage. A longer, 1.8 m deep wave flume and towing carriage will also be available for the wave energy experiments. This longer flume has an advanced computer-controlled wave maker that can generate periodic waves, solitary waves, conoidal waves, breaking waves, and also irregular waves to better simulate the ocean wave field. It also has a self-circulation system that can produce currents up to 1 mps. Instrumentation includes multiple wave gauges and data acquisition systems, a 3D Laser Doppler Velocimeter and a 3D Particle Image Velocimeter, video cameras, high speed cameras, and flow meters.

Experiments will be conducted under different wave conditions, examining single devices as well as series of devices arranged in different patterns. An additional area of interest is the use of man-made wave focusing structures to enhance the performance of wave power devices. Laboratory experiments will explore the possibility of developing practical wave focusing lenses.

Grid Integration

The integration of intermittent renewable energy systems, including wave power, is a challenge for utilities, affecting the quality of power distributed as well as the economic dispatch of generating units. While wave energy systems are expected to be more predictable and less transient than wind and photovoltaic systems, there have not been any detailed assessments of the integration of large scale ocean energy systems into the grid.

HNEI, in partnership with GE Global Research Center (GE GRC) and local utilities, is developing detailed dispatch and dynamic models for the various Hawaiian Islands. These models, based on the GE GRC MAPS (dispatch) and PSLF (dynamic) models, are able to accurately evaluate the effect of intermittent energy sources on system stability and power quality. These projects are already underway, funded by USDOE.

With their small and isolated grid systems and relatively high penetration of renewables, the islands of Hawaii and Maui are excellent case studies to apply these validated models to investigate the effect of linking ocean energy systems with other renewables. By integrating wave power performance data from the planned field tests with high fidelity grid models and advanced wave forecasting techniques, the Center will be able to assess the value of grid-connected wave power facilities.

The behavior of mixed portfolios of conventional and renewable power systems on Maui and Hawaii is already being modeled, focusing on identifying technology systems or operating strategies such as energy storage and advanced forecasting that can respond to rapid grid frequency fluctuations. Wave energy technologies will be integrated into this analysis. This study will help utilities properly site and size storage devices, address interconnection issues as well as the reliability of wave forecasting techniques, and compare operational characteristics of different wave energy technologies.

OTEC is expected to be a baseload technology which could help stabilize a grid which has a high penetration of intermittent power sources. The effect of grid-connected OTEC systems on power quality management and unit dispatch, however, has never been evaluated. The Center will include OTEC in its modeling activities.

The Oahu grid will also be modeled. Oahu has an installed electricity generating capacity more than five times that of any other island, and presently uses fewer renewable resources. Testing ocean power systems on three different islands, each with unique grid characteristics, allows an evaluation of the operation of these technologies under different energy regimes.

Environmental Compatibility

HNEI's Center will also analyze the compatibility of ocean energy technologies with the environment, fisheries and other marine resources. The study will include three components:

1) evaluation of chemical and biogeochemical threats posed by discharges associated with wave energy devices;

2) an assessment of the impacts of ocean energy installations on marine life; and

3) the effects of OTEC sea water removal and discharge on the food web and the potential for degradation of the thermal resource.

Chemical and biogeochemical impacts of OTEC operations have been studied previously [3,4,5,6], but the impacts of hydrokinetic and other ocean energy devices are less understood, particularly with respect to tropical and island environments. Possible environmental effects include the release of anti-biofouling agents; the disposal of removed biofouling; lubricants and surfactants released during operations and inadvertent spills; nutrient-rich groundwater released from cable shore crossings; and particulate matter released during the installation of moorings and shore crossings.

As a specific test case, the Oceanlinx demonstration planned for Maui will be analyzed to determine and rank the significance of these possible effects. Methods to eliminate or mitigate significant impacts will be explored.

Regarding potential impacts on marine biota, a number of activities are planned. Different types of ocean energy installations—e.g., buoy arrays, floating platforms, and suspended OTEC pipelines—will be analyzed to identify the full spectrum of possible impacts of biofouling on marine animals. Objects in the ocean are also known to attract and aggregate fish and other organisms. Installations may entangle certain animals, and may be used as haul-outs and resting sites by others. The noises created by ocean installations can alter the acoustic environment. In addition, the electromagnetic signatures of ocean devices may be detected by animals which use such signals for navigation and positioning.

In order to understand, predict and mitigate the impacts of ocean energy installations on animals, it is necessary to understand whether they will be attracted, repelled or unaffected by a particular device, and to evaluate how different designs affect these responses. The literature contains a significant body of information on animal responses to marine structures and anthropogenic disturbances which will be applied to these analyses, as will additional information collected during field tests.

The effects of OTEC will be investigated through numerical modeling. The Regional Ocean Model System (ROMS) will be applied to characterize local environmental impacts of an isolated OTEC plant. The large OTEC sea water flow rates will be idealized as point sinks and point sources in this model. Results will help select the depth and type of OTEC effluent discharge that will produce minimal perturbations. Since there is concern that release of highly concentrated nutrients from the deep ocean into the photic layer may alter primary production [7,8], this phenomenon will be explored by incorporating a nitrate-phytoplankton-zooplankton-detritus submodel within ROMS.

The issue of degradation and global sustainability of the ocean thermal resource will also be studied. Closely spaced commercial OTEC systems may interfere with each other and alter the ocean temperature profile, resulting in a drop in performance and possible negative environmental impacts. The modeling methodology developed for a single system will be extended to arrays of OTEC plants within selected regions, such as the area around the main Hawaiian Islands. Finally, General Circulation Models will be employed to determine whether global OTEC resources are limited by the rate of deep cold seawater formation in polar regions, as suggested by simple one-dimensional analyses [9,10].

Reliability and Survivability

The viability of ocean power technologies will be affected by their ability to resist corrosion in the harsh marine environment. General corrosion, pitting, crevice corrosion and galvanic corrosion may occur. In addition to the ubiquitous chloride ion, sulfuric acid exposure is an increasing concern in Hawaii due to emissions from the Kilauea volcano.

Marine installations are also vulnerable to biocorrosion, which is a serious problem for power generation facilities and the offshore oil and gas industry [11,12,13]. Microbial-influenced corrosion alone accounts for 20-30% of all corrosion losses (about US$30-50 million annually). Biocorrosion occurs when complex microbial consortia interact with metallic surfaces through the establishment of multispecies biofilms. Biofilms can modify the metal-solution interface by drastically changing the types and concentrations of irons, pH and oxygen levels. The mechanism of biocorrosion is complex and insufficiently understood [14].

The Center’s corrosion studies will leverage facilities at the UH Hawaii Corrosion Laboratory. The Laboratory has established eight atmospheric test sites, including two in marine settings, at different locations in Hawaii that take advantage of the state’s diverse microclimates and environments [15]. It also operates a state-of-the-art corrosion, electrochemistry, and materials characterization facility. The Laboratory specializes in synthesizing hybrid ceramic-polymer (ceramer) coatings for corrosion protection and has developed several novel coatings for aluminum and zinc that have shown exceptional promise in marine environments.

Test facilities will be set up at the Center’s four field sites to investigate corrosion in the splash-spray zone, surface waters, and deep ocean water. Vulnerable materials used in wave energy devices and OTEC components will be identified, and standard sample coupons and ceramer coatings will be prepared and tested.

Biocorrosion will also be explored using molecular methods to identify the composition of fouling communities, classic taxonomic approaches, and Scanning Electron Microscopy. Innovative marine coatings, containing natural compounds extracted from algae and sponges and conductive polymers, will be tested in the laboratory to determine their effectiveness in providing protection from biocorrosion.

4 Ocean energy project updates

OTEC

On November 18, 2008, during a trip to Asia by Hawaii Governor Linda Lingle, a partnership was launched between Taiwan Industrial Technology Research Institute (ITRI), a non-profit government-sponsored research institution, and Lockheed Martin Corporation which will involve the development of a 10 MW OTEC pilot plant. ITRI has agreed to join in a feasibility study and will collaborate in the initial pilot plant, to be located in Hawaii. The aim of the agreement is to strengthen mutual understanding and bilateral cooperation in the area of ocean thermal energy conversion.

Lockheed Martin Corporation has developed and studied OTEC technology for over 30 years. Much of the R&D was performed at NELHA, located on the Kona coast of the island of Hawaii. Lockheed's Hawaii projects included the mini-OTEC barge which was the first closed-cycle, at-sea OTEC plant to generate net electricity. Mini-OTEC was deployed off NELHA in 1979. Lockheed's plans for a 10 MW pilot and discussions with the Hawaiian Electric Company (HECO) were already underway at the time of the agreement with ITRI.

Lockheed Martin intends to employ low-cost composite materials and new construction and welding techniques to reduce the capital costs of an OTEC plant. Their aluminium heat exchanger concept builds upon the lessons learned from earlier USDOE-funded research. Heat exchanger technology is critical, as heat exchangers are expected to command over half of the capital construction costs of a 100 MW OTEC plant.

They envision using a standard semi-submersible center hull platform, as utilized in the offshore oil and gas industries. Deep water platform technology is mature, with approximately 100 floating production platforms built and installed in water depths up to 2400 m (7800 ft).

Lockheed Martin has been awarded a cooperative agreement contract with USDOE, with a maximum value of $1.2 million, to demonstrate innovative technologies which will enable ocean thermal energy power generation. Under the terms of the cooperative agreement, which will support the Hawaii pilot plant, Lockheed Martin will demonstrate a cold water pipe fabrication approach using modern fibreglass technology and recent low-cost composite material manufacturing methods at prototype and pilot plant scales. Lockheed's offices based in Manassas, Virginia, will lead the OTEC effort, while fabrication work will be performed at the company's Advanced Technology Center in Sunnyvale, California.

OCEES International, Inc. has also proposed a 1 MW OTEC facility at NELHA.

The U.S. Department of the Navy has awarded an OTEC feasibility study for its base in Guam to Makai Ocean Engineering, a Honolulu-based firm with extensive experience in deep water pipelines. U.S. Defense Department agencies have an internal goal to generate 25% of all energy from renewable sources by 2025.

Sea Solar Power, a Baltimore, Maryland company, has submitted a proposal to HECO for a 100 MW OTEC facility on a platform 6.4 km (4 mi) off the southwestern point of Oahu. The proposed Sea Solar and Lockheed projects were both mentioned in the agreement between HECO and the State of Hawaii, signed on October 20, 2008, to implement aspects of the Hawaii Clean Energy Initiative.

Oceanlinx

On February 4, 2008, Hawaii Governor Linda Lingle announced that Oceanlinx, an Australian wave energy conversion company, would install two or three of its oscillating water column (OWC) devices off the island of Maui, with a total generating capacity of approximately 2.7 MW.

The Maui Electric Company is working closely with Oceanlinx and intends to develop and fund the subsea and onshore substations, as well as the cable which will connect them. Maui Electric has also been speaking to community groups about the project, which has received preliminary endorsements from the fishing community as well as environmental organizations.

Oceanlinx has obtained a Memorandum of Understanding with Maui Electric's parent company, HECO, and has engaged Honolulu consultants to develop an environmental impact statement and pursue required permitting. Installation is expected by 2011.

Oceanlinx is currently working on improvements to its OWC design which will maximize its power output by tuning the internal chamber to the resonant frequency of Hawaii's wave regime. A new device which will test the upgraded design is expected to be deployed first in Australia.

Figure 2: Second-generation Oceanlinx OWC device demonstrated in Australia.

Ocean Power Technologies (OPT)

OPT has been testing its PowerBuoy in waters off the Marine Corp Base Hawaii in Kaneohe Bay since 2001 in a research program funded by the Office of Naval Research. Their 3rd buoy was deployed on October 28, 2008.

Deployment was supported by Hawaii diving and workboat subcontractors, including Sea Engineering. The buoy was anchored approximately 1.6 km (1 mi) off the coast, in 30.5 m (100 ft) of water.

This generation of PowerBuoy is based on OPT's proprietary design and is approximately 3.6 m (12 ft) in diameter and 15.8 m (52 ft) long. It weighs 15.4 tonnes (17 tons). Although smaller than the original buoy design, the new buoy's generating capacity has doubled and is now rated at a maximum output of 40 kilowatts. It is designed to be remotely monitored from OPT's New Jersey headquarters via radio link and internet.

During a brief period of operation in November 2008, the buoy produced measurable power. However, the buoy stopped working and was recovered in early December 2008 and returned to New Jersey to determine the cause of failure. Water infiltration in the electronics is a possible cause. As of April 2009, the buoy remains in New Jersey for complete failure analysis and repairs, and a date for its redeployment in Hawaii has not been set.

Figure 3: OPT's third buoy deployed in Kaneohe Bay, Oahu, November 2008.

SG2

Wave energy conversion company SG2, LLC has developed a buoy technology adaptable to a number of maritime applications, from generating electricity for onshore customers to products such as scientific buoys, navigational aids and remote sensing devices.

The device is based on a Faraday linear generator utilizing friction-reducing lubrication. It is intended to harvest energy from wind waves rather than from deep ocean swells. SG2 is establishing its corporate headquarters in Hawaii and is in the process of hiring employees. Currently, it operates out of Southern California and also has proposals and preliminary agreements for testing in Asia.

The company executed a brief at-sea test of its G2 (second generation) buoy in Kaneohe Bay during the first half of 2008. The test confirmed that power output increased 25 times over its G1 design, while the buoy's mass increased only five times. Output for the test buoy was in the range of 2.3 watts. SG2 is working on a third generation design.

The next step for SG2 is to deploy a 5x5 array of its buoys to determine the performance of individual buoys within an array as well as the influence of connected buoys on each other. The array demonstration will also test the connection and mooring system, presently under design by Sea Engineering. One or more sites affiliated with the HNEI National Marine Renewable Energy Center are under consideration. SG2 has also secured a Memorandum of Understanding with HECO.

SG2's academic partners include Scripps Institute at the University of California, San Diego; the University of Hawaii Institute of Marine Biology; and Faraday Laboratory of the University of Edinburgh.

WaveGen

The Scottish company WaveGen visited Hawaii in the fall of 2008 at the invitation of the State of Hawaii Department of Transportation (DOT). DOT's Harbors Division was particularly interested in the potential of WaveGen's "active breakwater" application, which incorporates multiple OWC devices in harbor breakwaters.

A series of meetings with state government officials, including Lt. Governor James Aiona, and the private sector were scheduled.

As a result of the meetings, WaveGen received bathymetric and tidal data and is conducting a preliminary feasibility review to determine whether further analyses are warranted.

The DOT Harbors Division operates and maintains ten commercial harbors throughout the major Hawaiian Islands, most of which are protected by breakwaters. While the majority of the state's harbors are in relatively protected leeward waters, several are exposed to the dominant, tradewind-generated waves on the northern and northeastern coasts.

The Harbor Division's Harbors Modernization Plan, while not specifically calling for the incorporation of ocean energy devices, does specify new breakwaters at Kahului Harbor and the reconstruction of Hana Pier to meet the current and projected demand for ocean transportation of cargo and passengers through 2030. WaveGen has noted that incorporating its devices in the construction of new breakwaters is more cost-effective than retrofitting existing infrastructure.

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