Wave Energy: a Pacific Perspective

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Abstract

This paper illustrates the status of wave energy development in Pacific Rim countries by characterizing the available resource and introducing the region's current and potential future leaders in wave energy converter development. It also describes the existing licensing and permitting process as well as potential environmental concerns. Capabilities of Pacific Ocean testing facilities are described in addition to the region's vision of the future of wave energy.

Key Words

renewable energy, marine energy, wave energy, Pacific Ocean, licensing, permitting, environmental impact

1. Introduction

The purpose of this paper is to provide an overview of the status of wave energy around the Pacific Ocean. While modern interest in ocean wave energy originated in the mid-1970, a resurgence of interest in the subject has taken root in the past decade. The US has recently seen the emergence of many device developers as well as multiple academic research efforts. Similar efforts are underway in other Pacific Rim countries. Accordingly, the subject has been attracting attention and support from federal and regional governments, including both research and business grants, the interest and cooperation of regulatory agencies, and the establishment of research and testing facilities. Private investments in wave energy have also been rising as the technology matures, and full scale deployments are becoming feasible.

A recent ocean energy status update for the US was completed by the Electric Power Research Institute (EPRI) in 2007, which devoted the majority of the report to tidal stream technology, but also outlined an estimated wave energy generation capacity and mentioned several notable development projects [1]. A similar report was written in 2008 by the National Renewable Energy Laboratory (NREL) citing the need for a more comprehensive assessment of the wave and tidal resource, improving technical evaluation of devices (via third parties), and the need to understand and possibly re-evaluate the existing regulations [2]. EPRI identified the regulatory process in the US as the primary hindrance to ocean energy development. In light of the above, this paper seeks to address three basic topics: resource and assessment, technology and development, and the regulatory process of wave energy in the Pacific Ocean.

The state of the art of wave energy resource assessment is discussed in Section 2, noting that almost all US assessments completed to date have been done using data from measurement buoys, and that wind/wave models are becoming more popular worldwide. The seasonal power trends at several locations are presented, as they may be of interest for comparison to European sites. Section 3 is devoted to describing the state of development of commercial technologies. This is done by giving an overview of the several companies viewed as the current leaders in the field, namely, Ocean Power Technologies, Columbia Power Technologies, and Resolute Marine Energy in the United States, and Power Projects Limited in New Zealand. Attention is given to past deployments and future plans.

The regulatory process will be described in Section 4, highlighting the agencies involved and permits required for offshore deployment in the North America. Since environmental impact plays a significant role in the regulatory process, Section 5 is dedicated to describing how environmental concerns are being addressed, using the Settlement Agreement for Ocean Power Technologies' current project in Reedsport, Oregon, as a case study. Section 6 presents the current US roadmap to ocean energy development, which primarily addresses technology. To that end, two efforts under development aimed at assessing technology performance are discussed. The first test site is the Pacific Gas and Electric WaveConnect project, and the other is the Northwest National Marine Renewable Energy Center, both of which are expected to be operational within the next two years.

By presenting the current state of wave energy in the Pacific Ocean, the authors hope to provide the reader with an overview the field's progress in the past few years, as well as a view to the future. From the assessments completed to date, it is apparent that a significant resource is available along vast stretches of coastline, from Alaska to New Zealand. With developers coming closer to full scale grid-connected deployments, increasing investment from both government and private sources, and a need to provide growing coastal populations with a diverse and clean source of energy, the outlook for wave energy is brighter than ever.

2. Wave Energy Resource and Assessment

Before a site is chosen for wave energy development, it is necessary to characterize the wave energy resource. Along with device performance data, an accurate assessment of the available resource is essential for anticipating power production. The power production statistics will ultimately determine whether a given project will be economically feasible. In this section an overview of state of the art energy assessment is given, followed by a description of the resource available in the Pacific Ocean.

2.1 Resource Assessment Techniques

Most energy assessment work done in the United States over the past few decades has been based on accelerometer buoy data. This section presents a simple assessment which uses only the derived wave parameters, typically the significant wave height and the peak period (of the wave spectrum). More rigorous assessments utilize the wave spectra directly. In the past decade it has become possible to base assessment on directional spectra measured directly using an ever-improving network of measurement stations. These stations are all catalogued by the

National Data Buoy Center (NDBC), although some of them are owned and operated by separate entities, such as the Coastal Data Information Program (CDIP). The earliest of these stations have simple parameter records dating back to 1975, while today dozens of stations in the Pacific Ocean are recording directional spectra.

Over the past decade it has become possible to utilize wind/wave hindcast models to generate maps of the wave resource. These models calculate the time-evolution of directional spectra over a geographical grid using wind vector data and bathymetry data as inputs. The wind vector data is derived from satellite based scatterometers, which infer winds based on radar measurements of the small scale roughness of the sea surface. Overall, the process is as follows: wind disturbs the water surface, radar backscatter measures the disturbance as a change in the backscatter intensity and correlates it to a wind vector via an empirical model, the wind vectors are then used as input for a wind/wave spectral model. In the United States, the NASA SeaWinds scatterometer has been deployed since June of 1999, while the wind/wave model WAVEWATCH III (NWW3) has been developed recently by the National Oceanic and Atmospheric Administration (NOAA). While no large scale US wave energy assessment using these tools has been published to date, such a task is well within reach.

The link still missing from the ability to predict real power output from a site is device specific performance data. Though we can show which areas of the ocean have the highest average energy flux, a given device will not necessarily produce the most power in those areas. The device performance data, likely in the form of a power matrix over wave height and period, must be convolved with the wave resource data in order to describe the actual expected power production. Some of the first steps toward this more complete description have been taken in New Zealand, where a power matrix from the Pelamis device was used to derive an expected power production map [3]. In the United States, the Northwest National Marine Renewable Energy Center (NNMREC) serves as a center for testing and standards, where the power performance characteristics of different devices may be established and verified. NNMREC's achievements and future goals will be discussed further in Section 6.

2.2 Wave Energy Resource in the US

The Pacific Ocean is vast and is subject to winds which generate powerful waves, especially in the winter. There are three general areas of interest for the development of wave energy in US Pacific waters: the west coast, Hawai'i, and Alaska. These areas are shown in Figure 1 using Google Earth snapshots, which also give a visualization of the bathymetry. For the purposes of this paper, the west coast will be split into the following parts: the Pacific Northwest (PNW, consisting of Washington, Oregon, and northern California), and California. Wave power analyses have been previously conducted by several authors for the PNW, California, and Hawai'i, but their methods and presentation differ. In order to allow for direct comparison, this paper presents a uniform, simplified analysis for each area. Data from offshore and nearshore measurement buoys in each region is presented along with summarized findings from previous studies. For the purpose of presentation in this section, 'nearshore' is taken as within 50 km of the shore.

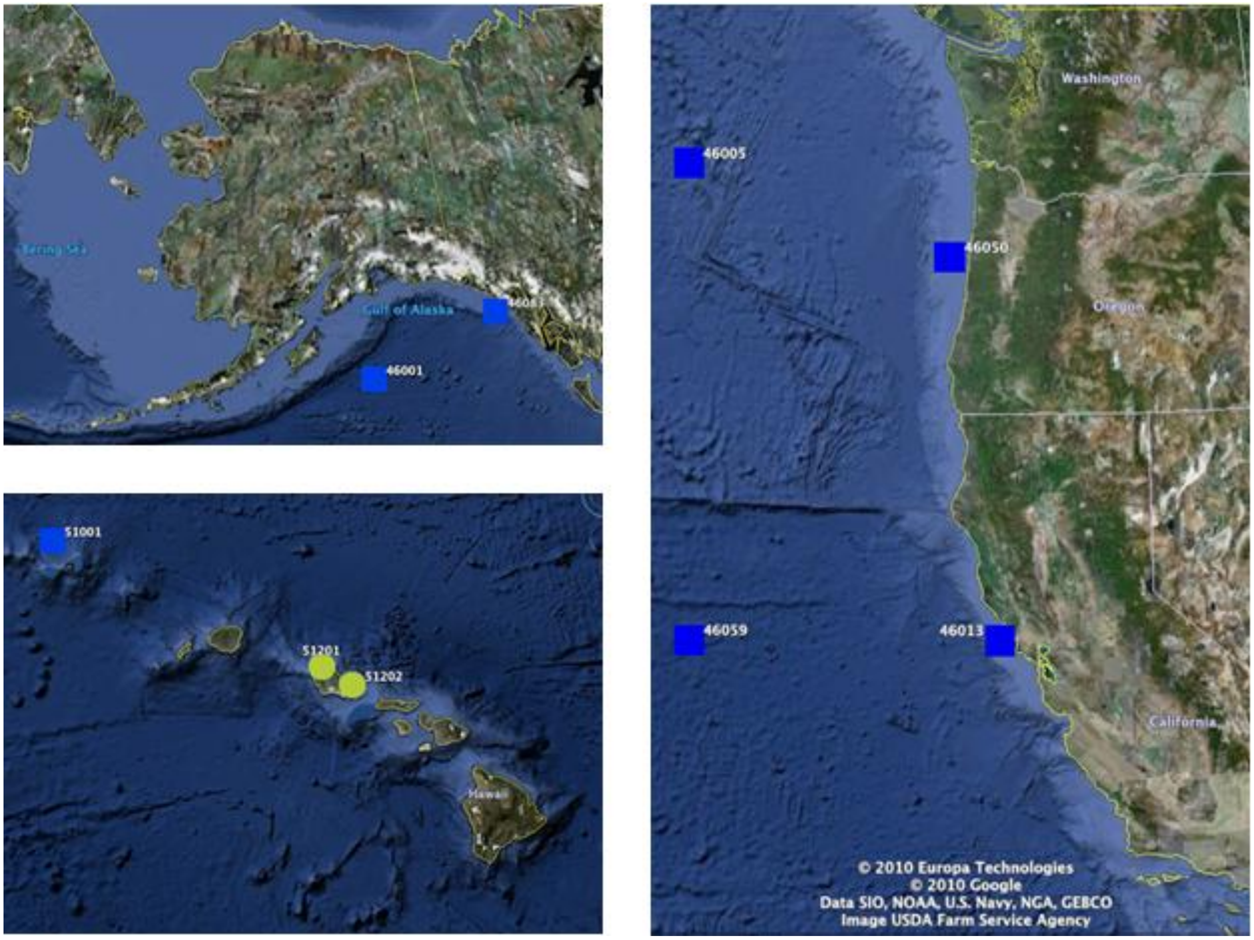

Figure 1: Google Earth view of US Pacific regions with wave measurement stations used in this study, where blue squares represent NDBC stations and yellow circles represent CDIP stations.

The stations used in this study are listed in Table 1. Parameter files from each station containing hourly values of both significant wave height (H_S) and peak period (T_P) were used between the years 2000 and 2009. The wave power (P) at each time was computed as:

$$P = \frac{\rho g^2}{64\pi} H_S^2 T_E \tag{1}$$

where $\rho = 1025$ kg/m^3 is the density of sea water, $g = 9.81$ m/s^2 is the acceleration of gravity, and T_E is the energy period which is approximated using the formula $T_E = 0.86 T_P$, assuming a Peirson-Moskowitz spectrum. This approximation is necessary in order to compute the wave power using the peak period, but it should be realized that it is only an approximation, true only if the spectrum is actually of the Peirson-Moskowitz form. Monthly power values from each respective month were averaged and missing data points were not compensated for. The average offshore and nearshore monthly power at the four regions are plotted in Figure 2.

The coastline of the Pacific Northwest is about 900 km long facing due west, receiving the powerful Pacific waves directly. This area also has a rather steep continental shelf; in most places, the 80 meter depth contour is within 20 km of the shore. These geographical features give the Pacific Northwest the most energetic accessible wave resource in the United States, estimated by EPRI to total about 440 TWh/year [1]. A detailed resource assessment utilizing buoy data was recently carried out by Lenee-Bluhm. This study shows that in general, the average annual power per unit coastline is above 40 kW/m in deep water, and attenuates to as low as 30 kW/m by the 50 m depth contour [4]. Figure 2 also shows that the offshore average monthly power is as high as 100 kW/m in the winter, but drops as low as 10 kW/m in the summer.

Table 1: Wave measurement stations used in this study

Station I.D.	Latitude (deg.)	Longitude (deg.)	Depth (m)	Distance (km)	Avg. Power (kW/m)
46002	42.57	-130.46	3500	480	51
46050	44.641	-124.5	123	35	35
46059	37.983	-129.997	4600	560	45
46013	38.242	-123.301	116	25	29
46001	56.3	-148.021	4200	300	44
46083	58.243	-137.993	136	45	33
51001	23.445	-162.279	3430	260	30
51201	21.673	-158.116	200	6	17
51202	21.415	-157.678	100	6	16

The remaining coastline of California is about 1000 km long and is oriented to the southwest. This, combined with its lower latitude, makes it slightly less prone to the highly energetic winter waves coming from the west and northwest, but also allows it to receive more waves from the southern hemisphere during the summer. The continental shelf is similar in California to that of the Northwest, although the southern coastline is less steep. A study done using SWAN in combination with buoy data by Beyene & Wilson indicates maximum annual average power of 32 kW/m on the northern California coast, and drops as low as 10 kW/m in the south [5]. The offshore power trends are similar to those in the PNW, though in Figure 2 it is seen that nearshore winter power levels are reduced.

Hawai’i is a unique location with respect to wave energy because of its isolation. The state currently imports nearly all of its energy resources, making a domestic power source such as wave energy more attractive and practical here than most mainland locations. According to the Energy Information Administration (EIA), electricity costs 29.2 cents/kWh in Hawai’i compared to the national average of 9.74 cents/kWh [6]. A detailed report by Hagerman indicates that each island except Maui could satisfy their entire electricity demand using 5-10% of the available wave energy [7]. Hawai’i is also unique because it sits in the tropics, virtually in the middle of the Pacific, thus it is subject to waves from the north in the winter, and from the south in the summer. This is evident by the difference in power incident on the north and east coasts of Oahu, as shown in Figure 2. Also, being a volcanic island, the continental shelf is extremely steep, the 80 m depth contour is within 4 km of the coast in most locations (and within 1 km of some). However, some of the wave energy is defracted around the islands, as the average annual power in offshore waters is about 30 kW/m, while the power nearing the coastlines is about 10-15 kW/m as found by Hagerman. The EPRI estimated total power available is 330 TWh/year, though much of the area included in the region of this estimation (extending all the up to Midway Island, 1300 km NW of Kaua'i) is remote and difficult to access [1].

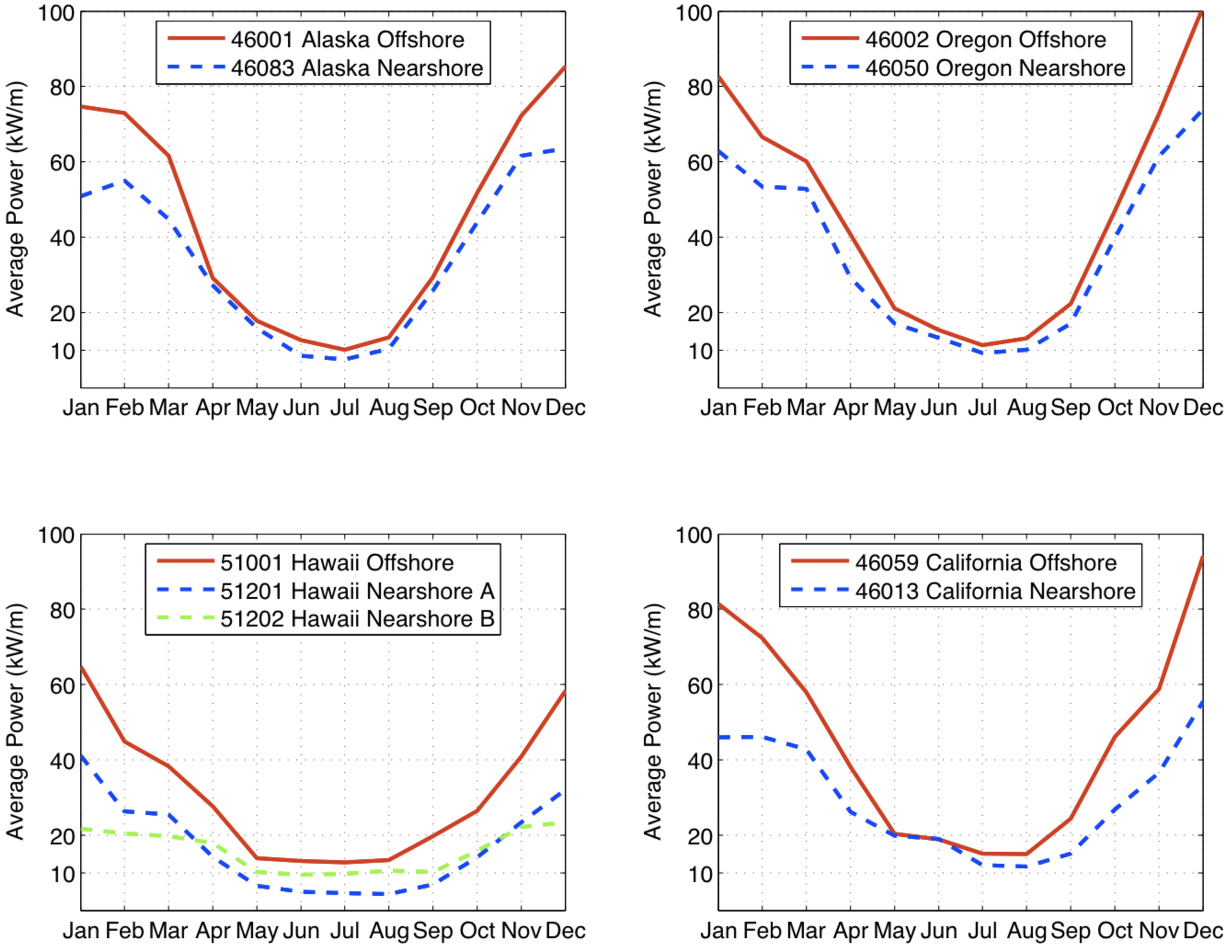

Figure 2: Average wave power at selected locations in the Pacific Ocean.

Alaska has a similar quality to Hawai'i in that many of its communities are relatively isolated, making domestically generaged wave energy more attractive. The average cost of electricity in Alaska is estimated by the EIA to be 14.7 cents/kWh, but isolated communities that rely almost exclusively on diesel generation can see costs approaching 50 cents/kWh [6]. The continental shelf on the southern coast generally extends farther out to sea than it does on the west coast of the lower 48 states. However, the shelf gradually dissappears further to the west along the Alutian Islands, making the conditions at the furtherst islands similar to those in deep water. The total power estimated by EPRI along the southern coast, including the Alutians (a chain over 3000 km in length), is 1,250 TWh/year [1]. However, much of this region is very remote, hosts small populations and lacks electrical distribution infrastructure. At the locations used in this study, the incident power resembles that in the Pacific Northwest.

2.3 Wave Energy Resource in Canada and New Zealand

The wave energy resource on the Pacific coast of Canada (i.e. the province of British Columbia) is very similar to that of the US Pacific Northwest. However, the coastline is unique in that it has large islands, Vancouver Island and the Queen Charlotte Islands, which sit near the edge of the continental shelf and intercept most of the wave resource. A study by Cornett used wind/wave hindcasting to assess Canada's offshore wave energy resource, finding that annual average power levels in deep water are between 40-45 kW/m, attenuating to 25 kW/m near the shore of Vancouver Island, and 35 kW/m near the Queen Charlotte Islands [8].

New Zealand recently commissioned a detailed wave energy resource mapping effort which used a SWAN model to forecast nearshore conditions using data from NWW3 nodes as input [3]. The results show that power levels are higher on the western coast, with yearly averages above 30 kW/m within 15 km of the shore. The most energetic region is the southwest tip of the south island, where their average power levels exceed 70 kW/m [3].

3. WEC Technologies in the Pacific Region

Over the past few years, wave energy development in the Pacific region has made significant progress. Several sites in the Pacific Northwest and Northern California have been commissioned to host deployments of full scale wave energy converters, which will allow developers to gain operational experience and further test their designs. There are many different developers who are researching wave energy conversion, some of the current front runners in terms of Technology Readiness Levels are described below [9]. This section gives an overview of the achievements, status, and future plans of Ocean Power Technologies, Columbia Power Technologies, and Resolute Marine Energy in the United States, and Power Projects Limited in New Zealand.

3.1 Ocean Power Technologies

Ocean Power Technologies (OPT), was founded by George Taylor and the late Joseph Burns in 1994. Between its offices in New Jersey, USA and Warwick, England, OPT now employs more than 50 people. Since its establishment, OPT has deployed multiple PowerBuoys in several locations, and has plans for more deployments in the future. In addition to utility scale PowerBuoys, the company has developed smaller autonomous systems designed to power scientific instrumentation, and self contained sub-sea power conditioning modules.

OPT's flagship technology, the PowerBuoy, is a point absorber that utilizes a hydraulic power take-off system which converts the relative motion between a heaving buoy and spar into usable power. Full scale testing of the PB40 (40 kW PowerBuoy) began in 2004 with a 24 month deployment off the coast of New Jersey that was not grid connected. Following this deployment, a modified PB40ES was deployed 1.2 km off the coast of Oahu, at the U.S. Marine Corps Base in Kaneohe Bay, Hawai'i in December 2009. This buoy is connected to the base's power grid through subsea cables.

In the European Atlantic, OPT has installed one PB40ES off the coast of Santoña, Spain, with permitting for up to 1.39 MW of generating capacity. They have also built a PB150 at Invergordon, Scotland, and plan to deploy it off the Scottish Coast [10]. A rendering of the PB150 can be seen below in Figure 3.

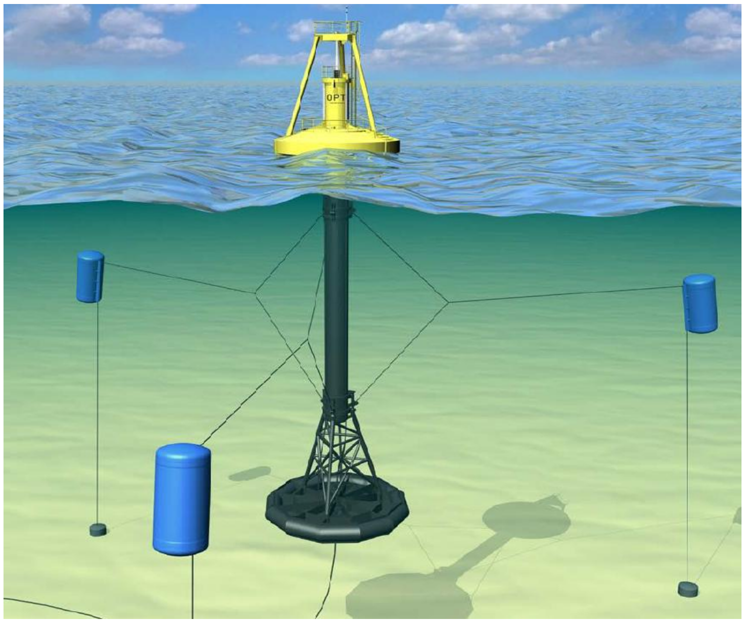

Figure 3: Ocean Power Technologies' PB150 [11].

In North America, OPT also seeks to deploy their PB150 WEC off the coast of Oregon. The company is in the process of securing rights to deploy about 4 km off the coast of Reedsport, Oregon, with possible incremental installation of up to ten PB150's over the next two to three years [11]. One buoy has been built to date at Oregon Iron Works, located just outside Portland. OPT has received $1.5 million in funding from the U.S. Department of Energy (DOE) to develop a 500 kW PB500 device.

3.2 Columbia Power Technologies

Columbia Power Technologies (CPT) of Corvallis, Oregon traces its roots back to research conducted at Oregon State University on linear permanent magnet generators by Professor Annette von Jouanne and the late Alan Wallace in 1998 [12-14]. CPT was founded in 2005 as a part of Greenlight Energy Resources Inc., a company with renewable holdings in wind, solar, and biofuels. The company is primarily financed by the U.S. Department of Energy, the U.S. Navy, and private investors. To date, CPT has conducted three ocean deployments, testing a first generation direct-drive point absorber buoy in 2007 [15]. In the fall of 2008, they deployed a second generation 10 kW device for a total of 5 days that was connected by an electrical umbilical to a power analysis and data acquisition system onboard the deployment vessel [16].

Starting in the fall of 2009, CPT began testing of their newest design, the Manta, shown in Figure 4. The Manta is a direct drive point absorber which harvests power from the torque applied by the passing waves on two floats. Tank testing was conducted in the O.H. Hinsdale tsunami basin, where the 1:33 scale WEC was subjected to both monochromatic waves and multidirectional spectra representative of the wave climates in both the Pacific and Atlantic Oceans. Following completion of this test, a 1:15 scale prototype was tested in the O.H. Hinsdale wave flume. Using a motion tracking technology called Phase Space which utilizes cameras to track the movement of LED wands mounted to the buoy's superstructure, test data was captured for verification of numerical models [17].

Figure 4: A rendering of Columbia Power Technologies' newest design, the Manta [18].

In the fall of 2010, CPT deployed a 1:7 scale (4.25 m tall and 2.6 m wide) Manta device off of Discovery Park, in the Puget Sound near Seattle, Washington. The wave resource at this location is expected to be a well-scaled representation of the Oregon wave climate. The buoy plans remain in the water for 6 months, and is not grid connected. CPT hopes to deploy a full scale Manta device in 2012.

3.3 Resolute Marine Energy

Resolute Marine Energy (RME) was founded in 2006 by William Staby. Rather than focusing on utility-scale power generation and high density offshore arrays, RME is initially targeting smaller-scale, wave- driven solutions which can be utilized in commercial applications such as desalination or micro-generation.

Hoping to make a quick impact on the market for niche autonomous wave energy systems, RME is currently developing a near shore device called SurgeWEC, aiming to help displace diesel generation in isolated coastal or island communities. This device employs a hinged paddle which they claim is dynamically tuned to the incoming wave climate. Incident waves cause the paddle to oscillate back and forth, which displaces a hydraulic piston, pumping seawater to shore via an underwater pipe. Once onshore, the water can be run through a reverse osmosis desalination system to produce fresh water for irrigation or drinking, or through a generator to produce power. RME hopes to conclude integrated component testing in late 2011, and to deploy a pilot-scale desalination project in the beginning of 2012.

In the long term, RME hopes to progress its design for a point absorber called 3D WEC which the company believes is well-suited for deployment in utility-scale, grid-connected offshore power projects, particularly those that employ a mix of wind turbines and wave energy converters. RME is currently planning reduced-scale ocean testing of the 3D-WEC in mid 2011 and full-scale ocean tests in 2012 [19].

3.4 Power Projects Limited

In New Zealand, Power Projects Limited is currently developing a point absorbing WEC which can take advantage of the country’s strong wave energy resource. The company deployed a 1:4 scale prototype with rated power of 2 kW intermittently from December 2006 to November 2008. A second 1:4 scale device has also been deployed intermittently since November 2009, but testing will continue with iterative modifications. A 1:2 scale (20 kW) device is scheduled to be constructed later this year, and deployment about 4km off the Taranaki Coast near New Plymouth is planned for 2011. Power Projects Limited receives funding from the New Zealand Marine Energy Deployment Fund [20].

4. Licensing and permitting in the US and Canada

Since wave energy is still a developing technology, and little is known about its impact, a WEC licensing and permitting framework has yet to be established in either the US or Canada. In the US, the state of Oregon will be one of the first states to have a full scale project, and significant efforts to support the development of wave energy are being undertaken. The Oregon Wave Energy Trust (OWET) has developed a series of licensing and permitting roadmaps in an attempt to ease the licensing and permitting process as well as clarify regulatory agencies’ requirements [21]. The Canadian government has a list of agencies which may be relevant to wave energy, but does not have established roadmaps [22]. Based on the suggested regulatory agencies included on this list, the licensing and permitting process in Canada will be similar to that of the US. This similarity is exemplified through government jurisdiction. In the US, states have power over waters up to 3 miles from shore, and the federal government via the Bureau of Ocean Energy Management, Regulation, and Enforcement, formerly the Minerals Management Service, regulates waters further than 3 miles from shore. A similar system exists in Canada, where provinces govern the territorial sea, defined as 12 nautical miles from shore, and the federal government regulates water further than 12 nautical miles from shore [23]. In both the US and Canada, state or provincial licensing and permitting is required, even if the device is deployed in federal waters, since state or provincial land may be affected. Other similarities include (but are not limited to): tribal and aboriginal allowances, overlapping migratory species acts, and required environmental assessments. While each state or province will have its own set of regulations, for this paper the Oregon regulatory process will be used as an example.

A summary of the necessary state and federal licenses and permits for a commercial project with grid connection in Oregon will be given in the subsequent sections, followed by a description of the federal action agencies which will likely require consultation before the licensing and permitting process can be completed. This process will be detailed by following the OWET developed roadmap for a commercial project with grid connection which implements the Traditional Licensing Process with a Settlement Agreement.

4.1 State Licensing and Permitting in Oregon

The permitting roadmap shown in Figure 5 is for a grid connected WEC deployed in Oregon state waters. If the device is within state lines and connected to the national grid, it requires a Federal Hydroelectric License from the Federal Energy Regulatory Commission (FERC) for grid connection, and State Hydroelectric License for using waters within state jurisdiction. First, the developer must apply for a FERC Federal Hydroelectric License and State Hydroelectric License is to file a Preliminary Permit Application (PPA). The state level PPA can be filed in conjunction with the federal PPA through the FERC. Since their input is required for PPA approval, it is prudent for WEC developers to first consult with federal, state and local agencies as well as the relevant stakeholders to address their concerns. If the PPA is approved, then the WEC developer is issued a Notice of Intent (NOI) and a Preliminary Application Document (PAD). Both documents are needed to file for the FERC and State Hydroelectric License.

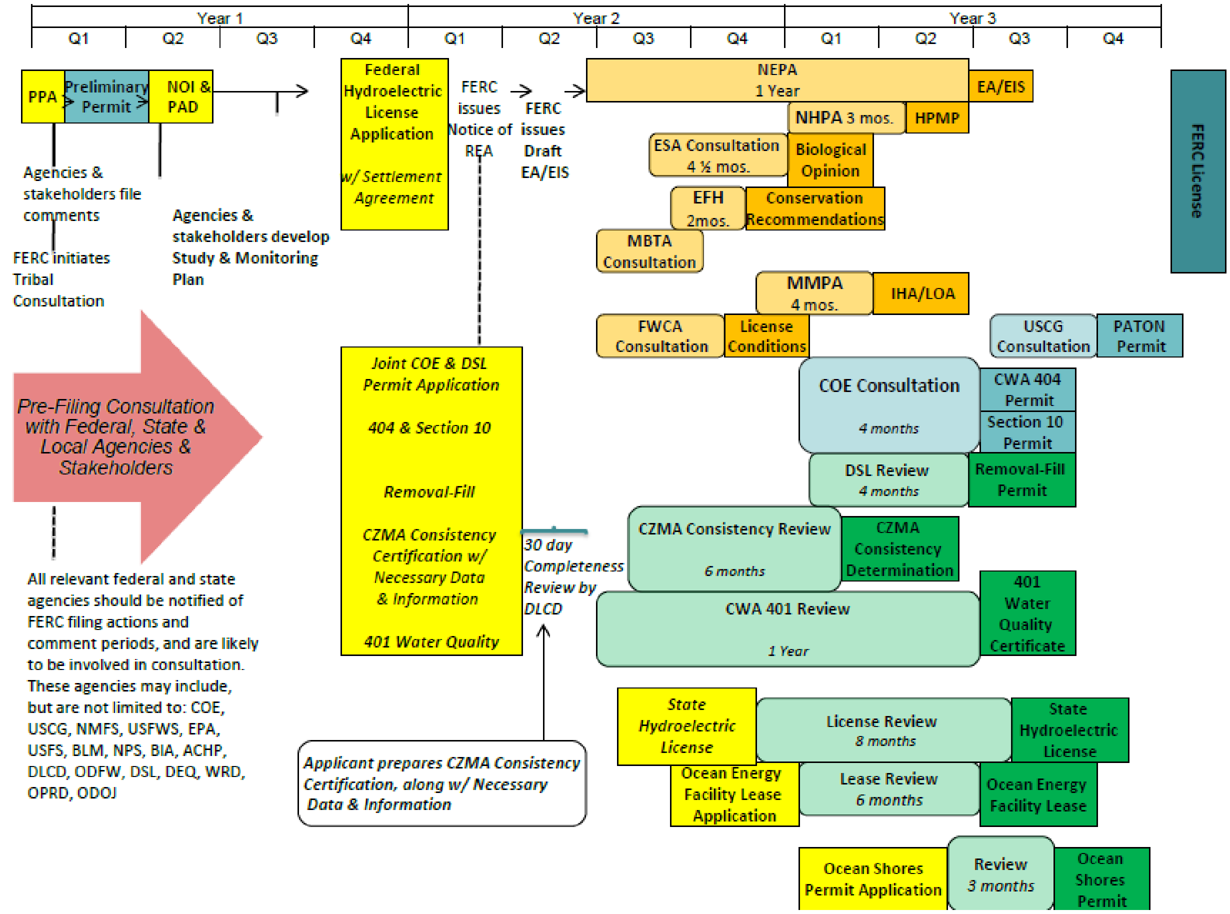

Figure 5: Oregon commercial wave energy project permitting roadmap, acronyms defined in Section 4 [21].

The permits required by the State of Oregon for any project in or affecting state land include: State Hydroelectric License, Ocean Energy Lease, Removal-Fill Permit, Ocean Shore Alteration Permit, Coastal Zone Consistency Certification and § 401 Water Quality Certification. Even if the project deployment is in federal waters, the project will need state permits for parts of the project that directly affect state lands, such as dredging or laying subsea cables.

The State Hydroelectric License is issued by the Oregon Water Resources Department (OWRD) and authorizes the right to acquire or hold right to use waters within the state. The Ocean Energy Lease is issued by the Department of State Lands (DSL) for commercial ocean wave energy device operation. The Removal-Fill Permit is issued by the DSL and is required to remove, fill or alter materials in state waters. This permit is required to place anchoring structures such as mooring lines or power transmission cables, and can be filed jointly on the federal and state level. The Ocean Shore Alteration Permit issued by Oregon Parks and Recreation Department (OPRD) is required for removal of products from the ocean shore such as those required to build a structure or lay cables under the ocean shore. The Coastal Zone Consistency Certification (CZCC) is issued by the Oregon Department of Land Conservation and Development (DLCD), a coordinating agency which insures that a proposed project is consistent with state's coastal zone management policies. The § 401 Water Quality Certification issued by the Department of Environmental Quality (DEQ) ensures that no federal license or permit authorizes activity that violates state water quality standards or becomes a future source of pollution. The § 401 Water Quality Certification is also required by FERC before it can issue the Federal Hydroelectric License. Both the CZCC and § 401 Water Quality Certification are required on the state and federal level, and can be completed through joint application on the state level.

4.2 Federal Licensing and Permitting in the US

The required federal permits for any grid connected project include: Federal Hydroelectric License, Army Corp of Engineers (ACOE) § 404 Permit, ACOE § 10 Permit, and Private Aids to Navigation Permit. The Federal Hydroelectric License is issued by FERC according to the Federal Power Act and gives the developer power to construct and operate a hydroelectric project. The § 404 Permit issued by the ACOE authorizes dredging and filling within US waters and insures compliance with permit conditions and consults with other agencies to evaluate potential impacts. This process often requires a biological assessment which will be described in more detail in Section 5.

The ACOE § 10 Permit ensures navigable waters for wildlife and requires consultation with the National Marine Fisheries Service (NMFS) and the United States Fish and Wildlife Service (USFWS) before issuing the permit. The NMFS and USFWS determine if the project affects threatened or endangered species, if so a 15-30 day public notice period is provided which allows time for public hearings before issuing a permit. Often the ACOE § 10 Permit also requires a biological assessment. The Private Aids to Navigation (PATON) Permit is issued by the United State Coast Guard (USCG) and grants the authorization for private installation, maintenance and operation of a properly marked structure. This navigational aid is required to stay in place until the structure is removed. It should be noted that there is some redundancy between the required state and federal level licensing and permitting.

4.3 US Federal Action Agencies

In many cases, federal licensing and permitting requires consultation with Federal Action Agencies. A Federal Action Agency is any federal department or agency proposing to authorize, fund, or carry out an action under existing authorities [24]. These consultations are shown in Figure 5 as stages in the FERC licensing process. For example, if a project is required to get a biological assessment, they must get appropriate National Environmental Policy Act (NEPA) documentation from FERC. NEPA requires evaluation of potential environmental impacts and assess alternatives before authorizing a project. Depending on the extent of potential impact, either an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) is required. An EA can take anywhere between 2-6 months and an EIS takes about a year to process. Both forms of biological assessment require consideration of federal, state, local, public and tribal input. An example of a biological assessment is the 2003 Environmental Assessment for the WEC deployment at the Marine Corps Base in Kaneohe Bay, Hawai'i [25].

If a project is thought to impact a listed endangered or threatened species, or its habitat, an Endangered Species Act (ESA) § 7 consultation is required for a FERC license. This ESA is administered jointly by the NMFS and the USFWS to insure that actions do not jeopardize a listed species or habitat. Once completed, NMFS and USFWS supply a biological opinion of either "jeopardy", "no jeopardy", or "reasonable and prudent alternatives" to FERC.

The Marine Mammal Protection Act (MMPA) makes it illegal to harass, hunt, capture, or kill any marine mammal prior to authorization granted by NMFS. Any wave energy project that is in a marine mammal habitat will be subject to the MMPA. NMFS has two authorization processes, an Incidental Harassment Authorization (IHA) and a Letter of Authorization (LOA). Once completed, MMPA must publish results and make available to public, given 30 days to submit comments on project proposal. Similarly, all wave energy projects will be subject to an Essential Fish Habitat (EFH) consultation issued by NMFS. NMFS administers the Magnuson-Stevens Fishery Conservation Act (MSA) which protects EFH from the water surface to the seafloor by issuing conservation recommendations.

The Fish & Wildlife Coordination Act (FWCA) requires FERC to consult USFWS and NMFS regarding fish and wildlife to prevent loss or damage of fish or wildlife resources. Based on the consultation, FERC will establish Fish and Wildlife License Conditions. According to the Migratory Bird Treaty Act, FERC must also consult the USFWS for migratory bird protection recommendations. The § 106 National Historic Preservation Act (NHPA) requires federal consultation by the State Historic Preservation Office and the Tribal Historic Preservation Office and consideration of public and tribal opinion. NHPA requires FERC to identify and assess effects of project on historic resources and often requires project to develop and implement a Historic Properties Management Plan (HPMP).

5. Environmental Concerns

Since the environmental impacts of wave energy are largely unknown, some form of biological assessment will likely be required in order for a project to be granted the required licenses and permits. Section 5.1 will outline a preliminary assessment which pinpoints potential environmental impacts of a wave energy project. While each site will have its own environmental concerns, Section 5.2 will use the OPT Reedsport, Oregon wave park Settlement Agreement as a case study to describe the site's environmental concerns and monitoring process.

5.1 WEC Preliminary Assessment

A preliminary assessment of the potential environmental impact of ocean renewable energy extraction was completed by Boehlert and Gill in 2010 [26]. This study lists environmental stressors and receptors potentially affected by a wave energy project. Stressors are defined as features of the environment that may change with deployment of a WEC and can have either negative or positive impacts on the environment. Receptors are defined as ecosystem elements with potential for response to a stressor. The purpose of a preliminary assessment is to pinpoint potential impacts that must be addressed before a project's licenses and permits can be granted. In most cases, the actual impact of these stressors and receptors are unknown and will likely require further research and continued monitoring.

The potential environmental stressors of WEC deployment listed by Boehlert and Gill include: physical presence, dynamic effects, chemical effects, acoustic effects, and Electro-Magnetic (EM) effects. The above surface presence of a WEC may impact seabirds and migratory birds, the surface presence of the device may be a hindrance for surface dwellers, and the below surface presence of mooring cables and power lines may form artificial reefs. The dynamic effects of WECs will likely have near and far field effects. WECs will most likely not differ much from other marine constructions with respect to chemical effects; however, one concern is hydraulic fluid leaking from a WEC with a hydraulic power take-off system. The acoustic effects of WECs on the environment are currently unknown, but it is expected that the construction phase will be the noisiest and most acoustically diverse phase of the project, whereas the operational phase will likely add to background noise. The main acoustic impact is expected to be on fish and marine mammals which use acoustics for communication, reproduction, orientation, and predator and prey sensing. EM effects will be produced by WECs with subsea cables to shore which produce low frequency Electro-Magnetic Fields (EMFs). The actual impact of EMFs on organisms is largely unknown, but can potentially impact large scale migration, finding mates, orientation and hunting.

Boehlert and Gill list the potential environmental receptors as: the physical environment, pelagic habitat, benthic habitat, fishes, marine birds and mammals. WECs may influence the physical environment by creating a shadow region, thus changing the wave height and influencing sediment transport and deposition which could lead to need for dredging or beach nourishment. A WEC will influence the pelagic and benthic habitat by creating a structure where there was previously none, which attracts more organisms and thus more predators. Large wave parks will act as marine reserves which will also attract organisms, and may affect species that migrate through the site.

The greatest foreseen impact of WECs is on marine birds and mammals. Sea birds are attracted to lighting above water, which WECs will be required to have for navigational purposes. WEC lighting may result in sea bird collisions, especially at night. However, experience with wind turbines suggests that birds are able to navigate through arrays of turbines and there are few records of bird collisions with offshore structures. Marine mammals are of concern because WEC mooring systems may lead to cetacean entanglement or collision; however, the likelihood of these events is highly dependent on the mooring configuration. This is of greatest concern for wave parks, which will require more complicated mooring configurations. A related concern is that some feeding whales swim with their mouth open which may cause the mooring line to become lodged in the whale's mouth. Additionally, if fish and invertebrates are concentrated around the site, cetaceans will be attracted to the area.

5.2 OPT Settlement Agreement for Reedsport, OR

Once a preliminary assessment has been completed, the stressors and receptors of concern for a particular site need to be addressed. The OPT wave park Settlement Agreement for a 35 year license for 10 PowerBuoys off the coast of Reedsport, Oregon will be used to exemplify specific environmental concerns at the site [10]. As shown in Figure 5, part of the federal permitting process involves drafting and signing of a Settlement Agreement by the main stakeholders and regulatory agencies involved in the project. A Settlement Agreement is an understanding between agencies and the developer detailing how to address unresolved issues of concern. The OPT Settlement Agreement outlines a plan for addressing environmental issues of concern by specifying continued monitoring plans and adaptive management of the Reedsport site.

Cetaceans were listed by Boehlert and Gill as potential receptors, accordingly the OPT settlement agreement mentions concern that cetaceans will not be able to detect mooring systems, which may lead to collision or entanglement. Cetaceans of specific concern in the PNW located within the OPT site include: grey whales, harbor porpoises, humpback whales, southern resident killer whales, sperm whales, sei whales, blue whales, and fin whales. Grey whales have not been federally listed as an endangered species since 1994, however they are still listed as endangered by the state of Oregon. This is of special concern for the OPT deployments off the coast of Reedsport, because the site lies within the grey whale migratory route between Baja California and the Bearing Sea. A three phase study plan is outlined in the Settlement Agreement to determine if whales can detect and avoid the wave energy project in all seastates. The first phase was a baseline characterization study that monitored whale behavior in and around the site between 2007 and 2008. Monitoring of the site will continue during and after installation with acoustic emission characterization during various seastates in phase two. Phase three, post-deployment monitoring, specifies a shore-based whale monitoring plan focusing on grey whales during the peak migration season. Little is known of the impact wave parks will have on whales, so an adaptive management scheme will be used to address migration and entanglement concerns based on the results of this study.

Species possibly affected by EMFs known to be present within the OPT site include: elasmobranches, Pacific salmon, green sturgeon, dungeness crab, and plankton. Elasmobranches present near the OPT deployment site that use EMFs for finding prey include: big skate, soupfin shark, dogfish, white shark, longnose skate, California skate, sandpaper skate and Pacific electric ray. Pacific salmon use magnetic fields for navigation in combination with other stimuli so EMFs are not expected to have much impact on them. However, a similar species of concern in the Reedsport area are chinook and coho salmon because they are ESA listed species. Similar to how cetacean concerns were addressed, the Settlement Agreement specifies plans for continued monitoring of EMF effects and implementation of adaptive management.

Another issue of concern addressed in the Settlement Agreement is that pinnipeds such as seals and sea lions may use PowerBuoys as resting places, especially if the site attracts salmon. Lighting of the PowerBuoys is also addressed in the Settlement Agreement, because lights will likely attract offshore birds possibly leading to collisions or fatality. This is of greatest concern to the ESA listed birds in the area, which include: marble murrelet, brown pelican and short-tailed albatross. Other concerns mentioned are how fish and invertebrates will respond to WECs, as well as how WECs will influence waves, current and sediment transport.

Although several ocean deployments have been conducted in the US, most have been short in duration, or conducted outside the PNW. For this reason, there is little knowledge of the affects of WEC deployments, and new projects must be approached with caution in order to limit negative environmental impacts. The OPT Reedsport, Oregon Settlement Agreement provides a framework for an adaptive management strategy for the site by drawing from the experiences of scientific studies conducted at the site, and during the construction of other related projects, such as offshore wind farms. If wave energy development is to progress with public support, environmental concerns must first be addressed.

6. US Path to Commercialization

While developers are making clear progress and the issues of regulation and environmental impact are beginning to be explored, it is clear that much work is still needed. This section discusses the current plans for moving forward towards commercialization in the US, which begin by addressing the technical issues. A common realization in the industry is that more testing needs to be conducted before many questions can be adequately addressed. Once a technology is established and deployed on a commercial scale, many issues such as environmental effects and effective policy will become clearer. Therefore, much effort has been directed towards establishing testing centers to help mature the technology and industry.

6.1 NREL Technology Roadmap

A roadmap for the development of hydrokinetic technologies in the US has recently been drafted by NREL [2]. This document is the result of consultation with various stakeholders in the US, while the overall structure is very similar to the UKERC Marine Renewable Energy Technology Roadmap [27]. The document was also informed by an EPRI marine renewable energy workshop [28]. The US roadmap includes a vision statement as well as a deployment scenario and strategies for both commercial and technological development. According to the vision statement, the US would like to see the establishment of a cost competitive wave energy industry by 2030, with 23 GW installed capacity by that time. While 23 GW is an ambitious goal, it has been compared to the 35 GW of currently installed wind energy capacity, with claims that similar progress can be expected between the two industries. The deployment scenario shown in Figure 6 shows how project scale is expected to progress.

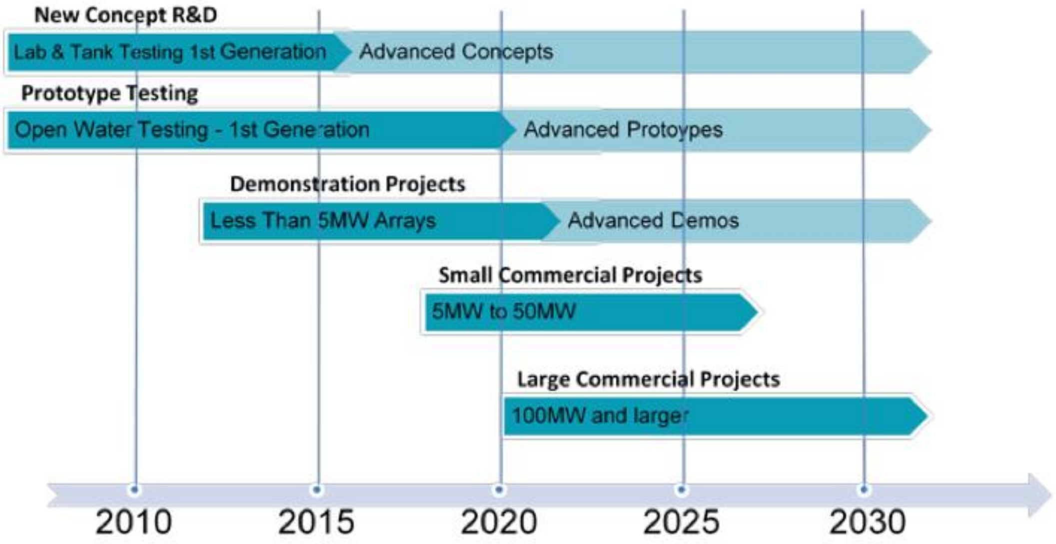

Figure 6. Deployment scenario for marine renewables in the US [2].

To aid in the commercial development called for above, a strategy has been formed which outlines seven major areas that need to be addressed. The issues of site selection, environmental research, R&D, and grid integration will likely be handled by both researchers and developers. The remaining issues of policy, market development, and economics will be handled by government agencies and supporting organizations such as OWET, which as noted in Section 4 has already created a framework for permitting.

The issue of technical R&D is further expanded in the roadmap to comprise a general technical strategy. Six areas in technology were identified for developmental focus, each being broken down into lists of more specific topics. Table 2 shows the primary areas of the technical strategy along with the more specific topics for those areas dealing with wave energy. As should be expected, these areas correspond to much of the research currently being done, particularly with respect to wave devices, as the inclusion of non-linear PTO models, array behavior and interaction, and device reliability and survivability are all difficult problems being addressed by developers and researchers alike. As is well known in Europe, the development of testing facilities is imperative to the advancement of the field. Accordingly, there has been increased attention devoted to developing such facilities.

Table 2: Technology strategy from the NREL Roadmap [2].

Primary Area	Specific Topics
Wave Devices	Device performance and dynamics models Advanced devise models: non-linear PTO and control Array prediction models System scaling and cost models Extreme event and reliability models Advanced concept and component development
Enabling technology	Seabed attachments Engineering design: standards and failure modes Environmentally friendly materials Lifecycle and manufacturing
Testing facilities and centers	Facilities: assessment and capacity building Capabilities: protocol and instruments Advanced testing technology: gap analysis Condition monitoring systems
Resource characterization	Spatial and temporal assessment and characterization Resource modeling and interaction with devices

6.2 NNMREC: A Testing and Demonstration Site

The Northwest National Marine Renewable Energy Center (NNMREC) was established by the US Department of Energy in 2008, and is meant to serve as a research and testing center. It is a joint effort between Oregon State University (OSU), conducting wave energy research, and the University of Washington, conducting tidal energy research. Other National Marine Renewable Energy Centers have been established in Hawai'i and Florida. NNMREC is close to completing the permitting process for its first testing site off the coast of Newport, Oregon.

While fundamental research is being done around the nation, there are several key facilities and developments in Oregon worth noting. The O.H. Hinsdale Wave Research Laboratory at OSU has a 104 m long wave flume and wide wave basin which can provide multi-directional spectral wave input to wave energy prototypes. Several tests of wave energy devices have already been conducted at this facility. The Hatfield Marine Science Center in Newport, Oregon, has experience in marine research and is working with OSU to assess the potential environmental impacts of wave energy to the Oregon coastal environment. Finally, a mobile testing package is being developed by NNMREC which will serve as a standardized platform on which various full-scale wave energy devices can be tested and certified. The testing package consists of a Power Analysis and Data Acquisition (PADA) unit that can be mounted directly to the device being tested. These units are self-contained and not grid-connected. It is envisioned that up to four devices could be tested at a time at the Newport site, each with its own PADA unit.

7. Conclusions

In recent years, it has become apparent that the current supply of electricity will soon be outmatched by demand. With global temperatures rising, petroleum sources dwindling, and increasing support to invest in clean and renewable sources of energy from the public, wave energy is again being considered as a critical component of the future energy portfolio. In Europe, significant advances have been made in the field of wave energy conversion, with several full-scale wave energy projects already in operation, or scheduled to be completed within the next year. With vast stretches of west-facing coastline, countries located in the Pacific rim are also looking to take advantage of the resource. Assessments of the energy available along the coasts of the US, Canada, and New Zealand shows that a significant resource exists, and can provide predictable, clean energy to populations which are moving ever closer to the coast.

With financing from government and private sectors alike, countless developers are researching WECs, are continually improving their designs, and moving closer towards the goal of commercialization. Dozens of companies are seriously pursuing wave energy in the Pacific Rim and several have identified themselves to be potential leaders, having already conducted large-scale testing. One area in which Pacific Rim companies are hoping to close the gap between themselves and their European competitors is ocean deployments. In the US, the PG&E WaveConnect project will allow up to four different WECs to be demonstatrated simultaneously in the waters off the coast of California. Further to the North off the coast of Oregon, the NNMREC mobile test berth is scheduled to be completed in 2012. This facility will have the capability to test WEC capacities totaling up to 1 MW, and will have full grid mimic capability.

With vastly increasing permitting requests in the past 5 years, government agencies have acknowldged that wave energy is a viable and important energy source. Federal and regional governments have recognized that resources must be dedicated to understanding the technologies, and creating a framework for the licensing and permitting of these devices.

In the US, the Minerals Management Service, the federal governemtns primary offshore energy regulatory agency, has been reorganized and renamed the Bureau of Ocean Energy Management and Regulation. This change has allowed the agency to be better equipped to deal with marine renewables, and recognizes the future value of this resource. Memorandums of Understanding have been filed between government agencies, which allows for an easier path towards commericalization for developers.

The topic of the environmental effects of WECs is still largely unknown. Significant public concern still exists about the impact of these devices on the ecosystem. In the end, much of the success of wave energy hinges on public approval, which influences government regulation, and ultimately the licensing and permitting of WEC projects. If the trust and approval of the public is to be gained, the cautious and environmentally responsible deployment and evaluation of WECs must be ensured by all stakeholders concerned.

The Pacific Ocean is home to some of the world’s most energetic waters, and provides ideal locations for wave energy projects. Renewable energy targets and increased governmental funding have created an environment which encourages expanding wave energy research and development efforts. Owing to a maturing technology, investments from private sources are becoming more prominent and important source of support for developers. The construction of infrastructure for device testing and new demonstration facilities promise to advance developers closer to commericialization. The future of wave energy in the Pacific Ocean appears bright.

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