Oregon Wave Energy Trust
Utility Market Initiative

Task 2.1.1: EPRI Wave Energy Technology Assessment

www.oregonwave.org

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The Utility Market Initiative was prepared by *Pacific Energy Ventures* on behalf of the Oregon Wave Energy Trust.

Task 2.1.1 was completed by the Electric Power Research Institute (EPRI).

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For information about this project, please contact Justin Klure at Pacific Energy Ventures:

Phone: (503) 475-2999

Email: jklure@peventuresllc.com

About Oregon Wave Energy Trust

The Oregon Wave Energy Trust – (OWET) - with members from fishing and environmental groups, industry and government - is a nonprofit public-private partnership funded by the Oregon Innovation Council in 2007. Its mission is to serve as a connector for all stakeholders involved in wave energy project development - from research and development to early stage community engagement and final deployment and energy generation - positioning Oregon as the North America leader in this nascent industry and delivering its full economic and environmental potential for the state. OWET's goal is to have ocean wave energy producing 2 megawatts of power - enough to power about 800 homes - by 2010 and 500 megawatts of power by 2025.

ELECTRIC POWER RESEARCH INSTITUTE

OFFSHORE OCEAN WAVE ENERGY: A SUMMER 2009 TECHNOLOGY AND MARKET ASSESSMENT UPDATE

Project:	Wave Energy Technology Assessment
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Author:	Roger Bedard
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1. SUMMARY

Installed Offshore Wave Capacity (as of June 30, 2009)	Less than 1 MW worldwide (The 2.25 MW Aguçadoura project is not deployed in Portugal at this time); 40 kW in the United States. Estimated annual incremental U.S. capacity additions: 2010 - 0.15 MW 2011 - 1.50 MW 2012 - 13.30 MW EPRI estimates a U.S. cumulative capacity by by 2015 of about 200 MW and 10,000 MW by 2025 (see table 8-1) Douglas Westwood estimates a US capacity of 5 MW and a worldwide capacity of 25 MW by 2013[1] Greentech Media estimates a worldwide capacity by 2015 of 1,000 MW[2]
Wave Energy Conversion (WEC) Technology Readiness	WEC is an emerging technology. About a half dozen full-scale prototype WEC devices have been demonstrated at sea over the past five years; about another dozen sub-scale prototypes have also been demonstrated and are now ready for full-scale demonstration. The first phase (three Pelamis units at 0.75 MW each totals 2.25 MW) of the world's first commercial 30 MW wave plant was deployed in Portugal; it first transmitted electricity to the grid in mid-2008. The three machine are now dockside due to financial difficulties of project majority owner Numerous project and device developers have initiated wave power plant projects off the shores of many countries.
Economic Status	The first project sale, announced in Portugal in 2005, was made possible by significant feed-in tariffs (~$0.45/kWh). The first U.S. commercial plant project, announced in 2006 by Ocean Power Technology at Reedsport, OR, was made possible through public support, private investment and state incentives. The first U.S. wave power purchase agreement (2 MW) was signed between Finavera and PG&E in late-2007 for a plant in Humboldt County, CA. but rejected by the California Public Utility Commission in late 2008 The first U.S. wave power plant license issued by FERC for a 1MW Makah Bay, WA project to Finavera was surrendered by Finavera as they abandoned the wave energy development space
Environmental Impact	Proper care in siting, installation, operation, and decommissioning may enable ocean wave energy technology to be one of the more environmentally benign electricity generation technologies. Pilot demonstration testing is needed to understand the interactions between the devices and their environment. Adaptive management will be used to

[1] The World Wave & Tidal Market Report 2009-2013", Douglas-Westwood
[2] Climate Change Business Journal, January/February/March 2009 page 25

	incorporate new information into decision making processes that will address project build out and cumulative effects
Regulatory Status	Wave power plant projects are being permitted in Europe (Pelamis plant in Portugal, UK Wave Hub, Santano in Spain, etc.) and Australia. The time, cost and complexity of the U.S. regulatory process can be difficult for river in-stream project developers The Federal Energy Regulatory Commission (FERC) has primary jurisdiction for licensing ocean wave energy under the Federal Power Act (FPA), both in state waters and on the outer continental shelf. The FERC has developed a six month license application process for pilot demonstration plants. The 2005 Energy Bill gives the Mineral Management Service (MMS) the jurisdiction to lease lands on the outer continental shelf (OCS), that is, 3 to 200 nm offshore. (except for the Gulf of Mexico where it is 12 nm). FERC announced that it will no longer issue preliminary permits for wave plants on the OCS (but will continue to do so for wave plans in state waters). MMS lease rules for alternative energy on the OCS were issued in April 2009 There currently are no leases for wave plants on the OCS nor are there any applications for leases for wave plants on the OCS
Government Support of Wave Energy Technology	European governments (particularly in the UK, Ireland, Portugal and Denmark) as well as those in Japan, New Zealand, and Australia, support the development of WEC technology and are now providing subsidies to stimulate a commercial market. The U.S. currently provides no production incentives or subsidies to wave energy projects. The U.S. DOE initiated a Waterpower R&D Program in FY 2008 with a Congressionally mandated $10 million which was followed by another Congressionally mandated level of funding for FY 2009 of $40 million. The Government provides only one-half the production tax credit for tidal in-stream as it does for commercially established wind power. The Government provides accelerated depreciation to wind projects but not to tidal in-stream projects The Murkowski/Inslee Marine Renewable Energy Promotion Act of 2009 would authorize as much as $250 million a year (up from the current authorization limit of $50 million per year) to expand federal research of marine energy, take over the cost verification of new wave, current, tidal and thermal ocean energy devices, create an adaptive management fund to help pay for the demonstration and deployment of such electric projects and provide key additional tax incentives. This bill was approved by the Senate Energy Committee in June 2009. It appears that the stimulus monies distributed to the DOE for renewable energy will not include an allocation for marine energy.
Trends to Watch	Getting economical power from ocean waves will be difficult and will require the very best engineering skills. There are other skills required as well; chief among them are open-minded regulatory skills, communication outreach skills and negotiation skills for resolving conflict of sea space issues. More demonstration projects and early commercialization projects, including multi-megawatt “wave farms” over the next decade in Europe, South America and Australia (and the US if regulatory obstacles are overcome).

2. Introduction

Ocean waves are generated by the influence of wind on the ocean surface as depicted in Figure 2-1. Ripples on the surface create a steep slope against which the wind can push and cause waves to grow. As the wind continues to blow, the ripples become chop, fully developed seas, and finally, swells. In deep water, the energy in waves can travel for thousands of miles until their energy is dissipated on distant shores.

Individual waves represent an integration of all winds encountered as they travel over the ocean surface. Sea states (a wave height, period, phase and direction) can be accurately predicted more than 48 hours in advance. This predictability, along with the slow time rate of change of the resource, will allow time for grid operators to dispatch other generation resources to be brought on-line to balance the demand with the supply. This is a major advantage over wind generation. Other characteristics of renewable wave energy that make it especially attractive for electricity generation are its high power density (kW/meter of wave crest lengthy) and the potential for being relatively environmentally benign, if properly sited, sized, deployed and operated.

Ocean waves are composed of orbiting particles of water as illustrated in Figure 2-2. At the sea surface, the diameter of water particle orbits is equal to wave height. Orbital motion decays exponentially with depth, and its amplitude is only 4% of its surface value at half a wavelength down. The wave orbital motions are not significantly affected by the bottom in water deeper than half a wavelength. The vector field of particle motion is illustrated in Figure 2-3.

In deep water, wavelength is directly proportional to wave period squared. Therefore, a 10-second wave is four times longer than a five-second wave, and it will begin to feel the bottom in water that is four times as deep. Since the rate at which a wave travels (its phase velocity) is equal to wavelength divided by period, a 10-second period wave travels twice as fast as a five-second wave. The combined potential and kinetic energy of the waves travels at the velocity of the wave group, which in deep water is equal to half the phase velocity.

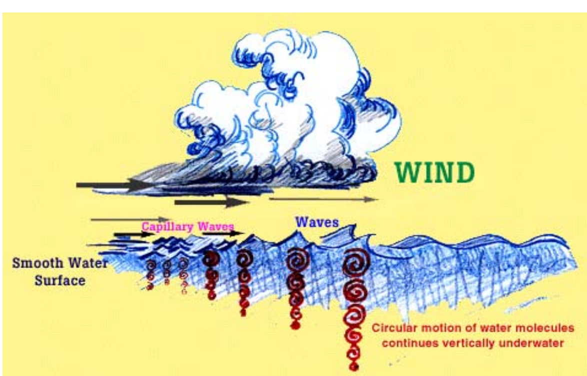

Figure 2-1
Wind Blowing Over Fetch of Water Produces Waves

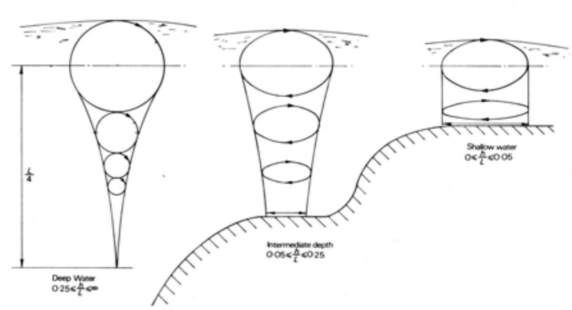

Figure 2.2
Particle Motion in Different Water Depths

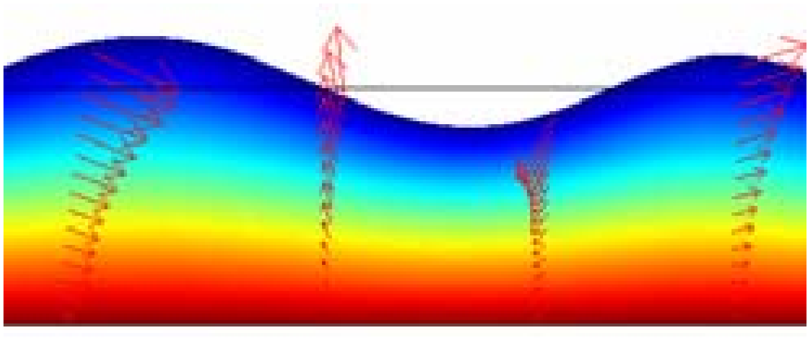

Figure 2-3
Vector field for particle motion in waves (Zurkinden et al (2007).

Wave power density (kW per meter of wave crest width) is defined as the flux of energy across a vertical plane intersecting the sea surface and extending to the depth of no sub-surface orbital motion (which is half the wavelength of the longest harmonic component). For a 16-second wave, this depth is 200 m, which is the approximate depth of the continental shelf edge

The power of ocean waves is expressed in kW per meter wave crest front. Figure 2-4 depicts that the power flux is that energy that crosses through a vertical plane one meter in length. Annual averages range from 10 kW to 100 kW/m wave front depending on site location.

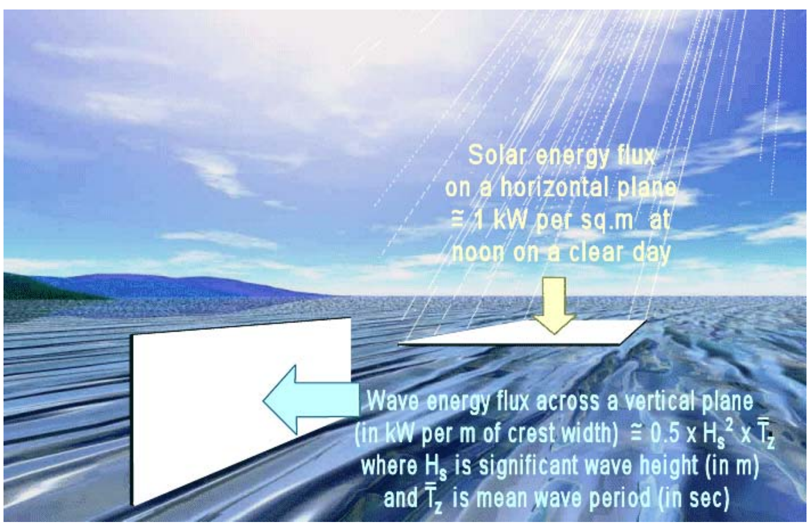

Figure 2.4
Wave Power Flux

3. U.S. Wave Energy Highlights in the 2nd Half of 2008 and 1st half of 2009

Interest in ocean wave renewable energy continues to grow in the United States. A brief accounting of notable Federal/State and Project/Device Developer activities within the sector during the 2nd half of 2008 and through May 15, 2009 is contained in this section which is organized as follows

3.1. Federal and state Highlights
3.2. Developer and Project Deployment Highlights

3.1. Federal and State Highlights

In 2005, the U.S. Congress authorized $50 million to conduct research and development on advanced water power energy generation technologies, including both marine and hydrokinetic technologies (wave, tidal, ocean current, in-stream hydrokinetic and ocean thermal), as well as conventional hydropower (any technology that uses a dam or diversionary structure). The FY09 appropriation was $40 million. This marks a significant increase in funding from the $10 million USD appropriated in 2008, which was the first year wave and tidal power research was supported by the Department.

DOE's wave and tidal power research is focused on assessing the potential recoverable energy from these resources in the U.S. and facilitating the development and deployment of technologies to fully realize this potential. Marine and hydrokinetic technologies represent a substantial opportunity for the U.S. to engage directly in an emerging area of energy science and discovery, while developing an entirely new suite of renewable technologies available to reduce emissions, revitalize stagnant sectors of the economy, and help states meet RPS targets.

The Department's priorities for wave and tidal power include:

1) Facilitating the deployment of prototypes and collecting data on their energy conversion performance and their environmental and competing-use impacts;
2) Determining the available, extractable and cost effective resources in the U.S;
3) Characterizing and comparing the wide variety of existing marine and hydrokinetic technologies;
4) Improving technology performance and reliability and reducing technology development costs; and
5) Minimizing the cost, time and negative impacts associated with siting projects.

In 2008, the majority of DOE funding for wave and tidal power was awarded to specific technology and project development efforts, selected through a competitive process. These awarded efforts included:

- The preparation of detailed design, manufacturing and installation drawings of a bi-directional air turbine for application in a floating oscillating water column;

- Engineering design, baseline environmental studies, and license construction and operation applications to help Pacific Gas and Electric, the largest investor-owned utility in California, develop a hub to deploy wave energy converters and connect them to the grid;
- The design, fabrication and testing of an improved turbine blade design structure for Verdant Power, Inc; and
- A program to conduct in-water testing and demonstration of tidal flow technology as a first step toward the deployment of a commercial tidal power facility by the Snohomish Public Utility District, a municipal utility in Washington State.

In addition, the Department selected and funded two National Marine Renewable Energy Centers, one at the University of Hawaii, and a second run jointly by Oregon State University and the University of Washington. Further, the DoE funded a market acceleration program, consisting of nationwide resource wave and tidal hydrokinetic resource assessments and a collaborative project to address navigation, and environmental issues as well as clarify the permitting process. EPRI was selected by the DoE to conduct the national wave energy resource assessment.

Two FY09 solicitations were issued by the Wind and Hydropower Technologies Program of the DOE in April 2009; 1) a Funding Opportunity Announcement (FOA) directed at industry partners and industry-led teams, and 2) a Program Announcement (PA) directed at DOE Laboratories to address technical challenges in water power development, as well as market acceptance barriers. The industry FAO consisted of 6 parts:

1. Marine and Hydrokinetic Energy Conversion Device or Component Design and Development
2. Marine and Hydrokinetic Site-specific Environmental Studies/Information
3. Advanced Water Power Market Acceleration Projects /Analysis and Assessments
4. Hydropower Grid Services
5. Environmental Mitigation Effectiveness
6. University Hydropower Research Program

The topic 3: Market Acceleration Projects /Analysis and Assessments consisted of 6 subparts:

3A. An assessment of off-shore ocean current energy resources along the U.S. coastline, excluding tidal currents, to determine maximum practicably extractable energy.

3B. An assessment of in-stream hydrokinetic energy resources, defined as energy that can be extracted from free flowing water in rivers, lakes, streams or man-made channels without the use of a dam or diversionary structure, in the U.S. to determine maximum practicably extractable energy.

3C. An assessment of projected life-cycle costs for ocean thermal energy conversion in the United States over time.
3D. An assessment of global and domestic U.S. ocean thermal energy resources to determine maximum practicably extractable energy.
3E. An assessment of projected life-cycle costs for wave, tidal, ocean current, and in-stream hydrokinetic power in the United States over time. .
3F. An assessment of the energy resources available from installing power stations on non-powered dams and in constructed waterways and the construction of new pumped storage facilities in the U.S. to determine maximum practicably extractable energy.

Alaska

In EPRI's estimation, Alaska possesses over 50% of the U.S. wave energy resource. A key limitation to the extraction of these resources is that most of the resource is found in remote areas and not adjacent to any electric transmission infrastructure necessary to provide power export capabilities at significant scales.

Yakutat, a coastal village known as the surfing capital of Alaska, has commissioned a wave energy feasibility study which is led by EPRI and re vision consulting. This remote fishing community is 100% reliant on diesel fuel for generating electricity and the residents pay about 60 cents/kWh for their electricity. The average load is about 700 kW and the peak load is about 1.5MW. The city is keen on learning whether they can reduce their dependence on diesel fuel and reduce their cost of electricity using the indigenous wave energy resources off their coast.

Hawaii

In October 2008, the University of Hawaii (UH) was selected as one of two national sites for development of a Marine Renewable Energy Center (MREC). The Hawaii MREC is managed by the Hawaii Natural Energy Institute (HNEI) at UH and funded by US DOE at approximately USD 1 million per year with equivalent cost share from UH and industrial partners. The Center will comprise an international partnership between academia, industry, local and federal government agencies, and NGOs. The objectives of the Hawaii project are to facilitate the development and implementation of commercial wave energy systems with one or more systems deployed and supplying power to the local grid at greater than 50% availability within five years, and to assist the private sector to move ocean thermal energy conversion (OTEC) systems beyond proof-of-concept to pre-commercialization.

The NMREC will work closely with energy developers to conduct supporting research on system performance and survivability, grid integration and environmental impacts, including completing necessary environmental studies and assisting industrial partners to acquire required permits. Partners include local engineering firms familiar with the permitting process.

The Center proposes to build upon current and proposed marine energy projects in Hawaii to accelerate establishment of up to three field test facilities for hydrokinetic systems and one for OTEC component testing. Proposed wave energy test sites include Pauwela Point on the northeast coast of Maui, building off the announced agreement between Maui Electric Company and Oceanlinx, at the Kaneohe Marine Corps Base on Oahu, where Ocean Power Technologies maintains an ongoing program, and off the Makai Research Pier located west of Makapuu Point on the eastern tip of Oahu. The latter site is proposed for obtaining long-term data series on wave energy resources, research on corrosion and innovative materials, and an easily accessible site for deployment and testing of small wave energy conversion devices and components. The Pier is already permitted for a range of marine research activities.

Oregon

Wave energy has the potential to play a significant role in Oregon's economic and energy future. The state recognizes that new jobs and clean energy will result from investing in this emerging industry. Oregon has made tremendous strides over the past few years in its wave energy developments.

Oregon Innovation Council granted $4.2 million to create the nonprofit Oregon Wave Energy Trust (OWET). It is OWET's mission to establish the state as the preeminent developer of wave energy in the United States, with the goal of producing 500 MW of clean power from its ocean—about 3-5% of the state's energy—by 2025. To achieve this mission, OWET's strategy is to maintain "technology neutrality" and focus its resources on reducing the barriers hindering the emerging wave energy industry's movement forward toward commercial development. OWET's major activities are grouped within four major program areas:

- ***Stakeholder Education and Engagement.*** Specific activities include: a) Coastal Community Open Houses, b) creating a statewide network of coastal economic and community development advisors, c) facilitating development of organized fishermen groups to participate in wave energy planning, d) showcasing at consumer events, e) producing a wave energy conference, and more.

- ***Regulatory and Policy***. Specific activities include development of Regulatory Roadmaps to help wave energy developers navigate the complex network of state and federal permit and license requirements. OWET actively monitors state legislative activities and provides wave energy industry information to legislative representatives and committees.

- ***Market Development***. OWET recently launched a Utility Market Initiative. This extensive project will produce an effective market strategy to integrate wave energy projects into the electric utility system and establish technical requirements to connect into the grid. OWET hopes to create a utility "pull" and wave energy "push" to help meet the target production goals. In addition to the Utility Market Initiative, an economic assessment of the wave energy industry to Oregon – which will include economic data for the fishing and crabbing industries – is underway.

- ***Research***. OWET directs and funds environmental and applied research projects to answer key questions about wave energy development. To date, it has completed baseline assessment studies on seabirds and whale migration at the proposed wave energy project sites. Throughout 2009, OWET will support additional research on seabirds, crab distribution, EMF, sediment transport, and create a planning tool to model cumulative effects of wave energy projects.

There are four projects off the Oregon Coast actively with FERC preliminary permits and engaged in the FERC licensing process:

- ***Reedsport*** – Ocean Power Technologies (OPT) is both the technology and project developer. OPT will use their Powerbuoy wave generating system.

- ***Coos Bay*** – OPT also plans to develop a project off Coos Bay.

- ***Winchester Bay (Reedsport)*** – Douglas County is the project developer, and Wavegen will be the technology provider.

- ***Tillamook County*** - Tillamook Public Utility District and the County of Tillamook are currently evaluating multiple project sites and will serve as the project developer. Their technology is not yet identified.

- ***Douglas County*** - Douglas County Public Utility District is working with WaveGen of the UK on the possibility of developing a 2-MW breakwater wave energy plant

Another major wave energy project in Oregon is the establishment of a test-berth facility. Oregon State University (OSU) and the University of Washington (UW) were awarded USD 6.25 million by the U.S. Department of Energy to develop the Northwest National Marine Renewable Energy Center (NNMREC). OSU plans to deploy various devices and subsequent environmental measurement devices at a location near Newport to study new technologies and evaluate potential environmental effects.

Other known projects at this time include:

- Columbia Power Technologies development of a new proprietary technology and their plans to develop their own energy project off Lincoln County/Newport beginning in 2011
- Global Energy Horizons ongoing commitment to developing a project in Oregon after they launch their Vancouver Island project

OWET has announced a goal 500 MW of wave power rated capacity deployed by 2025 (concurrent with Oregon's RPS of 25% energy produced by renewables by 2025) The 500 MW is an OWET goal and is not necessarily the State of Oregon's goal..

California

The California Public Utilities Commission rejected a power purchase deal between PG&E and Finavera Renewables. Pacific Gas and Electric Co.'s plan to buy power from what could have been the first ocean wave energy project in the United States was terminated when the state's Public Utilities Commission said no to the power purchase agreement (PPA). PG&E had signed the first commercial wave energy contract in the country by agreeing to buy power from a 2-megawatt project being developed by Finavera Renewables. The project called for setting up the wave energy farm about 2.5 miles off Eureka in northern California. PG&E and Canada-based Finavera had aimed to prove the feasibility of the emerging ocean wave energy through the deal, but the utilities commission didn't see it that way. The commission denied PG&E's request to approve the PPA because they believed that the wave energy project was not viable, the technology was too new and unproven, and the power purchase prices agreed by PG&E are too high.

3.2. U.S. Developer and Project Deployment Highlights

Columbia Power Technology Tests a Subscale Direct Drive Wave Buoy. Columbia Power Technology deployed and tested 10 kilowatt wave energy buoy that uses a prototype linear generator 2.5 miles off Newport Oregon over five days in September 2008. It successfully generated energy peaks in the 10kW to 15kW range in a relatively mild summer wave climate. The buoy design is self reacting to simplify mooring design to reduce mooring size and cost. Wave data was captured and will be used for additional lab testing on a laboratory linear test bed.. In addition, numerical and experimental modeling will be used to develop a utility scale device.

Columbia Power believes that they have devised a survivable cost effective method of using direct-drive permanent-magnet rotary (DDR) mechanisms for wave energy conversion (top left image). The design removes the need for gearboxes or hydraulics. The system converts heave- and surge-wave energy into high-torque rotary motion using DDR

generators to provide simple and reliable energy conversion. The design approach uses buoys which are placed offshore where the waves have the greatest amplitude and which employ a direct drive mechanism with the highest possible efficiency. Numerical and experimental evaluations by Columbia Power of buoys operating in heave-only (top right image) revealed theoretical extraction limitations of only (wave length)/2π, while a device operating in surge and heave can extract twice the energy (wavelength)/π. Numerical models suggest that the DDR design can deliver peak capacities ranging between 250 kW and 1MW depending on regional wave climates.

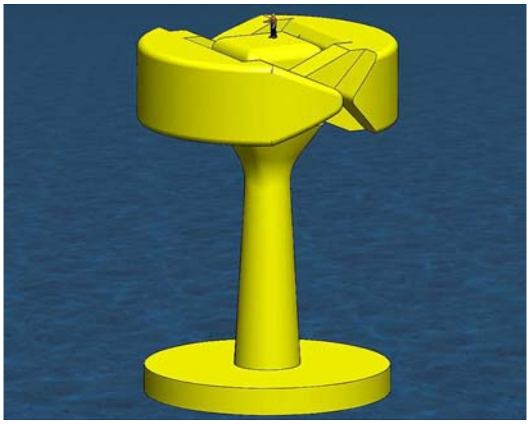

Figure 3-1
Columbia Power Technology

Kinetic Wave Power is testing its device, called a PowerGin™, at a "wave tank" testing facility at the University of Michigan. The patent pending PowerGin™ focuses wave energy into usable vertical displacement for higher energy capture. It has minimal frontal area reacting to wave impact yet a larger capture surface for greater output. It converts the wave action directly into continuous rotary motion

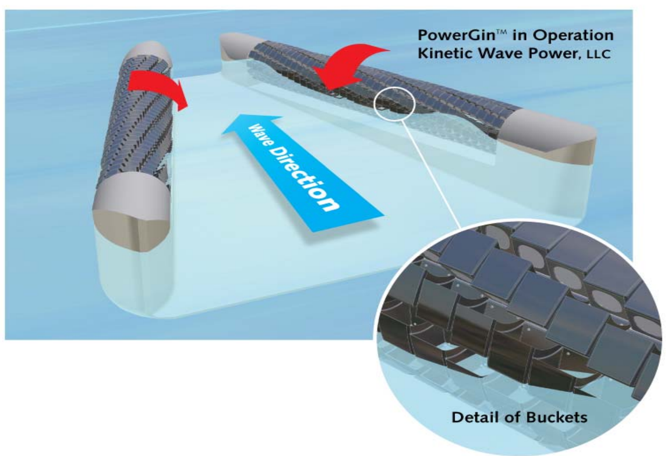

Figure 3.2.
Kinetic Wave Power PowerGinTM

Ocean Power Technologies (OPT) is pacing domestic wave energy development. (In addition to OPT, the U.S. has roughly a half dozen developers that are at the early stage of technology development). Recent highlights from OPT include:

- Reedsport, Oregon, U.S. - Development of 150 kW PowerBuoy is progressing near Reedsport, Oregon. The first PowerBuoy is expected to be ready for deployment in 2010. PNGC Power signed a funding agreement for the Reedsport project in August

2007. In 2008, OPT won a $2 million award from the US DOE in support of the Reedsport project. This was the first award for the building of ocean wave energy systems by DOE.

- Hawaii, U.S. - A 40 kW PowerBuoy, under contract with the U.S. Navy, has undergone 150,000 cycles of on-land testing and was deployed in late 2008 and produced power in accordance with its specifications. OPT received an additional $1.1 million in funding in April 2009 for the US Navy Hawaii Wave Power Project to support continuing upgrades and testing of the advanced PowerBuoy.
- Spain - A 40-kW PowerBuoy for OPT's project with Iberdrola in Spain was ocean tested in late 2008.
- Australia – In late 2008, OPT and Leighton Contractors signed an agreement to develop Wave Power Stations in Australia.
- United States – In early 2009, OPT and Lockheed Martin announced collaboration for Utility Wave Power Projects in North America.
- Scotland - OPT is currently working to develop its next generation 150-kW system, the PB150 (see Figure 3-3) . It expects the PB150 to be ready for ocean testing by year end 2009 at EMEC in the Orkney Isles, Scotland. The present schedule for development of the PB150 reflects management's decision to enhance the system design to allow for improved survivability in storm wave conditions, and to work with a third-party engineering group to attain independent certification of the design. OPT also believes that direct transition to its next generation PowerBuoy from the 150-kW PowerBuoy system will be accelerated by the measures now being undertaken in connection with the PB150’s design.
- Cornwall, UK - OPT is planning and developing a project for the South West of England Regional Development Agency (SWRDA) to install a 5-MW demonstration wave power station off the coast of Cornwall, England. This is part of SWRDA's "Wave Hub" project, for which OPT has been selected, among other developers, to test its wave technology.
- The company has also begun production of the first utility-grade underwater substation, or pod, for wave power. The pod will serve as the point at which energy generated by multiple PowerBuoys is aggregated prior to being transmitted ashore and will be completed for use in the Reedsport, Oregon wave farm and the UK Wave Hub wave farm.
- U.S. Navy Deep Ocean Application - In June 2007, OPT was awarded a $1.7 million contract by the U.S. Navy to provide autonomous

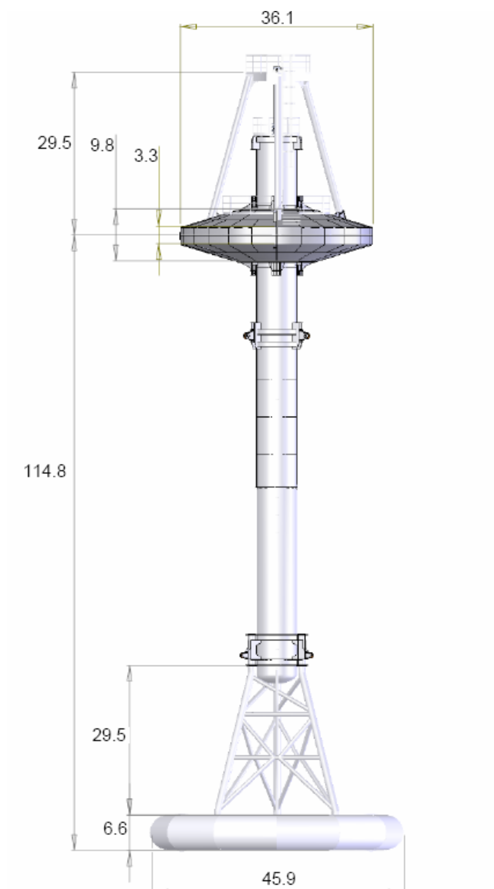

Figure 3-3
OPT PB150 (dimensions in ft)

PowerBuoy technology for its Deep Water Acoustic Distribution System (DWADS) for ocean data gathering. The PowerBuoy was ocean tested in late 2008. Subsequently in later 2008, OPT won a new $3 million contract for the second phase of the U.S. Navy's DWADS program.

- Western Australia - OPT has partnered with Griffin Energy, a leading Western Australian diversified energy supplier, to explore the development of a wave power station in Western Australia. This joint development agreement paves the way for the development of a wave power station capable of producing up to 10 MW, with potential expansion to 100 MW. In addition, OPT has partnered with Leighton Contractors to develop wave power stations in other portions of Australia.

Links to information about Ocean Power Technologies projects and products are listed below

Autonomous PowerBuoys: http://www.oceanpowertechnologies.com/power.htm
Underwater Substation Pod: http://www.oceanpowertechnologies.com/pod.htm
PB40ES; http://www.oceanpowertechnologies.com/pb40es.htm
PB150; http://www.oceanpowertechnologies.com/pb150.htm
Atlantic City, New Jersey; http://www.oceanpowertechnologies.com/ac.htm
Oahu, Hawaii http://www.oceanpowertechnologies.com/projects.htm
Santoña, Spain: http://www.oceanpowertechnologies.com/spain.htm
Orkney Isles, Scotland: http://www.oceanpowertechnologies.com/scotland.htm
Reedsport, Oregon: http://www.oceanpowertechnologies.com/reedsport.htm
Coos Bay, Oregon: http://www.oceanpowertechnologies.com/coos.htm
UK Wave Hub: http://www.oceanpowertechnologies.com/cornwall.html

Pacific Gas and Electric Company's (PG&E's) WaveConnect Project: In late 2008, PG&E was selected by the DOE for an award of a cost sharing grant of $1.2 million. In early 2009, PG&E received a decision of approval from the California Public Utility Commission to spend $4.8 million of ratepayer based funds towards the estimated design and licensing costs for the pilot WaveConnect project. PG&E received preliminary permits from the Federal Electric Regulatory Commission (FERC) for the two sites of interest in early 2008.

PG&E, incorporated in California in 1905, is one of the largest natural gas and electric service utilities in the United States. Its service territory encompasses from just north of Eureka, CA, (50 miles short of the Oregon boarder) to just north of Santa Barbara, CA. The company delivers about 80,000 GWh to its 5.1 million electric customers annually. PG&E's service territory borders 960km of Pacific coastline with wave power densities of 20-40kW/m, making wave power a renewable energy resource of strategic interest to the utility.

PG&E initially studied two sites in Northern California, near the cities of Fort Bragg and Eureka for establishment of its WaveConnect pilot project. Similar to the WaveHub in the U.K., the WaveConnect Project's goal is to assess wave energy's potential and examine the regulatory and environmental issues associated with such a facilities development. WaveConnect will provide the infrastructure to test small arrays of commercial wave power conversion devices in California, and therefore allow the emerging wave power industry and PG&E to gain a full lifecycle understanding of deployed technologies. In early May, 2009, PG&E announced that it was dropping the Mendocino County study as Port Noyo at Fort Bragg, CA was found to be unsuitable to support a pilot wave energy project. A commercial scale project could be supported out of either San Francisco or Eureka, CA, although support from the Eureka area would form the basis for major economic redevelopment of the area.

WaveConnect will provide the infrastructure to test small arrays of commercial wave power conversion devices in California as illustrated in Figure 3-4, and therefore allow the emerging wave power industry to gain a full lifecycle understanding of these technologies deployed in the state. PG&E is expected to release a Request for Information to worldwide wave energy developers in the summer of 2009 and issue a Request for Quote for a Power Purchase Agreement later in 2009. PG&E expects to file its WaveConnect pilot plant license application to FERC in the spring of 2010.

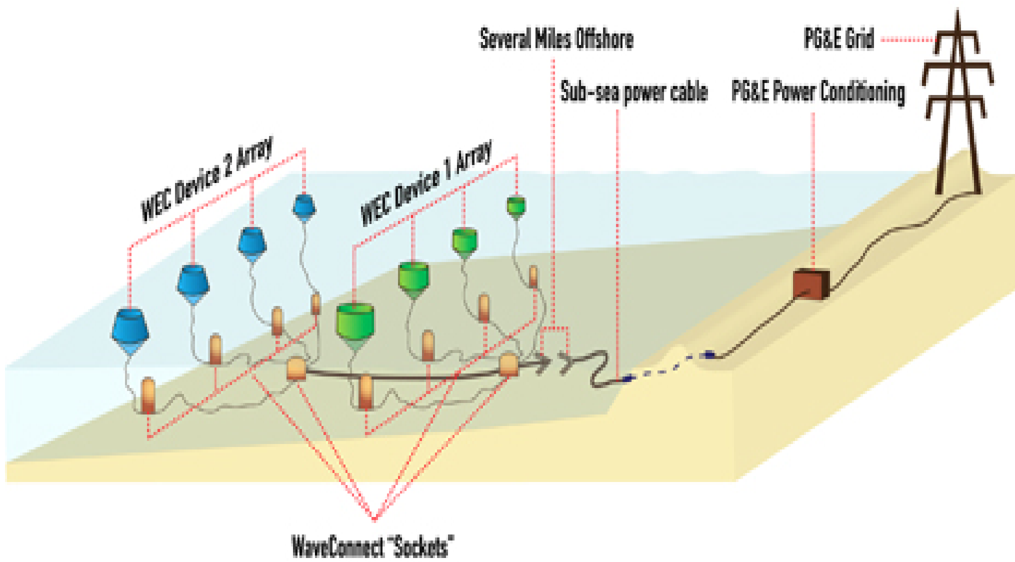

Figure 3-4
PG&E WaveConnect

SRI International demonstrated a novel ocean wave-powered generator in the ocean near Santa Cruz, California on December 8, 2008. This wave-powered generator is novel in that it uses SRI's Electroactive Polymer Artificial Muscle (EPAM™) technology, a rubbery material that can generate electricity by simply being stretched and allowed to return to its original shape. This "artificial muscle" technology can generate electricity directly from the motion of waves without the need for complicated and costly hydraulic transmissions that are typically found in other wave-power generators. In 2004, the technology was licensed exclusively to Artificial Muscle Inc., an SRI spin-off company. HYPER DRIVE has licensed the background technology for wave-power generator applications from Artificial Muscle Inc., and application-related technology from SRI International.

The EPAM™ technology allows rubbery polymers to change shape in response to applied electrical energy, much like biological muscles change shape in response to an electrical stimulus. As a generator, the technology operates in reverse — changing the shape of the polymer creates electrical energy. Since this solution requires few moving parts and is based on relatively low-cost polymers, there is great potential for low-cost production of electricity.

In its proof-of-concept demonstration, SRI showed that its wave-powered generator could be mounted on a typical buoy and operate in a marine environment. Although the power output of the buoy is quite modest, the same basic design can be used to produce significantly greater amounts of power. The long-term goal of this development is to design a system that will supply electricity to the buoy or to feed the power grid on land.

Oceanlinx Limited formally announced plans to provide electricity to Maui Electric Company wave energy project. The project, to be operational by the end of 2011, will provide up to 2.7 MW from three floating platforms located one-half to three-quarters of a mile to the north of Pauwela Point on the northeast coast of Maui. The cost, estimated to top $20 million, will be absorbed by Australia-based Oceanlinx and its investors. Oceanlinx has signed a Memorandum of Understanding (MOU) with Renewable Hawaii, Inc., an unregulated subsidiary of Hawaiian Electric Company, for possible passive investment in the project.

There are no major activities to report from other U.S. wave energy developers, which include, Independent Natural Resources Inc, Ocenergy, Ocean Wave Energy Conversion, Resolute Energy and VersaBuoy.

4. Worldwide Wave Energy Highlights in the 2nd Half of 2008 and 1st Half of 2009

Interest in ocean wave renewable energy is strong worldwide. A brief accounting of notable activities within the sector during the 2nd half of 2008 and through June 30, 2009 is contained in this section which is organized as follows

4.1. Canada Highlights
4.2. UK Highlights
4.3. Ireland
4.4. Continental Europe
4.5. Australia, New Zealand and Tasmania

4.1. Canada

Although the provincial government of British Columbia, Canada, estimates that there are more than 6,000 MW of potential wave energy in the province, no WEC projects are currently producing electricity. Renewable Energy Holdings PLC has applied for a permit to determine the suitability of a coastal region west of the Ucluth Peninsula in British Columbia for the company's CETO wave power technology. The investigative and monitoring work will begin once final testing of the system is completed in South West Australia in 2009.

SyncWave Systems Inc. Wave Energy Project Receives $2.7M in Government of Canada SDTC Funding. A next-generation technology developed in British Columbia that will convert ocean swell into renewable electricity is scheduled to be demonstrated off the West Coast of Vancouver Island in 2011 with support from Sustainable Development Technology Canada (SDTC), an arm's length, not-for-profit Corporation created by the Government of Canada. The SyncWave Power Resonator is a next-generation frequency-based wave energy converter that tunes itself to maximize energy capture from the ever changing ocean swell.

4.2. United Kingdom

The UK is maintaining its stature as the global leader in wave energy technology development. In an effort to solidify its leadership position in WEC development, the UK has established an installed marine energy capacity goal of 2 GW by 2020 and adopted an energy policy designed to attract and support WEC developers and equipment testing. The country contains three wave testing facilities and is home to many wave energy developers.

4.2.1. UK Wave Energy Developers

WEC developers in the UK with July 2008 to May 15, 2009 updates to report are:

- AquaMarine Power
- Checkmate Sea Energy
- Orecon
- Pelamis WavePower

The Aquamarine Power Oyster® is being deployed at EMEC Wave. Oyster is a hydro-electric wave energy converter, designed to convert renewable energy harnessed from ocean waves into usable electricity. Oyster® consists of an oscillator fitted with pistons and fixed to the near shore sea bed. Each passing wave activates the Oscillator, pumping high pressure water through a sub-sea pipeline to the shore. Onshore, conventional hydro-electric generators convert this high-pressure water into electrical power. Oyster® has been under development by Aquamarine Power since 2005, in partnership with the award-winning marine energy research group at Queens University, Belfast.

Following numerical modeling and wave tank testing at 1/40th and 1/20th scale, the first full-scale Oyster® was fabricated in Scotland in 2008. Oyster® has undergone initial onshore testing and the reliability of its design has been certified by independent third parties.

Installation of Oyster at the European Marine Energy Centre (EMEC) in Orkney is scheduled for summer 2009, and will be managed by Fugro Seacore, a geotechnical drilling and marine construction contractor. Sea trials are scheduled to commence in the autumn of 2009.

Aquamarine has an agreement with Airtricity, the renewable energy division of Scottish and Southern Energy, to develop future sites suitable for deployment of Oyster.

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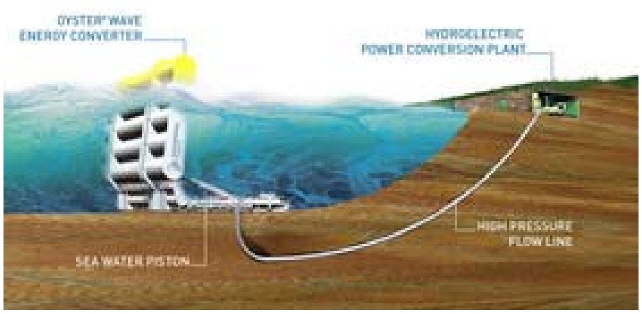

Figure 4-1
Aquamarine Power Oyster

Checkmate Sea Energy Anaconda trials were carried out in late 2008 and early 2009 . Checkmate is aiming for commercial production of the Anaconda, by 2014. Full scale devices are expected to be up to 200 meters in length and capable of generation 1 MW each. Trials were carried out in late 2008 and early 2009 with a 9 meter device in a wave tank in Hampshire, UK. Checkmate plans to next build a quarter scale device for sea trials, The Anaconda is made from fabric and natural rubber and used the incoming waves to drive a turbine in its tail as illustrated in Figure 4-2.

Figure. 4.2
Anaconda

Orecon is Selected for Deployment at the UK Wave Hub The Orecon Multi Resonant Chamber MRC is a multiple resonant chamber oscillating water column, which is deployed freely floating and is tension moored. The device has three vertical capture chambers with various lengths, which have (based on the length of each chamber) different oscillation frequencies based on chamber length (much as different length organ pipes have different resonant frequencies). This allows the device to have a higher overall system efficiency over a much wider range of different wave frequencies than other devices that may be tuned to a narrower resonance band. The multiple independent chambers supply air to three 500kW impulse air turbines, delivering a maximum rating of 1.5 MW. The turbines are directly coupled to an electrical generator. Power conditioning is onboard allowing the MRC to deliver grid compliant power at 33kV. The unit is tension moored to the seabed using a gravity anchor.

In March 2009, Wave Hub announced another wave energy development partner. Orecon Limited will occupy the fourth berth at Wave Hub. Construction of Wave Hub is expected to start in May 2010 and be completed by August 2010, with the first wave energy devices expected to be deployed in 2011. Orecon takes the place of Australian company Oceanlinx which was expected to use Wave Hub. The company has since received a grant from the Australian Government and has decided to make its next deployment in Australian waters.

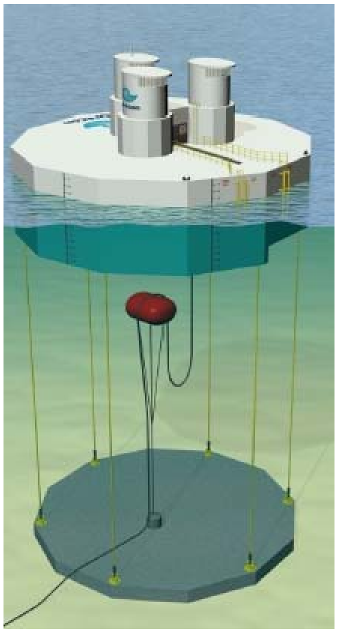

Figure 4-3
Orecon MRC

In May of 2009, Orecon signed an agreement with Portuguese developer Eneólica to establish a Joint Venture company to build and deploy Orecon's first full scale 1.5 MW MRC wave energy buoy. The site will be connected to the Portuguese electricity grid and will have a power output to 4.5 MW (3 Orecon units). Eneólica is a major Portuguese developer with its main focus on the production of electricity from renewable energy sources including wind, wave, solar, biomass and hydro power.

Pelamis WavePower Eon announced that it had ordered a more advanced P2 machine from Pelamis which, at 180 metres long, is about 40 metres longer than the Pelamis units in Portugal. It will be built at Pelamis's Leith Docks facility in Edinburgh.

4.2.2. UK Wave Energy Test Centers

The UK's wave testing facilities include:

- New and Renewable Energy Center (NaREC - subscale prototype testing in wave tank)
- European Marine Energy center (EMEC - single full scale prototype testing in natural waters)
- Wave Hub (arrays of full scale prototypes tested in natural waters

NaREC is a leading research and development platform for new, sustainable and renewable energy technologies located in Blythe, England. It's range of development, testing and consultancy services work to support the evolving energy industry and transform innovative new technologies into commercial successes. NaREC provides the emerging marine renewables industry the support it needs to transform winning concepts into commercial successes. NaREC services include:

- Complete in-house prototype development facilities for wave technology including a wave tank.
- Mechanical and electrical design engineering and procurement
- Electrical engineering consultancy and support for power conversion and drive train development
- Complete system testing from marine environment to grid connection
- Resource and feasibility assessment and consultancy
- Market analysis and research
- Project management, funding and investment co-ordination

The European Marine Energy Center (EMEC) is set to increases its deployments In operation since 2003, EMEC Wave has, to date, tested the Pelamis Wave Energy Converter prototype at its facility. EMEC envisions adding three new devices—Ocean Power Technologies 150 kW PowerBuoy, Oyster, and a P2 (second generation) Pelamis WavePower in 2009. Figure 4-4 illustrates the three WEC systems.

EMEC wave test site at Billia Coo in mainland Orkneys provides the world's only multi-berth, open sea test facility for wave energy converters. The EMEC offices and data facilities are in Stromness

Orkney was chosen because of its natural and man made resources., The wave test facility site receives uninterrupted Atlantic waves of up to 15 meters. Orkney is also the most northerly community connected to the UK national grid, has excellent harbor facilities and a significant professional community experienced in working with renewable energy.

The UK Wave Hub received approval to start construction. The UK Wave Hub received its consents in late 2007; in early 2008 it received the necessary funding approval to start its construction. The Wave Hub will provide a high voltage sub-sea cable about 16 km offshore and connect to the National Grid. However, due to economic issues, installation of the Wave Hub, the first device of its kind on the shores of the UK, is now planned for spring 2010—a year later than anticipated. Four wave devices were selected for initial installation at the Wave Hub: Eon with Pelamis Wave Power's Wave Energy Converter, Ocean Power Technologies' PowerBuoy, OceanLinx's OWC, and Fred Olsen Ltd's Buldra.

In early 2009, OceanLinx and Eon withdrew and Orecon was added.

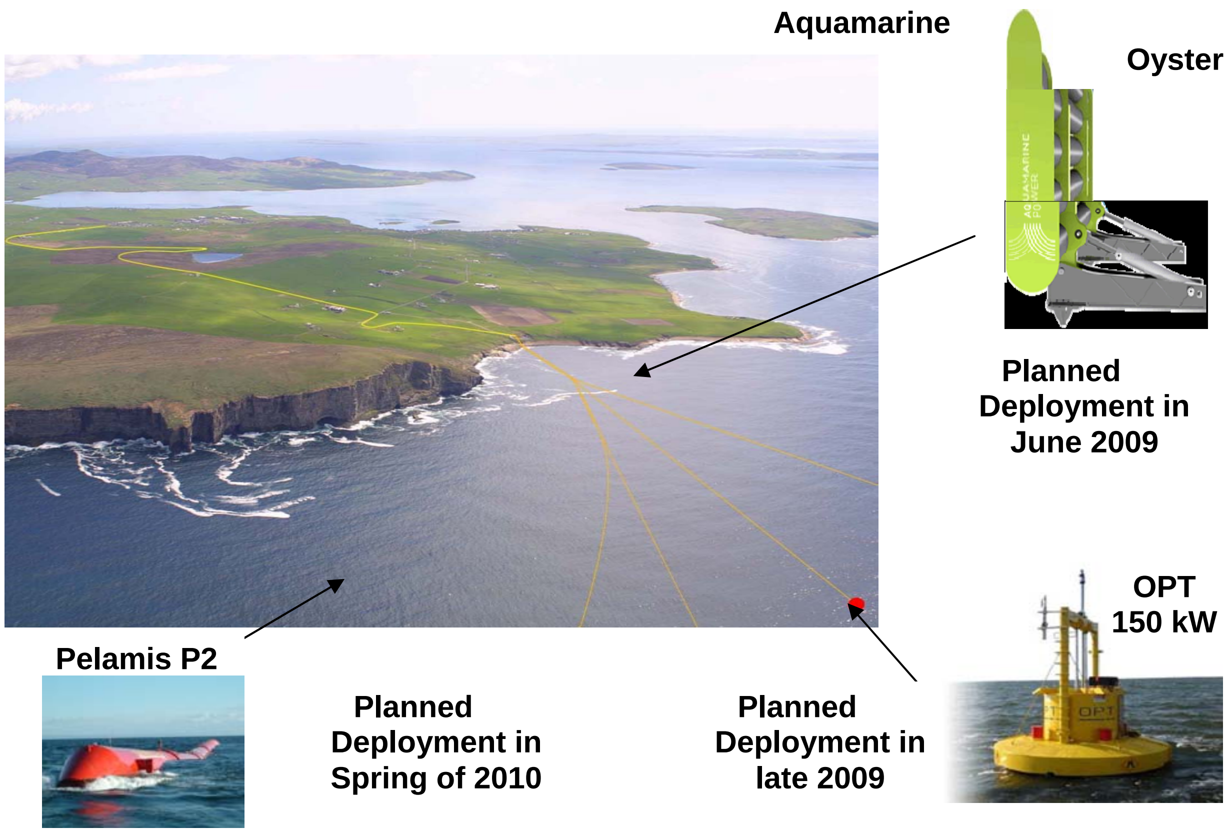

Figure 4-4
Expected EMEC Testing Configuration in 2009-2010

4.3. Ireland

WaveBob completed its subscale testing in Galway Bay in 2008 (Figure 4-5). WaveBob opened an office in Annapolis, Maryland in e2008.

OEBuoy. continued testing in the Galway Bay Wave Energy Test Facility in 2008 (Figure 4-6) .

Figure 4-5
Wave Bob

Figure 4-6
OEBuoy

4.3. Continental Europe

Portugal Aguçadoura Wave Energy Project is currentlysStalled. The Aguçadoura Wave Energy Project, a collaboration between Enersis and Babcock & Brown is located 5km off the Atlantic coastline of northern Portugal (substation at Aguçadoura). The first phase of this project deployed three P1-A Pelamis machines with a capacity of 2.25 MW (3 x 750kW). in 2008.

Figure 4-7
Pelamis at the dock

Figure 4-8
The 3rd Pelamis being towed into back to dock

Agucadoura Wave Park, the world's first commercial wave energy project has gone off line, at least for the time being. According to Pelamis, the three 750 kwh units were working as expected up through November, with a few unforseen difficulties. The units were towed ashore for repairs, but financial problems experienced by Babcock & Brown, which owns 77 percent of the project, have kept the units grounded. Figure 4-7 shows two Pelamis machines at the dock and Figure 4-8 shows the third unit being towed ack into dock, which is currently where all three units are at this time (June 30, 2009) due to financial difficulties of Babcock & Brown

WaveRoller, a prototype of a bottom-mounted flat plate oscillating device developed by the Finish Company AW-Energy ,was deployed in April 2007 in Peniche, 100 km north of Lisbon. In 2008, AW-Energy announced plans to construct a 1 MW plant.

Ongoing WEC testing and develop occurring in Denmark, Norway and Sweden. A grid-connected wave energy test site at Nissum Bredning in the north western corner of Denmark was built to enable various technology developers the ability to test and demonstrate their technologies at different scales. One such WEC device, the Wave Star, is currently being tested at a 24 meters long 1:10 scale model in Nissum Bredning until August 2008. Figure 9-10 depicts the Wave Star with the buoys lowered in the operational position and Figure 9-11 shows the buoys raised in the survival position.

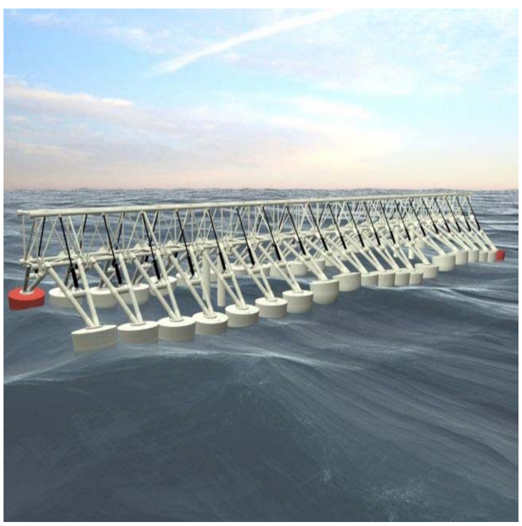

Figure 4-9
Wave Star during operation

Figure 4-10
Wave Star with buoys raised

Floating Power Plant A/S has constructed a 37 meter model for a full off-shore test at Vindeby offshore wind turbine park, located off the coast of Lolland in Denmark (see Figure 4-11). The test system named *Poseidon 37* is 37 meters wide, 25 meters long, six meters high (to deck) and weighs approximately 300 tons. The test plant was launched in Nakskov Harbour in May 2008 and was towed to the test site and installed in August 2008. Poseidon is based on the principle of oscillating water columns. It is designed for location offshore in areas with considerable flux and has a significantly higher installed effect, efficiency, and energy production compared with other wave energy systems.

In Sweden, the Seabased AB system, based on a three-phase, permanent magnet, linear generator, and especially developed to be used in ocean bed arrays and directly driven by point absorbers (buoys) on the surface, is being tested. Figure 4-12 shows the preparation of the generator for launch off the coast of Lysekil, Sweden. The WEC unit consists of a buoy coupled directly to the rotor of a linear generator by a rope. The tension of the rope is maintained with a spring pulling the rotor downwards. The rotor moves up and down at approximately the same speed as the wave. The linear generator has a uniquely low pole height and generates electricity at low wave amplitudes and slow wave speeds. Directly driven linear wave energy converters are deployed and coupled in arrays at intervals of 25-50 meters.

Figure 4-11
Floating Power Plant AS Poseidon

Figure 4-12
Seabased AB Linear Generator

4.5. Australia, New Zealand and Tasmania

Australia, New Zealand and Tasmania also pursuing wave energy projects Three known companies involved in developing wave energy in Oceana include 1) BioPower Systems Pty; 2) Oceanlinx; and 3) a partnership between Industrial Research Limited, the National Institute of Water and Atmospheric Research (NIWA), and energy industry consultants Power Projects Limited.

- BioPower Systems Pty Ltd, a Sydney, Australia based company, is planning to install a 250 kW prototype bioWAVE unit on the seabed off Tasmania in 2010. The unit will be deployed at King Island, which is currently powered by a combination of diesel generators, wind, and solar. BioPower Systems is working with Hydro Tasmania, which is a state-owned utility, to facilitate grid connection and to purchase the power. The prototype results are intended to provide information into the development program for a 1 MW commercial demonstration unit, which would be built and deployed at a later date. A subscale model of the bioWave is shown in Figure 4-13

- Oceanlinx Limited, which manufactures an oscillating water column device (see Figure 4-14), has made steady advances in a number of ongoing projects:
  1. The Oscillating Water Column (OWC) device deployed at Port Kembla has been operating since late 2006 with a overhaul (taking a few months) occurring last year. It has been back in service and operating again since March 2009. The Oceanlinx Port Kembla wave generator device is capable of generating peak power outputs of between 100 kW and 1.5 MW, depending on the location. This OWC wave energy device developed and installed by Oceanlinx can be viewed in high resolution on Google Earth. The MK 1 device can be viewed at 34° 27' 07.6" S, 150° 54' 06.8" E. Simply type these coordinates into the Fly To section, in the upper left hand corner of the Google Earth page.
  2. Port Kembla (New South Wales, Australia) - a PPA has been signed with Australian utility Integral Energy for the supply of electricity from a prototype 450kW unit.
  3. Portland (Victoria, Australia) - the permitting stage for the deployment of multiple units into a wave energy array is progressing.
  4. Rhode Island (USA) - a MOU was brokered with Rhode Island State Authority for a 1.5MW unit, followed by a 15 to 20MW electricity generating facility off the mainland.
  5. Hawaii (USA) – an MOU was signed with Maui Electric Company (MECO) in Hawaii for up to 2.7MW. MECO will contribute the transmission cables, both submerged and land-based and the project is scheduled to be deployed around the 2012 time frame

Figure 4-14
BioPower BioWave

Figure 4-15
Oceanlinx Oscillating Water Column

5. Wave Power and Energy Resources

A number of sources provide wave power and energy resource data for assessing potential sites, including in situ measurements, satellite measurements, and wind-wave models.

In 2004/2005, EPRI developed a methodology for wave energy resource estimation and wave energy conversion performance prediction. This information is contained in EPRI Report WP – 001 available under the EPRI wave page at www.epri.com/oceanenergy [Ref 1]. The EPRI assessments are for offshore wave energy conversion only and where based on the decades of statistical wave parameter data archived on the NOAA NDBC website. (www.ndbc.noaa.gov).

The intent of EPRI's 2004/2005 study was to assess the techno-economic feasibility of ocean wave energy conversion at representative sites in the six states named above. Its intent was NOT to map the U.S. ocean wave energy resource, but as we were continually asked the "what is the total potential U.S. wave energy potential" question, we did a preliminary assessment to answer to that question.

EPRI's preliminary estimate of the available U.S. offshore wave energy resource is 2,100 TWh/yr (exclusive of the Bering Sea north of the Aleutian Islands and exclusive of any resource < 10 kW/m) and is broken down regionally as shown in the Figure 5-1..

In terms of extractable wave energy resource for our preliminary assessment, the EPRI team assumed that 15% of the available resource could be extracted based on societal constraints of 30% coverage of the coastline with a 50% efficient wave energy absorbing device. Assuming an typical power train efficiencies of 90%, and a plant availability of 90%, the electricity produced is about 260 TWh/yr—equal to an average power of 30,000 MW (or a rated capacity of about 90,000 MW). This amount is approximately equal to the total 2004 energy generation from conventional hydro power (which is about 6.5% of total 2004 U.S. electricity supply).

EPRI, under DOE sponsorship, and with Virginia Tech and NREL, began a new assessment of the national U.S. offshore available and practically recoverable wave energy resource. The final product will include a geospatial database, verified and validated by a third party that displays wave power densities for specific geographic information system (GIS) coordinates, along with user-selectable annual and monthly statistical products, including the probability distributions of sea state parameters, which are needed by developers to estimate the annual and monthly energy yield of their devices and projects.

The expected users include policymakers, project developers, wave energy device developers, investors, universities, non governmental organizations, environmental groups, the Department of Energy, the military and the Coast Guard.

The wave power density, significant wave height (Hmo), energy wave period (Te), wave direction (primary wind-wave and primary and secondary swell waves) and bathmetry (iso-baths) will be displayed on a GIS map from a depth of 50 meters out to either a depth of 200 meters or a distance from shore of 50 nm miles, whichever occurs first. The GIS map will include the entire coastline of the contiguous 48 states, Alaska, Hawaii and Puerto Rico and will be broken down regionally. The NWW3 grid resolution for the U.S. offshore is shown in Figure

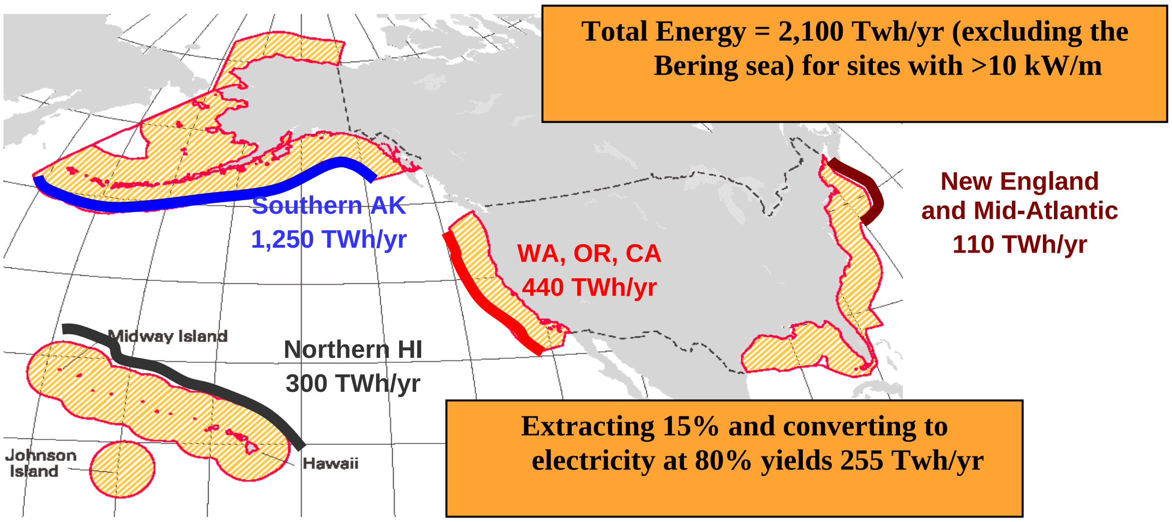

Figure 5-1
U.S. Wave Energy Resources

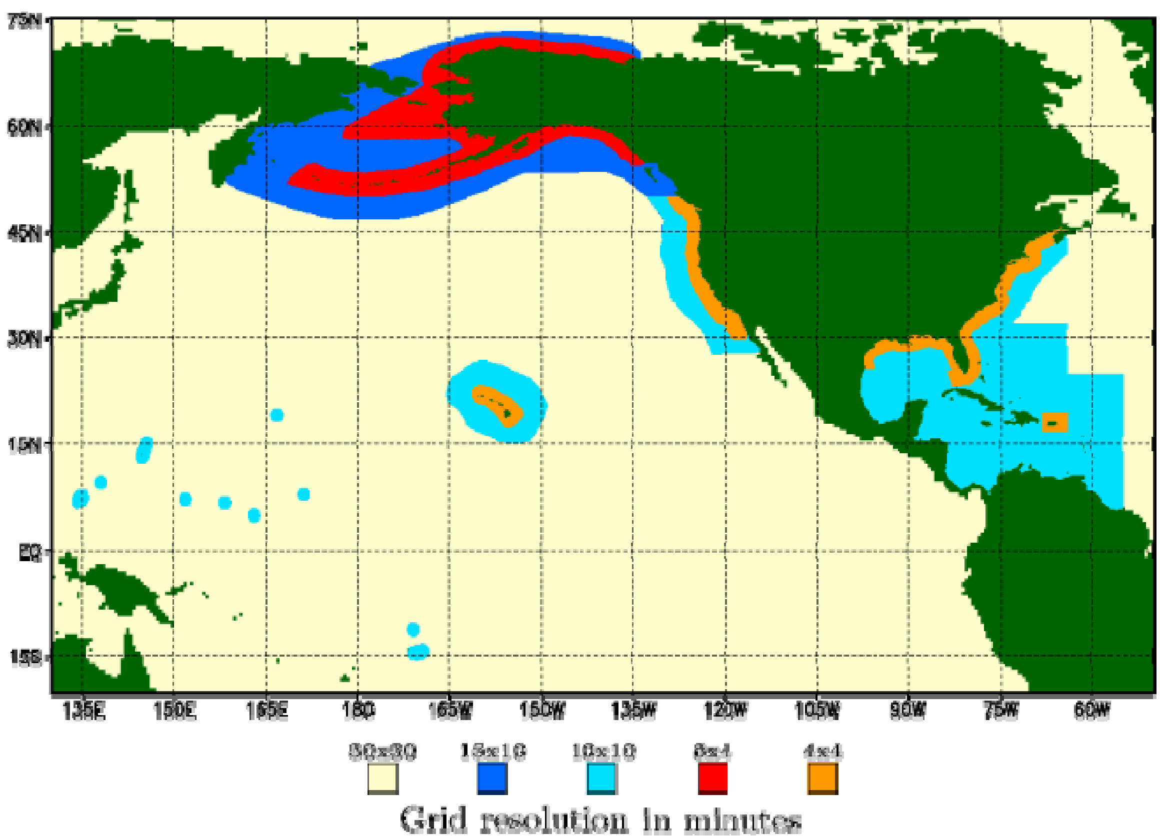

Figure 5-2
NOAA Wave Watch III Grid Resolution

The influence of the ocean floor reduces wave power levelsiIn shallow waters (<50 m). Submerged features such as canyons can also focus energy, leading to hot spots in close proximity to shore. A number of shallow-water wave transformation models take into account the bathymetry to calculate near-shore wave data. High resolution bathymetry is required. The input boundary condition for these shallow water models is the output from the NOAA WAVEWATCHIII™ model at the edge of the OCS. Experience with shore-based devices shows a need for extensive modelling in such locations.

5.1. Measurement Data Sources

The two largest inventories of long-term measured wave data in the U.S. are maintained by the National Data Buoy Center (NDBC) of the National Oceanic and Atmospheric Administration (www.ndbc.noaa.gov), and by the Coastal Data Information Program (CDIP) of Scripps Institution of Oceanography (http://cdip.ucsd.edu/).

NDBC data buoys are equipped with strapped-down accelerometers for measuring wave conditions derived from buoy heave response. Wave spectra are computed from 20-minute time-series measurements of sea surface elevation changes, and these records are archived at one-hour intervals. West Coast and Hawaii reference stations are shown in Figures 5-3 and 5-4, respectively.

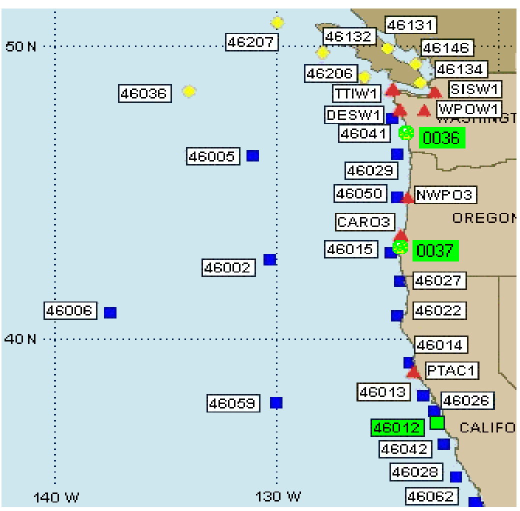

Figure 5-3
West Coast Reference Stations

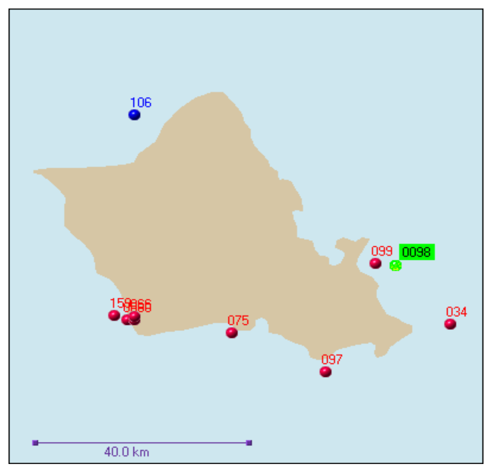

Figure 5-4
Hawaii Reference Stations (Point Makapuu is CDIP 0098)

5.2. Wind-Wave Model Data Sources

The operational ocean wave predictions of NOAA/NWS/NCEP are performed using the wind-wave model NOAA WAVEWATCHIII^{TM} using operational products of NCEP as input. The wind-wave model suite consists of global and regional implementations .as shown in Figure 5-5.

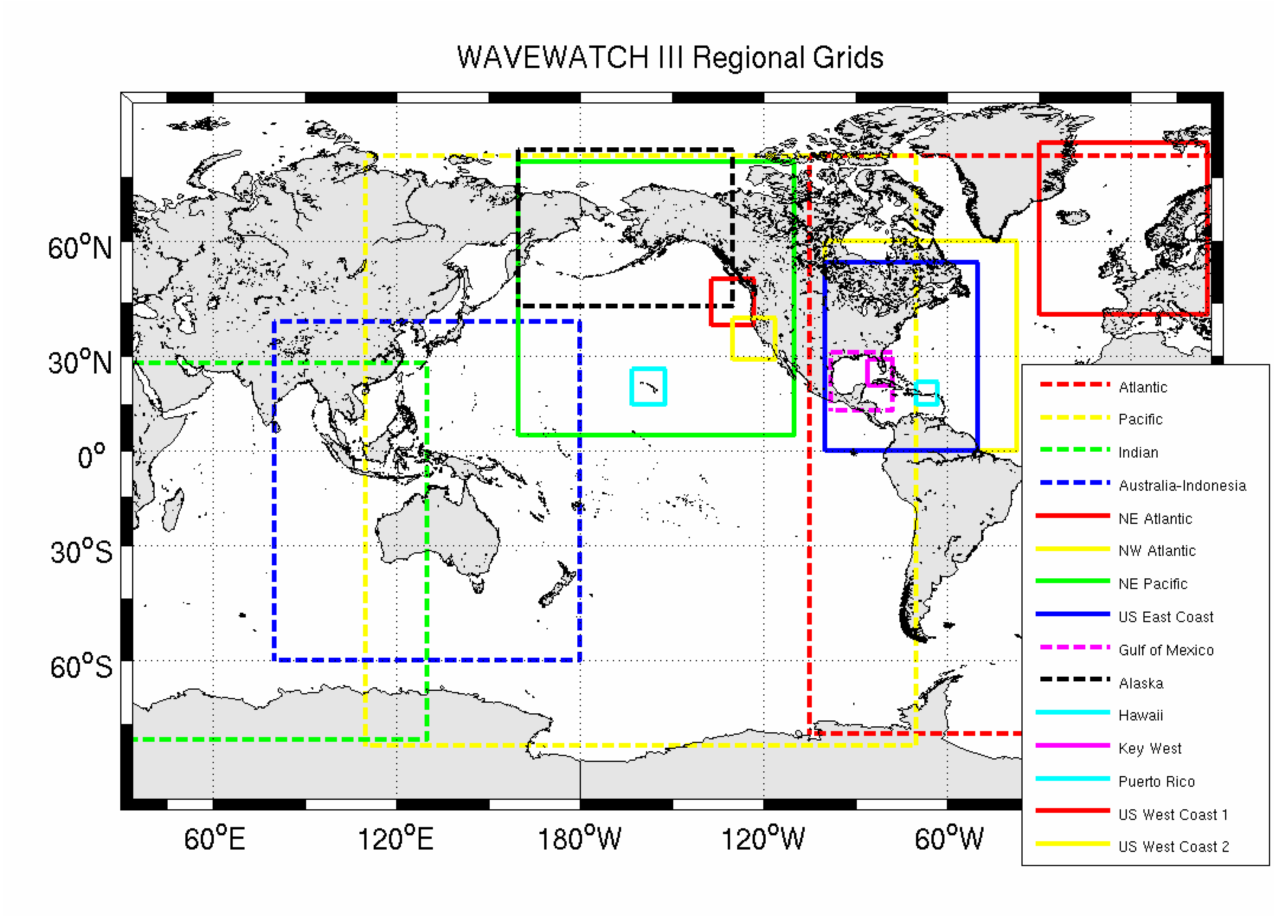

Figure 5-5
NOAA Wave Watch III Global Coverage

NOAA WAVEWATCHIII^{TM} [Ref 2] is a third generation wave model developed at NOAA/NCEP. It is a further development of the model WAVEWATCH I, as developed at Delft University of Technology [Ref 3] and WAVEWATCH II, developed at NASA, Goddard Space Flight Center. NOAA WAVEWATCHIII^{TM}, however, differs from its predecessors in many important points such as the governing equations, the model structure, the numerical methods and the physical parameterizations.

NOAA WAVEWATCH III^{TM} solves the spectral action density balance equation for wave number-direction spectra. The implicit assumption of this equation is that properties of medium (water depth and current) as well as the wave field itself vary on time and space scales that are much larger than the variation scales of a single wave. A further constraint is that the parameterizations of physical processes included in the model do not address conditions where the waves are strongly depth-limited. These two basic assumptions imply that the model can generally by applied on spatial scales (grid increments) larger than 1 to 10 km, and outside the surf zone.

All regional models obtain hourly boundary data from the global model. All models are run on the 00z, 06z, 12z and 18z model cycles, and start with a 6h hindcast to assure continuity of swell. All models provides 126 hour forecasts, with the exception of the NAH model (72 hour forecast).

Graphical products are maps and spectra. Binary and text products are GRIB files, spectral data and spectral bulletins For a more detailed description of the definition of the parameters see section 2.4 of the manual of NOAAWAVEWATCH III ™ [Ref 4].

5.3. Available Offshore Wave Resource Calculation Methodology

EPRI – Virginia Tech – NREL has developed and is using a ten (10) step methodology to calculate offshore wave energy resource estimates for the 2009 DOE Wave Energy Resource Assessment Project. The methodology, which incorporates archived hindcast WAVEWATCHIII™ fully partitioned spectral wave parameters at over 100,000 coastal grid points everywhere offshore the U.S., is presented below.

Step 1: Select deep-water "characterization stations" in depths >200 m, where NDBC buoys are co-located with WAVEWATCHIII™ spectral output locations and for each station, develop a joint probability distribution (JPD) table of overall significant wave height (Hm0) and wave energy period (Te).

- Hm0 and Te will be calculated using spectral moments (m0 and m-1) of the non-directional wind wave variance density spectrum (hereinafter referred to simply as the spectrum) from those times when the measurement archive and hindcast archive overlap
- Develop a measured JPD table and a hindcast JPD table for each calendar month, and characterize sea state probability as the fraction of time per month that each Hm0 and Te combination was measured or hindcast
- Annual JPD tables will be compiled by averaging all months for each sea state bin
- For each measured spectrum and hindcast spectrum in the time series used to populate the JPD tables, calculate wave power density (P) using the spectral formula for P
- Scatter plotting hindcast P (y-axis) against measured P (x-axis) for all spectra in the time series at a given characterization station will be used to determine the correlation coefficient between hindcast and measured wave power density.

- Similar scatter plots and correlation coefficients will be determined for hindcast vs. measured significant wave height and hindcast vs. measured wave energy period.

Step 2: For each annual JPD within each region, select a sub-population of sea state bins, including all sea states that have a >0.2% probability of occurrence (17.5 hr/yr).

Step 3: For each selected sea state bin, develop an average measured spectrum and an average hindcast spectrum, and calculate the wave power density associated with each of these average spectra, and compare with measured and hindcast wave power densities determined in Step 1, as a check on the spectral averaging results.

Step 4: For each selected sea state bin, test a few different theoretical spectral formulas (e.g. Bretschneider, JONSWAP, etc.) based on Hm0 and the peak wave period (Tp) of the partitioned wind wave and multiple swell components, also produced by WAVEWATCHIII™at each hindcast time step and apply the theoretical spectral formula to the partitioned hindcast time series to reconstitute the overall spectrum.

Step 5: For each "built-up" hindcast spectrum calculate the wave power density and again average all of the wave power densities to produce a mean wave power density for that sea state bin.

Step 6: Determine which theoretical spectral formula for the wave train partitions provides the best agreement with the average wave power density from measured spectra (as determined in Step 1) for a given region. It is anticipated that different regions will have different theoretical formula that provide the best fit.

Step 7: Apply the "best fit" theoretical spectral formula to the wave train partitions at all WAVEWATCHIII™ grid points, where the sea state parameters for all partitioned wave trains (not just wind sea and two swell components) will be specially made available by NOAA for this study, in two stages:

> First look will be the four-year period from 01-Feb-2005 through 31-Jan-2009. NOAA will post this fully partitioned 4-year hindcast in July 2009.
>
> Twelve years (from 01-Feb-1997 through 31-Jan-2009). The delivery date when NOAA will post the full 12-year hindcast has yet to be determined.

Step 8: Map the resulting annual and monthly values of Hm0, Te, and P for all WAVEWATCHIII™coastal grid points located between the 50 m and 200 m depth contours, and extend mapping to 50 nautical miles offshore wherever the 200 m depth contour lies within that distance.

Step 9: Keep track of the peak wave direction for each component wave train, and prepare wave power density directional distribution roses for the local wind sea, the primary swell, and the secondary at selected grid points (e.g., at every tenth grid point within the mapped zone).

Step 10: Using the NREL database of MMS lateral administrative boundaries, calculate the total annual wave energy flux (terawatt-hours per year) offshore each coastal U.S. state and Puerto Rico, based on the following wave crossings:

Across the mapping limit of 50 nautical miles offshore

Across the 200-m depth contour. Where this contour "wraps back on itself" the farther OFFSHORE contour will be used, indicating where waves first "feel the bottom"

Across the 50-m depth contour. Where this contour "wraps back on itself" the farther NEARSHORE contour will be used, indicating where waves finally leave the mapped zone, heading towards shore, and where finer-resolution bathymetry and wave propagation models must be used, using NOAA's fully partitioned WAVEWATCHIII™3 data for input

5.4. Practically Recoverable Wave Resource Calculation Methodology

The methodology to estimate the practically recoverable U.S. wave energy converted to electrical energy will be developed in 2010 by the EPRI-Virginia Tech- NREL Project Team and its NOAA, Military, university and device/project developer expert advisors

5.5. Wave Power Forecasting

Reliable electric power system operation requires precise balancing of supply and demand. Grid operators manage supply-demand balance on a minute to minute basis considering load forecasts and using current resources, rules and procedures. A lack of being able to predict the power available from a wave plant would make managing the reliability of the grid system more challenging than managing fossil fuel thermal generation

In 2007 EPRI conducted an investigation of the accuracy of forecasting wave power as a function of forecasting time horizon. [Ref 5]. In the original Bonneville Power Administration (BPA) cofunded wave energy study, WAVEWATCHIII™ forecasts were only available at NDBC buoy locations 100 nm or more from the coastline in very deep water. The EPRI Project Team accomplished the forecast accuracy study in two steps; namely:

1. Virginia Tech did the WAVEWATCHIII™ forecast accuracy comparisons to far offshore buoys
2. SAIC did the correlation from the far offshore buoys to a few buoys at about 50 m depth (the depth currently favored for offshore wave power plants)using time delay

NOAA WAVEWATCHIII™ now forecasts wave sea states down to 50 m depth. EPRI will be conducting a study for Pacific Energy Ventures and Oregon Wave Energy Trust in the late summer of 2009 making a 1:1 comparison of WAVEWATCHIII™ forecasts with a co-located 50 meter depth NDBC buoy measurement. (in other words, a time delay correlations between far offshore and 50 m depth buoys is no longer required– 50 meters being the depth about where wave power plants would be sited).

6. Wave Energy Conversion (WEC) Technology Description

Wave power research programs in industry, government, and at universities have established an important foundation for the emerging wave power industry over the last ten or so years. In the late 1970s and early 1980s, the UK regarded wave power as an alternative to nuclear generation and had the most aggressive R&D program in the world. Although the program contributed to important basic research on optimal control and tuning of wave power conversion devices, it ultimately stalled as oil prices dropped and government funding ceased. In the past decade, wave-powered generation has resulted in advances in resurgence while advances have resulted in a half dozen full-scale prototypes tested in natural waters over the last four years.

6.1 Harnessing Wave Energy

Wave energy extraction is complex and many device designs have been proposed. Four of the best known device concepts and their principle of operation are listed below (see Figure 6-1).

- Point absorber — A bottom-mounted or floating structure that absorbs energy in all directions. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors. The illustration shows a floating buoy, however, it could be a bottom-standing device with an upper floater.
- Oscillating Water Column (OWC) — At the shoreline, this could be a cave with a blow-hole and an air turbine/generator in the blow hole. Near shore or offshore, this is a partially submerged chamber with air trapped above a column of water. As waves enters and exits the chamber, the water column moves up and down and acts like a piston on the air, pushing it back and forth. A column of air, contained above the water level, is compressed and decompressed by this movement to generate an alternating stream of high-velocity air in an exit blowhole. The air is channeled through an air turbine/generator to produce electricity.
- Overtopping terminator —A floating reservoir structure with reflecting arms and a ramp so that as waves arrive, they overtop the ramp and are restrained in the reservoir. The collected water turns the turbines as it flows back out to sea and the turbines are coupled to generators.
- Attenuator or Linear Absorber — An example of the attenuator principle is a long floating structure that is orientated parallel to the direction of the waves. The structure is composed of multiple sections that rotate in pitch and yaw relative to each other. The four sections move relative to each other and this motion is converted at each hinge point to electricity by a hydraulic power converter system.

Example machines using each of the four types summarized above are shown in Figure 6-2 There are many other design concepts, but they are beyond the scope of this chapter.

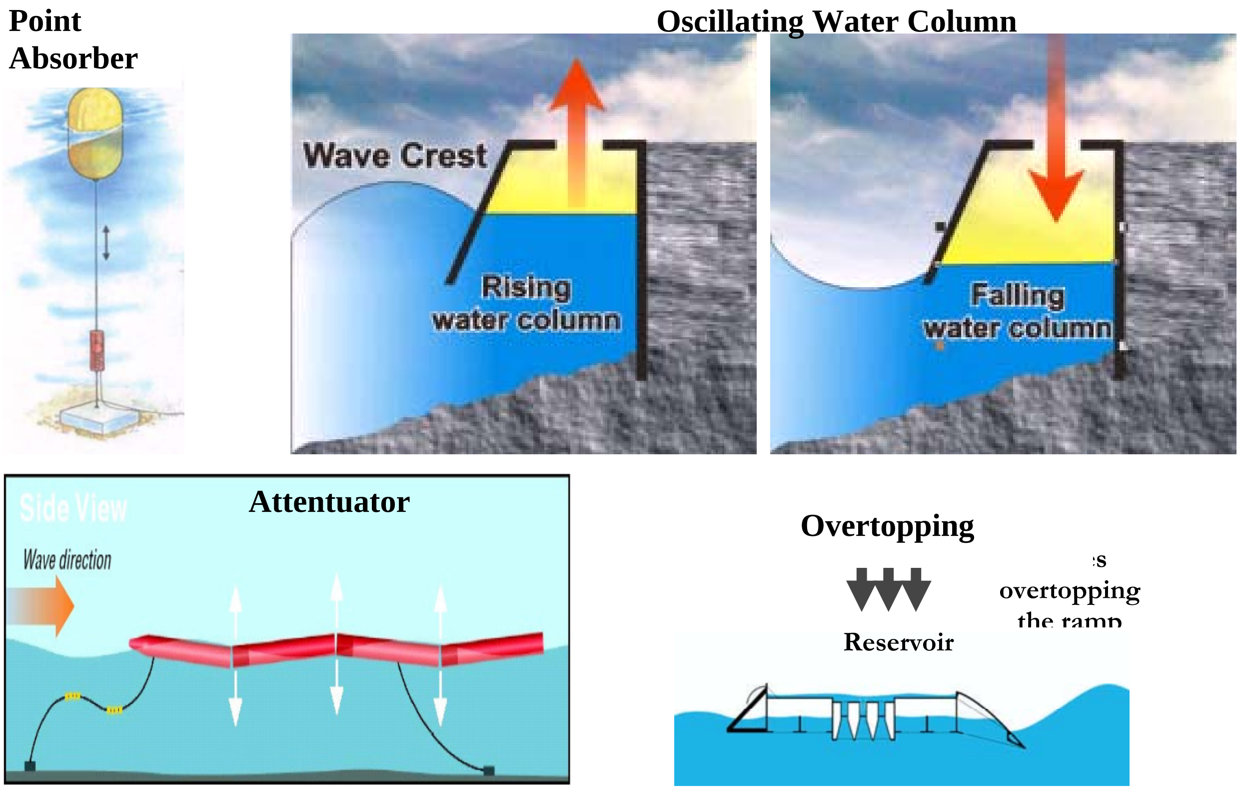

Figure 6-1
Wave Energy Device Principles

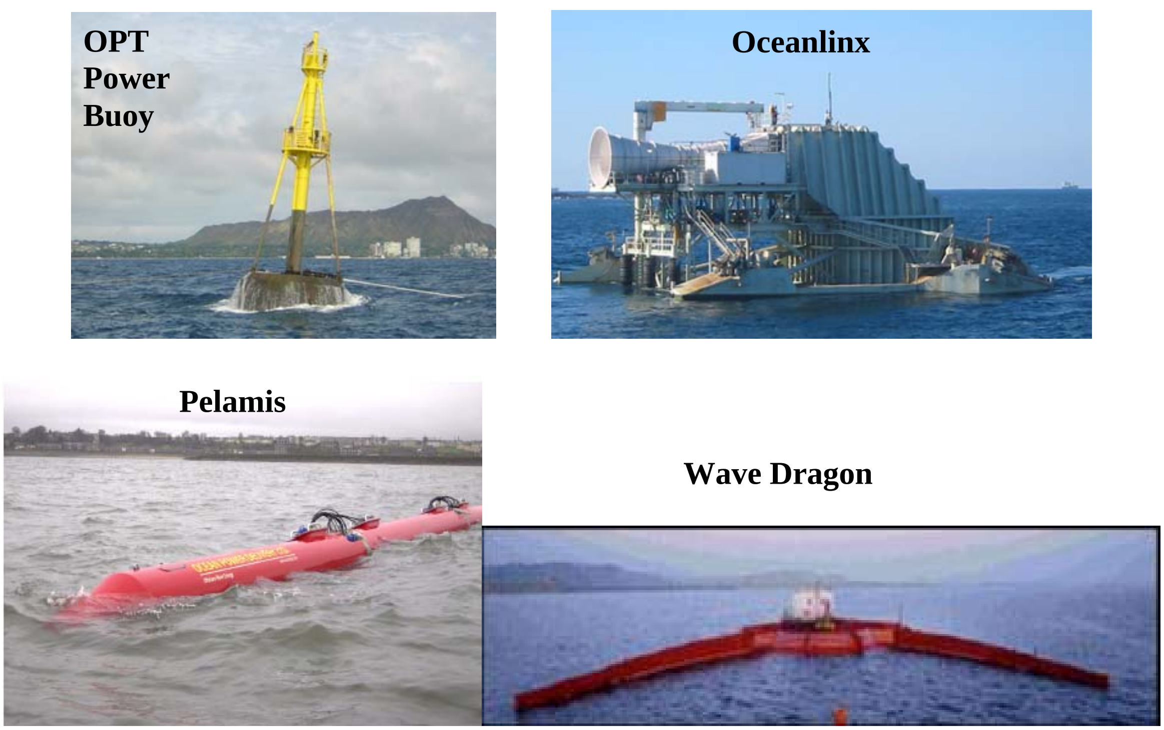

Figure 6-2
Wave Energy Device Concepts

6.2. WEC System Developers

Today, a number of small companies are leading the commercialization of technologies to generate electricity from ocean waves. In 2004, EPRI requested information from all known WEC device developers. The list of developers and the results of that survey are contained in Reference 6. . EPRI updated that survey in 2006 and the results are contained in Appendix A of Reference 7. EPRI again updated the list of known developers who have built and tested prototypes as of July 31, 2008, excluding those with only concepts or patents. Our latest 2009 update is shown below in Table 6-1 and survey details are now maintained by the DOE. http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx EPRI does not claim that this list is complete and we apologize to any WEC developers who have built and tested prototypes which we have missed.

Table 6-1
Wave Energy Conversion Device Developers as of June 30, 2009 (see notes below)

Device Developer(1) Website	Device Name(2)	Type(3)	Development Status(4)
Able Technologies abletechnologiesLLC. com	Wave Pipe	Point Absorber	Laboratory Proof of Concept
Artificial Muscles www.artificialmuscles.com	Unknown	Point Absorber	Experimental
Aquamarine Power www.aquamarinepower.com	Oyster		Technology Demonstration
AW Energy www.aw-energy.com	WaveRoller	Oscillatory	Technology Demonstration
AWS Energy www.waveswing.com	Archimedes Wave Swing	Point Absorber	Commercial Demonstration
BioPower www.biopowersystems.com	bioWave	Oscillatory	Technology Demonstration
C-Wave Limited www.cwavepower.com	C-Wave	Attenuator	Experimental
Checkmate Sea Energy www.checkmateuk.com	Anaconda	Articulating linear absorber	Laboratory Proof of Concept
College of the North Atlantic	Wave Pump	Point Absorber	Experimental
Ecofys www.ecofys.co.uk	Waverotor	Hydrodynmic Lift	Experimental
Energiesysteme GmbH http://members.aol.com/mamoenergy/	ECOWAS III	Unknown	Experimental
Finavera (formerly AquaEnergy) www.finavera.com	AquaBuOY	Point Absorber	Early Commercial

Fred Olsen Ltd	Buldra	Point Absorber	Technology Demonstration
Hidroflot s.L. www.hidroflot.com	Ocean Converter	Multiple Pt. Absorbers	Laboratory
Independent Natural Resources www.inri.us	SEADOG – water pump	Point Absorber	Early Commercial
Kinetic Wave Power www.kineticwavepower.com	Unknown	Patent Pending	Laboratory Proof of Concept
Manchester Univ of www.manchesterbobber.com	Bobber	Point Absorber	Laboratory Proof of Concept
Motor Wave www.motorwavegroup.com	Motor Wave	Point Absorber	Experimental
Ocean Energy Ltd www.oceanenergy.ie	Ocean Energy Buoy (OEBuoy)	Oscillating Water Column	Technology Demonstration
Oceanlinx (formerly Energetech) www.oceanlinx.com	Uiscebeatha	Oscillating Water Column	Commercial Demonstration
Ocean Power Technologies www.oceanpowertechnologies.com	PowerBuoy	Point Absorber	Early Commercial
Ocean Wave Energy Company www.owec.com	OWEC	Point Absorber	Laboratory Proof of Concept
Ocenergy www.ocenergy.com	Wave Pump	Point Absorber	Laboratory Proof of Concept
OreCON Ltd www.orecon.com	MRC1000	Floating Pt Abs & OWC	Technology Demonstration
Oregon State Univ www.eecs.orst.edu/msrf	Various direct drive buoys	Point Absorber	Technology Demonstration
Pelamis Wave Power www.pelamiswavepower.com	Pelamis	Attenuator	Early Commercial
Renewable Energy Holdings www.reh-plc.com	CETO	Point Absorber	Technology Demonstration
Renewable Energy Wave Pump www.renewableenergypump.com	REWP	Point Absorber	Experimental
Seabased AB www.seabased.com	Direct Driven Linear Gen	Point Absorber	Laboratory Proof of Concept
Seapower www.seapower.com	Floating Wave Pres. Vessel	Point Absorber	Experimental
SyncWave Energy www.syncwaveenergy.com	SyncWave	Point Absorber	Technology Demonstration
Surf Buoy www.cosmotheist.com/Surfbuoy.htm	SurfBuoy	Point Absorber	Experimental
Trident www.tridentenergy.co.uk/index.php	Direct Energy Conversion	Point Absorber	Laboratory Proof of Concept

Versabuoy Int'l www.vbuoy.com	VersaBuoy	Point Absorber	Experimental
Waveberg	Water Pump	Point Absorber	Experimental
Wavebob Ltd www.wavebob.com	Wavebob	Point Absorber	Technology Demonstration
Wave Dragon ApS www.wavedragon.net	Wave Dragon	Overtopping	Commercial Demonstration
Wave Energy AS www.waveenergy.no	Seawave Slot Cone Generator	Overtopping	Technology Demonstration
Wave Gen www.wavegen.co.uk	Offshore OWC	Oscillating Water Column	Commercial demo w/breakwater system; floating system status unknown
Wave Power Plant www.wavepowerplant.com	Sea Gate-1	Point Absorber	Experimental
Wave Star Energy www.wavestarenergy.com	Wave Star	Point Absorber	Technology Demonstration

1. This list excludes individual inventors with conceptual level only technology
2. Name given to the device
3. The principle of operation; Point Absorber, Attenuator, Overtopping or Oscillating Water Column
4. The following definition of development statuse was used

- Laboratory testing stage
- Experimental – Subscale at sea testing
- Technology Demonstration – Large size engineering prototype at sea testing whose purpose is to test for function and performance
- Commercial Demonstration – Large size manufacturing prototype at sea testing whose purpose is to test for commercial viability
- Early Commercial – Offering many units of large size for purposes of generating and selling the electricity produced

6.3 Survival in Storms and Hostile Marine Environments

Today's wave energy conversion technologies are designed to survive a 100-year wave occurrence and are the result of years of testing, modeling, and development by many developer organizations. Relative to long-term survival in the marine environment, oil and gas platforms using anti-corrosion and biofouling technology are surviving 50 years, including equipment in more hostile splash and tidal zones. Full-scale prototypes have been deployed, although not continuously, in natural waters since 2004. There are justified concerns over the survivability of devices. With relatively little real-world operation of projects, developers must prove that the survivability design is adequate. There will be device failures, but this is to be expected in the prototype stages.. The marine environment is extremely challenging and for devices to operate successfully in it will require significant investment.

6.4 Effect of Wave Power Plants on the Environment

Given proper care in site planning, deployment and operations, EPRI expects that offshore wave power will be one of the most environmentally benign electricity generation technologies and should not cause any permanent damage as long as the point of egregious cumulative effects is determined and avoided by limiting plant size and energy harnessing. Early demonstration and commercial offshore wave power plant projects should include rigorous monitoring of the environmental effects of the plant and similar rigorous monitoring of a nearby undeveloped site in its natural state (so that natural effects can be separated from induced effects in long-term trends).

In the time period of the second half of 2008 and the first half of 2009, two major reports on the environmental effects of wave energy were published. The findings of these two reports are summarized below

6.4.1. . Ecological Effects of Wave Energy Development in the Pacific Northwest NOAA Technical Memorandum NMFS-F/SPO-92, September 2008 [Ref 8]

A diverse group of some 50 marine scientists from around the country participated in a OSU sponsored wave energy environmental effects workshop held at the Hatfield Marine Science Center. The principal objectives of the workshop were 1) to develop an initial assessment of the potential impacting agents and ecological effects of wave energy development, and 2) to formulate a general conceptual framework of physical and biological relationships that can be applied to specific wave energy projects. Presentations on the physical and biological environment, the frameworks for environmental risk analysis (which were adopted for this workshop) set the stage for a common understanding among participants.

For the physical environment, workshop participants suggested there could be significant wave reduction resulting from wave energy production, with possible beach effects (e.g., changes to sediment transport processes); pilot projects to understand and model wave reduction effects are needed. Mitigation for physical changes should be developed through analysis of project geometry, density, and distance from shore; additionally, it was suggested that buoys should not be placed in sensitive areas (i.e., closer to shore than 40 m depth).

In the pelagic habitat, buoys will likely have a minimal impact on phytoplankton, but positive effects (through aggregation) on forage fish species—this in turn could result in attraction of larger predators. Structures need to minimize loose lines to reduce potential entanglement of marine turtle species. Adding structure may induce increased settlement of meroplankton species, and potential effects of electromagnetic fields (EMF) are currently unknown.

Immediate changes to the benthic habitat will likely result from modifications to water circulation and currents. Larval distribution and sediment transport may change both in the benthos and on beaches. Additionally, the fouling community growth on buoys, anchors, and lines may adversely affect the benthic environment if deposited into accumulations on the seafloor (e.g., by sloughing off or by routine maintenance of mooring lines and buoy structures).

Effects on the benthos will likely scale in a nonlinear fashion, affected by connectivity as multiple facilities interact—for example, as stepping stones for invasive species.

Wave energy development can affect community structure for fish and fisheries through changes in species composition and predator effects (e.g., attraction of predators that were previously absent). New structures may affect migration corridors (e.g., for salmon, Dungeness crabs, elasmobranchs, and sturgeon),potentially mediated through behavioral effects resulting from EMF, chemical, and acoustic signals. Effects on fishery access and gear entanglement are also anticipated, but were not topics of this workshop.

For marine birds, lighting and above-water structures may result in collisions and attraction to buoys. Structures may also alter food webs and beach processes, in turn affecting shorebirds. Data gaps to be filled include spatial and temporal abundance of birds, bird activity at night, important areas of bird activity that should be avoided, important migration patterns, and potential effects on seabird prey.

A diversity of concerns exists for marine mammals; the nature of mooring cables (slack v. taut; horizontal v. vertical; diameter) is critical to entanglement issues. Fundamental baseline data will be needed (mammal biology, presence/absence/species diversity, information on prey species) to understand projects' impacts and long-term buildout scenarios. There is some need for immediate monitoring of cetaceans (e.g., videography, beachings, tagging, vessel surveys) to understand how they interact with wave energy facilities.

Energy absorbing structures (e.g., buoys, wave snakes, etc.) affect a suite of receptors, and consequently should not be established within sensitive habitats and areas. (Shallow coastal waters are sensitive ecologically; some suggested that wave energy facilities should stay outside 100 m.) Impacts can be minimized by working with industry ahead of time. Energy devices that focus or trap water in the nearshore environment will be especially problematic due to the sensitive areas nearshore.

When addressing chemical effects, it is important to distinguish between spills as a source of chemicals (low probability but high impact) versus continuous release of chemicals, for example in fouling paints. It will be important to understand effects at the community level—do chemicals bioaccumulate and pass through trophic levels? Chemicals can move over a large area, depending on the currents. Information is needed on the nature of toxic compounds to be used, potential amounts that could be released, responses of receptors, and the fate of the contaminants.

New hard structures and lighting will be a part of any wave energy structure, requiring the industry to consider mitigation measures for devices breaking loose and debris accumulation. Important regulations under several laws (e.g., the ESA, EFH, MMPA, NEPA, and MBTA) must be closely followed as the industry develops. It is important to understand how new hard surfaces may alter bottom communities, as well as to synthesize existing data and use it to help answer questions about impacts and identify important environmentally sensitive areas that can be avoided.

The acoustics group noted that understanding noise coming from the buoys and cables and how fish and marine mammals will or could react is critical. It is possible to model noise from buoys and cables and use that information to assess impacts from various scales of wave energy facility build out, but it was noted that the synchrony of noise from buoys could exacerbate noise or create noise not previously considered. Wave energy facilities, depending on their size and layout, could create a sound barrier that mammals would avoid. Some fish species are especially sensitive to acoustics; this could result in food chain effects since some species are prey for marine mammals.

Electromagnetic effects from both induced and galvanic fields are most likely to affect animals that use EMF for orientation or feeding. Induced or galvanic fields are most likely to affect feeding, whereas magnetic fields will likely have greater effects on orientation. Salmon, crab, sturgeon, and sharks and rays (and albacore under certain oceanographic conditions) are the species most likely to be affected. Major areas of uncertainty exist on the effect of EMF on receptors, so before-and-after baseline assessment of local magnetic fields is needed. Controlled experiments are difficult and complex (confounded with other stressors).

The system view/cumulative effects group focused on issues likely to occur as projects scale up; risks are a function of the extent, density, and duration of project operation. In order to understand effects, impact thresholds need to be established. As projects scale up in location or implementation, new risk end points come into play that were not initially part of the assessment. Other activities can be displaced (e.g., fishing pressure allocated to other areas, marine mammals altering migration paths, etc.). Therefore, adaptive management is critical to address long-term impacts.

In conclusion, there is an urgency to the need for environmental studies of wave energy conversion. Throughout the workshop, the importance of evaluating ecological effects at any wave energy demonstration study sites or pilot scale facilities was stressed. These evaluations will help reduce uncertainty of effects for all stressors and all receptor groups, leading to improvements in the best practices for design of devices and arrays and to performance standards and monitoring requirements that can be applied to commercial-scale development.

6.4.2. Report to Congress "Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies" Prepared in response to the Energy Independence and Security Act of 2007, Section 633(b) November 21, 2008 [Ref 9]

Section 633(b) of the Energy Independence and Security Act of 2007 (EISA) called for a report to be provided to Congress that addresses (1) the potential environmental impacts of marine and hydrokinetic energy technologies; (2) options to prevent adverse environmental impacts; (3) the role of monitoring and adaptive management; and (4) the necessary components of an adaptive management program.

The EISA Report to Congress was prepared based on a review of peer-reviewed literature, project documents, and U.S. and international environmental assessments of these new technologies. The information was supplemented by contacts with technology developers, experts in state resource and regulatory agencies and non-governmental organizations, and input and reviews by Federal agencies (NOAA Fisheries, Minerals Management Service, U.S. Fish and Wildlife Service, National Park Service, Bureau of Indian Affairs, Federal Energy Regulatory Commission).

There are numerous conceptual designs for converting the energy of waves, river and tidal currents, and ocean temperature differences into electricity. Most of these technologies remain at the conceptual stage – they have not yet been tested in the field or as prototype, full-scale devices. Consequently, there have been few studies of their environmental effects. Most considerations of the environmental impacts have been in the form of predictive studies and environmental assessments that have not yet been verified.

The assessments have identified common elements among these technologies that may pose a risk of adverse environmental effects. These potential impacts include the alteration of currents and waves; alteration of substrates and sediment transport and deposition; alteration of habitats for benthic organisms; noise during construction and operation; emission of electromagnetic fields; toxicity of paints, lubricants, and antifouling coatings; and interference with animal movements and migrations. Project installation and operation will change the physical environment. Effects on biological resources could include alteration of the behavior of animals, damage and mortality to individual plants and animals, and potentially larger, longer-term changes to plant and animal populations and communities. Some effects are expected to be minor, but the potential significance of many of the environmental issues cannot yet be determined owing to a lack of experience with operating projects.

Although there have been few environmental studies of these new concepts, a preliminary indication of the importance of each of these issues can be gained from published literature related to other technologies, e.g., noises generated by similar marine construction activities, EMF emissions from existing submarine cables, and environmental monitoring of active offshore wind farms. Experience with other, similar activities in freshwater and marine systems will also provide clues to effective impact minimization and mitigation measures that can be applied to these new renewable energy technologies. However, some aspects of the environmental impacts are unique to the technologies, and will require operational monitoring to determine the seriousness of the effects. This is particularly true for the cumulative effects of large numbers of ocean energy or hydrokinetic devices that will comprise fully built-out projects. Impacts to bottom habitats, hydrographic conditions, or animal movements that are inconsequential for a few units may become serious if large, multi-unit projects exploit large areas in a river, estuary, or nearshore ocean. For some environmental issues it will be difficult to extrapolate predicted effects from small to large numbers of units because of complicated, non-linear interactions between the placement of the machines and the distribution and movements of aquatic organisms. Assessment of these cumulative effects will require careful environmental monitoring as the projects are deployed.

Evaluation of monitoring results might be usefully conducted in an adaptive management framework. There are numerous state and federal agencies and environmental laws and regulations that will influence the development of marine and hydrokinetic technologies. Federal licensing of these renewable energy projects is the responsibility of the Federal Energy Regulatory Commission and the Minerals Management Service. Their licensing decisions will include input from other federal and state agencies, tribes, environmental groups, and other stakeholders. After a licensing decision has been made and operation of the energy project has begun, the identification (and correction) of environmental impacts will depend on appropriate monitoring.

The ability to modify the project in order to mitigate unacceptable environmental impacts identified by operational monitoring might be based on application of adaptive management principles reflected in the project license conditions. In the context of marine and hydrokinetic energy technologies, adaptive management is a systematic process by which the potential environmental impacts of installation and operation could be evaluated against quantified environmental performance goals during project monitoring. Early information about undesirable outcomes could lead to the implementation of additional minimization or mitigation actions which are subsequently re-evaluated. An adaptive management process is particularly valuable in the early stages of technology development, when many of the potential environmental effects are unknown for individual units, let alone the eventual build out of large numbers of units. Basing the environmental monitoring programs on adaptive management principles, as advocated by many resource and regulatory agencies, will take advantage of ongoing research and monitoring to help refine technology designs and to improve environmental acceptability of future installations.

6.5 Permits for Offshore Wave Power Plants

As of June 30, 2009, the FERC has issued one construction and operation license and 13 preliminary permits (a preliminary permit gives the permit holder the first right of refusal to a site for a three-year period to study the site and file a construction license application) and has four applications for preliminary permits pending:

- One (1) construction and operation license applied for and granted to Finavera for its 1 MW Makah Bay Wave project (which apparently will not be built and operated despite the six years and many millions of dollars invested to get the license)
- Thirteen preliminary permits with eight still active
- Five applications for preliminary permits in the pending stage at the FERC

The location of these sites, all in the Pacific Northwest, are shown in Figure 6-3 and the five pending (the P number is the FERC docket number and further information can be obtained by going to the FERC website (http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/permits.asp). Table 6-2 lists the licenses issued, Table 6-3 lists the preliminary permits issued, and Table 6-4 lists the applications for preliminary permits which are pending.

Table 6-2
FERC Licenses

FERC #	Project Location	Capacity	Applicant	Status
P-12751	Makah Bay, WA	1 MW	Finavera Renewables	License Granted 12/21/07

1. Finavera has announced that they are withdrawing from wave energy and has filed with FERC to relinquish the license

The FERC had issued 13 preliminary permits as shown in Table 6-3; however, it pulled permit P-12752 in Humboldt because Finavera did not satisfy the reporting requirements to meet the FERC's strict scrutiny and Finavera and PG&E each dropped one and OPT dropped two preliminary permits leaving a total of 8 active remaining

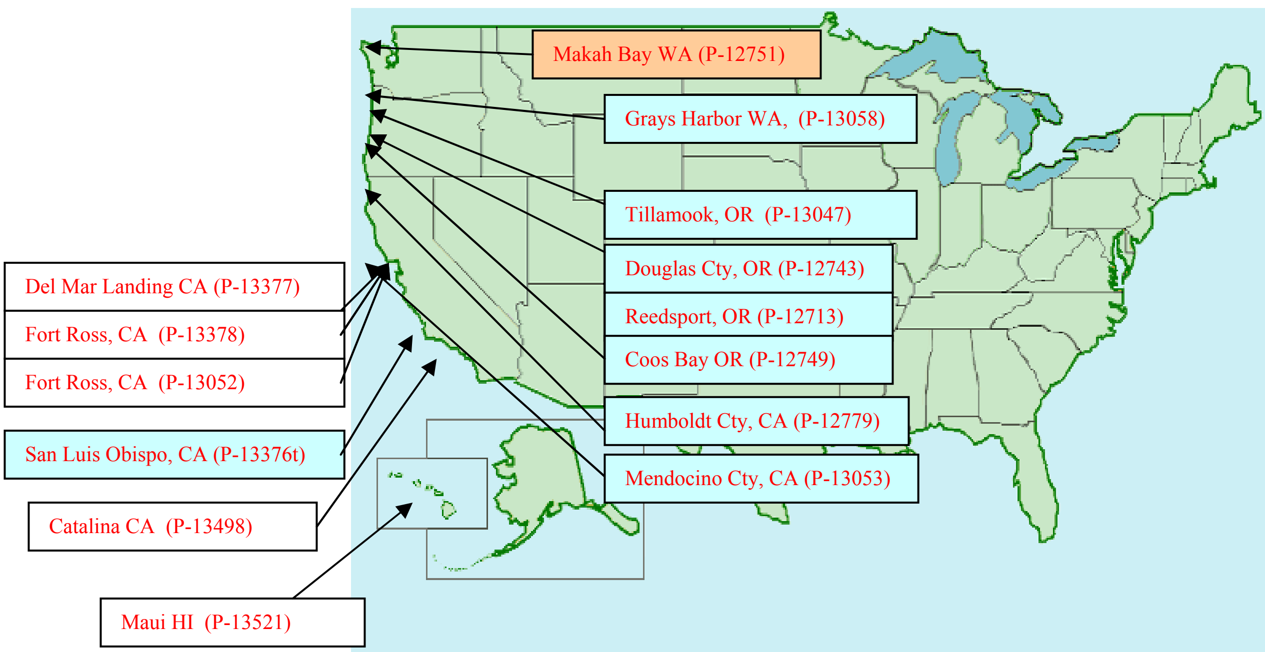

Figure 6-3
U.S. Wave Power Plant Preliminary Permit Locations
Issued Construction and Operation License
Issued and Valid Preliminary Permit
Pending Preliminary Permit

Table 6-3
FERC Preliminary Permits Issued

FERC #	Project Location	Applicant	Prel Permit Issued	Status
P-12713	Reedsport, OR	OPT	2/6/07	In progress
P-12743	Douglas County, OR	Douglas County	4/6/07	Filed NOI and PAD 6/30/08
P-12749	Coos Bay, OR	Oregon Wave Energy	3/8/07	In progress
P-12752 (1)	Coos County OR	Finavera Renewables	4/26/07	Permit Granted and later retracted
P-12753 (1)	Humboldt County, CA	Finavera Renewables	2/14/08	Permit Granted and later retracted
P-12779	Humboldt County, CA	PG&E	3/13/08	In progress
P-12781 (2)	Mendocino County, CA	PG&E	3/13/08	PG&E will surrender
P-13047	Oregon Coastal Wave Energy, Tillemook County	Tillemook Devel -opment Entity	5/22/08	In progress
P-13075	Centerville OPT Humboldt County CA	Ca Wave Energy Partners	6/27/08	OPT surrendered 6/1/09
P-13058	Grays Harbor Ocean Energy and Coastal Protection	Washington Wave Co LLC	7/3/08	Progress report overdue 6/30/09
P-12750	Newport OPT Wave Park	Oregon Wave Energy II, LLC	1/29/09	OPT surrendered 3/17/09
P-10352	Green Wave San Luis Obispo	Green wave LLC	5/7/09	In progress
P-13053	Green wave Mendocino, CA	Green wave LLC	5/1/09	In progress

1. Finavera has announced that they are withdrawing from wave energy
2. PG&E has announced that they are dropping the Mendocino County site from further consideration due to port unsuitability

There are 5 preliminary permit applications pending as shown below.

Table 6-4
FERC Preliminary Permits Pending

FERC #	Project Location	Applicant	Application Date
P-13376	Del Mar Landing	Sonoma County CA	2/26/09
P-13377	Fort Ross South	Sonoma County CA	2/26/09
P-13378	Fort Ross South (maybe FERC meant North	Sonoma County CA	2/26/09
P-13498	Swarve Catalina	SARA	6/2/09
P-13521	Maui, Hawaii	Oceanlinx	6/23/09

6.6. Overview of Regulatory Status for Offshore Wave Power Plants

Agreements between the Federal Energy Regulatory Commission (FERC) and the Mineral management Service (MMS) in early 2009 have produced the following permitting, licensing and leasing framework

Table 6-5
FERC , MMS and State Lands Permitting, Licensing and Leasing Framework

	State Seabed Lands (1)	**Federal Seabed Lands (2)**
Preliminary Permits	FERC	None
Pilot Licenses	FERC	FERC
Construction and Operation Licenses	FERC	FERC
Leases	State Department	MMS

(1) To 3 nm miles except in Texas and Gulf of Mexico states where state lands extend to 12 nm
(2) On the Outer continental shelf (OCS)

The regulatory permitting, licensing and leasing processes associated with U.S. ocean wave projects can be quite involved, complex, lengthy, and costly. Indeed, regulatory issues represent the primary barrier to the ocean wave energy development in the United States.

Since 1920, construction and operation of a non-federal hydroelectric project in the U.S. has required a license issued by the FERC in accordance with the Federal Power Act. In 2004, through legal interpretation from the FERC, wave energy hydroelectric projects were placed under FERC licensing jurisdiction.

Meanwhile, the 2005 Energy Policy Act (EPACT05) has given jurisdiction for leasing on the outer continental shelf to the Department of Interior's Mineral Management Service (MMS). In addition to FERC and MMS, approvals to install and operate a pilot project are still required from many other federal, state, and local regulatory agencies (upwards of 20 different agencies).

The period of the second half of 2008 and the first half of 2009 saw many developments on the regulatory front including

1. A FERC pilot license
2. A agreement between FERC and MMS for licensing projects on the OCS resulting in FERC with primary jurisdiction for licensing and with a statement by FERC that they will no longer issue preliminary permits for ocean wave plants on the OCS
3. A rule issued by MMS for leasing ocean wave plants on the OCS

These three developments are summarized below

6.6.1. FERC Pilot Plant License

In 2008, FERC rolled out a licensing process for hydrokinetic pilot projects tailored to meet the needs of entities interested in testing new technology, including connection with the interstate grid, while minimizing the risk of adverse environmental impacts. The goal of the pilot process is to allow developers to test new hydrokinetic technologies, to determine appropriate siting of these technologies, and to confirm their environmental effects, while maintaining FERC oversight and agency input. The process completes licensing in as few as six months to allow for project installation, operation, and environmental testing as soon as possible.

Projects eligible to use this process are of limited size, are removable or able to shut down on short notice, and are not located in waters with sensitive designations. The resulting license would be short-term and include rigorous environmental monitoring and safeguards.

To date, there have been no pilot licenses sought for wave power projects

6.6.2. FERC–MMS Memorandum of Agreement on Licensing Wave Power Plants on the OCS

Ending a longstanding conflict over which agency oversees offshore alternative energy, Interior Secretary Ken Salazar and FERC Chairman Jon Wellinghoff signed a memorandum in March 2009 clarifying their agencies' responsibilities for leasing, licensing and regulating all renewable energy projects on the outer continental shelf.

Under the agreement, Interior's Minerals Management Service has exclusive jurisdiction over the production, transportation or transmission of energy from offshore wind and solar projects. MMS and FERC will share responsibilities for hydrokinetic projects, such as wave, tidal and ocean current.

MMS will issue leases, easements and rights of way for offshore areas for hydrokinetic projects. The agency will conduct any necessary environmental reviews related to those actions, including those under the National Environmental Policy Act.

FERC will issue licenses and exemptions from licensing for the construction and operation of offshore hydrokinetic projects and will conduct any necessary environmental analyses for those actions. FERC's licensing process will actively involve relevant federal land and resource agencies, including Interior.

An applicant must first receive a lease from MMS for a site before FERC could issue a license for a project there. FERC will not issue preliminary permits for offshore projects. MMS will require that construction and operation cannot begin without a license or exemption from FERC, except when FERC notifies MMS that one is not required.

Each agency can choose at its own discretion to become a cooperating agency in the other's preparation of an environmental analysis. The agencies also will coordinate to ensure that operations regulated by FERC comply with all applicable laws.

6.6.3. MMS Leasing Rules for Wave Plants on the OCS

On April 22, 2009, the Department of the Interior's Minerals Management Service ("MMS") issued final rules for granting leases, easements, and rights-of-way for renewable energy project activities and alternate uses of existing facilities located on the U.S. Outer Continental Shelf ("OCS"), as well as methods for sharing revenues generated by this program with nearby coastal states. Renewable energy projects covered by the proposed rule include, but are not limited to, offshore wind, wave, current, and solar energy projects.

While the final rule did not vary significantly from MMS's July 2008 proposed rule, MMS did make some relevant changes in response to comments from industry and nongovernmental organizations. In particular, the final rule:

- Allows consideration of nonmonetary factors in the competitive bidding process for a lease, such as the use of innovative technology suited to a specific site;
- Gives developers with five-year limited leases the option to interconnect with the transmission grid for commercial power sales;
- Bases operating fees on a calculation pegged to the wholesale power price rather than the retail power price and stipulates that MMS will not charge such fees until a project is generating power commercially;
- Lets developers limit the number of National Environmental Policy Act documents and associated environmental reviews by submitting site assessments and construction plans simultaneously, and anticipates that MMS will conduct such reviews for commercial leases at the lease sale stage, which may minimize future additional reviews;
- Gives MMS flexibility to waive the requirement that a certified verification agent oversee facility construction at a give site; and
- Provides that MMS will use mechanisms available under the Freedom of Information Act to protect appropriately designated proprietary data and information.

Importantly, the final rule did not address the concerns that small businesses have with the bonus bid system or noncompliance penalties. Despite industry comments, the standard commercial lease terms were not extended beyond 25 years; however, additional years were added for construction time. Citing language in the Outer Continental Shelf Lands Act that requires competitive bidding, the final rule does not give automatic priority to limited leaseholders for a subsequent commercial lease on a site. However, MMS may give weight to limited leaseholders. For an overview of the final MMS rule regulating offshore renewable energy and additional detail on how it varies from the proposed rule, go to: www.stoel.com/showalert.aspx?Show=5398.

6.7. WEC Power Plant Areal Footprints

Use of sea space by wave energy power plants is of critical concern to many of the national stakeholders engaged in understanding the issues of whether or not energy generation will be one of the multiple uses of our nations oceans. The ocean are held in trust by the Government for the good of the society as a whole and are currently being used for multiple purposes (i.e., commercial fishing, recreation, commercial shipping, dump sites, military training, etc)

The footprints of some of the existing technologies for a 10 MW and a 100 MW wave power plant are shown in Table 6-6. The Orecon machine, the only tension moored device in the table, will have the smallest footprint. Slackly moored devices such as the Pelamis and the PowerBuoy will require larger footprints. The Oyster is a near shore device that operates only in the surge zone

Table 6-6
WEC Device Areal Footprints

	Absorber Dimensions		Footprint Single Unit	
	Length (m)	Width (m)	Length (m)	Width (m)
Pelamis P1 (1)	123	4.6	300	150
OPT 500 PowerBuoy (2)	18	18	100	100
AquaMarine Oyster (3)	12	18	30	30
Orecon MRC (4)	30	45	245	130
	Farm Arrangement Footprint 10MW			
	# Devices	# Rows	Length (km)	Width (km)
Pelamis P1 (1)	19	2	1.0	0.90
OPT 500 PowerBuoy (2)	20	3	0.70	0.30
AquaMarine Oyster (3)	33	1	1.0	0.03
Orecon MRC (4)	6	1	1.47	0.13
	Farm Arrangement Footprint 100MW			
	# Devices	# Rows	Length (km)	Width (km)
Pelamis P1 (1)	210	4	10	1.80
OPT PowerBuoy 500 (2)	200	3	8	0.30
AquaMarine Oyster (3)	333	1	10	0.03
Orecon MRC (4)	68	4	4.16	0.52

1. Based on preliminary design performed by EPRI for Oregon Pelamis Wave Power Plant – see EPREI Report WP-006-OR available under the wave page at www/epri/com/oceanenergy/
2. Based on March 2008 Coos Bay Preliminary Application Document filed with the Federal Energy Regulatory Commission. Project size estimates based on 100 m lateral spacing and 100 m between rows for PB500 PowerBuoys. Overall 100 MW project size includes three (3) transit lanes. Each lane is 400 meters in length.
3. Based on Aquamarine Power website 300 kW machine located at 15 meter depth and 12 X 18 meter size (EPRI assumed assume 12 meter lateral spacing)
4. Based on input provided by Orecon MRC rated at 1.5 MW

7. Design, Performance, Cost, and Economic Feasibility Issues

7.1 WEC Sites

EPRI has investigated the attributes required for a good wave energy site. Reports which document the EPRI site assessments are contained in References 10 through 14 under the wave page at www.epri.com/oceanenergy for Hawaii, Washington, Oregon, and Maine, respectively.

There are many factors to consider when evaluating potential sites for a wave energy plant. Primary factors are:

- First and foremost, a high annual wave energy climate
- A nearby harbor with sufficient depth and size and port infrastructure to support the assembly and deployment of the plant as well as maintenance operations
- A transmission and distribution system that can flow the power from the wave plant into the grid and a substation interconnection point close to shore
- An existing easement for the submerged cable from the wave power plant to shore (and possibly under the beach to the substation); for example, the existence of an outflow pipe
- A bathymetry that provides a depth of about 60 minutes within 2 to 3 miles of shore
- A sandy seabed (for anchor placement) and a sandy route to shore for trenching the submerged cable
- Minimum conflicts of sea space use (e.g., fishing, crabbing, whale migration, etc.)
- Local labor to be trained for employment in this new industry

7.2 WEC Devices Studied

For each site, point designs for both a single-unit demonstration and a commercial wave power plant were used to estimate cost and performance. Performance estimates were developed using local wave data obtained from measurement buoys and performance data supplied by the manufacturer. Two manufacturers provided sufficient information such that EPRI could perform a design and performance analysis: Pelamis WavePower and Oceanlinx. Cost estimates were developed by creating a detailed breakdown of the various cost centers and outlines of installation and operation procedures, and by cross checking them with a variety of sources, including local operators, the design team, local manufacturers, and similar offshore projects in the oil and gas and offshore wind industries.

7.3 WEC Design, Performance and Cost

In 2004, EPRI performed an Offshore Wave Power Feasibility Definition Study examining five locations and two WEC technologies. Offshore Wave Power Plant Feasibility Reports have been published for sites in Hawaii, Oregon, San Francisco, Massachusetts, and Maine (References 15 through 19). Table 7-1 shows the performance and cost numbers for single unit Pelamis pilot plant and 300,000 MWh/yr commercial scale plants; one located on the East Coast at Wellfleet, Massachusetts and the other on the West Coast at Reedsport, Oregon.

Table 7-1
Cost and Performance Estimates for Wave Power Plants

Rated Capacity	**0.75 MW Wellfleet MA**	**103 MW Wellfleet MA**	**0.75 MW Reedsport OR**	**90 MW Reedsport OR**
Plant Size (number of units x unit size, MW)	1 X 0.75	206 X 0.5	1 X 0.75	180 x 0.5
Annual Electrical Energy at Busbar (MWeh)	964	300,000	1,000	300,000
Plant Nameplate Rating (MW)	0.75	103	0.75	90
Technology Description	Linear Absorber (Pelamis)	Linear Absorber (Pelamis)	Linear Absorber (Pelamis)	Linear Absorber (Pelamis)
Physical Plant				
Seabed, km^2	<0.5	18.5	<0.5	16.2
Unit Life, Years	20	20	20	20
Scheduling				
Development time, Months	(1)	(1)	(1)	(1)
Construction time, Months	12	24	12	24
Capital Cost ($/kW)				
Month/Year Dollars	December 2006 (2)	December 2006 (2)	December 2006 (2)	December 2006 (2)
On shore transmission and grid interconnection	985	62	820	30
Subsea cables	1,433	50	424	22
Mooring	344	248	344	248
Power Conversion Modules	2,172	1,324	2,172	1,324
Structural sections	1,202	520	1,202	520
Facilities	0	124	0	141
Installation	895	125	9989	134
Construction Mgmt and Commissioning	708	117	594	115
Contingencies	(3)	(3)	(3)	(3)
Less State Renewable Inv Tax Credit (4 & 5)	<85>	<12>	<1,559>	<118>
Total Plant Cost (TPC)	7,651	2,558	4,987	2,416
AFUDC (interest during construction)	*650*	*309*	*424*	*238*
Total Plant Investment	8,300	2,870	5,410	2,654
Owner Costs				
Due Diligence, Engineering, Permitting, Legal, Financial fees, etc	(6)	(6)	(6)	(6)
Total Capital Requirements	8,300	2,870	5,410	2,654
Yearly O&M Costs (% of TPC per year)	N/A (7)	0.5	N/A (7)	0.45
10 Year One Time Retrofit Costs (% of TPC)	N/A (7)	1.0	N/A (7)	0.97
Unit Availability (%)	85	95	85	95
Confidence and Accuracy Rating				
Technology Development Rating	Pre Commercial	Pre Commercial	Pre Commercial	Pre Commercial
Design & Cost Estimate Rating	Simplified	Simplified	Simplified	Simplified

1. Development time for permitting is an unknown at this early point with emerging ocean energy technology
2. The costs are in November 2004 dollars in References 15 through 19 and were adjusted with a 3% inflation to Dec 2006 $
3. Contingency costs are built into each of the subsystems
4. The Oregon credit is 25% of the project cost up to a maximum of $10 million
5. The Massachusetts credit is 9.5% of the installation cost
6. Cost of permitting is an unknown at this early point with emerging ocean energy technology
7. O&M costs for a pilot plant cannot be estimated

The DOE will place a contract in early 2010 for a new wave energy life cycle cost assessment. There are no actual real cost numbers at this point in time except for single unit production numbers which the technologies developers hold to be confidential

7.4 WEC Economic Feasibility

The costs and cost of electricity (COE) estimates made by EPRI were for the first commercial-scale (100 MW) wave plant. It is an established fact that learning through production experience reduces costs—a phenomenon that follows a logarithmic relationship such that for every doubling of the cumulative production volume, there is a specific percentage reduction in production costs. The specific percentage used in this study was 82%, which is consistent with documented experience in the wind energy, photovoltaic, shipbuilding, and offshore oil and gas industries.

As occurred with PCs, flat-screen TVs, wind turbines and PV panels, the costs of WEC devices will decline as the industry moves toward larger-scale manufacturing and higher cumulative production. The industry-documented wind energy learning curve is shown as the top line in Figure 7-1. This curve was developed by EPRI based on data from a multitude of sources. The lower and higher bound cost estimates of wave energy are also shown in Figure 7-1. The 82% learning curve is applied to the wave power plant installed cost but not to the O&M component of the cost of electricity (which is why the three lines are not parallel).

The adoption of ocean power technologies will be based upon the value of electricity these devices generate and supply to the grid as well as their ease of integration with the grid. In addition to installed capital cost, operations and maintenance (O&M) cost will also play a significant role. O&M costs related to unplanned maintenance is a major factor in the overall cost of electricity.

EPRI's economic assessments have been based on a book lifetime of a wave power plant of 20 years. The cost flow profile for wave energy, much like many renewable energy technologies, is heavily front end loaded. Wave power plants will have a cost of electricity that is comprised or 90% or more from initial capital costs and installation costs. Typical fossil fuel power plants experience fuel and ongoing operations that are about 80% of the plant's cost of electricity.

Levelized COE takes into account all fixed and recurring costs of a wave power power plant as a function of the electrical energy it generates. The costs, annual energy produced and financial assumptions upon which the Figure 7-1 estimates are based are documented in EPRI WP-006-OR available at www.epri/com/oceanenergy/ [Ref 15]

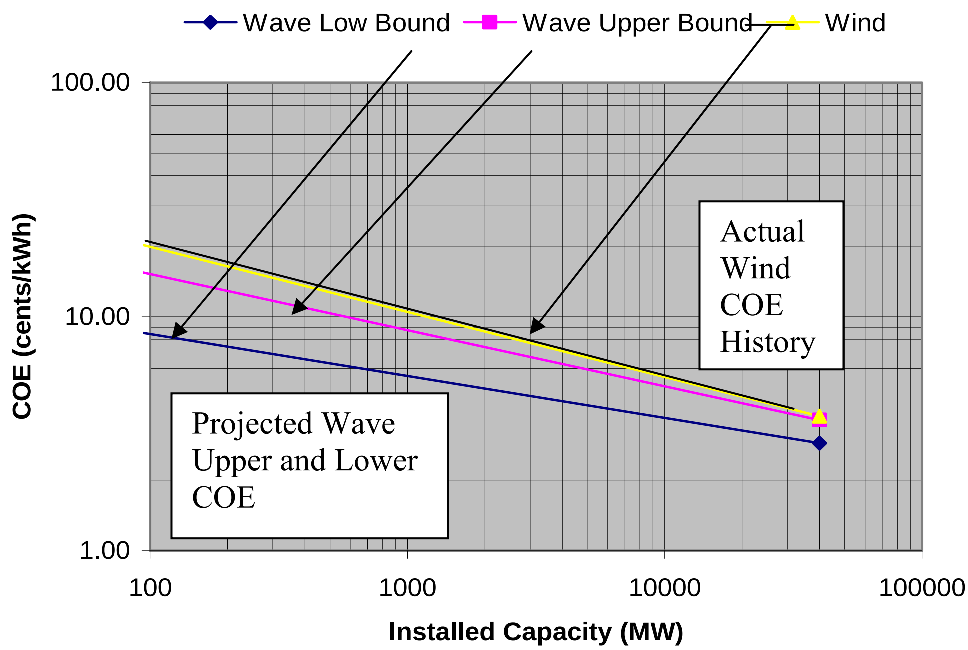

Figure 7-1
Levelized COE Comparison to Wind–Oregon Example Fed & State Financial Incentives

While there are some federal and state tax incentives to build renewable power systems, these incentives are insufficient to finance early adopter projects at small scale. As a result, developers will be put in the position of having to push for large commercial installations to drive cost down, and in the process may be forced to assume the significant technical, economic and environmental risks of deploying unproven technologies at large scale.

Dozens of institutional investors in U.S. renewable energy projects pulled out of the market when the nation's liquidity dried up last in 2008. Some found more lucrative investments elsewhere while others found themselves unable to take advantage of tax credits because they lacked the profits to take advantage of them. The American Recovery and Reinvestment act (ARRA) of 2009, approved February 19, 2009, changed the investor ground rules. The new ARRA gives investors, owners, operators and financiers a choice of government credits that may help push renewable projects forward.

Large insurance companies and investment banks that engage project developers provide the majority of the renewable project financing. The ARRA offers a number of potentially useful incentives that can be tailored to individual project needs. The key provisions are:

- The PTC in-service deadline is extended through 2012 for wind projects and 2013 for other renewable projects, including ocean wave
- Project financiers may now elect the ITC in lieu of the PTC
- Project financiers may elect a cash grant in lieu of the ITC
- The ITC-subsidized energy financing penalty is removed

- CREBs get more funding ($1.6 billion in new CREBs is added)

A good reference on the ARRA can be found in "TC, ITC or Cash grant/ An Analysis of the Choice Facing Renewable Power projects in the United States" published in march 2009 by the Lawrence Berkeley Renewable Laboratory and the National Renewable Energy Laboratory. The entire report is available at http://eetd.lbl.gov/EA/EMP/reports/lbnl_16422.pdf

It is clear that a sensible policy for this emerging industry needs to provide a technology-specific financial support mechanism and encourage technology diversity to spread technology risks. In order to provide optimal support for these emerging technologies, it will be crucial to have technology developers carry the technical risks and reward for the delivery of electricity, possibly through a mechanism such as the European feed-in tariffs.

The infrastructure cost (i.e. subsea electrical collector system and pre-deployment studies) of small scale ocean energy farms oftentimes exceeds the cost of the technology themselves, and the time horizon to establish them is significant given the present regulatory and environmental uncertainties. Sharing of this infrastructure between different device developers could lower the overall project cost at the small scale required to gain commercial confidence. Decoupling the site development process from the immense challenges technology developers are facing in their technology developments would allow them to focus more of their attention and resources on technological challenges. In addition to the obvious economic advantages of providing such facilities to the industry, it will also provide a controlled environment to reduce operational and environmental risks. In the US, such facilities are encouraged through the establishment of test centers and early commercial adopter sites.

8. Installed Capacity and Estimated Growth

Installed offshore wave capacity as of June 30, 2009 in the U.S. is zero and is about 1 MW worldwide; The first shore-based grid-connected wave power unit was deployed in Scotland in July 2000 and has since operated successfully. The first offshore grid-connected wave power unit deployed was the ¼ scale WaveDragon in Denmark in 2003 and closely followed by a full scale Pelamis at the European Marine Energy Center (EMEC) in the Orkneys in July 2004. Based on the successful testing of the ¼ scale WaveDragon, the company moved to Wales with the expectation of funding to build a full scale prototype and based on successful testing, Pelamis WavePower announced the first commercial sale of an offshore wave power in May 2005 to Enersis of Portugal.

Table 8-1 presents the EPRI estimate of U.S. offshore wave capacity (in MW) that could come online in the U.S. between 2009 and 2015 assuming that current regulatory barriers are overcome, that wave plants can be permitted at about the same cost as on-land wind plants, and that Congress provides the same incentives to the wave energy industry as those for the wind energy industry.

In general, EPRI expects that wave energy will experience a growth rate faster than that of wind during the last ten years, although these predictions depend largely on overcoming regulatory barriers and government support and incentives for the emerging wave energy industry. EPRI estimates that there could be 10,000 MW of wave energy plant capacity by 2025.

Table 8-1
Installed and Planned Wave Energy Capacity in U.S. (as of June 30, 2008)

Developer	Project Name-Site	Pre - 2009	2009	2010	2011	2012	2013	2014	2015
Ocean Power Tech (1)	Kaneohe, HI	0.04							
Ocean Power Tech	New Jersey	0.04							
Finavera (2)	Makah Bay, WA								
Ocean Power Tech (3)	Reedsport, OR			0.150	1.5	3.5		5	
Oregon Wave Energy	Coos Bay OR						5		25
PG&E	Humboldt County, CA					5			40
PG&E (4)	?								
Oceanlinx	Hawaii					2.8			
San Luis Obispo CA	Green wave Energy							5	
Mendocino CA	Green Wave Energy							5	
Douglas County Wave	Douglas County, OR					2			
Tillamok Intergov	Tillamook County, OR						2		5
Not identified at this time							5	25	50
TOTAL NEW	YEARLY CAPACITY		-	0.15	1.5	13.3	12	40	120
	CUMULATIVE	0.08	0.08	0.23	1.7	15	27	67	187

1. In Navy waters and was constructed and operated without the need for a FERC license
2. Finavera surrendered its license.
3. The OPT 2 MW pilot plant deployment has been delayed from 2008 to 2009, at the earliest, due to regulatory issues
4. PG&E has dropped Mendocino from further preliminary permit study and will be adding a second site

Study forecasts 86MW of wave and tidal capacity by 2013[3] A total of 86 MW of wave and tidal current stream capacity will be installed worldwide in the next five years according to a new study, "***The World Wave & Tidal Market Report 2009-2013***", published by energy business

[3] http://www.wave-tidal-energy.com/home/news-archive/36-research/160-study-forecasts-86mw-of-wave-and-tidal-capacity-by-2013, dated Feb 16, 2009, retrieved May 7, 2009

analysts Douglas-Westwood. Speaking at the launch of the first edition of the report recently, Adam Westwood, Renewable Energy Manager at Douglas-Westwood stated that, “Both the wave power and tidal current stream energy sectors are emerging industries. Whilst development activities run back some 30 years, with over 200 concept technologies, commercialization of leading technologies in both sectors is only just beginning."

The report, which runs to almost 200 pages, provides a review of different technological concepts and devices employed in both existing and future projects, with analysis of the impact of current and new technologies on the industry and identifies the key players in the business. It also identifies and analyses the very different market mechanisms in each country, which impinge directly on the viability of wave and tidal technology in the area.

The report uses the same in-depth modeling process that is adopted for others in this series, says the company, and presents worldwide market forecasts for both sectors for the 2009-2013 period. It also includes five years of historic data for comparison.

"The past five years", says Westwood, "have been characterized by small-scale and full-scale deployments from a wide number of technology developers. The next five years will, however, see commercial-scale activity increasing significantly. A total of 135 units are forecast for deployment over the period. Of these, 74 are commercial-scale units – 55% of the total.

"The UK is forecast to be the biggest market, and is expected to install 51 MW of the total capacity (60%). The UK is so dominant due to three main factors. Firstly, the excellent wave and tidal resources that exist around the coastline; secondly, the market mechanisms and funding in place, which are comparatively strong and give more investor confidence than in other countries; and thirdly, the UK is home to a large number of wave & tidal device developers, including some of the early market leaders.

"The USA is expected to be the second largest market, with 11 MW (12%) of overall capacity. Portugal with 9 MW (10%) and Canada with 6 MW (7%) are the other most significant countries."

In their “Forecasting the Future of Ocean Power” report {Ref 24] Climate Change Business Journal, January/February/March 2009 [Ref 23], Greentech Media and Promethus Institute identify 24 companies developing WEC technology, he largest number of companies – 10 - -is pursuing the point absorber approach. Co-author Travis Bradford told CCBJ that here is a ”high degree of certainty” that at least one and probably several of then companies designing WECs will see commercial success within a few years.

9. R&D Needs

EPRI, with support from the U.S. Department of Energy's Office (DOE) of Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies Program, sponsored a workshop for the water power industry (marine and other hydrokinetic- tidal and river currents, energy and conventional hydropower and pumped storage) in October 2008. The purpose of the workshop was to identify and prioritize research, development, deployment and demonstration (RDD&D) needs which will further the deployment of conventional hydro/pumped storage and emerging MHK technologies and increase domestic, low-carbon energy production. The priorities identified may be used to shape EPRI's research agenda and DOE's research agenda and will support R&D initiatives throughout both the public and private sectors.

The US RDD&D Needs Workshop used the 12 topics from the UK Marine Energy technology Roadmap [Ref 25] as the starting point for developing the US technology needs. These 12 are:

1) Resource Modeling
2) Device modeling
3) Experimental Testing
4) Moorings & Sea bed attachments
5) Electrical Infrastructure
6) Power Take Off and Control
7) Engineering Design
8) Lifecycle & Manufacturing
9) Installation, O&M
10) Environmental
11) Standards
12) System Simulation

Four other topics identified by the Steering Committee prior to the workshop and two other topics identified by the participants of the workshop during the workshop were:

1) Materials – low cost, corrosion and biofouling
2) Storage
3) System configuration evaluations
4) Vision, Goals, Objectives and Roadmap
5) Master Generation and Transmission Plan
6) Education

The three highest prioritized topical areas were

1). Testing (development including experimental through pilot demonstration)
2) Environmental (which will require device testing and deployed projects)
3) Standards

Once funding is available, specific programs and projects for high priority topics identified in this workshop should be developed and implemented.

Clearly, the RDD&D topics of "Environmental", "Standards" and "Testing" need to be addressed in a comprehensive fashion. Also, these topics may warrant further consideration in follow-on meetings to be explored in more detail with knowledgeable experts in the field.

Topics falling below the high priority ranking with less consensus are still important, and need to be addressed, but are not as urgent [Ref 24].

10. Conclusions

Considerable potential exists for generating electrical power from wave energy off the coast of the United States and many other places in the world. Wave energy climates are the most energetic for coasts facing west in the latitudes of 35 to 55 degrees in the northern and southern hemispheres. In the U.S., the prime locations (i.e., those with a good wave climate, port infrastructure, coastal grid infrastructure) are:

- Northern California and Hawaii – excellent wave energy climate, good coastal grid infrastructure, good ports, and high electricity prices.
- Oregon – excellent wave energy climate, good coastal grid infrastructure, good ports, but low electricity prices.
- Washington – excellent wave energy climate, poor coastal grid infrastructure (the load is in the Seattle area and there is no transmission infrastructure to get power across the Olympic peninsula), good ports, but low electricity prices.
- Alaska – excellent wave energy climate, poor coastal grid infrastructure (the relatively small load is in the Anchorage, Fairbanks, and Juneau areas and there is no transmission infrastructure to get power there), good ports, and high electricity prices.

The recoverable potential to provide electricity from wave energy resources is estimated by EPRI to be about 6.5% of today's electric consumption in the United States. Initial studies suggest that given sufficient deployment scale, these technologies will be commercially competitive with other forms of renewable power generation. However, significant technical, economic, operational, environmental and regulatory barriers remain to be addressed in order to allow this emerging industry to move forward with commercial development.

The experience related to ocean energy is limited to a few prototype installations and provides a limited understanding of economic, operational, environmental and regulatory issues. It will be critical for the success of this industry to gain a full understanding of all life cycle-related issues over the coming years to pave the way for larger scale commercial deployments. Such understanding can only be gained in a practical way from the deployment of demonstration and early commercial adopter systems or as many are saying "We need hardware in the water!" Early commercial adopter systems will not only address technology related issues, but will also provide confidence to regulators, the general public and investors. Both market push (R&D) and market pull mechanisms (economic incentives to encourage deployment) will be required to successfully move this technology sector forward and develop the capacity to harness wave energy from the ocean.

11. Resources and References

11.1 Internet Resources

EPRI: www.epri.com/oceanenergy

European Wave Energy Thematic Network: www.wave-energy.com

Department of Transportation and Industry (UK): www.dti.gov.uk/renewable

Australian Renewables including Wave Energy: www.greenhouse.gov.au/renewable/index.html

Danish Wave Energy: www.waveenergy.dk

European Wave Energy Research Network (EWERN):www.ucc.ie/ucc/research/hmrc/ewern.htm

European Wave Energy Thematic Network: www.wave-energy.net

World Wave Atlas: www.oceanor.no/projects/wave_energy

World Energy: www.worldenergy.org/wec-geis/publications/reports/ser/wave/wave.asp

11.2 References

EPRI Wave Power (WP) Reports are available on our website www.epri.com/oceanenergy/

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5. EPRI-WP-012 Feasibility of Days-Ahead Output Forecasting for Grid Connected Wave Energy Projects in Washington and Oregon, Dec 2007.
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11. WP-003-HI Results of Survey and Assessment of Potential Offshore Wave Energy Site Locations in Hawaii, May 2004.

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13. WP-003-OR Results of Survey and Assessment of Potential Offshore Wave Energy Site Locations in Oregon, May 2004.
14. WP-003-ME Results of Survey and Assessment of Potential Offshore Wave Energy Site Locations in Maine, May 2004.
15. WP-006-OR System Level Design, Preliminary Performance and Cost Estimate–Oregon, Nov 2004
16. WP-006-HI System Level Design, Preliminary Performance and Cost Estimate–Hawaii, Nov 2004.
17. WP-006-ME System Level Design, Preliminary Performance and Cost Estimate–Maine, Nov 2004.
18. WP-006-MA System Level Design, Preliminary Performance and Cost Estimate–Massachusetts, Nov 2004.
19. WP-006-SFa System Level Design, Preliminary Performance, and Cost Estimate–San Francisco, California, Pelamis Offshore Wave Power Plant, Dec 2004 and WP-006-SFb System Level Design, Preliminary Performance, and Cost Estimate–San Francisco Energetech Offshore Wave Power Plant, Dec 2004.
20. "Forecasting the Future of Ocean Power" Greentech Media. October 2008
21. UKERC Marine (Wave and Tidal Current) Technology Roadmap, 2008
22. "The World Wave & Tidal Market Report 2009-2013", Douglas-Westwood
23. Climate Change Business Journal, January/February/March 2009 page 25
24. EPRI Marine and Hydrokinetic Energy RDD&D Prioritized Needs Report (not yet published)