Arnold Schwarzenegger
Governor

CALIFORNIA OCEAN WAVE ENERGY ASSESSMENT

PIER FINAL PROJECT DRAFT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission) conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California. The Energy Commission awards up to $62 million annually in electricity-related RD&D, and up to $15 million annually for natural gas RD&D. The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration
- Transportation

California Ocean Wave Energy Assessment is the final report for the California Ocean Wave Energy Assessment project (contact number 500-02-014) conducted by Mirko Previsic. The information from this project contributes to PIER's Renewable Energy Technologies Program Area program.

For more information on the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier/ or contact the Energy Commission at (916) 654-5164.

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Abstract

This report investigates the potential to generate electricity from ocean waves along California's coastlines. The report's main focus is on the assessment of the deep water wave energy resource. In addition, it assesses today's technology options, economics, environmental impacts and permitting with respect to developing this resource. In order to achieve the above objectives, data from about 100 measurement station were assessed and statistics created suitable for wave energy conversion, a summary of which is represented in volume I and a compilation of representative result are presented in forms of a wave energy atlas for California in volume II. Literature reviews and targeted research was used to assess technology options, economics and environmental and regulatory issues.

California has over 1200 km of coastline, and the combined average annual deep water wave power flux is over 37,000 megawatts (MW) of which an upper limit of about 20% could be converted into electricity. This is sufficient for about 23% of California's current electricity consumption. However, economics, environmental impacts, land-use and grid interconnection constraints will likely impose further limits to how much of the resource can be extracted. Although technology is still at a relatively immature stage, economic projections indicate that wave power could become cost-competitive over the long-term.

Keywords: wave energy, ocean energy, resource, power, technology, economics, environmental impacts, permitting

Executive Summary

This report was commissioned by the California Energy Commission to investigate the electricity generation potential of ocean wave energy resources located along the California coastline. In addition, the report assesses the current technical and economic status of ocean wave energy technologies and identifies requirements that might be imposed by those regulatory parties responsible for permitting ocean wave energy systems located in the state. The intent was to provide the California Energy Commission and other policy making bodies with objective and quantitative information upon which to make informed decisions regarding the development of the state's wave energy resources.

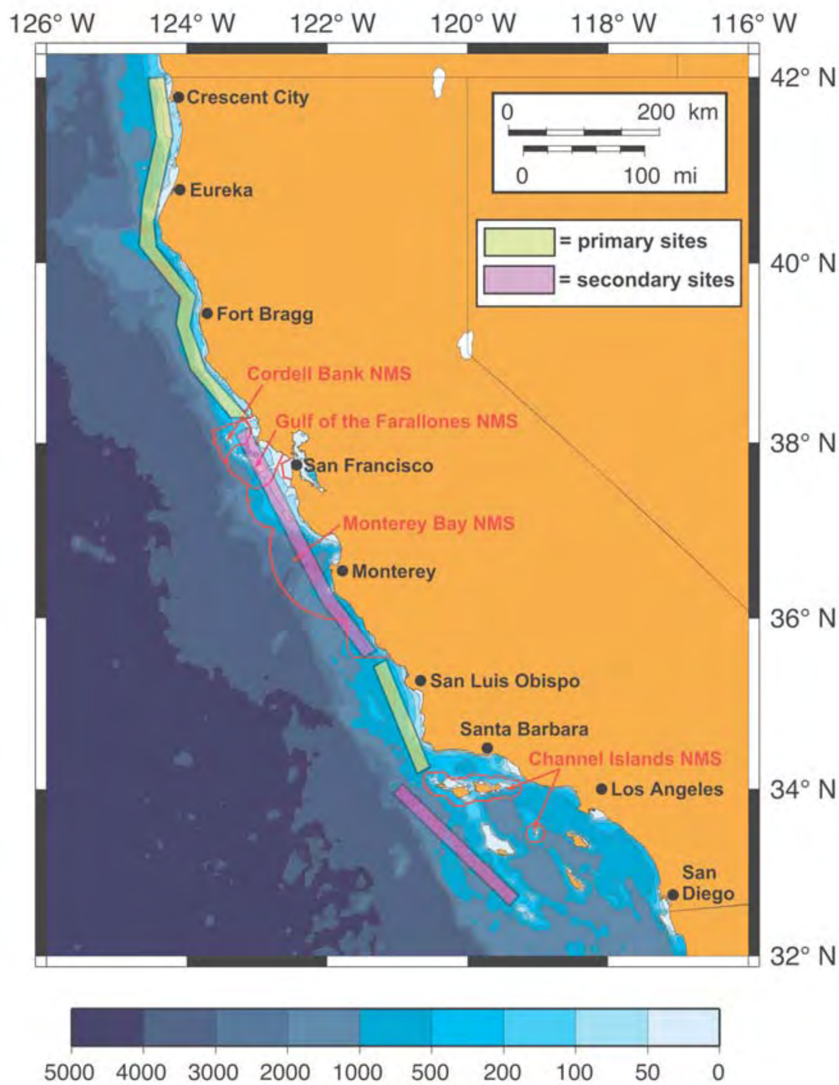

Figure 1 - Primary and secondary sites in California

Estimates of California's wave energy resources were developed from extensive statistical information on wave characteristics off the state's coastline. The wave energy resource information was then converted to estimates of potential electricity generation based on wave energy system performance factors. Costs of generating electricity from wave energy systems were predicted using economic models. Cost models were used in lieu of historical capital and operating costs as there are currently no commercial-scale systems in operation. Permitting requirements and regulatory agencies involved in siting ocean wave energy systems were developed from surveys.

To assess the wave energy resource off California's coast, the coastline was divided in 2 categories, primary and secondary sites. Primary sites were defined as locations with the following attributes; reasonable permitting process, excellent wave conditions and deep water (i.e., water depth greater than 50 meters) within 10 miles from the coast. Sites with these characteristics are expected to yield optimal wave energy economics. Secondary sites were defined as locations for which it will be difficult to obtain permits (e.g., marine sanctuaries) or sites that have to be located further offshore because of wave shadowing effects (e.g., Channel Islands in Southern California). Secondary sites would likely be developed only in the longer term due to their higher costs and permitting constraints. Grid interconnection restraints were not evaluated as part of this study, but could present further limitations to where wave power plants could be located.

There is more than 1200 km of useable coastline along California, and the combined annual deep water average power flux of the primary and secondary sites is over 37,000 megawatts (MW). The following table provides a breakout of the primary and secondary wave energy resources along ten one degree latitude study areas.

Cell	Landmark	Power Density	Primary Sites Length	Secondary Sites Length	Primary Sites Power	Secondary Sites Power
1	San Diego	32.2 kW/m	0 km	162 km	0 MW	5,213 MW
2	Los Angeles	32.2 kW/m	35 km	104 km	1,126 MW	3,347 MW
3	Santa Barbara	26.4 kW/m	127 km	0 km	3,357 MW	0 MW
4	Monterey	29.7 kW/m	0 km	127 km	0 MW	3,766 MW
5	Santa Cruz	28.0 kW/m	0 km	127 km	0 MW	2,838 MW
6	San Francisco	30.3 kW/m	104 km	18 km	3,147 MW	545 MW
7	Sonoma	32.2 kW/m	127 km	0 km	4,087 MW	0 MW
8	Mendocino	28.5 kW/m	130 km	0 km	3,709 MW	0 MW
9	Humboldt	33.7 kW/m	116 km	0 km	3,910 MW	0 MW
10	Del Norte	27.8 kW/m	81 km	0 km	2,253 MW	0 MW
	Total		**720 km**	**538 km**	**21,589 MW**	**15,709 MW**

Table 1 - California's wave energy resources along ten one degree latitude cells

In order to maintain a high capacity factor, which has a key impact on economics, wave energy conversion devices are tuned to the lower summer wave energy climate. As a result, only a portion of the total available energy will be extracted. Furthermore, taking into account the need for inter-device spacing, it was found that the amount of energy that can be extracted is likely limited to between 9% and 30% of the total energy flux using available technology. The large range of values reflects different technology options available today. It was found that the upper limit to economically tap into ocean waves is at about 20% of the primary resource. Based on this assumption an average 7460MW might be expected to generate up to 65 TWh per year from California's ocean waves. California's 2005 total energy generated (including energy imports) was 288 TWh, meaning that it would be technically possible to meet about 23% of California's electricity needs with ocean wave energy. However, it should be noted that environmental impacts, land-use and grid interconnection constraints will likely impose further limits to how much of the resource can ultimately be developed.

Wave energy conversion technologies have made great strides in the past few years toward commercial readiness. There are at the time of this writing a total of 6 in-ocean prototypes being tested in; Australia, US (Hawaii), UK and Portugal. Policy makers in the UK and Portugal responded to early pilot testing successes with the implementation of incentive programs to support the first commercial wave farms. As a direct result of such programs, the first commercial multi-megawatt wave farm is being constructed in Portugal and several more are in the planning stages in Portugal and the UK.

Despite significant progress in recent years, ocean wave energy conversion technology remains in an early stage of development. Similar to wind power in the 1980's, device developers are pursuing a large number of very different device concepts at various scales and there is no consensus as to which technology is superior. This is typical for early stage markets where no technology lock-in has occurred.

Economic projections indicate that ocean wave energy can become cost competitive with other forms of generation in California in the long term, if appropriate policies are created to support early adoption of technologies. Like any renewable technology, economics of wave power generation schemes is sensitive to energy density at the deployment site and as a result the choice of appropriate site is critical. An assessment of likely commercial opening costs by the Principal Investigator in 2004 indicated a cost of electricity from a large (100MW+) generation scheme of 11.2 cents/kWh[1] ($2004 real). The opening cost projections were based on a plant consisting of 213 Pelamis devices installed at a deployment site of San Francisco with a power density of 21kW/m. Additional sensitivity studies indicated that if the same plant was installed at higher energy density sites in Northern California the energy cost could drop below 8 cents/kWh. As with any power generation technology, cost of energy from early systems is high and is subsequently reduced as the installed capacity base grows.

Environmental impacts from wave energy conversion devices are site- and technology-specific. Structures associated with wave energy can have environmental impacts similar to other structures placed offshore, in virtue of their physical presence in the water, as well environmental effects unique to wave energy devices as such. Each specific project proposed for California will have to undergo a project-specific environmental review. Adverse impacts to the environment can often be avoided or reduced by careful project design and siting, and occasionally compensation can be provided to offset adverse effects.

Wave energy projects proposed for offshore California will be subject to a high level of public and regulatory scrutiny, and must meet a variety of federal, State and local environmental standards. Early involvement of stakeholders and regulatory agencies helps identify areas of concern, so that environmental issues can be addressed during the siting and design phase of the project. As discussed earlier, many adverse environmental effects can be avoided or reduced through careful project siting and design, helping to streamline the environmental regulatory process.

1.0 Introduction

Ocean wave energy is one of the most concentrated and widely available forms of renewable energy in coastal areas. The worldwide coastal wave energy resource potential is estimated at > 2 TW[2]. This compares to the currently worldwide installed electric capacity of 3.5 TW[3]. The fact

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[1] System Level Design, Performance and Cost – San Francisco California Pelamis Offshore Wave Power Plant, December 2004. Available for download from www.epri.com/oceanenergy

[2] An Overview of Wave Energy Technologies: Status, Performance and Costs, T W Thorpe 1999

[3] EPRI 2004

that 37% of the worlds population lives within 60 miles of a coastline[4] establishes a good match between resource and demand and will allow for a widespread adoption of emerging technologies that generate electricity from ocean waves. California has over 1200 km of coastline and a combined annual deep water average power flux of over 37,000 megawatts (MW). California features a high-energy wave climate and deep water close to shore[5] and major population centers. These are all indicators that ocean waves could make an attractive economic case to supply renewable energy to the state of California.

The purpose of this current wave energy resource study is to investigate the potential for ocean wave power in California. The main focus of the study is to provide a reasonable estimate of the ocean energy potential available and the magnitude of the extractable resource. In addition, technology, economics, environmental effects and permitting are assessed to provide a comprehensive picture of the realistic potential for ocean wave energy in California.

To estimate the total primary deep water wave energy resource, the data sets of about 100 wave measurement stations were used and a wave atlas was created with statistics that can be used to estimate the performance of wave energy conversion devices. In addition, a high-density digital bathymetry model was used to generate maps for the representative study areas. Volume II of this report contains all the representative statistics of the report.

Literature reviews and surveys with representative manufacturers were used to identify representative technology options. While there were a great number of developers at various stages of R&D, only those that are actively pursuing in-ocean testing at present were considered. In addition, shoreline technologies were excluded from the review because a preliminary investigation showed that the potential for such technology in California was very limited.

Wave energy conversion technologies have made great strides in the past few years toward commercial readiness. There are at the time of this writing a total of 6 in-ocean prototypes being tested in Australia, Hawaii, the United Kingdom (UK) and Portugal. Policy makers in the UK and Portugal responded to early pilot testing successes with the implementation of incentive programs to support the implementation first commercial wave farms. As a direct result of such programs, the first commercial multi-megawatt wave farm is being constructed in Portugal and several more are in the planning stages in Portugal and the UK.

To come up with reasonable economic projections, a base case developed by the Electric Power Research Institute (EPRI) for a commercial size (100MW+) wave power plant was used. The base case study was specifically developed for a site in San Francisco. Data was then extrapolated to a total of 14 measurement stations and the economic impact of different wave energy densities analyzed. Finally, learning curves were used to compare wave energy to wind at equivalent deployment levels.

[4] Who lives on how much coastline, EPA 1998

[5] 2-10 miles at most sites in Northern California with the exception of San Francisco. South California

Environmental issues and permitting in California were assessed from literature review of similar projects, which includes offshore wind, offshore oil and gas and other projects. The assessment included California-specific environmental issues such as gray-whale migration etc. A review of applicable laws and regulatory agencies involved in the permitting process is provided as well.

The report is organized into two volumes. Volume I contains an assessment of the California wave energy resource, a technology review, an economic section and a permitting and environmental effects section. Volume II is a compilation of all the relevant wave statistics and is meant to provide a basis for further R&D efforts in this field.

2.0 Wave Energy Resource

2.1. Wave Power Basics

Ocean waves are generated under the influence of wind on the ocean surface. Once ripples are created on the surface, there is a steep side available against which the wind can push and waves begin to grow. In deep water, waves can travel for thousands of miles without losing much power until their energy gets dissipated on a distant shore. Representing an integration of all the winds on an ocean surface, ocean waves are very consistent and sea states can be predicted accurately more than 48 hours in advance[6].

Ocean waves are an oscillatory system in which water particles travel in orbits. As the water depth decreases, the oscillation becomes smaller. Close to shore, in shallow water, the ocean waves are influenced by the ocean floor, which results in a loss of energy because of the friction of water particles on the ocean floor.

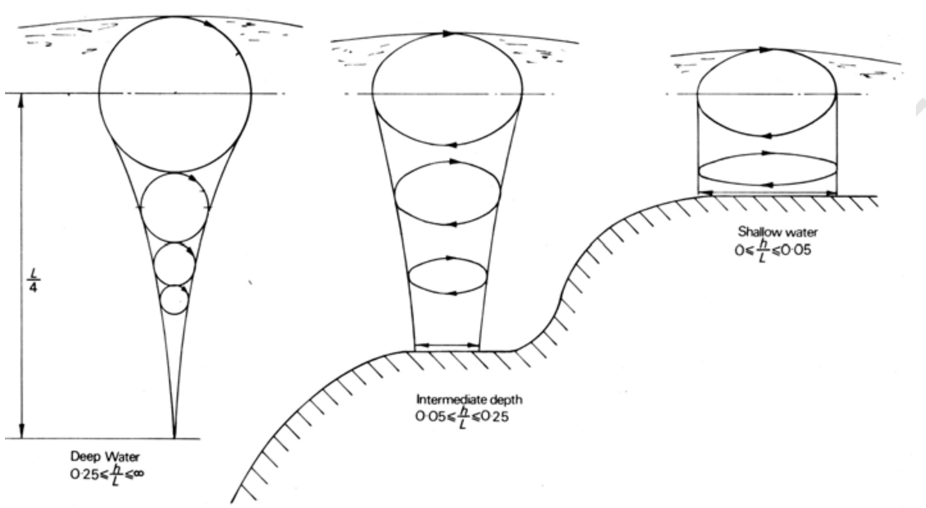

Figure 2 - Water particle orbits of an ocean wave

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[6] NOAA's WAVEWATCH III model is an example of a 3rd generation wind-wave model allowing wave predictions more then 48 hours in advance.

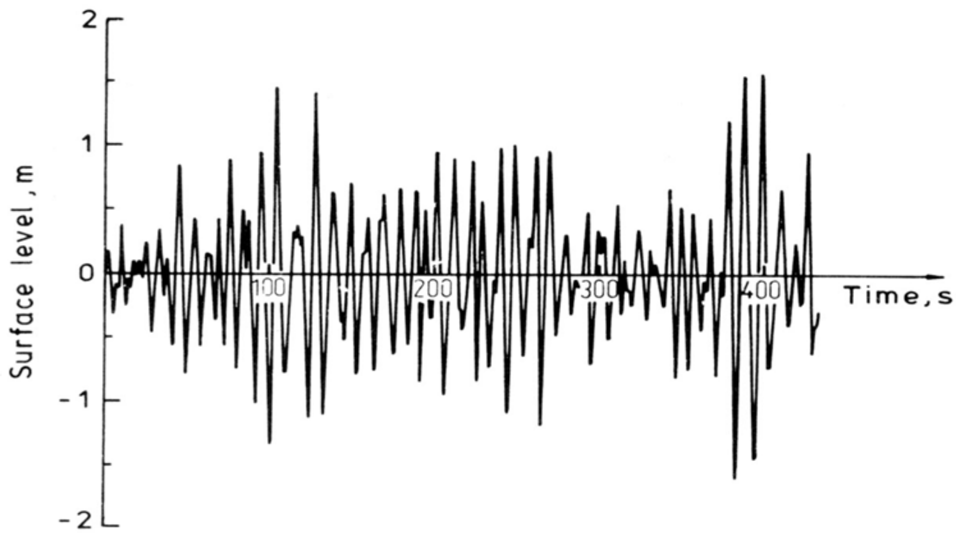


Figure 3 - Short-term variability of ocean waves

Ocean waves are a complex, strongly variable phenomenon. Real seas contain waves that vary considerably in height, period and direction. However, real seas remain relatively constant (Typically wave grouping occurs with repeating patterns having a timeframe of a few minutes) over the period of a few hours thereby comprising a sea state that can be described by a directional spectrum. The directional spectrum shows the distribution of energy in frequency f and direction θ.

In order to describe such sea states and to determine their characteristics relevant to wave energy utilization, statistical parameters derived from the wave energy spectrum must be used. Sea states are often summarized in terms of wave height, period and direction parameters. The spectral parameters used in the characterization of wave energy resource are the significant wave height H_s, energy (mean) period T_e (and spectral peak period T_p), mean direction ($\bar{\theta}$) and wave power level (P; i.e., the flux of energy per unit length of wave crest). The variation in sea states during a period of time (e.g. month, season, year) can be represented by a scatter diagram, which indicates how often a sea state with a particular combination of H_s and T_e occurs.

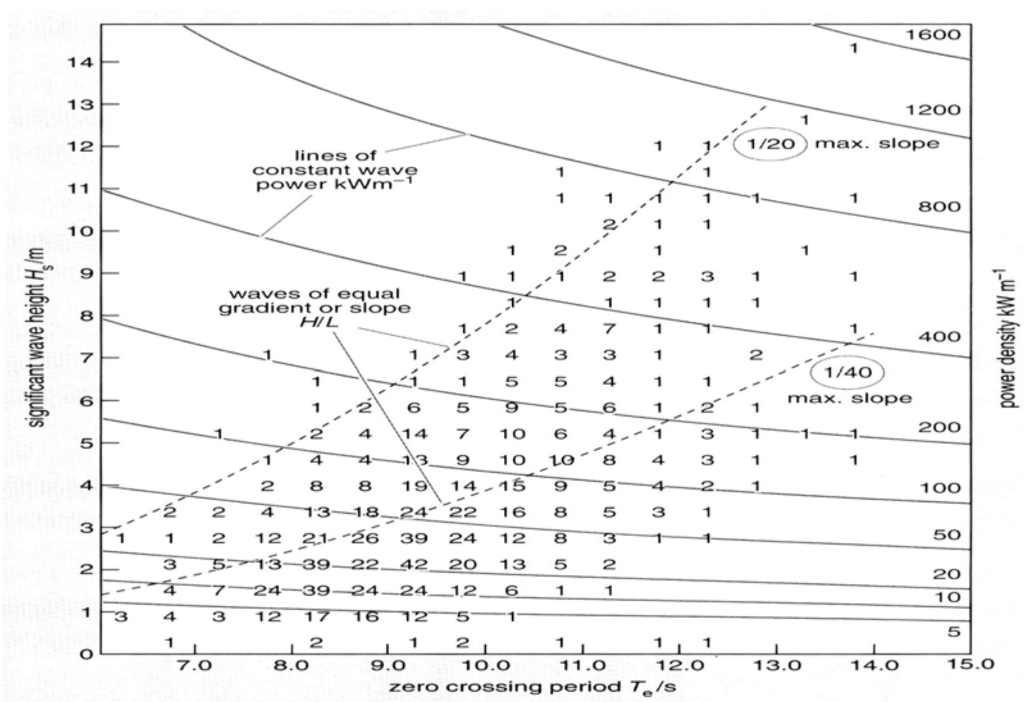


Figure 4 - Typical scatter diagram

In deep water (i.e., when the wavelength is smaller than twice the water depth), the power level in each sea state can be computed by:

$P = 0.49\ H_s^2\ T_e = 0.412\ H_s^2\ T_p$

If H_s is expressed in meters and T_e in seconds, P is given in kW/m. The average wave power level P_{ave} during a period of time can be determined from a scatter diagram corresponding to the same time period by:

$P_{ave} = \Sigma P_i\, W_i\ /\ \Sigma W_i$

Where W_i is the number of times that sea states with power levels P_i occur. Due to the strong seasonal and inter-annual variability of ocean waves, assessment of wave energy resource should be based on a long time series of wave data. The recommended duration is ten years. A five-year period is considered to be satisfactory, however, and assessments based on a shorter period (two or three years) still provide a valuable estimate.

In the deep waters of the open ocean, the wave energy resource is consistent over distances on the order of a few hundred kilometers[7]. This applies to large ocean basins, such as the Pacific Ocean. As waves approach the shore through waters of decreasing depth, waves are modified by a number of phenomena such as refraction and diffraction. As a result, the wave energy resource can vary significantly over distances of 1 km or much less in shallow waters,

[7] Based on data from the Coastal Data Information Program run by SCRIPPS Institute of Oceanography

depending on the local bathymetry. The energy level close to shore is usually significantly lower than offshore due to bottom friction. In addition, wave crests tend to become parallel to the shoreline in shallow waters. The local influence of the bathymetry can also have a focusing effect on ocean waves, resulting in local "hot-spots" that are favorable for near-shore or shore-based wave power conversion.

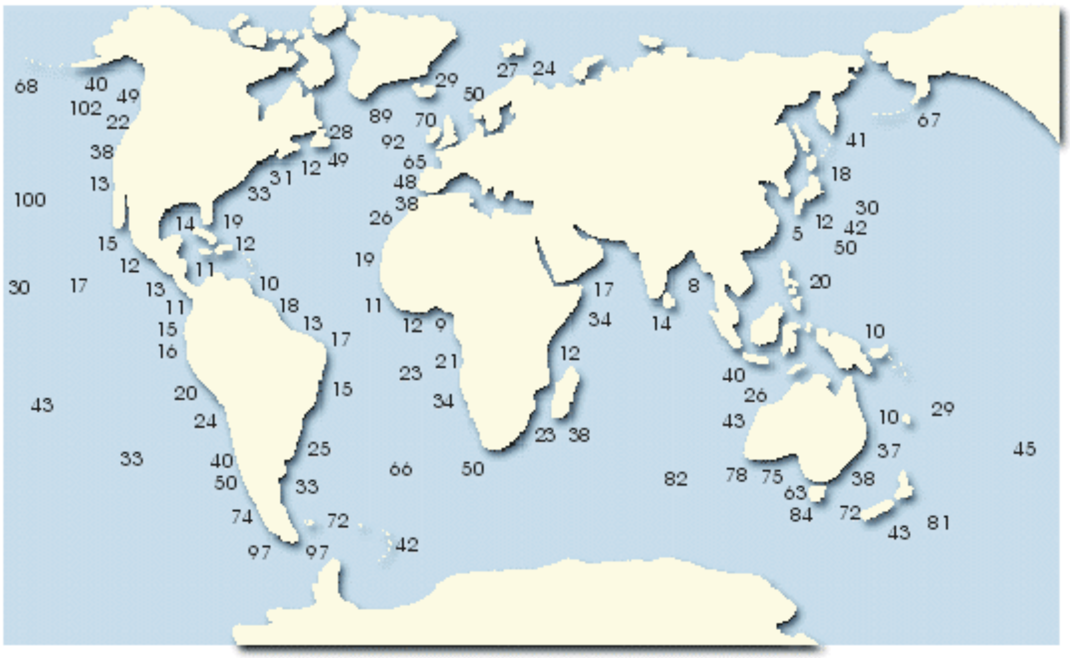


Figure 5 - Annual average wave power densities worldwide in kW/m

For the purpose of this study, only deep-water wave data has been analyzed (water depth > 50 m). If onshore wave power is being considered in selected locations, the deep-water wave statistics can be used as an input for mathematical shallow-water wave transformation models. Readers that would like to learn more about ocean waves are referred to traditional physical oceanography textbooks and wave energy literature.

2.2. Methodology and Data Sources

In California, a vast amount of wave data is available from historical measurements. Data sources that were available for this study and its verification include:

- Coastal Information Data Program (CDIP), Scripps Institute of Oceanography
- National Data Buoy Center (NDBC), NOAA
- Wave Information Study (WIS) results
- Pacific Ocean Reanalysis Wind 50-year time series
- Comprehensive Ocean-Atmosphere Data Set (COADS)

COADS data are derived from ship observations of wave parameters, and they are excluded from this study because they have proven to be inaccurate for the following reasons:

- average significant wave heights observed by ships are significantly less than buoy measurements, possibly due the fact, that ships tend to avoid stormy areas.
- COADS estimates of dominant wave period are shorter than the measured wave period and may be due to the difference in sea and swell observations.
- the variance of wave direction is much larger for COADS observations than for wave buoy measurements.

For analytical purposes, the California coastline was divided into 10 boxes and deep-water wave statistics suitable for wave power conversion were created for each box shown in the figure below.

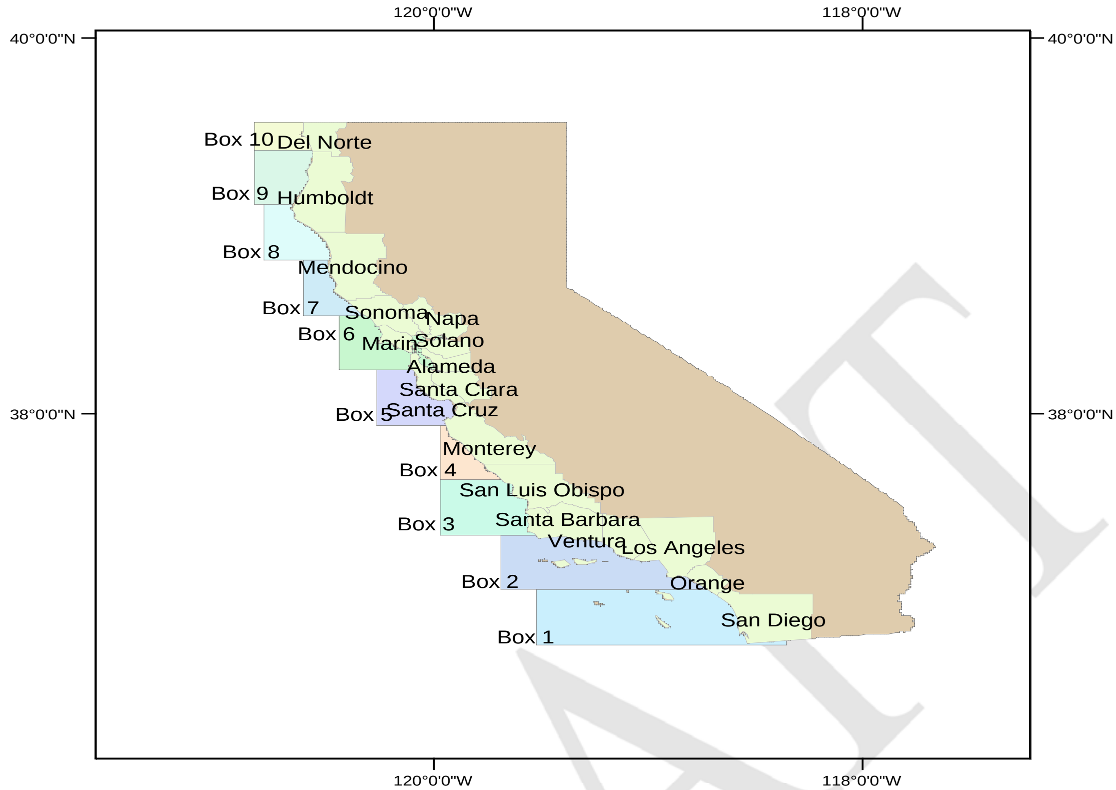


Figure 6 - Ten one-degree latitude cells analyzed in this study

There are roughly 100 wave measurement sites from which data were derived. Of these, 30 are located in deep water (water depth > 50 m) and were used to analyze the deep-water wave energy potential. A large amount of time was devoted to verifying the accuracy of the data sets and cross-checking them with other data sources. The following table lists all the wave measurement buoys that were available for this study.

Measured Wave Data Sources for California Wave Statistics

Study Box	Station Number	Station Name	Latitude (deg N)	Longitude (deg W)	Depth (m)	Data Coverage	Calendar Years with 12 Months of Wave Data
	NDBC and CDIP Measurements						
10	46027	St. Georges	41.85	124.38	60.0	1983-2001	1984-2001
	0025	Crescent City S	41.74	124.18	9.1	9/1980-1/1983	1981-1982
9	0112	Humboldt Bay Outer	40.95	124.43	248.7	4/1980-6/1981	
	0012	Humboldt Bay Inner	40.88	124.23	43.0	3/1980-9/1982	
	46022	Eel River	40.72	124.52	274.3	1982-2001	1982-1990 1992 1995-2001
8	46030	Blunts Reef	40.42	124.53	82.3	1984-2001	1985-1998 2000-2001
	0094	Cape Mendocino	40.29	124.74	325.6	3/1999-2/2000	
7	0030	Noyo	39.44	123.89	94.0	5/1981-6/1982	
	0031	Noyo Basin S	39.42	123.80	6.0	11/1981-6/1982	
	0032	Noyo Harbor H Dock	39.42	123.80	6.0	10/1981-6/1983	
	46014	Pt. Arena	39.22	123.97	264.9	1981-2001	1981-2001
	ptac1	Point Arena	38.96	123.74	31.1	1984-2001	
6	46013	Bodega Bay	38.23	123.33	122.5	1981-2001	
	0029	Point Reyes	37.95	123.47	548.6	12/1996-7/2002	
	0021	Stinson Beach	37.90	122.65	9.1	5/1980-7/1982	1981
	0056	San Francisco Wharf 45	37.82	122.42	13.4	3/1986-10/1989	1987-1988
	0041	San Francisco	37.81	122.43	7.6	12/1982-6/1984	1983
	0040	San Francisco Alioto's	37.81	122.42	7.0	3/1986-10/1989	1987-1988
	0065	Hyde St, San Francisco	37.81	122.42	12.1	9/1988-12/1989	1989
	46026	San Francisco	37.75	122.82	52.1	1982-2001	1983-1986 1991-1998 2000-2001
	0023	Pacifica	37.63	122.50	10.0	8/1980-12/1982	1981-1982
	0062	Montara	37.55	122.52	15.5	12/1986-3/1992	1987-1989
	0047	Farallon	37.51	122.87	102.4	1/1982-10/1995	1982 1987 1991
5	46012	Half Moon Bay	37.45	122.70	87.8	1980-2001	1981-1999 2001
	0007	Capitola Pier	36.97	121.95	6.1	12/1977-11/1979	
	0008	Santa Cruz Pier	36.96	122.02	8.4	1/1978-7/1981	1978-1979
	0006	Santa Cruz Harbor	36.95	122.00	13.1	10/1977-9/2001	1978 1981-1983 1987 1989 1992-2000
	0018	Seacliff	36.95	121.92	8.2	8/1978-5/1980	
	0044	N Monterey Bay	36.95	122.42	318.1	10/1979-4/1988	1982-1983
	0108	Santa Cruz Offshore	36.89	122.07	60.9	6/1978-8/1981	1980
	0009	Moss Landing	36.81	121.79	6.1	2/1978-9/1979	
	46042	Monterey	36.75	122.42	1920.0	1877-2001	1998-2001
	0061	Marina	36.70	121.82	15.0	12/1986-10/1995	1987-1993
	0010	Monterey Harbor	36.60	121.89	13.4	2/1978-7/1982	1980
4	46028	Cape San Martin	35.74	121.89	1111.9	1983-2001	1984-1998 2001
3	0076	Diablo Canyon	35.21	120.86	22.9	6/1983-7/2002	1985-1986 1989 1992-1994 1997-2002
	46062	Point San Luis	35.10	121.00	379.0	1997-2001	1998-2001
	46011	Santa Maria	34.88	128.87	185.9	1980-2001	
	46023	Pt. Arguello	34.71	120.97	384.1	1982-2001	1982-1995 1998-2001
	0120	Point Arguello Harbor Outer	34.57	120.63	5.8	5/1978-9/1979	
	0019	Point Arguello Harbor Inner	34.57	120.63	2.5	5/1978-4/1980	1979
2	0119	Point Arguello	34.49	120.72	83.0	5/1978-9/1986	
	0063	Harvest Platform	34.47	120.68	204.0	1/1987-4/1999	1987-1995 1997-1998
	0071	Harvest	34.46	120.78	548.6	12/1995-7/2002	1999-2002
	0011	Point Conception	34.45	120.43	16.8	6/1979-12/1979	
	0048	Point Conception Offshore	34.42	120.42	201.2	8/1978-12/1979	
	0017	Santa Barbara	34.40	119.69	7.6	10/1979-1/1983	1980-1982
	0107	Goleta Point	34.33	119.80	182.6	6/2002-7/2002	
	0090	Montecito	34.33	119.64	61.0	10/1995-2/1996	
	46054	Santa Barbara W	34.27	120.45	447.1	1994-2001	
	46063	Point Conception	34.25	120.66	598.0	1998-2001	
	46053	Santa Barbara	34.24	119.85	417.0	1994-2001	
	0081	Ventura	34.18	119.48	53.0	1/1995-3/1995	
	0111	Anacapa Passage	34.17	119.43	109.7	6/2002-7/2002	
	0005	Channel Islands	34.17	119.24	6.1	1/1977-9/1983	1977 1979-1982
	0038	Point Mugu	34.09	119.11	45.7	10/1982-7/1983	
	0141	Port Hueneme	34.09	119.17	38.0	3/1991-4/1991	
	0088	Santa Cruz Island W	34.07	119.83	55.0	10/1995-12/1995	
	0089	Santa Cruz Island E	34.06	119.58	55.0	10/1995-11/1995	
	0087	Santa Rosa Island	34.04	120.09	35.0	10/1985-12/1995	
	0105	Malibu	34.02	118.68	20.0	6/2002-10/002	
	0103	Topanga Nearshore	34.02	118.58	20.0	10/2001-1/2002	
	0102	Point Dume	33.98	119.00	365.0	6/2001-7/2002	2002
	0110	Santa Cruz Island	33.97	119.64	73.2	3/1984-11/1985	
	0080	Santa Cruz Canyon	33.92	119.73	320.0	9/1986-6/1989	1988
	0104	Hermosa Nearshore	33.86	118.42	20.0	1/2002-6/2002	
	0028	Santa Monica Bay	33.85	118.63	365.8	3/1981-7/2002	2001-2002
	46045	Redondo Beach	33.84	118.45	147.9	1991-1999	
1	0101	Torrey Pines Inner	32.93	117.27	20.0	4/2001-7/2002	2002
	0113	Scripps Canyon N	32.88	117.27	35.0	9/2002-11/2002	
	0115	Scripps Canyon NE	32.88	117.26	30.0	9/2002-12/2002	
	0114	Scripps Canyon NW	32.87	117.26	35.0	9/2002-11/2002	
	0116	Scripps Canyon S	32.87	117.26	28.0	9/2002-12/2002	
	0073	Scripps Pier	32.87	117.26	6.8	5/1976-7/2002	1977-1978 1980 1987 1989-2002
	0046	Point La Jolla Wind	32.86	117.35	182.9	10/2001-7/2002	2002
	0095	Point La Jolla	32.85	117.35	179.8	7/1999-7/2002	2000-2002
	0016	Mariners Basin	32.77	117.25	6.1	8/1978-7/1981	1979
	0015	Quivira Basin	32.76	117.24	6.7	4/1978-7/1981	
	0022	Mission Bay Channel Entran	32.76	117.26	6.7	7/1980-10/1980	
	0014	Mission Bany Entrance	32.76	117.27	11.9	8/1978-7/1995	1981-1982 1987-1988
	0002	Ocean Beach Pier	32.75	117.26	6.7	4/1976-10/1979	1997
	0093	Mission Bay	32.75	117.37	122.5	2/1981-8/1998	1987-1990 1992 1994
	0074	San Diego Channel Entranc	32.66	117.23	13.2	2/1993-3/2001	
	0091	Point Loma	32.63	117.44	180.0	11/1995-7/2002	
	0086	Silver Strand	32.59	117.14	6.7	7/1979-9/1979	
	0055	Imperial Beach N	32.58	117.14	10.2	1/1988-12/1996	1990-1996
	0001	Imperial Beach	32.58	117.14	6.1	12/1975-3/1978	1977
	46047	Tanner Banks	32.43	119.53	1393.5	1991-1993	1992 2000-2001

Stations in Red are operated by Scripps' CDIP and Blue by NOAA's NDBC. Less Than 100 m not processed

White stations processed in conglomerate. Light blue stations processed individually.

2.3. Overview of Results

Most of the wave energy incident upon California's shoreline originates from storms in the Northern Pacific Ocean. Point Conception divides California into two distinct near-shore wave climates. Southern California's lower energy wave climate can be attributed mainly to the abrupt change of the coastline to a south-west facing coastline south of Point Conception and the shadowing effects of the Channel Islands located off the Santa Barbara County coast. Northern California has no such shadowing effects and as a result has higher energy levels.

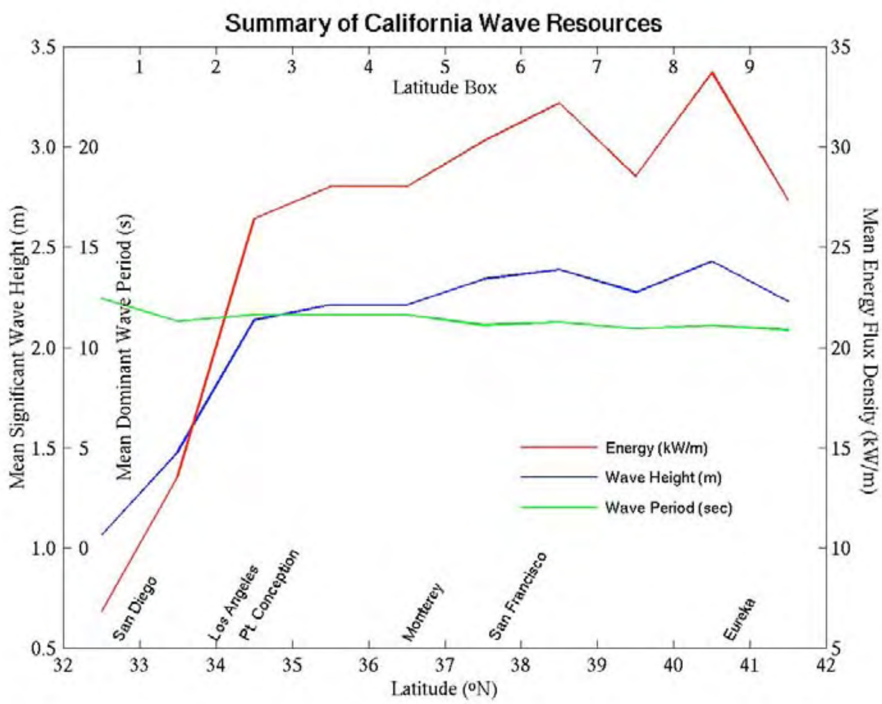


Figure 8 - California Wave Energy Resource Summary

The shadowing effects in Southern California are illustrated by Figure 8, which shows the swell height within that region and the effects of blockage by Point Conception and the Channel Islands.

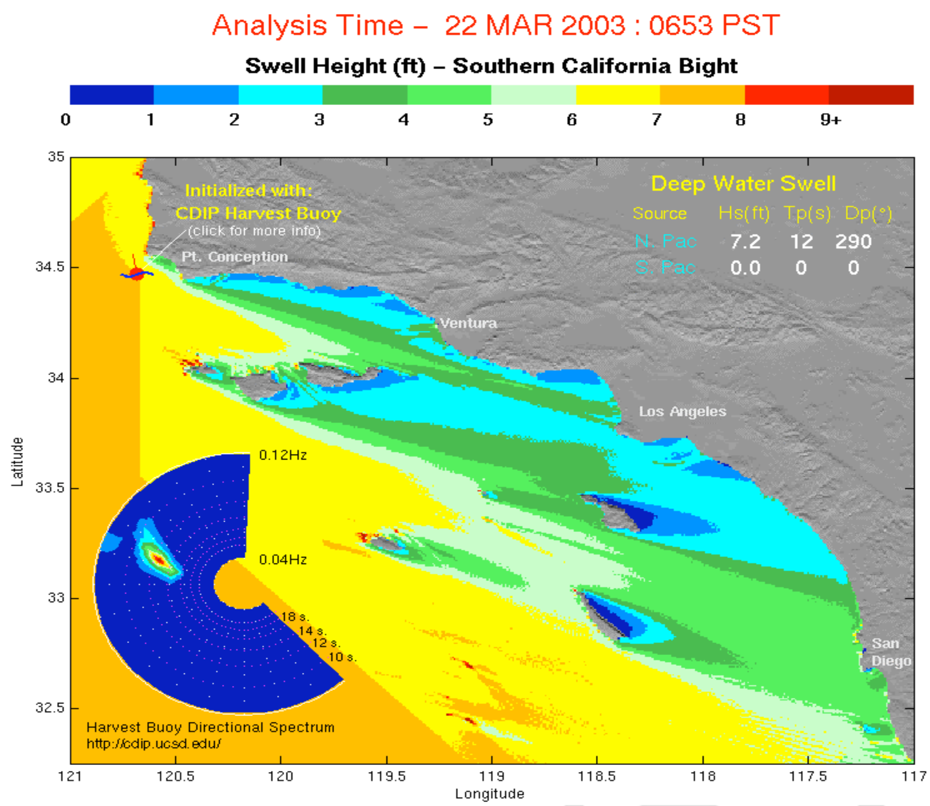


Figure 9 - Shadowing effects of the Channel Islands on southern California

Figure 8 and Figure 9 show that the wave energy close to shore in Southern California is much lower then far offshore. Wave energy levels have a direct effect on the economic viability of wave power systems and therefore near-shore locations in Southern California are not well suited for wave power conversion.

The offshore potential (outside of the Channel Islands), has energy levels similar to Northern California. However, in order to use this energy commercially, long power transmission cables would be required (roughly 60 miles) to connect offshore wave farms located there to the grid. This has been proven feasible in a number of projects using High Voltage DC Transmission (HVDC) lines, but it would require a fairly large wave power conversion scheme to make it economically attractive. A typical example of a HVDC subsea cable is the proposed Trans Bay Cable Project consisting of installation of a 55-mile-long high voltage direct current cable in San Francisco Bay, from a terminus in the City of Pittsburg in Contra Costa County to a terminus in the City of San Francisco in the vicinity of Potrero Point.

Northern California has a good wave energy resource available close to shore because the ocean depth increases quickly to the west. This increases its economic attractiveness because of reduced cost for the electrical connection to shore and reduced cost for O&M activities. Figure 10 illustrates the 100 m and 200 m contour lines along the California coastline, using a digital elevation model. Installation locations for wave power conversion devices in California are expected to be between the 50m and 100m contour line. The proximity of these deployment sites to shore has a favorable impact on power generation cost.

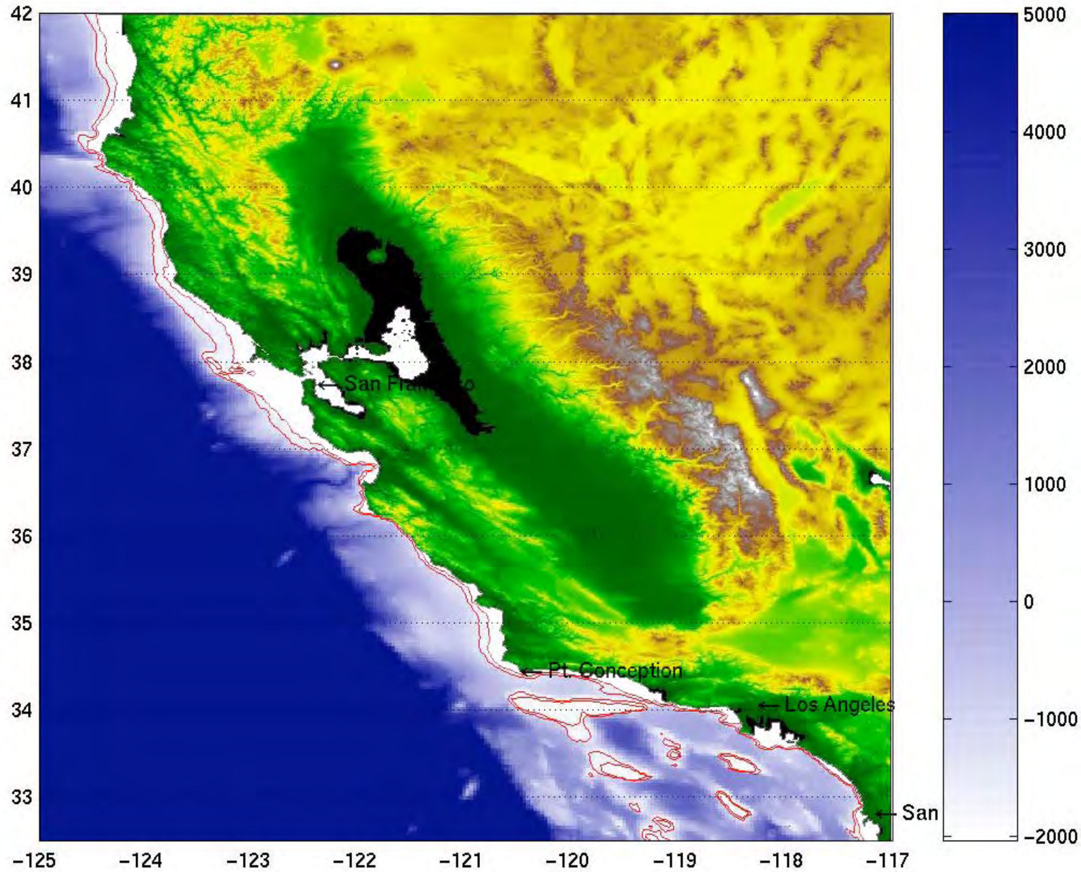


Figure 10 - California Digital Bathymetry

2.4. Wave Statistics for Northern California

The wave energy potential in Northern California (north of Point Conception) provides a good resource for wave power conversion. The deep water average wave power density is over 30 kW/m in that region. Because the wave energy resource in Northern California is consistent over hundreds of miles, only one location (Box 9) is analyzed here in the main report as a representative location. Detailed statistics for each of the ten one-degree latitude cells analyzed are contained in Volume II.

Measurement Buoy	Station ID 46022 Eel River
Coordinates	40.72° N / 124.18° W

Water Depth 274.3 m

Average wave power density 33.71 kW/m

Full year data sets used 1982-1990, 1992, 1995-2001

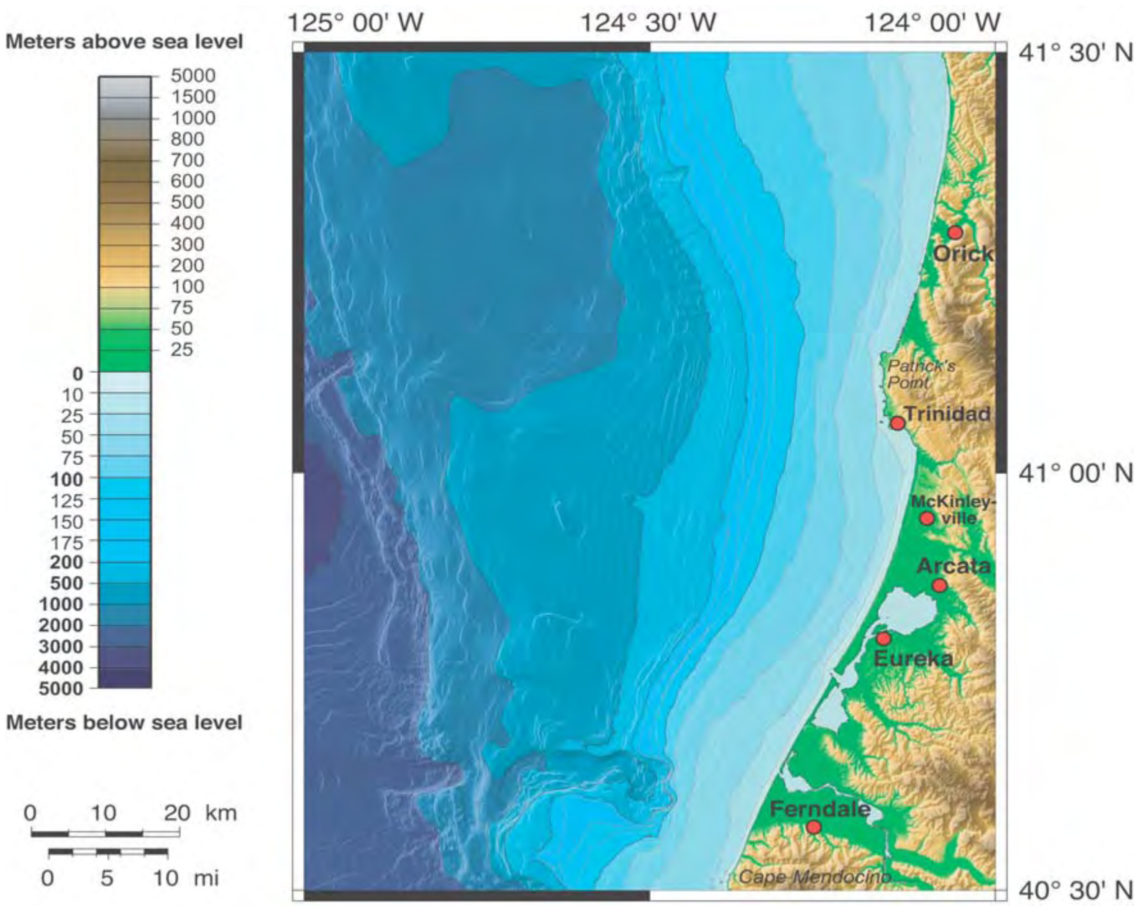


Figure 11 - Bathymetry for Latitude Cell 9

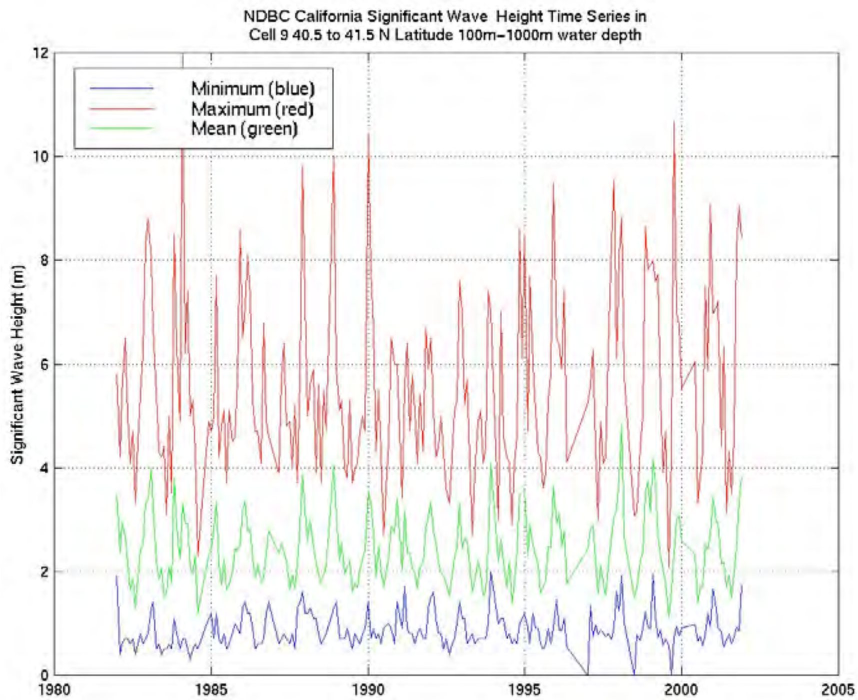


Figure 12 - Time series used for statistical analysis in cell 9

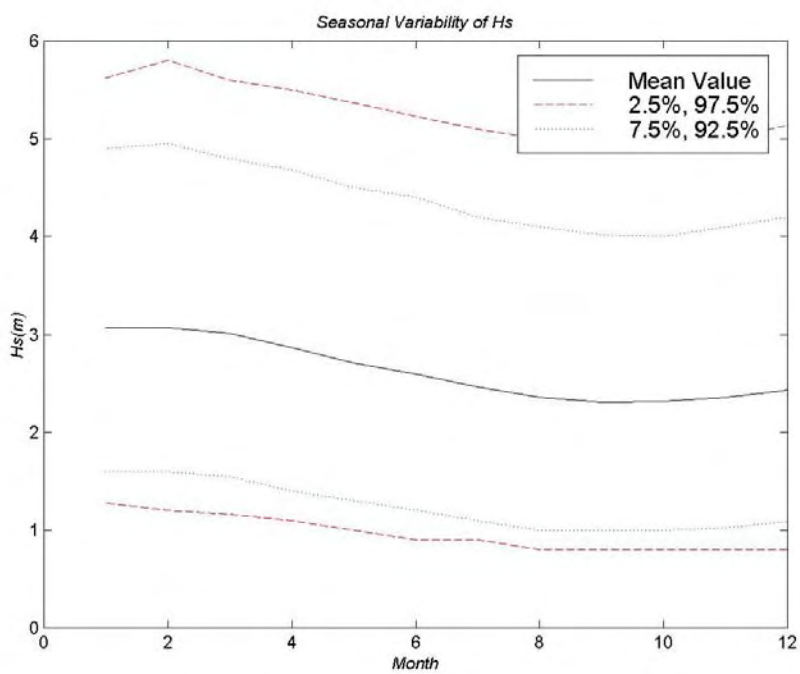


Figure 13 - Seasonal variability of wave height (Monthly) in cell 9

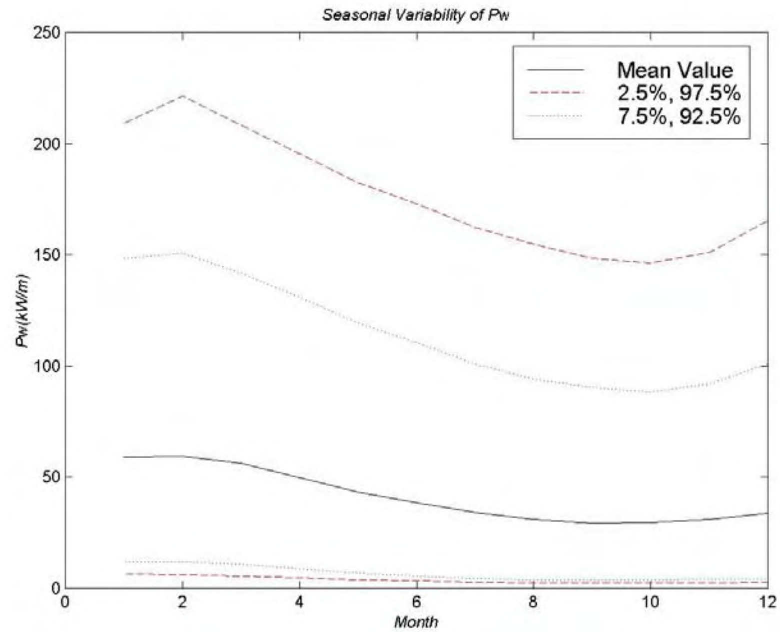


Figure 14 - Seasonal variability of wave power (P_W) in cell 9

Table 2 - Scatter Diagram for cell 9

		Tp (sec)										
		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
Hs (m)	0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**0**
	0.5 - 1.0	0	0	0	0	3	1	2	2	1	0	0	**10**
	1.0 - 1.5	0	0	7	8	33	16	21	34	22	3	0	**143**
	1.5 - 2.0	0	0	13	31	51	30	36	50	38	6	0	**256**
	2.0 - 2.5	0	0	2	40	56	26	39	42	31	10	0	**245**
	2.5 - 3.0	0	0	0	20	36	11	24	34	20	8	1	**154**
	3.0 - 3.5	0	0	0	6	19	5	12	24	17	5	1	**88**
	3.5 - 4.0	0	0	0	2	11	3	7	16	11	2	0	**52**
	4.0 - 4.5	0	0	0	0	5	2	4	9	7	1	0	**28**
	4.5 - 5.0	0	0	0	0	2	1	2	4	4	1	0	**14**
	5.0 - 5.5	0	0	0	0	1	0	1	2	2	0	0	**6**
	5.5 - 7.0	0	0	0	0	0	0	0	1	2	0	0	**4**
	7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**0**
	9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Total	**0**	**0**	**23**	**106**	**217**	**95**	**147**	**218**	**156**	**36**	**2**	**1000**

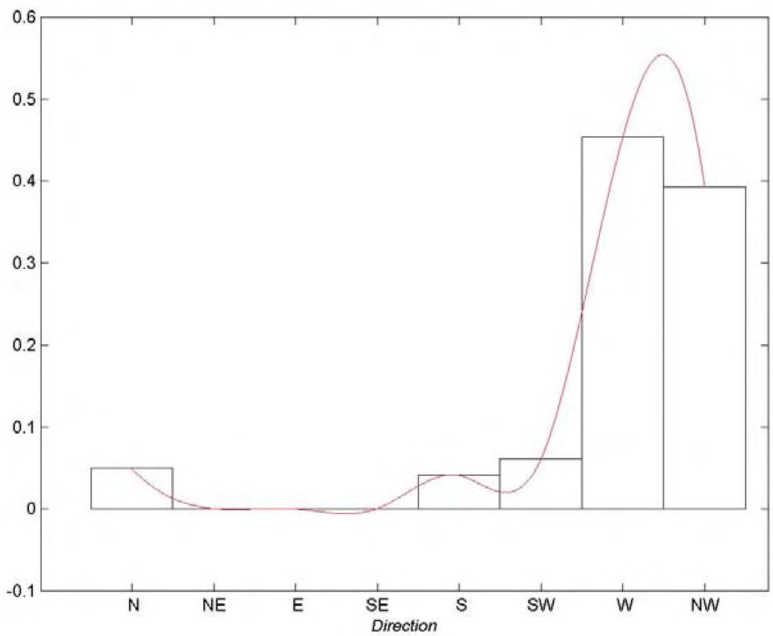


Figure 15 - Directional Distribution of waves in cell 9

2.5. Wave Statistics for Southern California

Southern California has a relatively low energy density near-shore because of the wave shadowing effects previously discussed. This wave energy density will have a significant impact on the economics of wave energy schemes deployed there. While some wave power conversion devices could potentially be adapted to this lower energy wave climate, most of the R&D has been carried out on devices better suited for higher energy wave climates such as the one found in Northern California or the UK. In deep waters outside the Channel Islands, wave energy levels are however comparable to North California. The distance to shore however will likely require large scale deployments to create attractive economics, making it a difficult case for early stage adoption. For this main report, latitude cell 2 has been chosen as a representative location for the near-shore wave climate in Southern California.

Measurement Buoy	Station ID 46045 Redondo Beach
Coordinates	33.84° N / 118.45° W
Water Depth	147.9 m

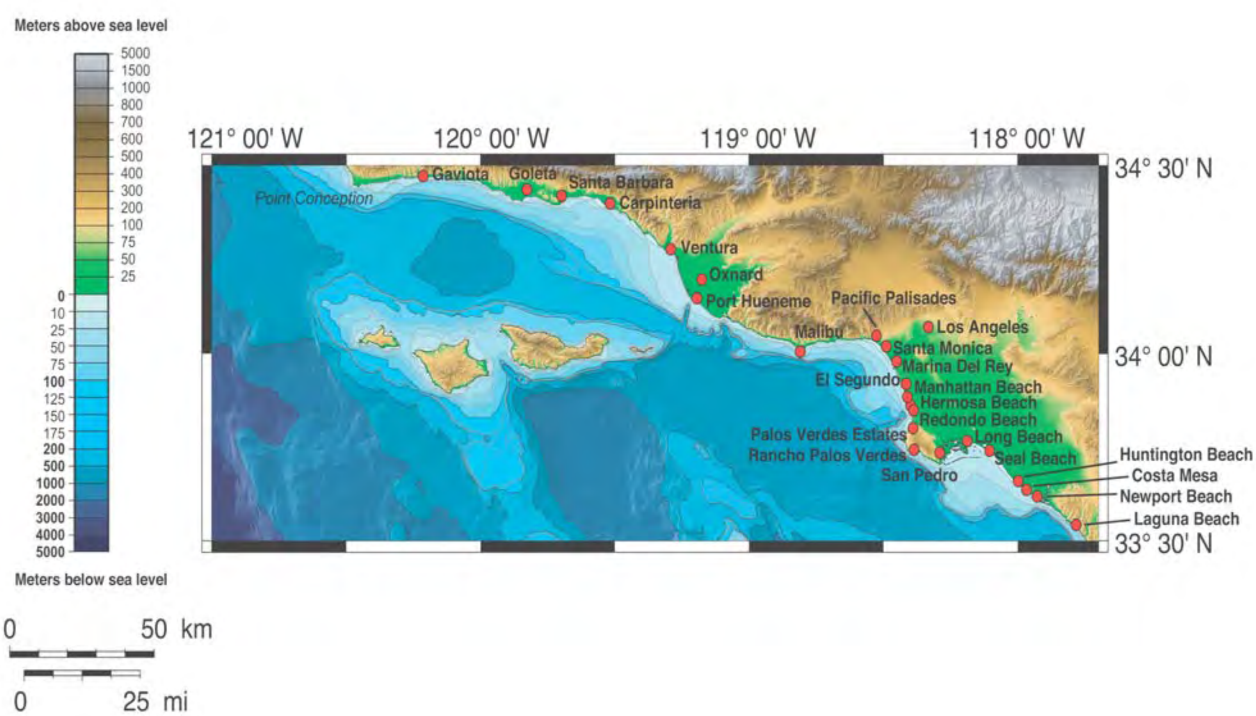


Figure 16 - Bathymetry for Cell 2

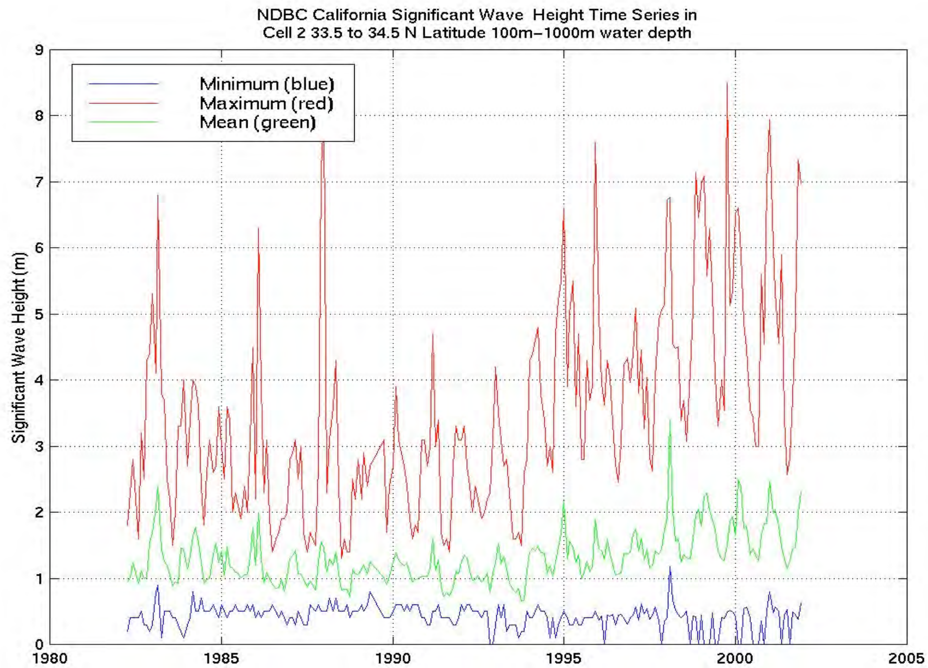


Figure 17 - Time series used for assessment in cell 2

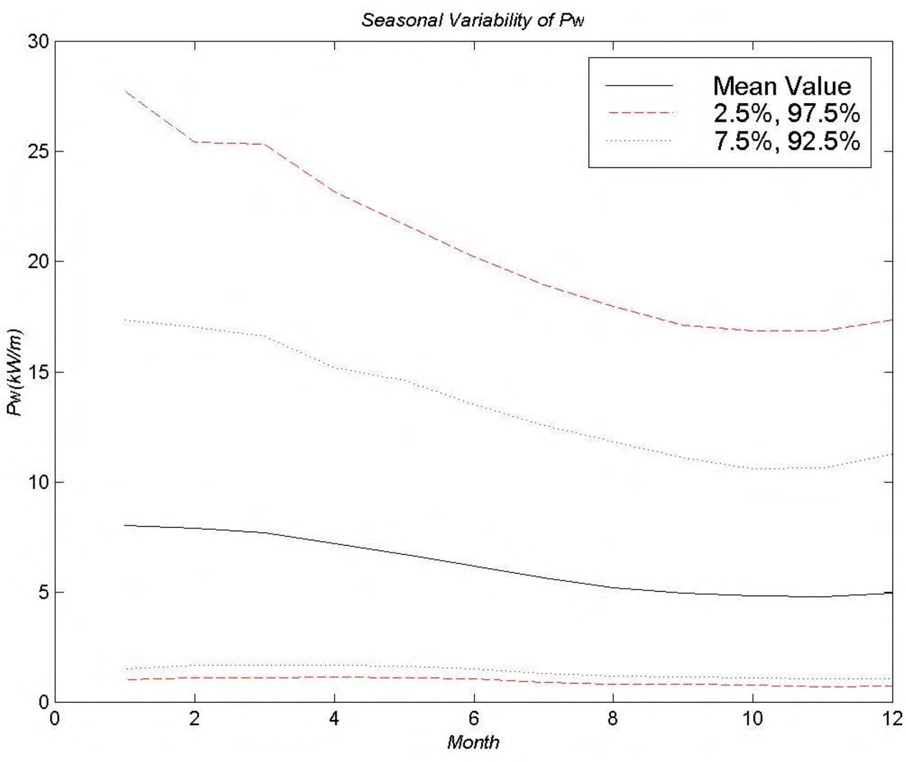


Figure 18 - Seasonal variability of power density (kW/m) in cell 2

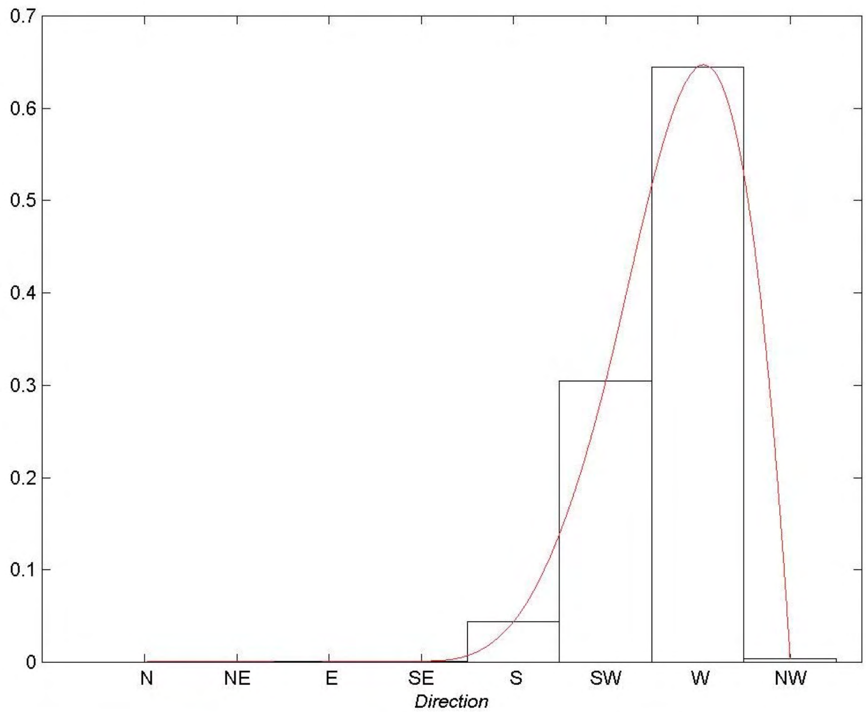


Figure 19 - Directional Distribution of waves in cell 2

2.6. Wave Power Offshore Southern California

West of the outer islands in Southern California, the wave energy potential has similar levels to those in Northern California and would be well suited for the deployment of wave energy conversion systems. However, the distance to High-voltage transmission lines and demand centers is roughly 60 miles. A site to be deployed in these waters would require a fairly large schemes to become economically competitive. Figure 20 shows the seasonal variability observed at the Tanner Banks buoy, which is located west of the outer islands in Southern California. Detailed statistics of this wave climate can be found in Volume II.

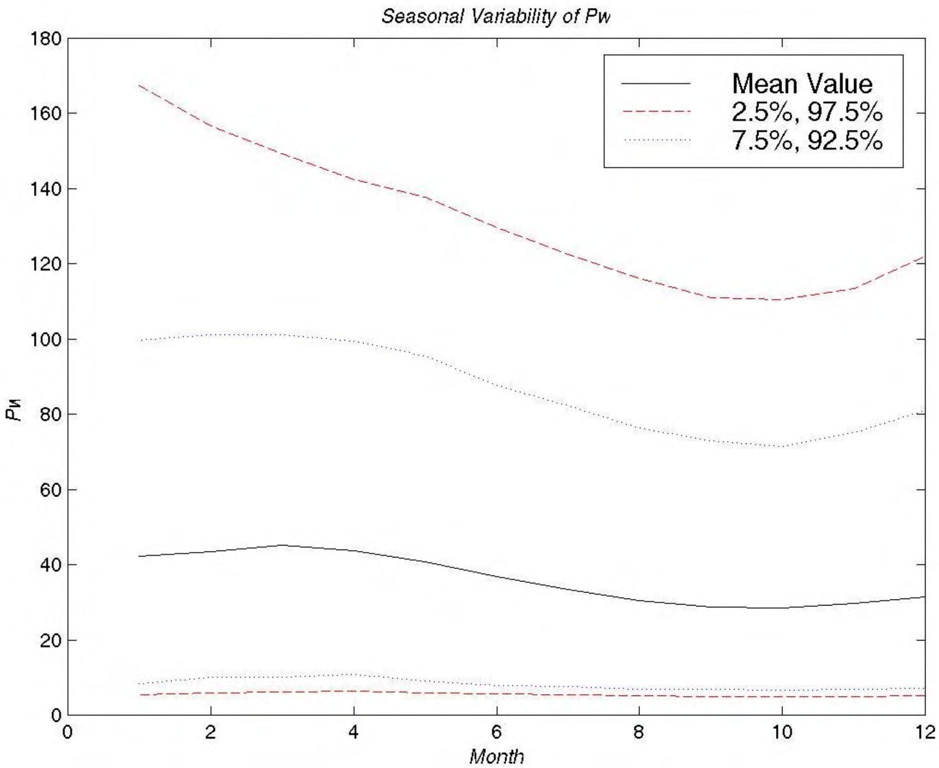


Figure 20 - Seasonal variability of Power Density (kW/m) for Tanner Banks west of the outer islands in South California

2.7. Inter-annual Variability and Long Term Trends

Wave statistics show a high inter-annual variability, with El Niño and La Niña events being caused by the reversal of equatorial trans-Pacific currents between Peru and Australia. The climatologic mean or "normal" years are interspersed between El Niño and La Niña events. Seymour (1996) has shown conclusively that the occurrences of El Niño events have increased significantly since the early to mid-nineties. Graham and Diaz (2001) show a Pacific-wide steady increase in storm frequencies, wind speeds, and wave energy over the last 50 years since 1950. They used National Center for Atmospheric Research (NCAR) reanalysis winds to perform hindcasts of long wave statistics in the Pacific.

2.8. Extreme Wave Height Conditions

The maximum significant wave height is a critical wave parameter that can have economic and safety impacts on wave farms. Extreme waves can snap moorings and have a destructive impact on such constructions. Since it only takes one rogue wave to do this, wave farm developers must take the maximum wave height statistics into account. Professor Dick Seymour of the Scripps Institute of Oceanography (private communications) states that a good "rule of thumb" is to take the largest measured significant wave height from a CDIP or NDBC buoy measurement and multiply it by a factor of 2. It is important to understand that measurement buoys measure incident waves over a 1-3 hour period and then analyze the time series to come up with statistical parameters such as the significant wave height (H_s). However extreme waves are not being individually recorded. Time series data show that significant wave heights of 10 m to 11 m occur every few years in Northern California. The extreme design condition for a wave power scheme should therefore be set at about 22 m. Additional safety factors might apply to comply with the regulations of an offshore insurance company.

2.9. Shallow Water Wave Power Resource

As waves approach the shoreline, they lose energy because of water particle-friction with the ocean floor. This energy loss is very site specific and will need to be evaluated on a case-by-case basis, if devices are to be deployed in shallow waters. Figure 21 shows the wave power density as a function of water depth, based on a number of shallow water buoy measurements in North California. It can be used as a general indicator of the near-shore potential, but has to be used with caution as the wave power density in shallow waters can vary significantly depending on local conditions.

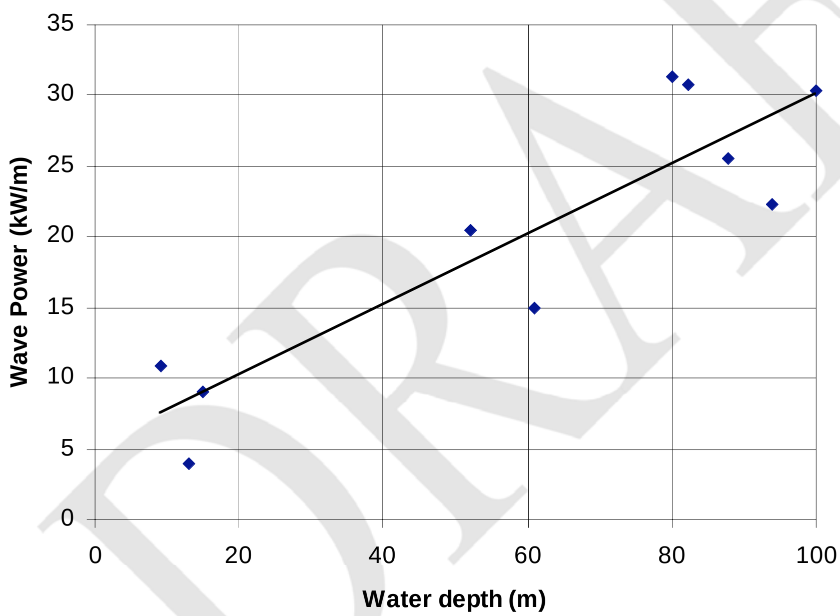


Figure 21 - Power Density as a function of water depth in Northern California

3.0 Wave Energy Conversion (WEC) Technologies

More than 1000 patents were filed for wave power conversion (WEC) machines over the last 50 years, with a number of device types proving to have technical and commercial potential. A focus is provided on technologies that are nearing commercial readiness to provide the reader with an understanding of technologies in respect to commercial readiness. As such only devices that are at the time of writing undergoing sea-trials are being considered.

WEC technologies convert the slow, pulsing mechanical motion of ocean waves (0.1 Hz) to a steady electric output with a frequency of 50-60 Hz and a voltage level suitable for grid interconnection. This electricity is then be transmitted to shore and interconnected with the electric grid.

Because there are few locations in California that would permit the implementation of shore-based WEC devices, such as existing harbour walls, the main focus here has been on near-shore and offshore technologies. Offshore locations have advantages in terms of a higher energy wave resource, lower environmental impacts and larger resource potential (WEC farm). The following represents presents a high-level device classification based on their installation location.

Shoreline Devices: Shoreline devices have lower maintenance and installation costs than do offshore devices and do not require moorings and long underwater electrical cables. The less energetic wave climate at the shoreline can be partly compensated by the concentration of wave energy that occurs naturally at some locations by refraction and/or diffraction. The three major classes of shoreline devices are the oscillating water column (OWC), which has a demonstrated field case, the convergent channel (TAPCHAN), and the Pendulor. Several shoreline OWC prototypes have been built in Norway, China, UK (LIMPET), Portugal (Pico Island); incorporated in a breakwater (harbour of Sakata, NW Japan) or placed outside it (Trivandrum, India). Unless integrated into a breakwater, such shoreline devices require significant modification to the shoreline. Because associated environmental impacts will prevent significant deployments in California with the exceptions of a few breakwaters that could potentially be leveraged (I.e. Fort Bragg and Crescent City), no further discussion is provided on shoreline technology.

Near-Shore Devices: Near-shore devices are structures situated in shallow waters (typically 10 to 25 m water depth). The Oscillating Water Column (OWC) is the main type of device. Companies that are at present developing near-shore devices include Energetech and WaveGen. Both developers use OWC device types.

Offshore Devices: Offshore devices are situated in water depths of more than 40 m. Several prototypes have been deployed worldwide, with many more under development. The current state of wave energy conversion technology is comparable to where wind energy was in the 1980's; developers pursue a wide array of technological approaches and it is not yet clear what technology will prove the most economic choice.

While devices for the on-shore and near-shore environment are tethered or rigid mounted, offshore devices are usually deployed freely floating. It is almost impossible to classify all the device types under development. For illustration purposes a few of the more popular concepts are outlined below.

3.1. Buoyant Moored Device

A device of this type floats on or below the water surface and converts the orbital motion of surface waves into electricity using an absorber system. There are an endless number of potential configurations and the following is just presented as a reference. The absorber is moored to the seabed either with a taut or slack mooring system. Figure 22 shows two possible configurations for a buoyant moored device. The illustration to the left shows a taut moored device that extracts energy from the relative motion between the buoy and the sea floor. In this case, the up and down movement activates a piston pump to create pressurized fluid. The illustration on the right shows a slack moored hinged contour device, or attenuator, in which the energy of oscillating waves is captured by the movement of hinges that link adjacent floating panels.

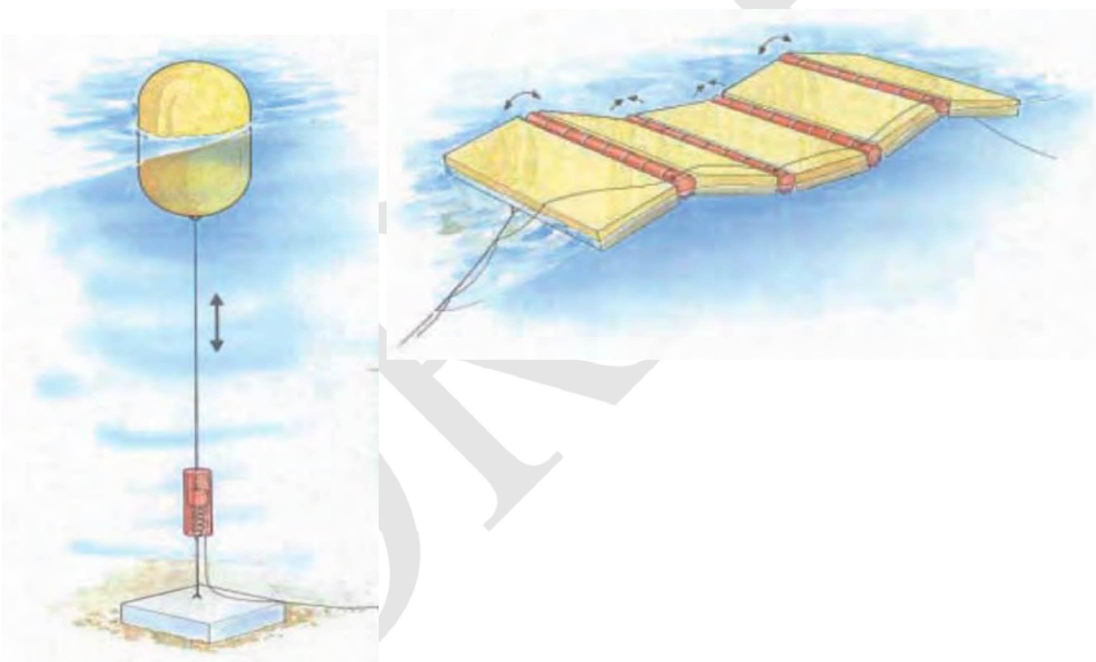


Figure 22 – Buoyant moored devices

3.2. Oscillating Water Column (OWC)

An oscillating water column (OWC) uses an enclosed column of water as a piston to pump air. These structures can float, be fixed to the seabed, or be mounted on the shoreline. An OWC device uses an air turbine to convert air flow into a high frequency rotational output required by the turbine machinery.

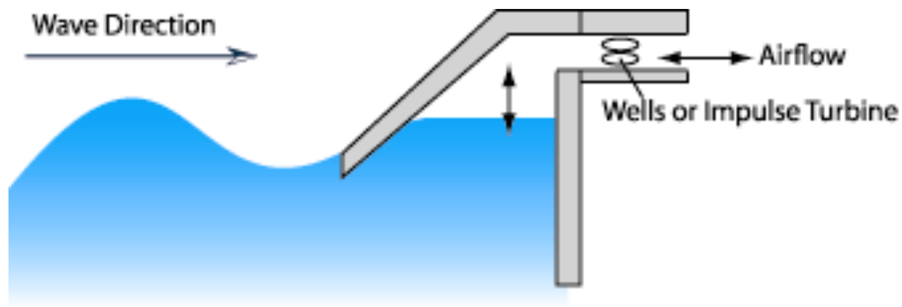


Figure 23 - Oscillating water column principle

3.3. Overtopping Devices

An overtopping device uses a ramp, up which waves can run and overtop into a basin located behind it. The basin then empties back into the ocean, driving a low-head turbine. An overtopping device, can be fixed mounted to the shore or be deployed freely floating.

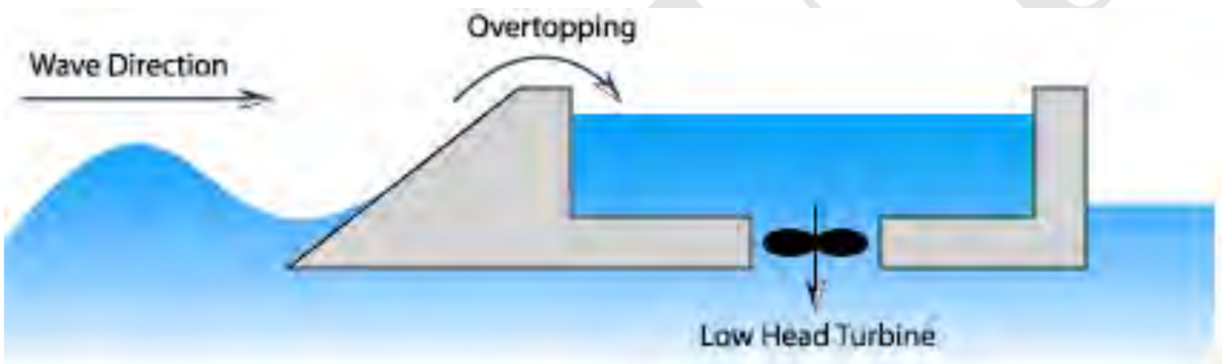


Figure 24 - Overtopping principle

3.4. Power Conversion Turbo-Machinery

The challenge to overcome is converting the slow oscillating motion of ocean waves into the fast rotational motion typically required for a generator. At the same time, the system should have some form of energy storage capability to smooth power output over multiple wave crests, and the ability to tune itself to optimize power capture based on incident wave power levels. A wide variety of power conversion systems are under development. Designs that are mature today are using air turbines for oscillating water column devices, hydraulic absorber systems for buoy systems, low-head water turbines for overtopping devices and direct linear induction generators.

Oscillating water column devices use air turbines to convert airflow into electricity. The most well-known development in this area has been the Wells turbine, which converts the bi-directional flow of the air in an oscillating water column into a unidirectional output using symmetrical aerofoil blades. The Wells turbine has fixed blades and has proven to be a reliable and simple conversion mechanism. The maximum efficiency of the turbine is around 65%. As operating conditions vary from the design optimum, the efficiency also decreases accordingly as shown in Figure 25. Because of the variable nature of ocean waves, it will operate most of the time under partial load conditions, which results in average efficiencies of between 25% and

40% depending on the wave conditions. To solve the issue of inherently low power conversion efficiency, some developers have come up with alternative configurations using variable pitch turbine designs to optimize power output and have also added active valves to be able to better tune the system to the incident wave power levels and optimize overall device performance.

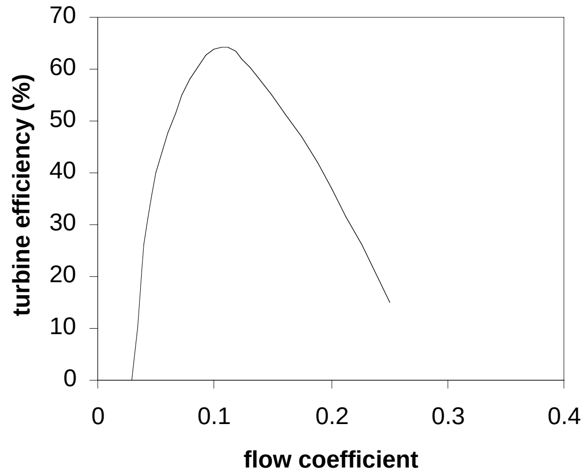


Figure 25: Typical Wells turbine efficiency

Most of the buoy-based and hinged contour devices feature a hydraulic power conversion system. In such a system, piston rams convert the motion of the absorber device into hydraulic pressure, which in turn drives a generator. Accumulators can be used to smooth the power output and increase the power quality of a given device. The advantage of hydraulic power conversion systems is that the components are readily available and are widely used in the offshore oil & gas industry. A typical hydraulic conversion train using volumetric displacement pumps, which converts the slow movement of an absorber system first into hydraulic pressure and then into electricity using a standard generator, will show average efficiencies of 70-80%, which are significantly higher then air-based systems. Further increases in efficiency can be achieved by using water-based hydraulics and specialized components, which are better adapted to the requirements of a wave power conversion device in terms of useful life and efficiency.

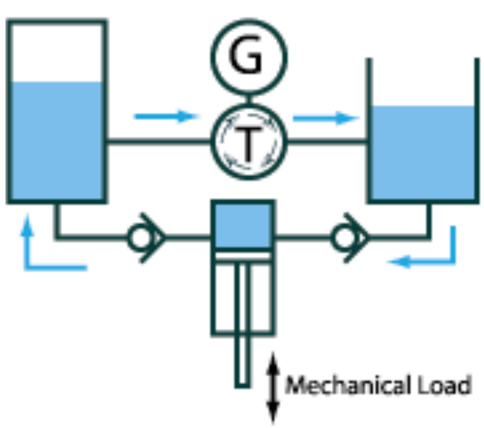


Figure 26: Simplified hydraulic power take-off

Low-head water turbines are used in overtopping devices and are based on available technology from the hydropower industry. Efficiency levels are high and the adaptation of low-head turbines using variable speed power conversion systems allow for variable power output and optimized control over the flow rate.

Linear direct induction machines have been evaluated for wave power conversion in a number of studies. Because these devices eliminate an intermediary conversion step, they have the promise to reduce many of the maintenance issues associated with the energy conversion process and could potentially increase power conversion efficiency. Archimedes Wave Swing recently deployed a 2MW pilot unit, which features a linear, direct induction generator.

There are over 25 device developers at various stages of technology development. There are however only 6 developers that are presently testing near-shore and offshore wave energy prototypes in the ocean with technology that may be applicable to the State of California in the near-term. These developers with a link to their website are listed below.

Table 3 - Developers with ongoing in-ocean tests

Device	Company	Website
Archimedes Wave Swing	AWS Ocean Energy	www.waveswing.com
Energetech OWC	Energetech	www.energetech.com.au
Pelamis	Ocean Power Delivery	www.oceanpd.com
Power Buoy	Ocean Power Technologies	oceanpowertechnologies.com
Wavebob	Clearpower	www.clearpower.ie
Wave Dragon	Wave Dragon	www.wavedragon.net

The following table provides an overview of critical dimensions of the various devices. The annual production was computed by applying the devices performance to the same reference wave climate on the US west coast. Average Power density at the Oregon reference site is 26kW/m, which is representative for California locations.

Table 4 - Up-Scale Consideration for 300,000 MWh Reference Commercial Plant (100MW)

Company	Width (m)	Length (m)	Annual Production (MWh)	Number of Devices Required to generate 300,000 MWh/yr
Ocean Power Delivery	3.5	120	1337	224
Energetech	35	18	2275	132
Wave Dragon	260	150	12,000	25
Wave Swing	9.5	9.5	3078	117
WaveBob	15	15	1147	262
OPT Power Buoy	5	5	NA	NA

The following section provides an outline of these technologies to provide the reader with an understanding of critical dimensional and performance parameters. For more details on any of these technologies, the reader is directed to the developers' websites.

3.5. Predicting Performance for wave energy conversion devices

Ocean wave energy conversion devices respond to individual waves differently. The wave height, period and directionality all affect the device performance. The two main parameters looked at is the wave period and wave height. In order to predict a devices performance, one needs to know the devices performance in each sea-state. This performance can then be reflected in a performance table. This performance table can then simply be multiplied by the frequency distribution table for the site to arrive at an equivalent energy output for a particular site. The following illustration shows a typical device power conversion profile.

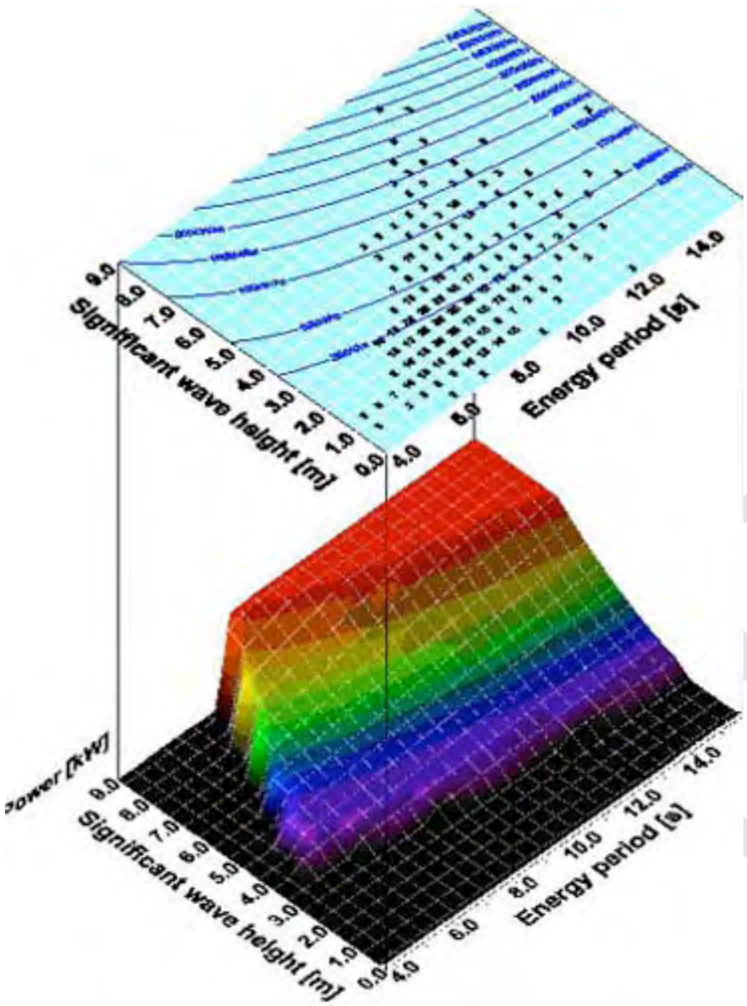


Figure 27 – Typical power capture of a wave energy conversion device. Source: The Carbon Trust

3.6. Technologies with a mature development status

3.6.1. Energetech

<u>Specifications:</u>

Parabolic Width:	35m
Structural Steel Weight:	450tons
Centerline Device Spacing:	60-90m
Rated Power:	500kW – 2MW (depending on wave climate and device dimensions)
Power Take Off:	Variable Pitch Air Turbine
Water Depth:	Shore based to 50m

Energetech is developing an oscillating water column that can be deployed in water depths of up to 50m (150feet). The device features a parabolic focusing wall, which is used to focus waves onto the oscillating water column. The oscillating water column converts that motion into electrical energy. The key innovative feature of the device is the reversible (or 2 –way) variable pitch blade air turbine used which raises the average conversion efficiency from roughly 30% to 60% compared to the fixed pitch blade designs. The device is standing on a number of legs (piles) and is being held in place by a tethering system. A full-scale device was deployed in October 2005 at Port Kembla, Australia. Testing has been ongoing since then.

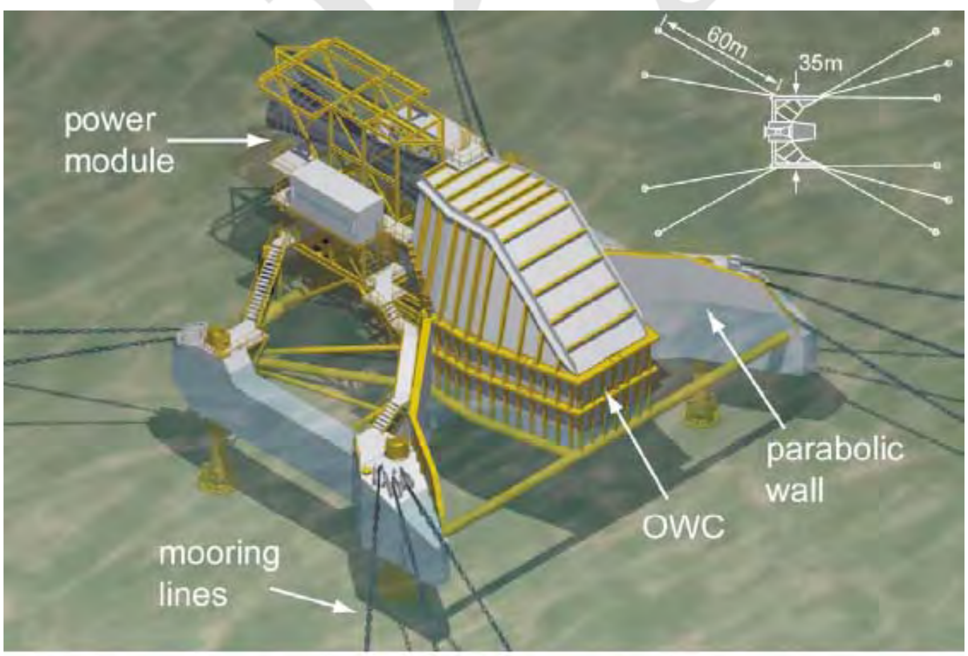


Figure 28 - Energetech Oscillating Water Cullomn

3.6.2. Ocean Power Delivery

Specifications:

Total Device Length:	150m
Device Diameter:	3.5m
Centerline Device Spacing:	150m (2-3 Rows stacked)
Structural Steel Weight:	380tons
Rated Power:	300kW – 750kW (depending on wave climate)
Water Depth:	>50m
Power Take Off:	Hydraulic using bio-degradable fluids

Ocean Power Delivery is developing a freely floating hinged contour device. The device looks like a snake, floating on the ocean surface. The device consists of 4 tubular sections, connected by 3 hinges. The 4 sections move relative to each other and the hinges convert this motion by means of a digitally controlled hydraulic power conversion system. The total device length is 150m (450 feet), with a tube diameter of 3.5m. A full-scale, grid-connected, pre-production prototype was built and deployed in October 2004 and testing is ongoing since. Testing is carried out at the European Marine Energy Test Center in Orkney (Scotland). Ocean Power Delivery is currently building the first commercial plant in Portugal and shipped the first unit for this plant in March of 2006.

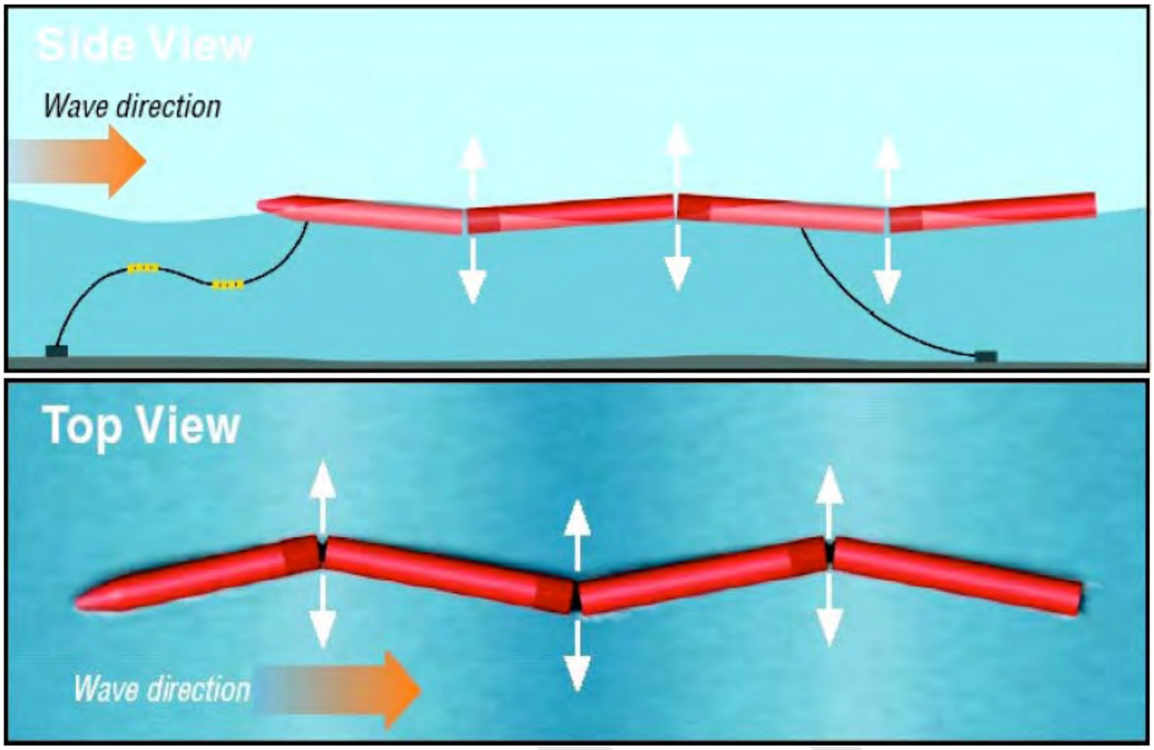


Figure 29 - Pelamis Function Principle

3.6.3. Wave Swing

<u>Specifications:</u>

Device Diameter:	9.5 m
Device Amplitude:	7m
Water Depth:	43m
Centerline Device Spacing:	80m
Rated Power:	4 MW (depending on wave climate)
Power Take Off:	Linear Direct Induction Generator

Wave Swing is a bottom standing completely submersed point absorber, with a linear direct generator to convert the oscillatory motion into electricity. The upper floater traps air inside, forming an effective spring element. Pressure differences on the top of the float (created by surface wave action), will set the top floater into motion and the system starts to oscillate. The device was deployed in October 2004 and testing was declared complete in December 2004. In March of 2006, the company secured funding to move forward with the detailed design of a pre-commercial prototype.

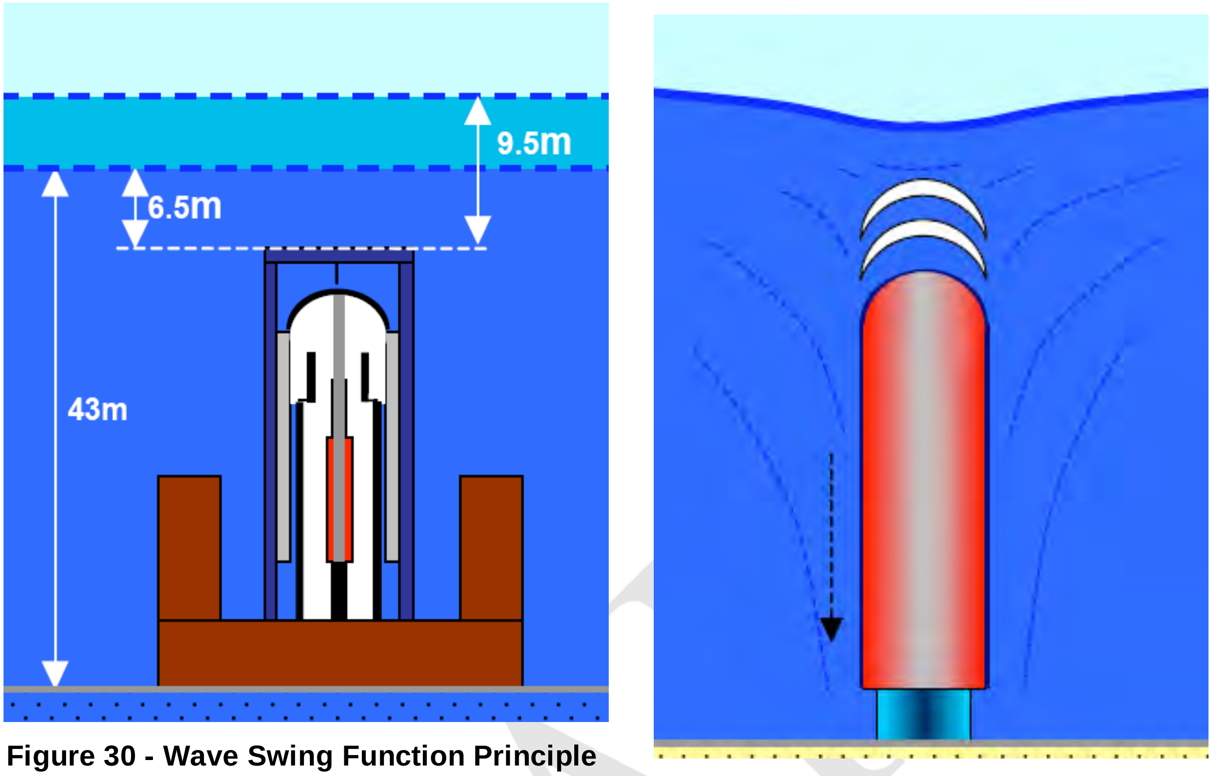


Figure 30 - Wave Swing Function Principle

3.6.4. WaveBob

<u>Specifications:</u>

Buoy Diameter: 15m

Draught (water): 30-40 m

Centerline Device Spacing: 50m

Structural Steel Weight: 440 tons

Rated Power: 250 kW (depending on wave climate)

Water Depth: > 50m

Power Take Off: Standard Oil hydraulics using bio-degradable fluids

WaveBob is a freely floating symmetrical point absorber that is tuned to the incident wave action using a proprietary system to change the devices natural resonance frequency, without changing the floats draught. In addition, a digitally controlled power take off allows the device to dynamically change the damping, which can be used to further tune the system in real-time. Wavebob provided a limited amount of information for assessing their technology. A sketch showing the appearance of the Wavebob above the water line is provided. A quarter scale device was installed in march 2006 in Galway Bay near the coastal town of Spiddal in Ireland. No further details were available from the developer at the time of this writing.

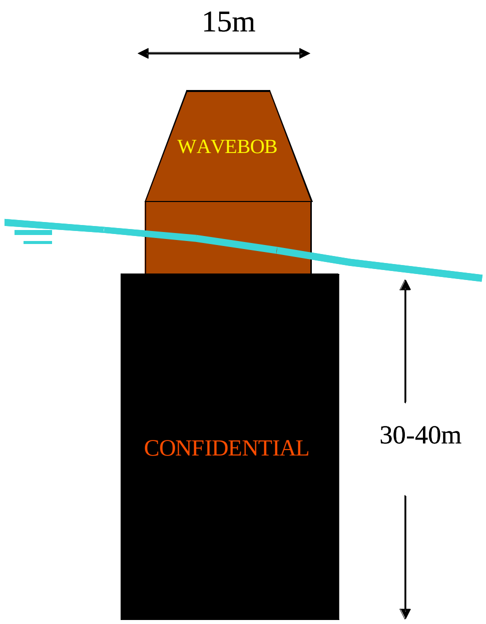


Figure 31 - Wavebob Dimensional Outline

3.6.5. Wave Dragon

<u>Specifications:</u>

Device Width:	260 m
Reservoir size:	8,000m^3
Water Depth:	>25m
Centerline Device Spacing:	700m
System Weight:	22,000 tons (includes steel, concrete and ballast)
Rated Power:	4-7 MW (depending on wave climate)
Power Take Off:	Adapted Kaplan Turbines (for low head) with Permanent Magnet Generators (250kW per turbine)

Wave Dragon is a large overtopping device, which combines a double curved overtopping ramp and two reflector arms, which are used to focus energy onto the overtopping basin. Multiple modified Kaplan-Turbines are used to convert this low pressure head into electricity using direct-drive low speed Kaplan turbines. Device output depends on the wave climates and is in the range of 4-7MW. It is today, the largest device (by rated capacity and physical size) under development. The device is slack-moored and is able to swivel in order to always face the wave direction. A 1:4 scale prototype was tested in scaled sea conditions in Nissum Brending, a fjord in the northern part of Denmark from March 2003 to January 2005. Since then, the company has focused on the development of a full-scale demonstrator to be deployed at the southwest Wales coast in the UK.

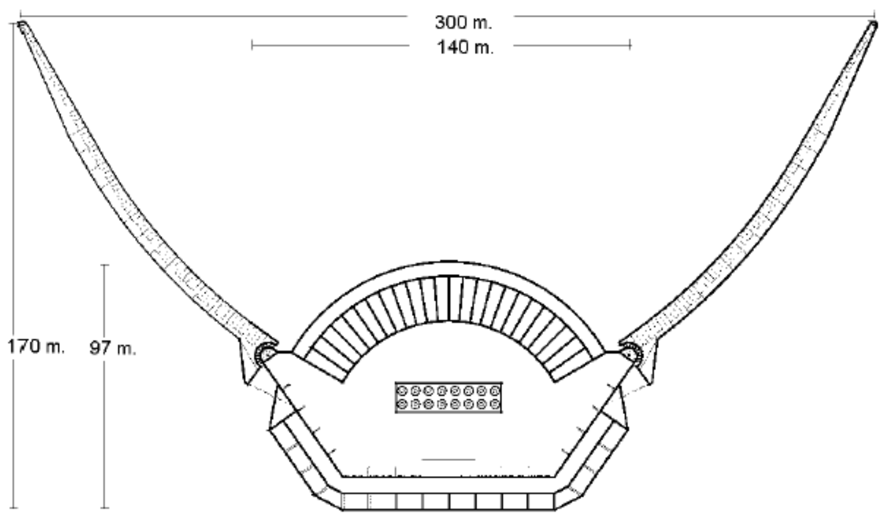


Figure 32 - Wave Dragon Dimensional Outline

3.6.6. Ocean Power Technologies (OPT)

<u>Specifications:</u>

Buoy Diameter:	5m
Buoy Height:	20m
Centerline Device Spacing:	N/A
Structural Steel Weight:	17 tons
Rated Power:	40 kW (for Hawaii demo project)
Water Depth:	30m
Power Take Off:	Oil hydraulics

The Power Buoy developed by Ocean Power Technologies, USA, consists of a 5m diameter buoy. The buoy is mounted on a long tubular structure that is likely used to provide reaction mass to the system. The system is moored directly to the seabed with a clump-anchor. Current individual demonstration units are rated at 40 kW. Very little technical information was available from the developer to further assess their technology. Based on various illustrations, it appears however, that the device has undergone fundamental changes over the past few years. OPT's prototype testing in Hawaii is ongoing.

Figure 33 - Picture of OPT Power buoy

3.7. Wave Farm Dimensions and Extraction Densities

A wave farm needs to face the principal wave direction and is installed at a suitable water depth. In California, the principal wave direction is between W and NW and wave farms will ideally be arranged in rows of devices along the coastline at a suitable water depth. A wave energy conversion device needs to directly exposed to the wave action. If a device is placed behind a row of wave energy converters that already take power from the waves, the performance will be reduced and as a result economics are sub-optimal. Some floating technologies require large inter-device spacing, because the device is able to 'swing' around a slack mooring. Devices, which are mounted on the seafloor (AWS) or on a fixed structure (Energetech) allow these devices to be installed more closely together.

Little research has focused on the understanding of device spacing and hydrodynamic device interactions in a wave farm. To understand the spacing assumptions and likely device layouts better, the following 3 examples show layout options for fundamentally different device types.

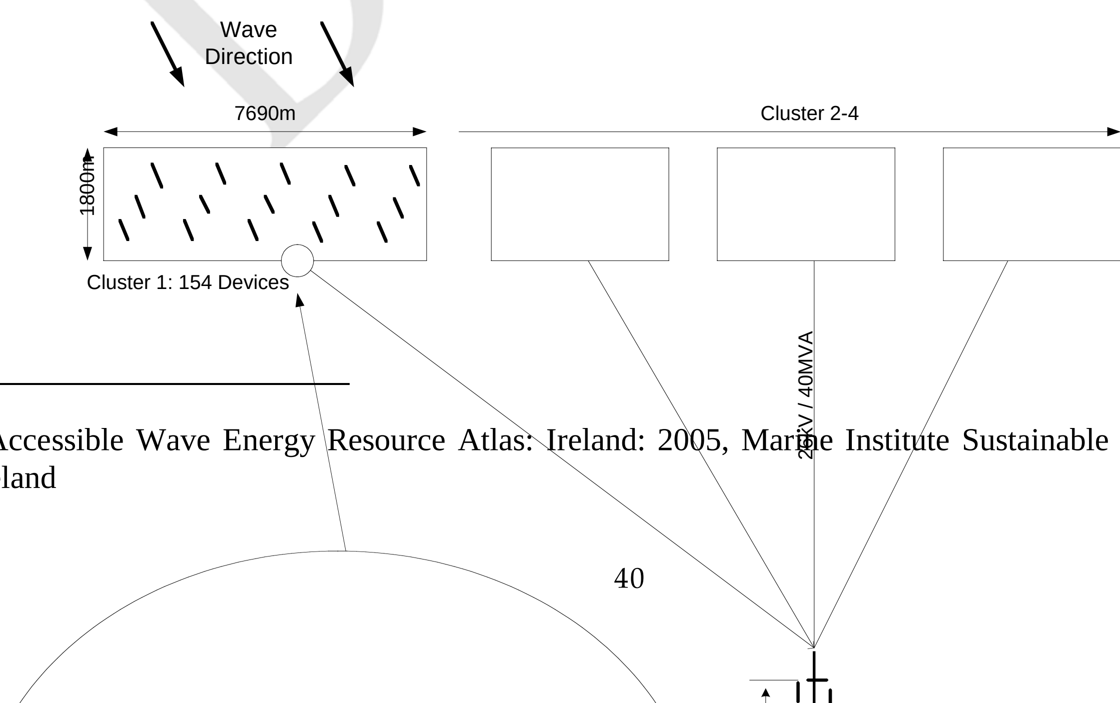
A wave farm consisting of 40 Pelamis devices would occupy an area of 0.6km wide by 2.1km length[8]. Based on EPRI's work a Pelamis device in a 21kW/m wave climate would put out 1337 MWh/year. For a wave farm consisting of 40 devices, the total annual output would be 53,480MW/year. In other words, each km of coastline would produce about 25,467MWh per year. This results in an average power delivered of roughly 2.9MW for each km of coastline.

A wave farm consisting of Wave Dragon's would require devices lined up in a row with a centerline spacing of 700m. Based on the performance estimates made by Wave Dragon, each device would put out roughly 12000 MWh per year. As a result, each km of coastline would produce about 17,142 MWh per year. This results in an annual average power delivered to the bus bar of 1.9MW for each km of coastline.

A wave farm consisting of Energetech's OWC's would consist of a row of device with a centerline spacing of 60m. Energetech's device is predicted to produce about 2,275 MWh/year in a 21kW/m wave climate. This means that each km of coastline with deployed devices would produce 37,916 MWh/year. This results in an annual average power delivered to the bus bar of 4.3MW/km.

All of the above estimates were made assuming a 21 MW/km wave climate. Given the above data, this would mean that the devices could on average extract between 9% and 20% of the total energy in a typical wave energy conversion scheme. As shown above, extraction densities, are highly technology dependent. Some devices that act as terminators (such as Energetech's OWC) could be built with closer spacing. If all gaps were eliminated this could yield a power extraction density that is about 30%. For the purpose of estimating the exploitable energy potential from waves in California it was assumed that the upper limit of extracted energy would be about 20% of the incoming energy.

The following illustration (figure 34) is a schematic representation of a typical 100MW+ commercial wave power plant using OPD's Pelamis device. It shows the devices arranged in a row(s) facing the principal direction, the footprint being a long 'thin-line' stretching parallel to the coastline. This arrangement is characteristic of all devices regardless of technology.



[8] Accessible Wave Energy Resource Atlas: Ireland: 2005, Marine Institute Sustainable Energy Ireland

Figure 34 - Typical Wave Farm Layout showing a 100+MW Pelamis Wave Farm

3.8. Electrical Systems within a Wave Farm

3.8.1. Voltage Levels

In order to connect a wave farm to the grid, the power needs to be transmitted through an armored umbilical cable to shore. While small (100kW) demonstration systems can be connected directly to shore at the generator voltage level, a wave farm with larger capacity will need to be connected at a higher voltage level to shore to keep the transmission losses low. The following options are available, based on state of the art sub sea cable technology:

500 kW – 10 MW 11 kV AC (single 3-phase cable)

10 MW – 40 MW 33 kV AC (single 3-phase cable)

40 MW – 100 MW	33 kV AC (multiple 3 phase cables)
100 MW +	100-200 kV AC (single cables laid in parallel)

For transmission distances longer than 100 km and power levels of more than 100 MW, High Voltage DC (HVDC) becomes an attractive alternative. HVDC could be used, for example, to connect a large wave farm outside the Channel Islands in southern California to the grid in Los Angeles or San Diego. Conventional HVDC transmission been in use for nearly 50 years, and has been successfully utilized for long distance submarine applications, such as 250km crossings of the Baltic Sea.

3.8.2. Cables

Umbilical cables to connect offshore wave farms (or wind farms) to shore are being used in the offshore oil & gas industry and for the inter-connection of different locations or entire islands. In order to make them suitable for in-ocean use, they are equipped with water-tight insulation and additional armor, which protects the cables from the harsh ocean environment and the high stress levels experienced during the cable laying operation. Submersible power cables are vulnerable to damage and need to be buried into soft sediments on the ocean floor. If bedrock is present, cables can be protected by protective steel pipes as shown in Figure 35 (right picture).

Figure 35 - Armored submarine cable

3.9. Grid Synchronisation and Power Quality

Electricity is supplied at a specific quality level, expressed in terms of standard thresholds for the following:

- Voltage imbalances
- Slow voltage fluctuations
- Rapid voltage fluctuations and flicker

- Harmonics

The voltage quality rules governing network access for generating plant operators define minimum network characteristics at the connection point and minimum technical conditions for the plant. These rules are determined to ensure that consumers enjoy supply quality within applicable standards.

While the technologies and components used for the generation and interconnection of wave farms are similar to that found in offshore wind-farms, some of the technologies will need to be adopted to fit particular wave energy device-types. Recent advances in permanent magnet generator technologies and variable speed drives (AC-DC-AC) alleviate many issues related to power quality and grid synchronization. Other novel technologies, such as the High-Voltage-DC (HVDC) transmissions used to connect large offshore wind or wave farms to the grid, have further advantages to be able to deliver reactive power and provide much more "intelligent power", which can be used to stabilize local grid infrastructure.

3.10. Operation & Maintenance

Operational aspects present the largest unknown element associated with wave power conversion because there is virtually no operational experience with actual wave farms. However, the offshore oil & gas industry and the offshore wind industry are coping with very similar issues on a daily basis and there is a reasonable understanding of some the O&M issues and resulting economic implications.

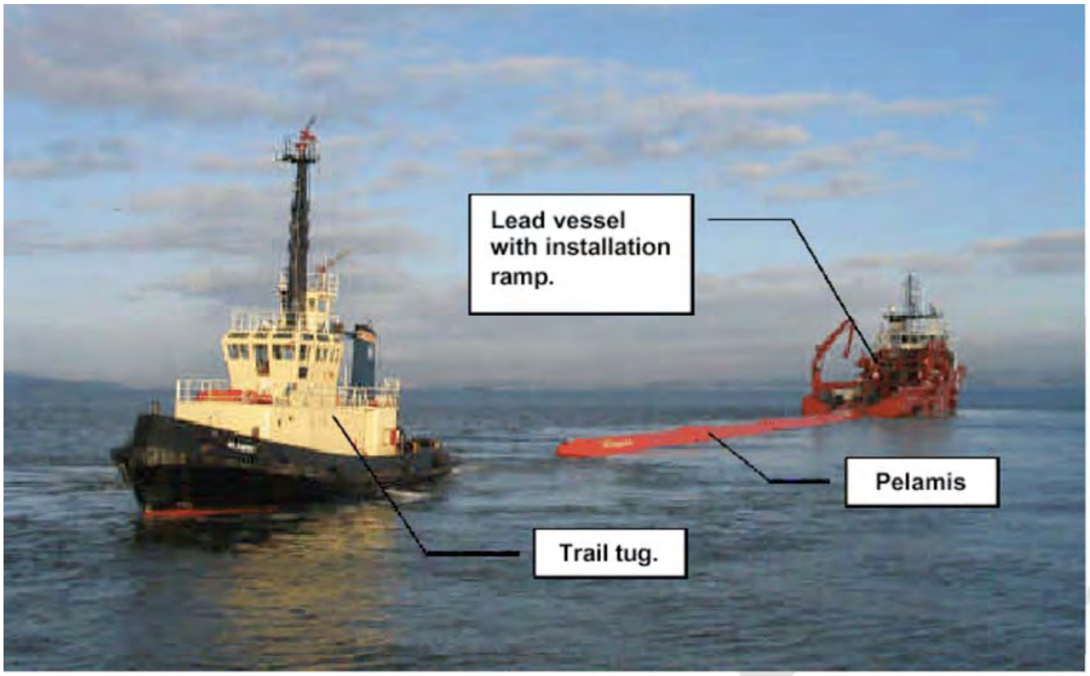


Figure 36 - Pelamis Deployment

Operation of offshore installations, such as oil & gas platforms, wind farms or wave farms, is more difficult and expensive then equivalent onshore installations. Offshore conditions cause more onerous erection and commissioning operations and accessibility for routine servicing, and maintenance is a major concern. During harsh winter storm conditions, a wave farm may be totally inaccessible for a number of days due to sea, wind and visibility conditions.

Even under favorable weather conditions, offshore operation and maintenance tasks are more expensive than onshore. Costs depend on the distance of the wave farms from shore, the exposure of the site, the size of the wave farm, the reliability of the wave power conversion units and the maintenance strategy under which they are operated. The severe weather conditions experienced by an offshore wave farm dictate the requirement for highly reliable components coupled with adequate environmental protection for virtually all components exposed to sea conditions. Consequently, the requirement for remote monitoring and visual inspection becomes more important to maintain appropriate unit availability levels.

4.0 Performance, Cost and Economics

Wave Energy is an emerging technology, with little operational experience. As an emerging technology, it will rely on government subsidized programs to accomplish initial deployments. In this section, opening costs for this technology is estimated, then learning cost reductions are applied to the wave power systems. The purpose is to enable the comparison of the cost of an offshore commercial scale wave farm versus the cost of an equivalent wind farm assuming the same level of production experience for both technologies.

4.1. Economic Base Case for Comparison to Generation Alternatives

Very little data is available to date on cost, performance and economics of wave power plants as there is limited experience with in-ocean tests. Experience shows that it is difficult to extrapolate from prototype experience to commercial systems. In 2004, EPRI carried out a study to assess the cost, economics and performance of a commercial sized wave power plant producing 300,000MWh (100MW wind equivalent) per year. This was done to evaluate the potential cost competitiveness of this resource to other alternatives. The wave climate at the deployment site (off San Francisco) has an energy level of about 21kW/m, which is lower then some of the more attractive sites in Northern California. However, it appears that higher energy levels could be accessed further offshore from this site, which would yield better economics as a result. The following shows an outline of the Methodology for the cost and economic predictions.

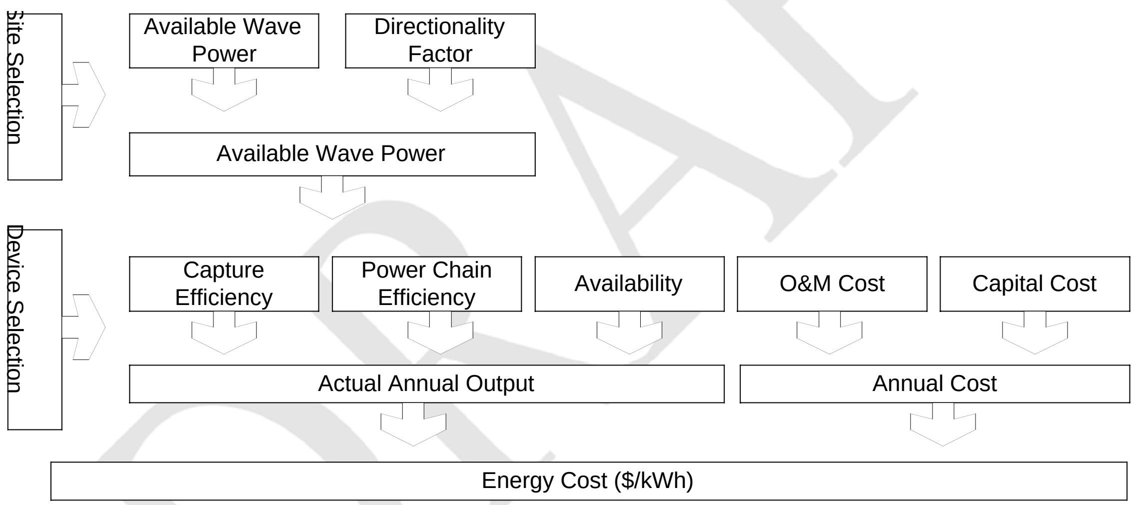


Figure 37 - Methodology to derive cost of electricity

The following simply summarizes the assessment of 2 technologies, the Energetech OWC and Ocean Power Delivery's Pelamis, carried out by the Principal Investigator in 2004. For details on the study, the corresponding reports can be downloaded from www.epri.com/oceanenergy. The concept level design assumed that both wave farms were installed at the same location in a wave climate of 21kW/m. Performance predictions were made using the wave scatter diagrams for the San Francisco buoy NDBC 46026, which is located about 24km west (seaward) of San Francisco. Detailed wave data on that buoy can be found in volume II of this report.

Table 4 - Cost Performance and Economic Comparisons for 2 commercial plant point designs deployed off the coast in San Francisco (Cost in $2004)

	OPD Pelamis	**Energetech OWC**
Wave Farm Specs		
Wave Power Density at Site	21 kW/m	21 kW/m
#Devices	213	152
Rated Capacity per device	500kW	1000kW
Annual Output per Device	1407 MWh/year	1973 MWh/yr
Annual Output at busbar	299,691 MWh/yr	299,896 MWh/yr
Installed Cost		
Absorber Structure	$52M	$76M
Power Conversion System	$133M	$67M
Mooring	$25M	$20M
Balance of Station	$52M	$54M
Total Installed Cost	$262M	$217M
Construction Financing	$17M	$22M
Total Plant Investment	$279M	$251M
O&M		
Insurance	$2.6M	$1.9M
Parts	$5.2M	$4.3M
Operations	$5.2M	$4.3M
Total O&M	$13M	$10.6M
10-year refit	$28.7M	$15.7M
Economics		
Project Life	20 years	20 years
Fixed Charge Rate (Real) [9]	6.9%	6.9%
Levelized COE (Real)	11.2 cents/kWh	9.8 cents/kWh

[9] Utility economic model is used. Includes Federal and State wind tax incentives. Details on the methodology can be download from www.epri.com/oceanenergy

Estimating costs for a technology with little commercial experience introduces uncertainties into the predictions. Uncertainties for this type of cost and economic projection can be estimated by the level of detail used in the assessment and the stage of technology developed. Based on experience with other technology development activities in the power sector, EPRI has created a rating system that can be used to estimate cost uncertainties. Based on this rating system the uncertainties in the above projections are likely in the range of +35% / -25%. Uncertainties will reduce as the technology gains further commercial experience.

The following chart shows a breakdown of the major cost centers in the Pelamis reference case and how they contribute to the levelized cost of electricity. As such it shows the breakdown of all annualized cost components.

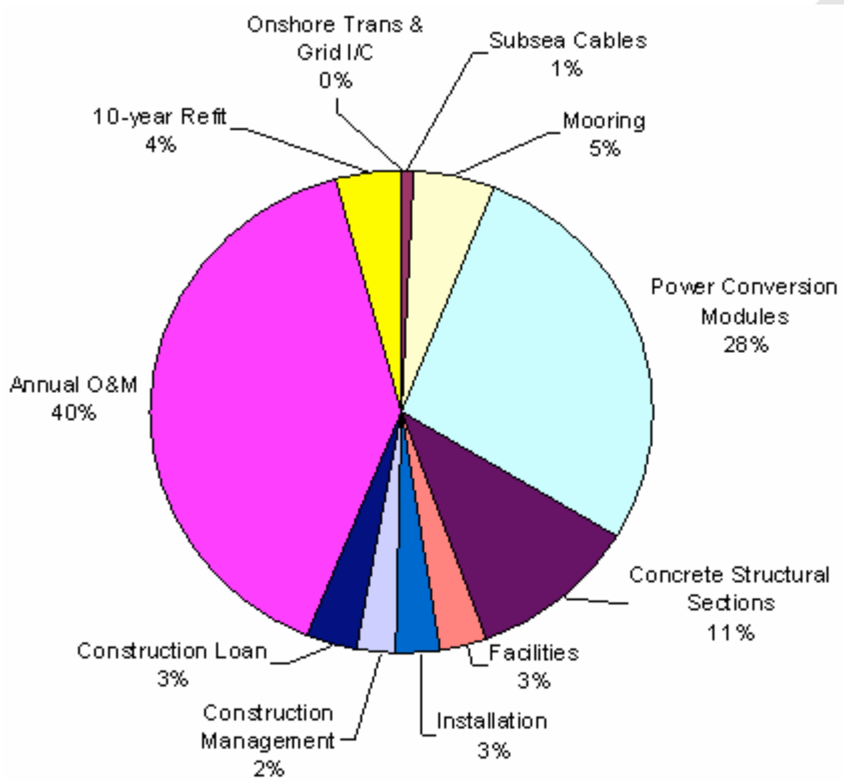


Figure 38 - Levelized Cost breakdown of commercial sized plant

The figure clearly shows that over 40% of the cost of electricity produced by an offshore wave energy plant is borne by the annual O&M and the 10-year refit cost. This is mainly an attribute of the early stage of technology development. As technology matures and reliability increases such cost will get lower. In addition, insurance cost for such emerging technology is higher then comparable onshore projects. O&M costs for modern wind farms makes an impact on the cost of electricity of less then 1 cent/kWh. If O&M on offshore wave power farms was equally low in cost, it would have a significant impact on the cost of electricity from such plants. Various companies have proposed the use of specialized servicing vessels and other operational measures that could significantly reduce these costs.

4.2. Impact of Resource Density on Wave Farm Economics

Like any renewable energy conversion scheme, ocean wave energy is very sensitive to power density of the resource. In order to evaluate the impact of the power level on the cost of electricity, it was decided to use the EPRI cost baseline data (presented in table above) and to re-compute the machine performance for a total of 14 different measurement locations along the California coast. Wave data from CDIP and NOAA stations in Northern California located in various water depths were used for the analysis. The performance was recomputed by applying the machine performance in each sea-state to the scatter diagram at the measurement location, and then the power take off of the machine was optimized (by adjusting the rated machine limits) for lowest cost of electricity. All other cost parameters were left the same. The following plot shows the results. The blue dots show the actual results, the red line is a best fit to these results.

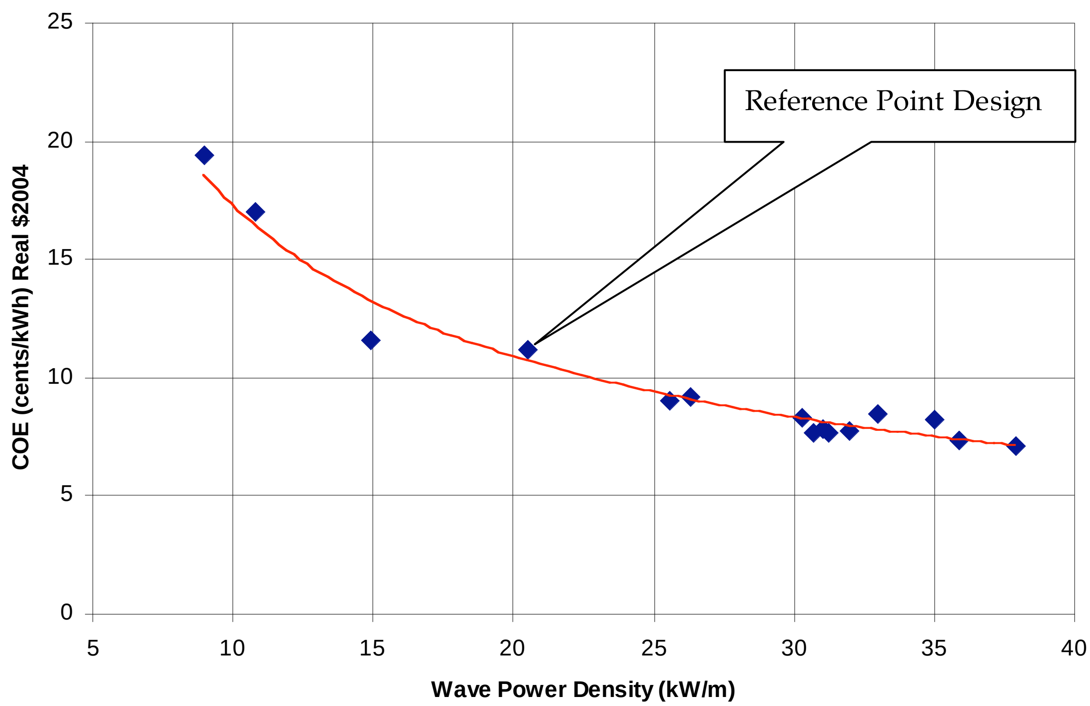


Figure 39 - Projected cost of electricity of a commercial scale (213-units) Pelamis wave farm at various locations in California

Figure 39 shows clearly that a higher energy wave climate will yield a lower COE for a given project.

4.3. Other Key Economic Factors

A second impact on cost of electricity is the scale of a wave power plant. It is clear that fewer units will produce electricity at higher cost, then a large array of devices such as the reference 100MW+ plant outlined above. Infrastructure and grid interconnection cost are oftentimes fixed cost that can be shared in larger projects over a larger number of devices, but have a significant impact on energy cost for smaller projects. In addition, smaller production volumes will lead to higher cost, because tooling costs tend to dominate if only a few devices are built. As a result, small demonstration wave farms may produce electricity at much higher cost then shown above. In order to demonstrate the technology and gain confidence in it's performance and maintenance costs, as well as demonstrating environmental impacts however it will be necessary to develop a phased introduction that may span over several years.

The installation of relatively unproven technologies will require investors to take higher risks. Higher risks are typically reflected in higher cost of capital which might be significantly above the rates for commercial large scale power projects. This in turn compounds the issue of higher cost for the introduction of commercial technologies.

To date, a wide variety of different wave energy conversion technologies are pursued by different developers. There is no consensus today about which technology will ultimately be most cost competitive. Even more so it is unclear which technology will prove to be best suited for the US west coast. The US west coast in general and California in particular has its own bathymetry, wave climate and infrastructure constraints which might be better suited to some devices then others. Targeted research could go a long way in identifying technologies that are better suited then others.

To address the above barriers to deployment, policy makers in the UK and Portugal (both of which have an excellent wave energy resource like California) have created an incentive structure specifically targeted to wave power conversion power plants. As a direct result of such policy, the first commercial multi-MW power plant is being built in Portugal and many more schemes are in the planning stages in the UK and Portugal.

4.4. Future Cost of Electricity

Wave energy today is where wind energy was in the 1980's. Subsidies will be required for the initial adoption of technology in the market place. In order to make available environmentally effective technologies (or technologies that have characteristics that are deemed to be of societal benefit), which are cost competitive, governments support these technologies through funding of RD&D and through price subsidies or other forms of deployment policy. Crucial questions concern how much support a technology needs to become competitive and how much of this support has to come from government budgets. Learning curves make it possible to answer such questions because they provide a simple, quantitative relationship between cost and the cumulative production or use of a technology. There is extensive empirical support for such a cost-experience relationship from all fields of industry, including the production of equipment that transfers or uses energy.

Cost reduction goes hand-in-hand with cumulative production experience and follows logarithmic relations such that for each doubling of the cumulative production volume, there is a corresponding percentage drop in cost. Related industries such as wind, photovoltaic's and ship-building have shown progress ratio's between 78% and 85%. It is likely that wave energy will show cost reductions which are similar to wind energy at about 82%.

How a learning curve is used to show the deployment investment necessary to make a technology, such as wave energy, competitive with an existing technology, such as wind or other generation alternatives. The illustration below shows the cost of electricity from wind in the European Union between 1980 and 1995. It does not, however, forecast when the technologies will break-even. The time of break-even depends on the deployment rates, which the decision-maker can influence through policy.

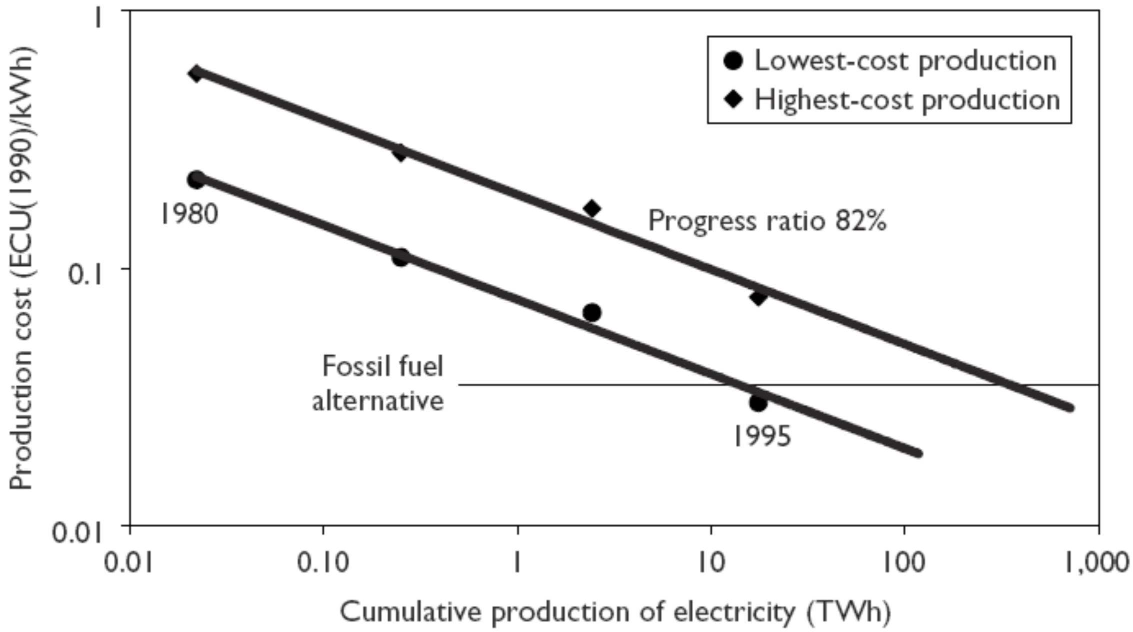


Figure 40 - Electricity from wind energy in the EU 1980 - 1995

In order to compare the economic competitiveness of wave energy with wind and answer the question if wave energy will ever become cost competitive to other sources of renewable energy the following figure is useful to consider. It shows the relative cost of wave energy using the commercial plant outlined above as entry cost-point and an 82% progress ratio. It shows that wave energy can successfully compete with wind at equivalent installed capacity. The upper and lower bound for wave energy is based on the present uncertainty in cost predictions for wave power stations. It shows that even if the worst case holds true, wave energy is still competitive relative to wind.

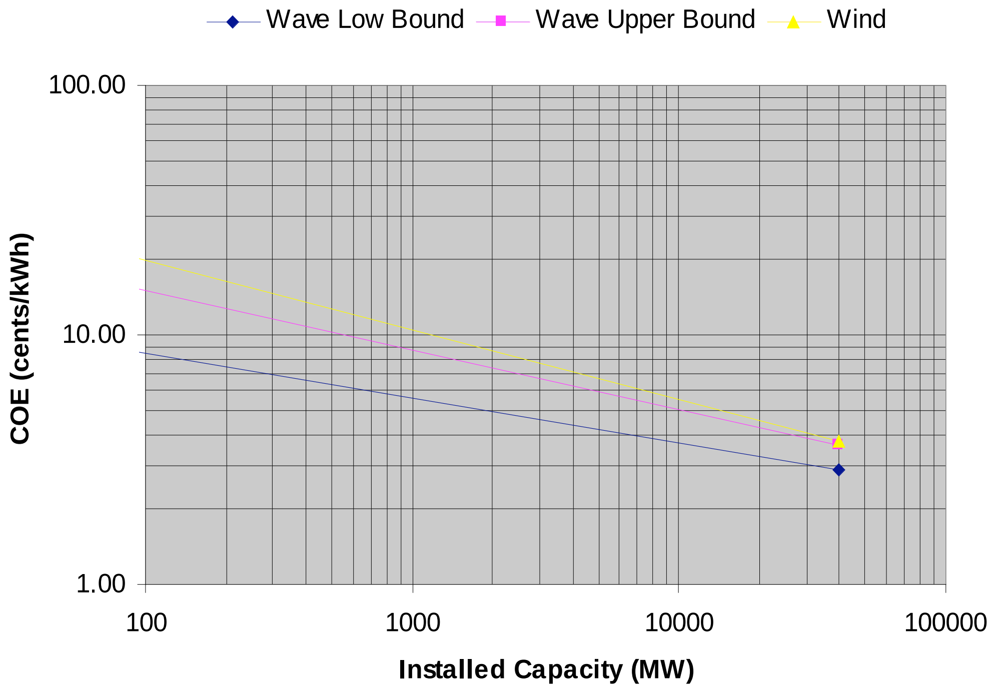


Figure 41 - Projected cost reduction of wave energy compared to wind equivalent installed capacity

Favorable policies attract the private markets to invest into sectors. The following figure shows both public as well as total investments in wind energy during the period between 1980 and 1998 in Germany. It can be seen that these investments were highly leveraged by private market forces. Before 1989, there was no real market for wind turbines in Germany. At that time, the Federal Ministry for Science, Education, Research and Technology (BMBF) announced the "100 MW Wind Program". In 1989 and 1990, an operator of a wind power plant could receive 0.08 DM/kWh (German Mark) from this program and 0.09 DM/kWh from the utility for electricity delivered to the grid. Investment subsidies were given at the start of the program and there were additional grants offered by the Federal States (Länder). The "Electricity Feed Law" (EFL) which came into effect January 1991 further benefited the use of wind power. The EFL stipulated that the utilities had to pay the operator 90% of the average tariffs for the final consumer. For 1999 this amounted to 0.1652 DM/kWh. The "100 MW program" was enlarged to a "250 MW program" in 1991. For the period of 1984-1998, learning investments (Government Subsidies) for wind turbines were only 12% of the total investments. Figure 42 shows a knee in the total investment in wind energy, which can be attributed to the phase-out of government subsidies during that period, leading to an investor uncertainty. However, after a shake-out period, private market forces picked up again and growth continued. This is just one of many example of a well-designed policy framework leading to adoption of technology in the market place and allowing for cost to be driven down. It is interesting to note that despite a gradual phase-out of government subsidies total investments continued to grow between 1996 and 1998, hinting at the fact that the technology is becoming more cost-competitive to other energy sources.

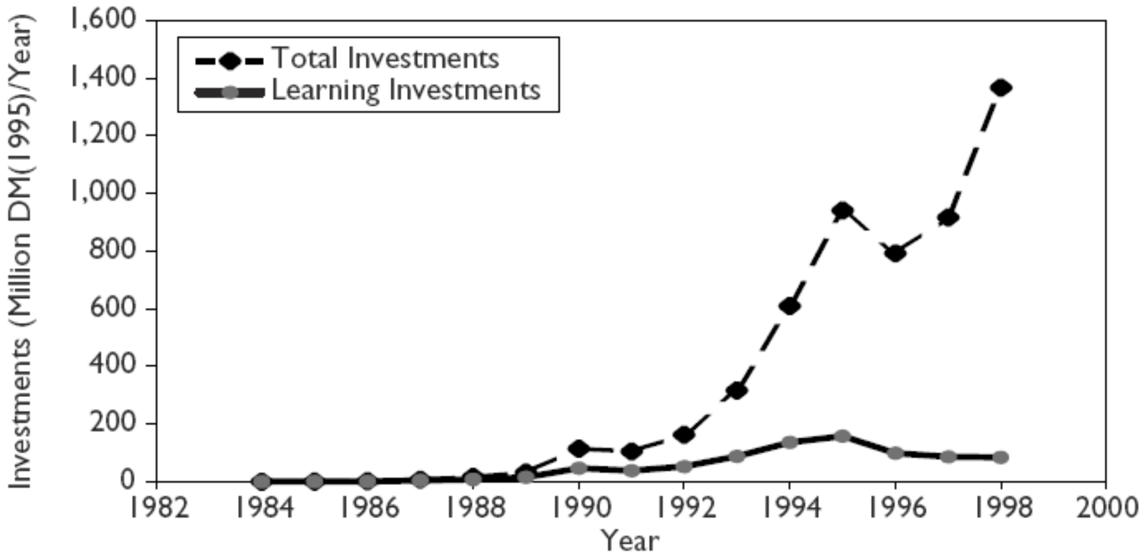


Figure 42 - Investments in wind turbines in Germany

5.0 Environmental Issues

The construction, operation, and decommissioning of structures in the water and on land have the potential to affect terrestrial and marine environmental resources. Each project will have unique effects on the environment, depending on two things: the design of the device (including the size of the array), and the specific environmental characteristics of the project site. In California, every potential project is required to undergo a project-specific environmental review (see the section on environmental regulation, below). Depending on the design of the project and on the site characteristics, a particular project may have impacts ranging from minimal to very significant.

This report cannot assess the potential environmental impacts of all wave energy devices anywhere off the coast of California. Rather, the goal of this section is to alert the reader to the different types of potential impacts wave-energy structures might have on the environment. In many cases, adverse impacts can be avoided or reduced by careful project design (e.g., structural design, siting, materials used, and construction and operation requirements). In some cases, a project proponent may be required to compensate for adverse impacts. Some wave energy devices may be inconsistent with existing environmental laws, regulations, or standards, in which case these projects could not be installed off the coast of California.

Potential environmental issues posed by wave-energy devices include:

- Coastal processes
- Marine biology
- Onshore effects
- Water quality
- Air quality
- Visual resources
- Use conflicts
- Geology

Each of these issue areas is discussed in more detail below.

5.1. Coastal Processes

The purpose of a wave-energy device is to remove energy from ocean waves and convert that energy into electricity. Reducing the energy available to coastal processes could result in changes to sediment transport patterns, beach nourishment, coastal erosion, and other similar coastal processes. Depending on the design of the project, wave energy structures could act as breakwaters, jetties, or groins. Reduced wave energy levels could also increase the competitive advantage of faster growing algae and kelp species over wave-resistant species (e.g. giant kelp over bull kelp, fleshy algae over coralline algae).

5.2. Marine Biology

5.2.1. Sensitive habitats

Areas of hard bottom, kelp forests, and eelgrass beds are all highly productive, sensitive habitats that are found in the near-shore environment. These habitats are afforded special protection under several State and federal environmental laws. Offshore structures and pipelines running to shore have the potential to affect these habitats by physically displacing or destroying areas of these habitats.

5.2.2. Sensitive species

Marine mammals and species listed as threatened or endangered with federal or State governments are provided special protection under the Marine Mammal Protection Act and the federal and State Endangered Species Acts. Many of these species make use of the offshore and near-shore environment, and structures placed in these environments have the potential to adversely affect these species.

5.2.3. Noise

Anthropogenic noise in the marine environment can be introduced by construction activities, such as pile driving, and decommissioning activities, such as the detonation of explosives. Underwater noise of certain levels and frequencies can injure or kill marine mammals, birds, and fish.

5.2.4. Migration

Grey whales migrate annually along the coast of California from their feeding grounds in the Arctic Sea to their calving grounds in the coastal lagoons of Baja California. The annual migration occurs from November to May, and whales can be sited from the surf zone to two nautical miles offshore. Large offshore arrays could interfere with this migration pattern.

5.2.5. Shading

Structures at or near the ocean surface have the potential to interfere with the highly productive micro-layer and upper reaches of the water column, by restricting the amount of sunlight available to primary producers. A reduction in primary production can have indirect consequences throughout the local ecosystem.

5.2.6. Entrainment and impingement

Structures that pump seawater are likely to entrain plankton, larvae, and other small organisms, removing them from the marine ecosystem. Intake pipes can impinge, or trap, larger animals such as fish and invertebrates.

5.2.7. Electromagnetic Radiation

The artificial magnetic and electric fields (associated with submarine electric cables) can interfere with orientation in migrating animals, and with the feeding mechanisms of elasmobranchs (group of fishes which includes the sharks, rays, and skates). At the present time the significance or scale of these impacts is not clear.

5.2.8. Incidental use of structures

Depending on the design of the structures, marine mammals such as sea lions and seals could use structures at the water surface as haul-out areas, and marine birds will likely use them for roosting or nesting. Wave energy structures could affect these animals, and conversely, these animals could affect the structures. Certain devices or measures (e.g., barriers, hazing, etc.) may prevent animals from using the structures; however these devices can be harmful to marine fauna.

Any solid structure placed in the water has the potential to act as a fish attractor, which in turn can attract fish predators, ultimately changing the local marine ecosystem and adversely affect fish populations. Regulators are especially concerned about the effects on managed fish populations and essential fish habitat.

5.3. Onshore Effects

Components of a wave-energy facility that must be located onshore have the potential to affect vulnerable elements of the terrestrial environment. Potential onshore impacts include disruption of sensitive species and habitats such as wetlands, coastal dunes, and riparian corridors. In addition to biological resources, onshore elements of a project could adversely affect cultural resources, agricultural land, traffic, visual resources, recreation, and the public's access to the shore. Public safety issues related to geology, accidents, and intentional acts of destruction are also concerns.

5.4. Water Quality

Water quality can be affected in a variety of ways by structures place in the ocean. Increases in turbidity can smother benthic organisms and filter-feeding marine biota, and can be caused by construction/decommissioning activities and by ongoing operations. Anti-fouling products used to treat structures placed in the marine environment can leach toxic contaminants such as copper and tin. Hydrocarbon-based lubricants, such as grease and oil, can be toxic if released accidentally into the marine environment. Vessels used in the construction, maintenance, and decommissioning of offshore structures can, in the event of a collision, accidentally release diesel fuel and oil.

5.5. Air Quality

Many areas of coastal California are out of compliance with State and/or federal air quality standards. Air emissions can be created by vessels and diesel-powered equipment used during construction, operation, and decommissioning of a project.

5.6. Visual Resources

Many areas of coastal California are well-known for their scenic attributes, and the beauty of highly scenic areas is protected under local and State laws. A large-scale offshore industrial facility has the potential to disrupt the scenic beauty of California's coastline, and adverse visual impacts can be exacerbated by navigational markings required by the Coast Guard, such as signs and night lighting.

5.7. Space and/or Use Conflicts

Commercially-viable build-out of some wave-energy devices could involve arrays covering large areas. A large array of wave energy devices could potentially impose an exclusion zone on commercial fishing. The physical presence of structures in the water could also affect recreational boaters. Additionally, any device designed to remove wave energy from the near-shore environment has the potential to affect recreational surfers in the area. Other uses of the marine environment that would be incompatible with the presence of a wave-energy device include commercial shipping (i.e., shipping lanes), military exercises, and scientific research. California is currently exploring the possibility of expanding its system of designated marine protected areas; existing and newly created MPAs would not be appropriate locations for wave-energy arrays.

5.8. Geology

California is seismically active, and the offshore area is not an exception. Projects must be designed to withstand forces associated with seismicity, liquefaction, and tsunamis. A site-specific geotechnical analysis is generally required for the installation of offshore structures.

If subsea power or communications cables are required between the offshore array and an onshore facility, the shore landing of these cables can affect sensitive surf zone and beach habitats. Recently, Horizontal Directional Drilling (HDD) and Horizontal Directional Boring

(HDB) have increasingly been used to install cable conduit from an onshore landing to offshore waters. These methods cause fewer adverse environmental impacts compared to the more traditional trenching method; however, these methods have the potential to release drilling mud into the ocean, especially if the local geological formation is prone to fracture.

5.9. Existing Information

To date, there is a very little data available specifically on the environmental impacts of wave energy conversion devices. Some studies in Europe are beginning to examine environmental impacts and to document demonstrations. We refer the reader to Section E of the Wave Energy Thematic Network at www.waveenergy.net. In the US, the Electric Power Research Institute (EPRI) has published several reports on wave energy conversion, available for download at www.epri.com/oceanenergy .

In 2003, the Department of the Navy prepared an Environmental Assessment under NEPA for the proposed installation and testing of a Wave Energy Technology project at Marine Corps Base Hawai'i (MCBH) Kane'ohe Bay. The proposed project involved the phased installation and operational testing of up to six Wave Energy Conversion (WEC) buoys off the North Beach at MCBH Kane'ohe Bay for a period up to five years. Each buoy was expected to produce an average of 20 kW of power, with a peak output of 40 kW of power for each buoy. The WEC buoys would be anchored in about 100 feet of water at a distance from shore of approximately 3,900 feet. Mechanical energy generated from the up and down motion of the buoy would be converted into electrical energy. The power would be transmitted to shore by means of an armoured and shielded undersea power cable connected to a land transmission cable. The land cable would be routed to the existing MCBH Kane'ohe Bay electrical grid system.

In the Environmental Assessment, the Navy identified the following issue areas for analysis under NEPA: shoreline physiography, oceanographic conditions (i.e., coastal processes), marine biological resources, terrestrial biological resources, land and marine resource use compatibility, cultural resources, infrastructure, recreation, public safety, and visual resources. None of these resources were found to be significantly affected by the proposed installation and operational testing. Installation procedures were designed to minimize impacts on living coral and benthic communities by avoiding areas of rich biological diversity and high coral coverage.

California's environment and environmental regulatory structure are vastly different from those of other states and other countries. Therefore, care should be taken when applying the information in these reports to projects proposed for California.

5.10. Summary

Environmental impacts from wave energy conversion devices are site- and technology-specific. Structures associated with wave energy can have environmental impacts similar to other structures placed offshore, in virtue of their physical presence in the water, as well environmental effects unique to wave energy devices. Each specific project proposed for

California will undergo a project-specific environmental review, under the regulatory structure described in more detail in the following section. Adverse impacts to the environment can often be avoided or reduced by careful project design and siting, and occasionally compensation can be provided to offset adverse effects. Some technologies may not be consistent with California's environmental standards, and therefore may not be appropriate for installation.

6.0 Permitting Issues

The environmental permitting process for projects located offshore California is complex, involving a variety of federal, State and local resource management agencies. This section of the report will outline the jurisdictional and permitting framework as it applies to wave energy projects operating offshore California.

6.1. Ocean Jurisdictions

The zones establishing national sovereignty over sea, airspace and economic resources is complex, with overlapping legal authorities and agency responsibilities.[10] The United Nations Convention on the Law of the Sea[11] establishes the sovereignty of a coastal nation over its territorial seas (out to 12 nautical miles[12]) and defines exploitation rights in the Exclusive Economic Zone (out to 200 nm). As shown in the figure below, in the United States the boundary between State and federal jurisdiction is located three nautical miles from the coastline. States have jurisdictional authority over and title to submerged lands out to three nautical miles offshore. Beyond the three-mile limit, the federal government is the primary jurisdictional authority, with the right to manage and develop resources in the seabed, including oil, gas, and all other minerals. Coastal states retain some approval authority over some projects in federal waters, as will be discussed below.

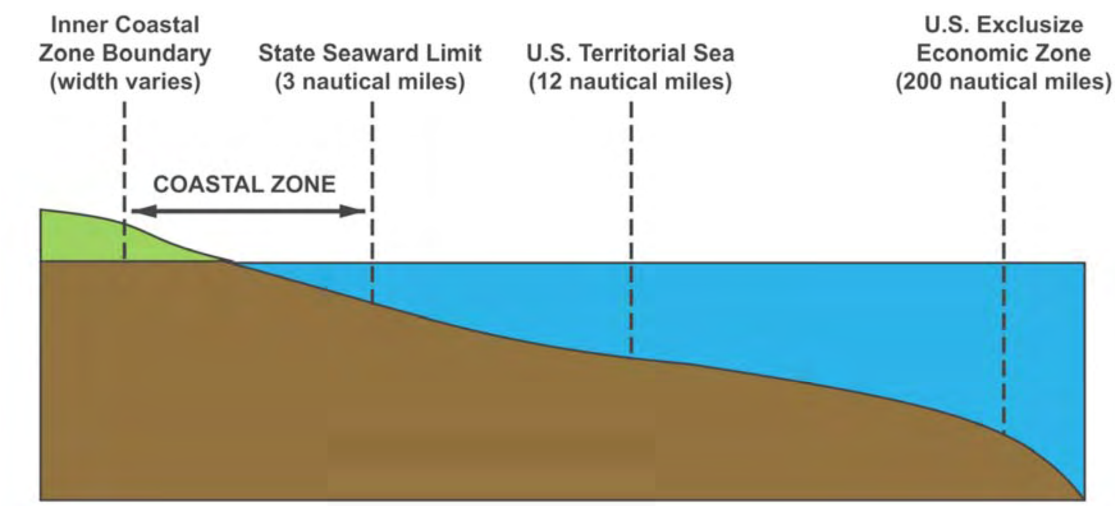


Figure 43 - Primary Maritime boundaries

Wave energy devices may be located completely in State waters (i.e., all project elements located within three nautical miles of shore), or in both State and federal waters, with elements of the project located both beyond and within the three-mile limit (i.e., an array located 5 miles

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[10] See http://www.oceancommission.gov/documents/prepub_report/primer.pdf

[11] UNCLOS contains a legal framework covering navigation, maritime boundaries, fisheries, the marine environmental, etc. Since 1994, 138 nations have joined this Convention.

[12] A nautical mile is approximately 6076 feet.

offshore, with sub-sea transmission cables running to an onshore transmission facility). The location of a particular project determines which regulatory authorities apply and which approvals are required, as outlined below:

For projects located completely within State waters, required approvals include:

- Project-specific environmental review under NEPA (for federal agencies) and CEQA (for State agencies);
- A license from the Federal Energy Regulatory Commission;
- A license from the US Coast Guard;
- A permit from the Army Corps of Engineers under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act;
- Possible federal consultation with NOAA Fisheries and/or the US Fish and Wildlife service under the federal Endangered Species Act, the Magnuson-Stevens Fishery Conservation Act, and/or the Marine Mammal Protection Act;
- A General Lease from the California State Lands Commission;
- A Coastal Development Permit from the California Coastal Commission;
- An Authority to Construct and a Permit to Operate from the regional Air Pollution Control District;
- A 401 Certification, and possibly an NPDES permit and Waste Discharge Requirements from the Regional Water Quality Control Board and/or the State Water Board;
- Possible State consultation with the California Department of Fish and Game under the California Endangered Species Act; and
- Local approvals for those aspects of the project which are located onshore.

For a project located both in State waters and federal waters, required approvals include:

- Project-specific environmental review under NEPA (for federal agencies) and CEQA (for State agencies);
- A lease from the Minerals Management Service (for those elements in federal waters);
- A license from the Federal Energy Regulatory Commission;
- A license from the US Coast Guard;
- A permit from the Army Corps of Engineers under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act;
- An Authority to Construct and a Permit to Operate for air emissions from the federal Environmental Protection Agency;
- An NPDES permit for wastewater discharge from the federal Environmental Protection Agency;
- Possible federal consultation with NOAA Fisheries and/or the US Fish and Wildlife service under the federal Endangered Species Act, the Magnuson-Stevens Fishery Conservation Act, and/or the Marine Mammal Protection Act;

- A General Lease from the California State Lands Commission (for those elements in State waters);
- From the California Coastal Commission, a federal consistency certification for those elements of the project in federal waters, and a coastal development permit for those elements of the project in State waters;
- A 401 Certification from the Regional Water Quality Control Board and/or the State Water Board;
- Possible State consultation with the California Department of Fish and Game under the California Endangered Species Act; and
- Local approvals for those aspects of the project which are located onshore.

This list is intended to provide general guidance, and is not meant to be comprehensive. Depending on the location of the facility, additional regulatory review may be required, for example, if the project is located in a National Marine Sanctuary, or if it may disturb cultural resources. Conversely, a small pilot project located wholly in State waters may not require, for example, a license from FERC, and other aspects of the environmental review process may not be as demanding.

The federal and State agencies listed above, and their respective legislative authorities, are discussed in more detail below.

6.2. Federal Agencies[13]

6.2.1. Minerals Management Service

With the passage of the Energy Policy Act of 2005 (EPAct), Public Law 109-58 (H.R. 6), the Minerals Management Service (MMS), a bureau of the U.S. Department of the Interior, was assigned jurisdiction over Renewable Energy and Alternate Use Program projects, such as wind, wave, ocean current, solar, hydrogen generation, and projects that make alternative use of existing oil and natural gas platforms in federal waters. A new program within MMS has been established to oversee these operations on the U.S. Outer Continental Shelf. At the time of this writing, MMS is preparing a programmatic environmental impact statement that will focus on generic impacts from each industry sector based on global knowledge, and identify key issues that subsequent, site-specific assessments will consider. The programmatic EIS will focus on the environmental, cultural, and socioeconomic impacts associated with establishing a national alternative energy program and rules.

As part of this EIS, three study areas for the State of California were defined. Maps of these areas, showing jurisdictional boundaries can be downloaded from http://ocsenergy.anl.gov/. A draft EIS and draft rules are scheduled to be published February 2007 and final rules in the late summer of 2007. MMS will coordinate with other agencies in the permitting of offshore

[13] Much of the legal information in this section is courtesy of the documentation and analysis from the landmark Ocean Energy Resources website from the Law Offices of Carolyn Elefant. See http://www.his.com/~israel/loce/ocean.html

renewable energy projects. At the time of this writing, it is not certain how this new program for ocean energy developments will affect the licensing and permitting process for offshore wave power plants. For further information on the EIS and rulemaking process please visit http://ocsenergy.anl.gov/.

6.2.2. Federal Energy Regulatory Commission

Pursuant to the Federal Powers Act[14], FERC is an independent agency regulating interstate transmission of natural gas, oil, and electricity and hydropower projects. FERC also has regulatory authority over the terms and rates for power supply contracts from a wave power project to a local utility.[15] FERC issues licenses for private hydropower development on navigable waterways, federal lands, and commerce clause waterways. The hydropower licensing process includes consulting with a wide range of stakeholders, identifying environmental issues through a scoping process and preparing an environmental assessment of the project under NEPA (see below). Licenses are issued by Commission Order. This traditional licensing process takes several years to complete and the license is issued for thirty to fifty years.

In 2003, FERC determined through a first-time legal interpretation that the AquaEnergy Group demonstration project in the State of Washington falls under the jurisdiction of the Federal Powers Act.[16] FERC determined that a wave energy buoy is a hydropower project, with a "power house" that uses water to generate electric power. If such a device generates electricity that will be sold onto the grid, the project falls under the licensing authority of FERC. This determination is legally murky, raising questions about whether the definition of "navigable waterways" extends to coastal waters up to 12 nm from shore, and whether the determination is consistent with the State Lands Act and the Outer Continental Shelf Lands Act. As a result of this decision, it is likely that wave energy devices will be subject to FERC's licensing authority.

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[14] "….it shall be unlawful for any person….for the purpose of developing electric power, to construct, operate or maintain any dam…reservoir, power house or other works…across navigable e waters of the US or upon any part of public lands or reservations of the US…except in accordance with a license….[issued by FERC].

[15] In most cases, small developers obtain certification as a "qualifying facility" (QF) or "exempt wholesale generator (EWG) to avoid regulation as a utility or in some cases, obtain more favorable rate treatment. FERC also has jurisdiction over sales by a developer to a utility which are known as "wholesale sales." In most cases, wholesale rates established in a contract between the supplier and purchaser and are then submitted for review to FERC to ensure that rates are "just and reasonable." Retail sales, i.e., sales directly to the end user are regulated by the state utility commissions. Interconnection with the utility means that the demo project has to get in the queue with all other new users of the lines. (Reference: Law Office of Carolyn Elefant).

[16] See http://www.ferc.gov/legal/court-cases/pend-case.asp and scroll down to the AquaEnergy Group.

6.2.3. U.S. Army Corps of Engineers

Under Section 404 of the Clean Water Act, the discharge of dredged or fill material into waters of the United States requires a permit from the USACE. The Corps also has permitting authority under Section 10 of the Rivers and Harbors Act[17], which requires a permit for the placement of structures altering or obstructing navigable waters outside of State limits. Wave energy projects that involve the placement of structures in the water will almost certainly require a permit from the Corps.

6.2.4. Federal Consultation Agencies

Under the federal Endangered Species Act and the Magnuson-Stevens Fisheries Conservation Act, a federal agency such as MMS, FERC or the Corps may be required to formally consult with NOAA Fisheries and/or the USFWS, if a proposed project under that agency's regulatory authority has the potential to adversely affect listed species, designated critical habitat, or essential fish habitat. The agency may also consult with NOAA Fisheries regarding marine mammal concerns under the Marine Mammal Protection Act. NOAA Fisheries will become involved in a wave project if it is located within a protected area such as a National Marine Sanctuary. National Marine Sanctuaries often transcend federal and State jurisdictional boundaries and may extend to the seafloor and subsoil resources (see "Marine Protection, Research and Sanctuaries Act"). There are four National Marine Sanctuaries along the California coast: Cordell Bank, Gulf of the Farallones, Monterey Bay, and Channel Islands.

6.2.5. U.S. Environmental Protection Agency

The US EPA is responsible for issuing wastewater discharge permits, called National Pollution Discharge Elimination System (NPDES) permits, under the Clean Water Act for projects in federal waters. This agency also regulates air quality in coordination with the State, and may issue an Authority to Construct or Permits to Operate for projects located in federal waters.

6.2.6. U.S. Coast Guard

The U.S. Coast Guard regulates maritime security, and requires that structures in the water be appropriately marked so they don't become a hazard to navigation. The Coast Guard is also involved in oil spill prevention and response efforts.

6.3. Federal Regulations

There are over forty principle statutes addressing potential environmental impacts at the federal level,[18] but only a handful are directly relevant to wave power jurisdictions.[19] A description of the most important and relevant statutes, and a more extensive table of applicable federal regulations, is presented below. The primary federal regulations applicable

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[17] See 43 U.S.C. section 403: "It shall not be lawful to build or commence the building of any wharf, pier…or other infrastructure in any port, roadstead…or other water of the US except on plans recommended by the Chief of Engineers and authorization by the Secretary of the Army."

[18] For a brief summary of specific laws see: http://www.csc.noaa.gov/opis/html/legal.htm#BNDs

[19] Ocean Thermal Energy Conversion Ac (42 U.S.C. sec. 9101); Coastal Zone Management Act (CZMA)

to a specific wave power project will be different depending on design and location of the project. Because wave power is a nascent industry in California and the United States, this list will almost certainly change in the future.

6.3.1. National Environmental Policy Act (NEPA)

NEPA requires that the environmental consequences of a proposed project must be considered before a federal agency makes a discretionary decision to licence, permit or otherwise allow a project to go forward. Some small-scale projects qualify as "categorical exemptions," requiring very little environmental review. Most wave power projects, however, will require either an Environmental Assessment, in which the agency finds that the project will not cause significant adverse impacts to the environment, or, for large-scale projects with significant adverse effects, an Environmental Impact Statement. The EIS process generally requires coordination among multiple agencies and stakeholder groups, a public comment period, and formal certification by the agency.

Relevance: Every wave power project requiring authorization from a federal agency will be required to undergo a project-specific environmental review under NEPA. For large projects, the NEPA process is often conducted in coordination with the State-level CEQA process (see below), with a federal agency leading the NEPA review and a State agency as the CEQA lead.

6.3.2. River and Harbors Act

Section 10 of this Act prohibits the obstruction or alteration of navigable waters of the United States without a permit from the United States Army Corps of Engineers (USACE). For the purpose of this regulation, "navigable waters of the United States" include the U.S. Territorial Sea as defined prior to 1988 (i.e., extending three nautical miles seaward from the shoreline). Limited authorities extend across the outer continental shelf for artificial islands, installations and other devices.

Relevance: Any wave power project sited in "navigable waters of the United States" that will involve the construction and placement of floating and/or fixed structures, laying of power transmission lines, dredging, or any other activity that obstructs or alters the seabed and overlying waters will need to obtain a "Section 10 Permit" from the USACE.

6.3.3. Clean Water Act

Section 404 of the Clean Water act prohibits the discharge of dredged or fill material into waters of the United States without a permit from the USACE. For the purpose of this regulation, "waters of the United States" include the U.S. Territorial Sea as defined prior to 1988 (i.e., extending three nautical miles seaward from the shoreline). The term "dredged material" means material that is excavated or dredged from waters of the United States. The term "fill material" means any material used for the primary purpose of replacing an aquatic area with dry land or of changing the bottom elevation of a waterbody. The term "discharge of fill material" means the addition of fill material into waters of the United States (e.g., riprap, seawalls, breakwaters, artificial islands, etc.). The placement of pilings may or may not constitute discharge of fill material (refer to Section 323.2).

Section 401 of the Clean Water Act gives certification authority to State governments over activities that may result in discharge into their navigable waters – i.e., before any federal permit or license can be issued for any activity which may result in discharge, certification must be obtained from the government of the State in which the discharge will occur. In California, the State Water Resources Control Board (SWRCB) and the Regional Water Quality Control Boards (RWQCBs) are responsible for taking certification actions for activities subject to any permit issued by a federal agency.

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) Permit Program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches.

Relevance: A wave power project that discharges dredged or fill material into waters of the United States requires a Section 404 permit from the USACE. The Regional Water Quality Control Board must certify the Corps' Section 404 permit with a Section 401 certification. Any discharge of wastewater from a point source must be covered under an NPDES permit, issued by the US EPA in federal waters and by the Regional Water Quality Control Board in State waters. In some cases, the State Water Resources Control Board will issue either the 401 certification or the NPDES permit, or both.

6.3.4. Clean Air Act

The Clean Air Act establishes primary and secondary ambient air quality standards designed to protect public health and welfare. Stationary sources in federal waters are regulated by the US EPA, and in State waters by the regional Air Pollution Control District (APCD). Mobile sources, such as marine vessels, trucks, and automobiles, are regulated by the California Air Resources Board (CARB).

Relevance: The construction, modification, or operation of a wave energy facility that may emit pollutants into the atmosphere must first obtain an Authority to Construct and/or a Permit to Operate from the US EPA or the local APCD. Mobile sources of air emissions such as marine vessels may be required to meet exhaust emission standards set by CARB.

6.3.5. Title 33 -- Navigation and Navigable Waters

Under these regulations, the District Commanders of the United States Coast Guard have the authority to determine whether an obstruction in the navigable waters of the United States is a hazard to navigation and, if so, what markings (lights, fog signals, etc.) must be placed on or near the obstruction for the protection of navigation.

Relevance: The District Commander responsible for California (District 11) will need to authorize any wave power project and determine the necessary marking requirements. The authorization process will be coordinated with the Corps' permitting process..

6.3.6. Coastal Zone Management Act

The California Coastal Commission[20] has federal consistency review authority pursuant to the federal Coastal Zone Management Act (CZMA). For most projects that require a federal license or permit, the Commission must review the project and certify that it is consistent with the California Coastal Management Plan, of which the substantial policy component is the Chapter 3 resource policies of the Coastal Act. A project that can reasonably be expected to affect the coastal zone, such as a project that requires a permit from the Army Corps of Engineers for the placement of fill, is subject to federal consistency review under the CZMA. The Coastal Commission must determine that a proposed project is consistent with the California Coastal Management Plan before the federal agency can issue its license or permit.

Relevance: If the project occurs wholly within State waters (or other areas where the Commission has retained coastal development permit jurisdiction), the Commission's permit review satisfies federal consistency requirements. If a project is wholly or in part in federal waters, a separate federal consistency review would most likely be required.

6.3.7. Endangered Species Act/Fish and Wildlife Coordination Act

Section 7 of the Endangered Species Act directs all federal agencies to consult with the USFWS and NOAA Fisheries, to ensure that the actions they authorize, fund, or carry out do not jeopardize listed species or destroy or adversely modify critical habitat. The Fish and Wildlife Coordination Act provides that whenever an activity is planned to modify waters by a department or agency of the United States, that entity shall first consult with the USFWS, NOAA Fisheries, and with the State agency exercising administration over the fish and wildlife resources.

Relevance: Depending on the exact nature and degree of environmental impacts a wave power project has the potential to cause, the USFWS and/or NOAA Fisheries may be informally or formally consulted during the federal permitting process.

Table 5: Selected Federal Regulations

Legislative Authority	**Major Program/Permit**	**Lead Agency**
Federal Power Act	Issues license for any type of electric power generation within/or on navigable waters; interconnection is parallel process	FERC
Rivers and Harbors Act - Section 10	Regulates all structures and work in navigable water of the U.S. Extended out to 200 nm under the OCSLA for fixed structures/artificial islands	U.S. Army Corps of Engineers (District Office)

[20] The CZMA is administered by the California Coastal Commission for areas offshore the coastline of the Pacific Ocean, and by the San Francisco Bay Conservation and Development Commission for waters of San Francisco Bay and contiguous areas.

Legislative Authority	**Major Program/Permit**	**Lead Agency**
National Environmental Policy Act (NEPA)	Requires an environmental review for all major federal actions that may significantly affect the quality of the human environment	Lead agency varies depending on project Council on Environmental Quality
Coastal Zone Management Act	Jurisdictional rights to states to review activities that may affect the state's coastal resources	California Coastal Commission
Navigation and Navigable Waters	Navigation aid permit (markings and lighting)	U.S. Coast Guard
Clean Water Act, Section 404	Regulates discharge of dredged or fill material into waters of the United States	U.S. Army Corps of Engineers (District Office)
Clean Water Act, NPDES program	Regulates discharges of pollutants into the waters of the United States	U.S. Environmental Protection Agency
Clean Air Act	Establishes primary and secondary ambient air quality standards	U.S. Environmental Protection Agency
Migratory Bird Treaty Act	No "taking" or harming of birds determination	U.S. Fish and Wildlife Service Migratory Bird Conservation Commission
National Historic Preservation Act	Consultation on the protection of historic resources — places, properties, shipwrecks	Department of the Interior State Historic Preservation Offices
Magnuson-Stevens Fishery Conservation & Management Act	Conserves & manages fish stocks to a 200-mile fishery conservation zone & designates essential fish habitat	National Marine Fisheries Service (NOAA Fisheries)
National Marine Sanctuary Act (Title III)	Designates marine protected areas	National Ocean Service (within NOAA)
Endangered Species Act	Consultation on action that may jeopardize threatened & endangered (listed) species or adversely modify critical habitat. May require the preparation of a Biological Assessment	U.S. Fish & Wildlife Service National Marine Fisheries Service (NOAA Fisheries)
Marine Mammal Protection Act	Prohibits or strictly limits the direct of indirect taking or harassment of Marine Mammals	National Marine Fisheries Service (NOAA Fishereis)

Legislative Authority	Major Program/Permit	Lead Agency
	(Permits may be sought for "incidental take")	
Submerged Lands Act	Grants states a title for public lands/natural resources held in trust by the government	Minerals Management Service
Outer Continental Shelf Lands Act	Manages the OCS with leasing rights for minerals production. Also covers artificial islands, ,installations, and other devices located on the seabed	Minerals Management Service
Estuary Protection Act	Conserves estuarine areas	Fish and Wildlife Service

6.4. State and Local Authorities

Under most federal licensing and permitting regimes (e.g., FERC hydropower licensing, Section 404 permits), federal agencies must consult with the affected State, and in some cases require compliance with the State's laws and regulations. As with the federal regulatory process, the State permitting process will vary for each individual project depending on the location and design of the project. Onshore facilities will also likely require approvals from the local government (either City or County), possibly including a coastal development permit, a special use permit or a zoning change.

For the State of California, the key agencies involved in the permitting process are the State Lands Commission, the Coastal Commission, the regional Air Quality Management District, the regional Water Quality Control Board, and the Department of Fish and Game. The following table provides a short description of applicable California regulations:

Table 6: State and Local Agencies

S T A	State and local agencies	Any activity that has the potential to cause adverse effects to the human environment	CEQA assessment

T E	California State Lands Commission	Use of submerged/tidal lands or other public trust lands	General lease
	California Coastal Commission	Development within Coastal Zone (submerged/tidal lands or other public trust lands; lands not covered by certified LCP) Development that triggers a federal permit, that may affect coastal resources	Coastal development permit Federal consistency review
	California Air Resources Board Air Quality Management Districts	Any activity that may result in the production of air emissions	Authority to Construct Permit to Operate
	California State Water Resource Control Board Regional Water Quality Control Boards	Any activity which may result in discharge into State waters	Section 401 certification Waste discharge requirements
	California Department of Fish and Game	Any activity	Consultation under California Endangered Species Act
L O C A L	County/city governments	Development within Coastal Zone (where local government has a certified Local Coastal Plan)	Coastal development permit

6.4.1. California Environmental Quality Act (CEQA)

CEQA requires that the potential environmental effects of a proposed project be analyzed and disclosed, and that means to avoid or minimize those impacts be identified. As with NEPA, there are different levels of environmental review under CEQA, depending on the scale and location of the proposed project. An Initial Study and Negative Declaration is appropriate when an agency finds that the proposed project will not have significant adverse environmental effects, or if any adverse effects can be mitigated so that they are no longer significant after mitigation. An Environmental Impact Report is similar to an Environmental Impact Statement under NEPA – the EIR requires multiple agency and stakeholder coordination, and a public comment period. Unlike NEPA, CEQA specifically requires that a proposed project incorporate mitigation measures to avoid or substantially reduce significant environmental effects.

***Relevance**:* A wave power project subject to State authority will be required to undergo an environmental analysis under CEQA.

6.4.2. Submerged Lands Act/California State Lands Act

The Submerged Lands Act grants coastal states title to offshore lands out to three nautical miles offshore, as well as the rights to the natural resources on or within those lands. The federal government relinquishes its claims to the lands and resources, but maintains the right to regulate offshore activities for national defense, international affairs, navigation, and commerce. The State Lands Commission has jurisdiction over all State-owned tide and submerged lands, including the tidal and submerged lands adjacent to the entire coast and offshore islands of the State from the mean high tide line to three nautical miles offshore.

***Relevance**:* Any wave power project involving floating devices, seabed structures, and/or power transmission cables on State-owned tidal and submerged lands will require a General Lease from the State Lands Commission.

6.4.3. Coastal Zone Management Act/California Coastal Act

The California Coastal Act requires that any proposed project involving development in the coastal zone obtain a coastal development permit. The coastal zone extends from three nautical miles offshore to an onshore location that varies depending on location. On tidelands and submerged lands, the issuing agency for a coastal development permit is the California Coastal Commission, and the standard of review is the resource policies of Chapter 3 of the Coastal Act. For onshore development in areas where the local government has a certified Local Coastal Program, the issuing agency is the local government (either the City or the County), although the permit may be appealable to the Commission. The standard of review for a locally-issued CDP is the certified Local Coastal Program.

***Relevance**:* Wave power projects located within the coastal zone will require a coastal development permit from the Coastal Commission and/or the appropriate local government agency.

6.4.4. Clean Water Act/California Porter-Cologne Water Quality Control Act

As discussed above, Section 401 of the Clean Water Act requires that the State certify a project subject to the Corps' Section 404 permit requirements. Under the Porter-Cologne Act, all parties proposing to discharge waste that could affect waters of the State must file a report of waste discharge with the appropriate Regional Board. The Regional Board will then issue or waive waste discharge requirements (WDRs). It is important to note that while Section 404 permits and 401 certifications are required when the activity results in fill or discharge directly below the ordinary high water line of waters of the United States, **any** activity that results or may result in a discharge that directly or indirectly impacts waters of the State or the beneficial uses of those waters are subject to WDRs. In practice, most Regional Boards rely on applications for 401 certification to determine whether WDRs are also required for a proposed project.

Relevance: Any wave power project involving the discharge of dredged or fill material in waters of the United States will require a Section 404 Permit from the USACE, and a Section 401 Certification (and possibly WDRs) from the SWRCB or the appropriate RWQCB.

6.4.5. The California Endangered Species Act (CA ESA)

This Act parallels the main provisions of the federal Endangered Species Act, and is administered by the California Department of Fish and Game (DFG). The CA ESA establishes a petitioning process for the listing of threatened or endangered species, and prohibits the "taking" of listed species. During the CEQA process, State lead agencies consult with DFG to ensure that the proposed project is not likely to jeopardize the continued existence of any endangered or threatened species, or result in destruction or adverse modification of essential habitat.

Relevance: The California Department of Fish and Game consults on projects that have the potential to cause adverse effects to listed species.

6.4.6. Summary

Wave energy projects proposed for offshore California will be subject to a high level of public and regulatory scrutiny, and must meet a variety of federal, State and local environmental standards. Early involvement of stakeholders and regulatory agencies helps identify areas of concern, so that environmental issues can be addressed during the siting and design phase of the project. As discussed in the previous section, many adverse environmental effects can be avoided or reduced through careful project siting and design, helping to streamline the environmental regulatory process.

7.0 Conclusions

There is over 1200 km of coastline along California, and the combined average annual deep water wave power flux is over 37,000 megawatts (MW). It was found that based on currently available technology, the upper limit to economically tap into ocean waves is about 20% of the primary resource. Based on this assumption in average 7460MW or 65 TWh/year could be extracted from California's wave energy resource. In 2005 California's total energy generated (including energy imports) was 288 TWh. With other words, it is technically possible to meet about 23% of California's electricity needs with ocean wave energy. Environmental impacts, land-use and grid interconnection constraints may impose further limits to how much of the resource can be extracted. While it is difficult to quantify many of these limitations at this stage, the coastline was divided into primary and secondary sites. Figure 44 shows where these sites are located.

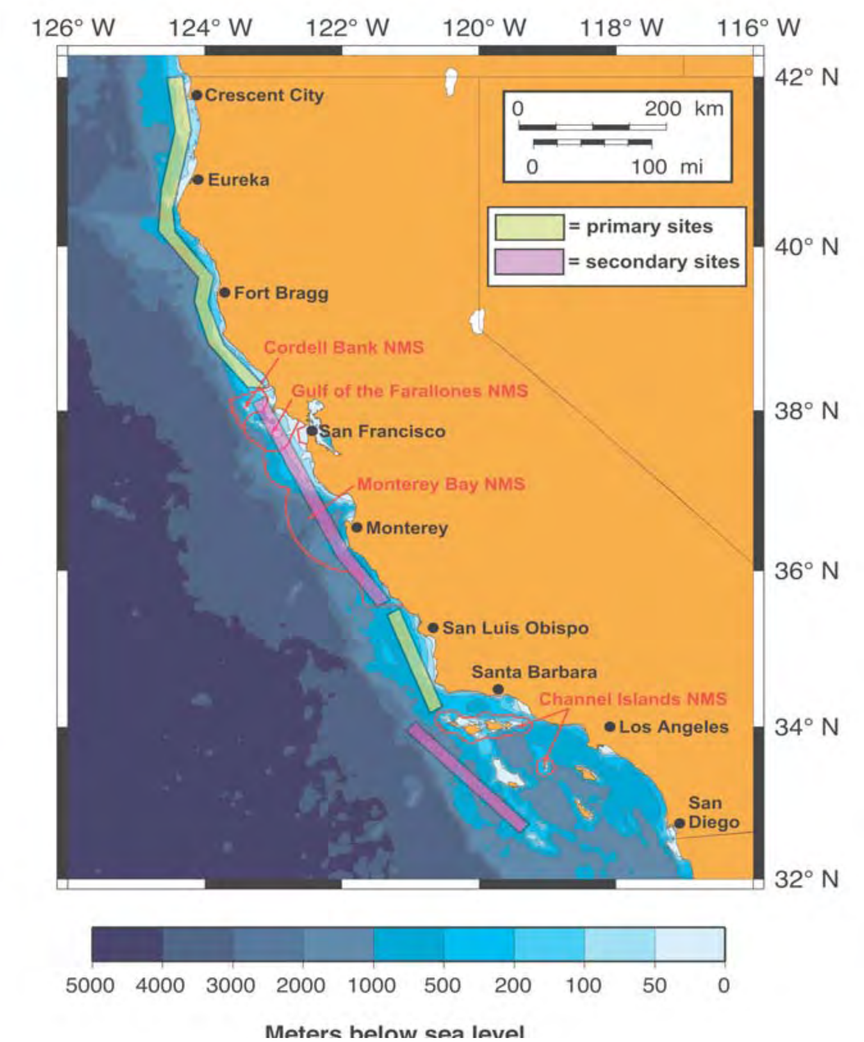

Figure 44 - Primary and secondary sites along the California Coastline

Primary sites were defined as locations with the following attributes; reasonable permitting process, excellent wave conditions and deep water (i.e., water depth greater than 50 meters) within 10 miles from the coast. Sites with these characteristics are expected to yield optimal wave energy economics. Secondary sites were defined as locations for which it will be difficult to obtain permits (e.g., marine sanctuaries) and sites that have to be located further offshore because of wave shadowing effects (e.g., Channel Islands in Southern California). Secondary sites would likely be developed only in the longer term due to higher costs to developing these sites and permitting constraints. The study showed that 58% of all sites are considered primary sites. Grid interconnection constraints were not evaluated as part of this study, but could present further limitations to where wave power plants could be located.

Wave energy conversion technologies have made great strides in the past few years toward commercial readiness. There are at the time of this writing a total of 6 in-ocean prototypes being tested in; Australia, US (Hawaii), UK and Portugal. Policy makers in the UK and Portugal responded to early pilot testing successes with the implementation of incentive programs to support the implementation first commercial wave farms. As a direct result of such programs, the first commercial multi-megawatt wave farm is being constructed in Portugal and several more are in the planning stages in Portugal and the UK.

Despite significant progress in recent years, ocean wave energy conversion technology remains in an early stage of development. Similar to wind power 20 years ago, a large number of very different device concepts are pursued at various scales by different developers and there is no consensus as to which technology is superior. This is typical for emerging industries. However individual technologies show much higher maturity and sea-trials allow the various vendors to fine-tune their technology focusing mostly on reliability aspects.

Economic projections indicate that ocean wave energy can become cost-competitive with other forms generation in California in the long term if appropriate policies are created to support early adoption of technologies. Like any renewable technology, economics of wave power generation schemes is sensitive to energy levels at the deployment site and as a result the choice of appropriate site is critical. Comparing the energy levels to European sites show that California has a good wave climate. An assessment of likely commercial opening costs by the Principal Investigator in 2004 indicated a cost of electricity from a large (100MW+) generation scheme of 11.2 cents/kWh ($2004 real). The opening cost projections were based on a plant consisting of 213 Pelamis devices installed at a deployment site of San Francisco with a power density of 21kW/m. A utility cost model was used to determine levelized cost reflecting industry standards. Additional sensitivity studies indicated that if the same plant was installed at higher energy density sites in Northern California the energy cost could be reduced below 8 cents/kWh. While these results appear to be promising, it is clear that projecting cost without any commercial experience bears a significant amount of uncertainty. Based on methodologies developed by EPRI, cost uncertainties at this stage are likely in the range of +35% to – 25%.

As with any power generation technology, cost of energy from early systems is high and is subsequently reduced as the installed capacity base grows. Learning curves in the wind industry indicate progress ratios of 82%. If the same progress ratios hold true for wave energy, it can be expected that the economic performance of wave energy systems would be on par with that of wind energy in the long term.

Initial wave farms will be much smaller in scale then the outlined 100MW+ baseline scenario outlined above. Pilot wave farms will likely start with a few units and installed capacities of less then 10MW. This is required to reduce technical uncertainties and proof the technologies and associated cost profiles (i.e. O&M and capital cost). Small-scale initial adoption is also required to properly demonstrate and measure environmental impacts of these technologies. Grid interconnection and other infrastructure expenses are oftentimes fixed expenses that impact the cost of electricity of small developments more prominently then larger scale adoptions. In addition the small scale results in higher manufacturing cost and the higher risk perceived by investors will require a shorter pay back period then large scale projects. All the above issues compound and result in significantly higher levelized cost of electricity for the first commercial installations in California.

Environmental impacts from wave energy conversion devices are site- and technology specific. Structures associated with wave energy can have environmental impacts similar to other structures placed offshore, in virtue of their physical presence in the water, as well environmental effects unique to wave energy devices as such. Each specific project proposed for California will have to undergo a project-specific environmental review. Adverse impacts to the environment can often be avoided or reduced by careful project design and siting, and occasionally compensation can be provided to offset adverse effects. Some technologies may not be consistent with California's environmental standards, and therefore may not be appropriate for installation.

Wave energy projects proposed for offshore California will be subject to a high level of public and regulatory scrutiny, and must meet a variety of federal, State and local environmental standards. Early involvement of stakeholders and regulatory agencies helps identify areas of concern, so that environmental issues can be addressed during the siting and design phase of the project. As discussed earlier, many adverse environmental effects can be avoided or reduced through careful project siting and design, helping to streamline the environmental regulatory process.

The benefits to the State of California include:

- Wave-derived energy could supply up to 23% of the States Energy needs. As such it is a significant renewable energy source that should be taped into strategically. In reality, this technical potential is limited by environmental, economic and other considerations.
- Wave energy is predictable up to 3 days in advance and is more consistent then most other renewable alternatives.
- A stable electric energy supply system consists of a balanced portfolio of supply options. Adding an additional supply option such as ocean wave energy significantly increases the overall system stability.

- The visual impact on the shoreline is expected to be minimal as devices installed are low-lying structures, deployed miles off the coast. Visual impacts have traditionally hindered the development electrical generation assets by triggering NIMBY (Not In My Backyard) sentiments.
- There is a potential to combine wave energy research efforts with other efforts to develop other offshore renewable energy sources such as Offshore Wind and leverage investment dollars.
- Wave energy is a renewable energy source with obvious long-term benefits, including: reducing dependency on foreign sources of energy, reducing electricity price volatility, displacing more polluting generation alternatives and reducing greenhouse gas emissions. Energy technologies drawing on renewable energy reduce the environmental impacts of the fossil fuel cycle.
- Development of a renewable energy industry creates jobs locally and reduces trade deficits, by keeping money in the local economy.

Risks:

- Cost competitiveness of ocean wave power conversion remains to be proven, especially as it pertains to O&M costs.
- There are considerable technical risks associated to the operation of in-ocean systems. Survivability of devices operating in this harsh environment still needs to be proven for many devices under development.
- Wave power devices are in an early stage of development (as compared to more mature renewable technologies such as wind) and there is no consensus as to what the winning technology choice would be. This is typical for emerging markets.

As with any renewable energy resource, the introduction of wave energy will require government support in form of subsidies and targeted R&D programs in order for it to become cost competitive. In the near-term, there are a few action items that could significantly reduce risks and move wave energy towards commercial readiness in California.

California faces some unique challenges in respect the implementation of wave energy conversion systems. They include longer period waves than some of the European sites, affecting their performance, strict environmental standards and un-tested permitting processes. In addition, California has a very different marine infrastructure with respect to offshore installation and operational considerations. If ocean wave energy conversion is to be pursued successfully in California, the above issues will need to be addressed in a carefully planned process. There are two areas that will need to be stimulated to allow for successful adoption of technology in the market place. They are targeted R&D and Support of early adoption of technology.

Targeted R&D will be required to focus all parties onto the process of creating the most cost effective technology options for the State of California by feeding local requirements back into the development process and provide a solid understanding of the fundamental drivers of economic competitiveness and answer the question of; ‘How can cost of electricity be driven down to become competitive with other generation alternatives'. This will require a solid fundamental understanding of the technologies involved and the ability to model the performance, survivability, operational requirements, cost and economics of various technologies. A heavy focus on R&D is typical for early adoption of technology in the market place. While it is unlikely that California based technology developers can compete with European wave power technology companies in the near future, research should focus on how European technology can best be implemented in California by providing a solid fundamental understanding of the economic drivers. Such integrated techno-economic modeling in the area of ocean wave energy has been pursued by EPRI for a number of years.

There is no substitute for 'Hardware on the Ground'. Support of early adoption in the market place in form of price support will focus technology developers on building the most cost effective power conversion machines for California. In addition, it will focus environmental groups, policy makers and R&D to find solutions to the 'real' challenges. The most cost-effective way to enable early implementations (First 10-50MW) is to establish a site in a favorable California location that can be used by multiple developers to test their machines and build-out into small commercial schemes. By providing a deployment site that is already permitted and has infrastructure in place to interconnect with the electrical grid and available local marine infrastructure to support deployment, operation and maintenance, the burden on device developers is lowered and as a result, they can focus on technology instead of site-development. Results of in-ocean testing can then be fed back into the R&D program. A successful example for such a shared infrastructure approach has been developed with the Wave Hub in South West of England that aims to create the UK's first offshore facility for the demonstration and proving of the operation of arrays of wave energy generation devices. Further information on this facility can be found at http://www.wavehub.co.uk/.

The above two focus areas should be supported by further study in the areas of; environmental impacts, permitting & consenting, grid interconnection studies and detailed resource assessment. These key areas are outlined below:

- As with most novel technology, Environmental Impacts are at present uncertain and will need to be assessed as a parallel effort to technology deployments.
- The permitting process in California is untested and could provide significant hurdles to any project developer in California. Development of sensitive processes that allow for technology deployment, while ensuring the protection of California's coastlines will be a critical step to move forward. Starting with a single test-site, will allow environmental organizations and regulators to become familiar with the 'real issues' involved.
- Detailed resource assessment. While there is plenty of information available for the deep-water wave energy resource available off the California coast, the wave climate in suitable deployment locations is not always well understood. Further modeling could greatly enhance the understanding of the wave energy resource in the most suitable deployment locations. Most of these modeling efforts could be carried out using computational modeling.
- Further study of grid-interconnection limitations. Many load centers in California are located near-shore (i.e. San Francisco, Los Angeles etc.); however, the shoreline population is typically at the end of the electric transmission infrastructure therefore limiting how much energy can be fed back into the grid. In addition, the best wave energy

deployment sites can be found in Northern California, which has a relatively low population density and the electric transmission infrastructure has been designed to deliver power to the end, not feed power back into the grid.

Much of the know-how to address the above issues is already available. Collaboration in all of the above areas with organizations such as; academia, EPRI's nationwide wave energy collaborative and European programs could significantly lower overall program cost and speed up the process to actual implementation.

Ocean wave energy could make a potentially significant contribution to California's future energy mix. While European ocean wave technology options are nearing the commercial stage, there are several issues that need to be addressed before these technologies can be adopted on a large scale in California. Research addressing these issues will be necessary if California is to develop its ocean wave resource to any significant extent. In view to risks associated with future energy supply options and the environmental impacts of fossil-based generation alternatives, an early investment into ocean wave energy can be viewed as an insurance policy against future price volatility and energy supply constraints for the State of California.

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