# The Odyssea Group Final Report

## Wave Energy Harvesting Device

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## Executive Summary

The objective of this project is to design a novel wave energy harvesting device to be located on the North Shore of Oahu, Hawaii at Kaneakua Cove. The device will be completely submerged in shallow depths of 20 to 50 feet of water and utilize the motion of a horizontal oscillating plate to harvest wave energy. The peak power output of a single unit is 156 MW-hr per year, which will be transported in the form of electrical energy to Oahu and supplied to the local power grid. The proposed device, named "Poseidon" has proven to be the most viable option in terms of economic and technical feasibility. The economic analysis contained in this report has estimated the initial cost of a single Poseidon device at $207,000, a net present value of $350,000, and a breakeven period between five and six years. An expansive list of tasks to be carried out for the completion of the project design is included in this report. An approximated 841 man hours will be required to complete these tasks.

# Contents

## List of Figures



## List of Tables

# 1. Introduction

The ocean transports some of the largest amounts of energy on the planet, which presents a tremendous opportunity for energy harvesting. The goal for The Odyssea Group is to bring energy to the communities on the North shore of Oahu in the most economical and nonintrusive manner utilizing a revolutionary new design for a wave energy converter (WEC). With the Hawaii Clean Energy Initiative in effect, which sets a goal for the state to become 100% sustained by clean energy before 2045, wave energy converters are highly desired [1]. This report consists of an in-depth location study, power output estimations, technical and economic feasibility study of three alternatives, environmental considerations, and a description of tasks to be performed for design completion.

## Description of Design

Existing WEC projects have been met with considerable challenges due to the majority of them being located on the water surface. Two major problems arising from surface dwelling devices include damage that occurs from interaction with large waves and the visual impact in near-shore locations. In order to combat these issues, a completely new design will be considered utilizing a fully submerged device. While this is a solution to the aforementioned problems, a variety of new problems arise when the device is submerged. Since a large portion of the energy from water waves is located on the surface, a submerged WEC will not be able to harvest and output as much energy as those on the surface. Therefore the design must be optimized to harvest a sufficient amount of energy while avoiding the complications that lie on the water's surface.

The proposed wave energy converter is comprised of a thin, submerged plate that is restricted to oscillate solely in the heave direction, which will be induced by the propagation of shallow-water waves over the device. The plate is connected to a generator that will convert its mechanical energy into electrical energy. A preliminary concept design of the proposed "Poseidon" device is seen in Figure 1.

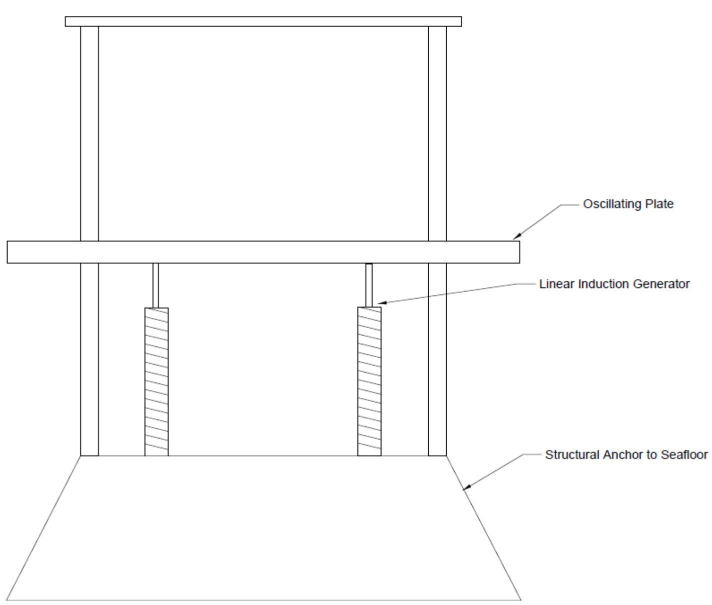


Figure 1 - Poseidon concept design

# 2. Site Location

Like many alternative energy methods, wave energy is highly dependent upon the resources a specific location has to offer. All wave energy devices include a component that is free to oscillate due to ocean wave forces. These oscillating components are attached to a generator, which generates electric current from the movement of the plate. Since the wave forces are the sole cause for the movement of the oscillating component, the wave climate at a specific location is one of the most important factor in power generation from a wave energy device. From a comparison of three site alternatives, the Hawaiian island of Oahu was chosen as the best suited location to harbor the Poseidon device. The criteria for site selection will be discussed in this section.

## Global Wave Information

A general assessment of wave information around the globe is performed to locate regions that harbor large amounts of wave energy for most of the year.

### *Significant Wave Height*

From linear wave theory, the mean energy density per unit surface area is given by:

$$E = \frac{1}{2}\rho g \zeta_a^2$$

Where $\rho$ is the water density, $g$ is the acceleration due to gravity, and $\zeta_a$ is the wave amplitude. Therefore, wave height is the most important factor in determining a location that provides the most wave height. Since the wave forces driving the oscillation of the component depends on wave height, a global investigation of significant wave heights and their seasonal variations is shown in Figure 2. From this figure, there are several locations having favorable significant wave heights for most of the year. These locations include regions in South Africa, Australia, Tasmania, New Zealand, Portugal, Iceland, Ireland, Chile, Northwest Coast of the United States, and the Hawaiian Islands.

### *Wave Period*

Since the wave energy device of interest consists of a submerged oscillating plate to drive the generator for the energy conversion, a shorter wave period will result in more plate oscillations, thus creating more power [2]. However, shorter periods correlate to local wind waves, which generally have smaller wave heights. Therefore, of the locations having large wave heights, those with shorter periods are more desirable. Figure 3 shows the seasonal variations of wave periods around the globe. From the figure, the previously mentioned locations all have relatively similar periods that increase with increasing wave height. A local, high-resolution study is required to find a location with shorter period waves while still maintaining wave height.

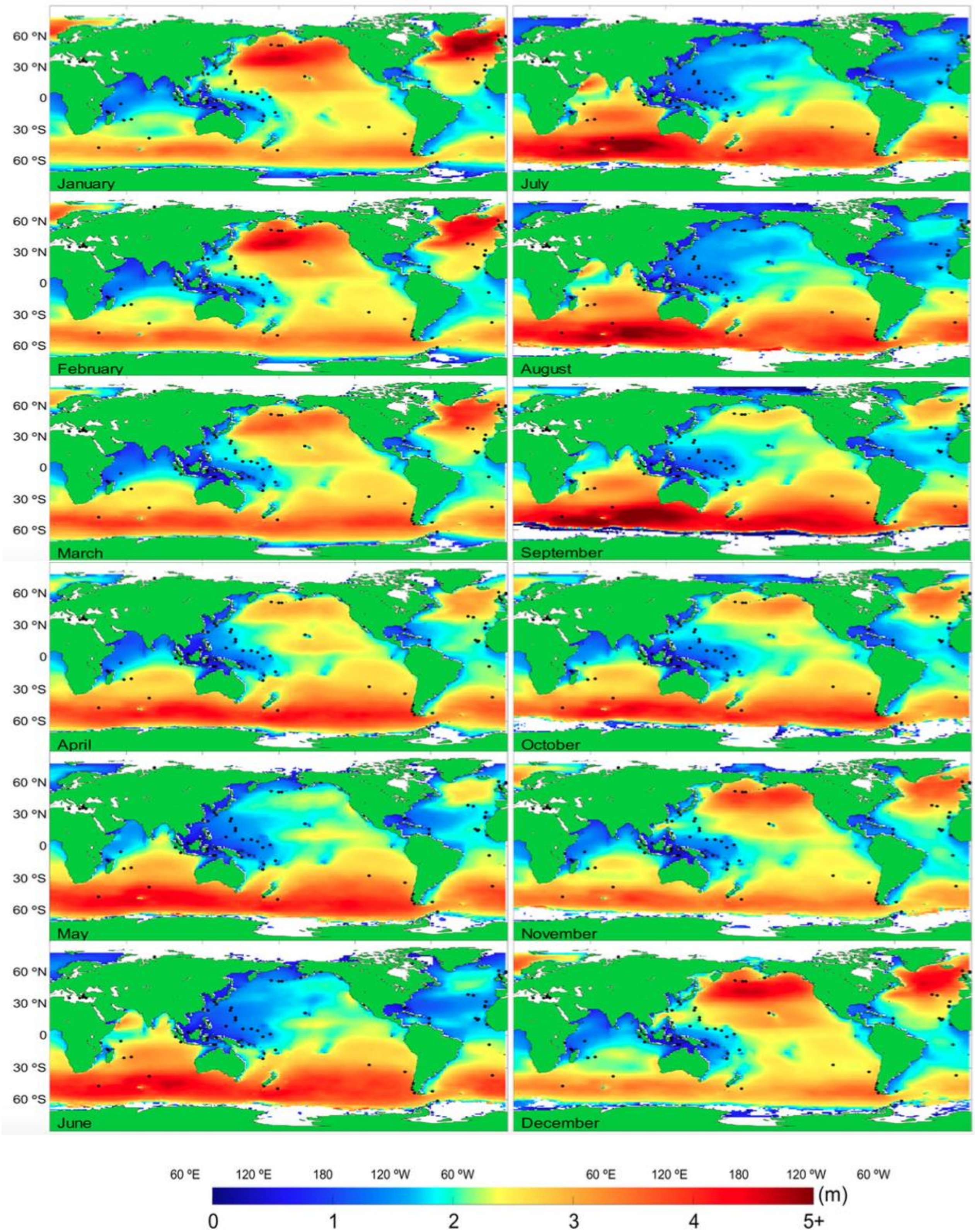


**Figure 2 - Monthly median significant wave height (Arinaga, Cheung 2012 [3])**

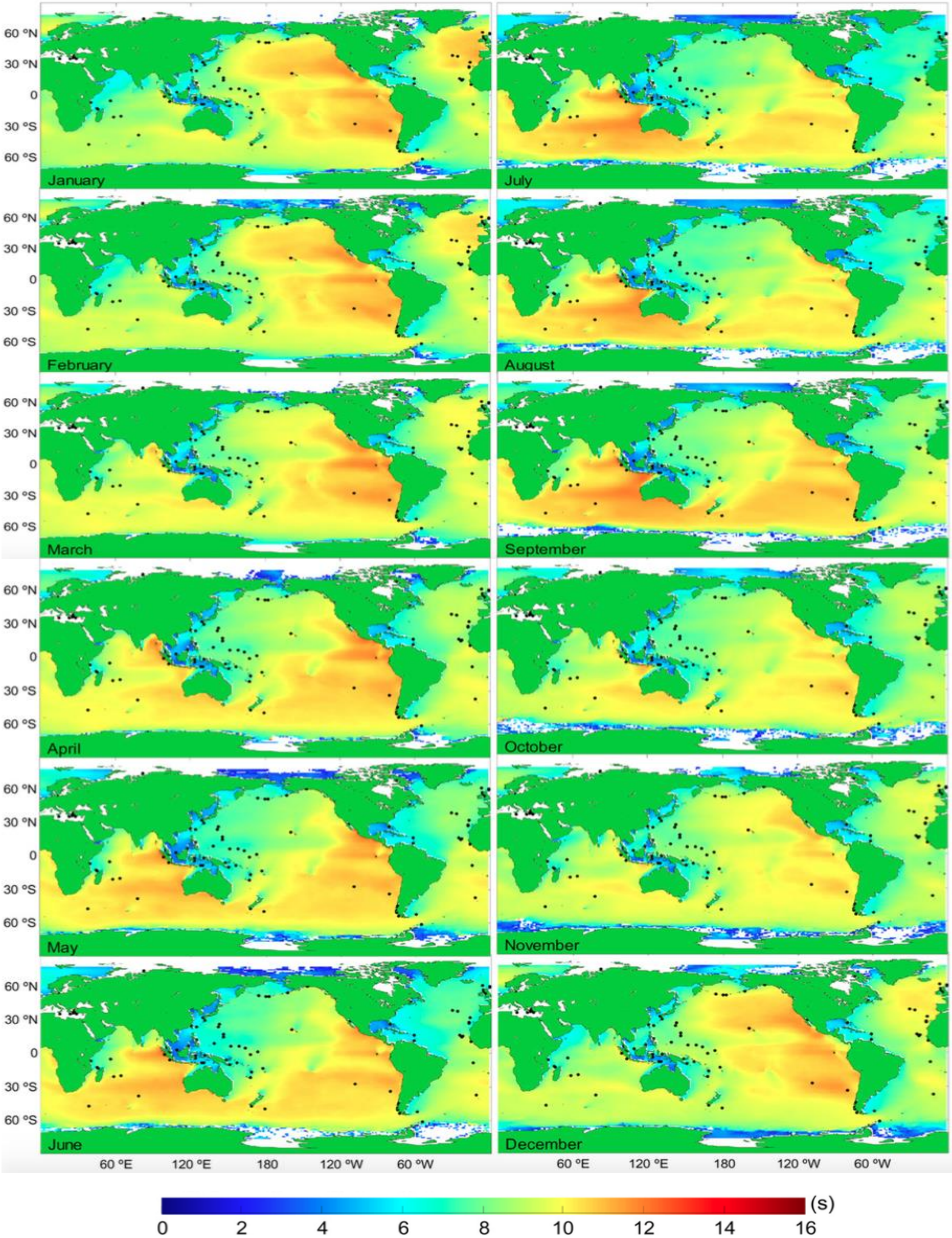


**Figure 3 - Monthly Wave Period (Arinaga, Cheung 2012 [3])**

## Location Selection

Although there are many locations that may provide the necessary wave resources required to convert wave energy to electricity, some locations may not be well suited to install a wave energy device for various reasons, including insufficient government support and low demand for additional energy resources. Taking this into account, three locations are considered in order to determine the site where the wave energy device will be installed.

### *South Australia*

Of all the locations, the southern coast of Australia is best suited for wave energy development considering only wave height. The median wave height for this coast is about 2.5 meters or greater throughout the year from Fig. 3. Although the wave resources are excellent for this location, the demand for additional energy resources, specifically wave energy, is less compared to other possible locations [4].

### *Portugal*

Portugal holds favorable wave resources as well as a high demand for renewable energy devices. Portugal has very few carbon-based energy resources, therefore the country is very dependent upon fossil fuel imports. To combat the extreme expense of sustaining fossil fuel imports for long time periods, Portugal has invested heavily in renewable resources, the largest being in hydroelectric power [5]. In fact, Portugal implemented the first commercial wave energy project in 2008, which initially consisted of three Pelamis devices, while 28 more were planned to be added. However, due to several technical problems of the device, the project began to lose financial backing and was eventually scrubbed. This failed attempt at harvesting wave energy may throw up some red flags to potentially investors in Portugal. Especially with the way the country is thriving on the already established alternative energy methods it has currently implemented, which have produced up to 70% of the nation's electricity in years with favorable weather conditions [5].

### *Hawaii*

Its large availability of wave energy is only one of the many reasons that make Hawaii a leading candidate to start producing electricity from ocean waves. Over 90% of the energy used in Hawaii is imported oil supply, even though it sits in a geographical hotspot for renewable energy resources [1]. In an effort to become more energy independent, the State of Hawaii implemented the Hawaii Clean Energy Initiative (HCEI) in 2008. The HCEI agreement originally stated that 70% of the state's electricity and transportation must come from clean energy sources by the year 2030. Of this 70%, only 40% would be from renewable energy sources, while the other 30% would be from conservation efforts. However, in 2014, the HCEI was replaced by the HCEI 2.0 agreement, which requires that 65% of the state's electricity and transportation will come from actual renewable sources by 2030; a large upgrade from the 40% in the original HCEI agreement [1].

This clean energy could come from a number of resources Hawaii has to offer, such as wind, geothermal, ocean thermal, solar, or wave power. One major disadvantage with many of these alternatives is that they require large, unaesthetic devices to captures this energy, such as a wind turbine farm or wave energy devices that float on the ocean's surface. Machines of this nature are highly undesirable since Hawaii is known for its natural beauty, which makes it one of the top tourist destinations in the world. However, the proposed wave energy device is submerged and fixed to the seafloor, which would allow the state to take advantage of its largest renewable energy resource without any cost to its visual beauty. Given the extremely high demand for renewable energy as well as the excellent wave resources, Hawaii is the chosen location to implement the wave energy device.

## Local Site Information

A high resolution, local wave study is performed for the Hawaiian Islands in order to determine a specific site in the island chain having the optimal conditions for energy harvesting. A bi-monthly local wave assessment of the Hawaiian Island chain is shown in Figure 4. It can be seen from this figure that the north side of the islands receive a median significant wave height of around 3 meters from November to December. These large wave heights are due to the northwest swells generated by storms occurring around the Aleutian Islands during these months [6]. While these months provide the largest wave heights, the island chain is located within the pacific trade wind belt, which means the Hawaiian Islands are susceptible to consistent northeastern trade winds creating local wind waves throughout the year.

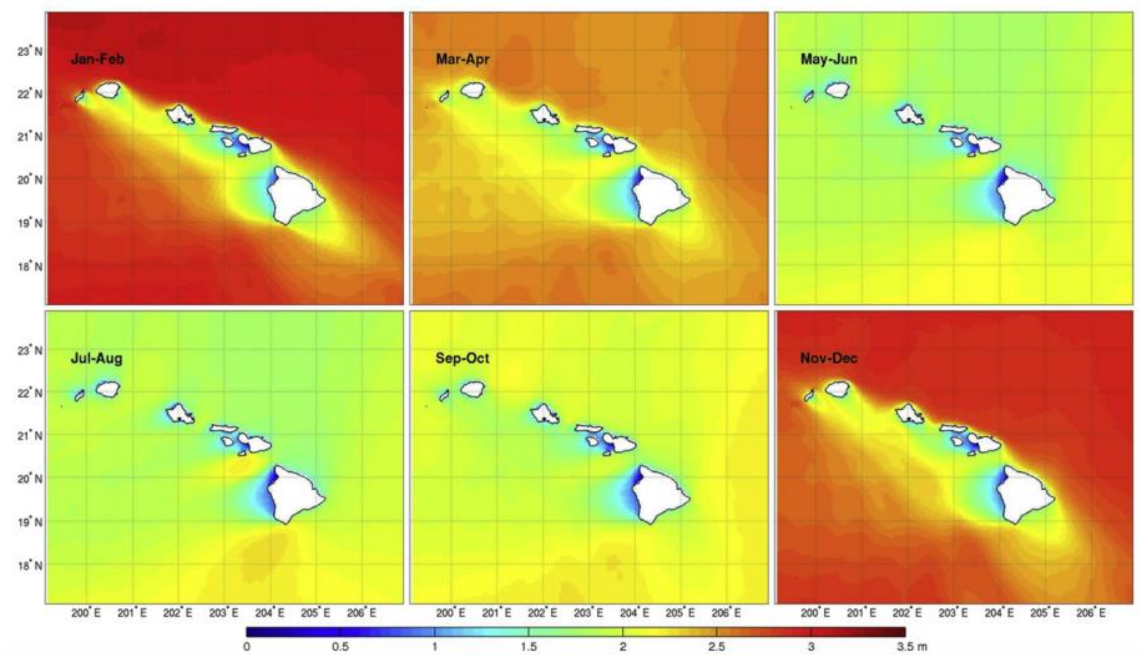


**Figure 4 - Bi-monthly median significant wave height from Hawaii WW3 (Stopa et al. 2013 [6])**

The shorter period of the trade wind waves is beneficial to the energy production of the device, however these waves have much smaller heights than the longer period winter swells. In addition to these two wave sources, the southern coasts in the island chain are susceptible to gentle southern swells due to cyclones off Antarctica in the summer months [6].

*Oahu*

Oahu holds the majority of the population in Hawaii and is by far the most developed of the eight major Hawaiian Islands. For these reasons, Oahu has highest energy demand. Therefore, it is desirable for the device to be located in close proximity to this island so that electricity would not have to be transported as far by means of a subsea cable, which would minimize energy loss.

Oahu is also a beneficial location since its north shore experiences some of the largest waves of all the islands. A high resolution, bi-monthly wave power study of the island can be seen in Figure 5.

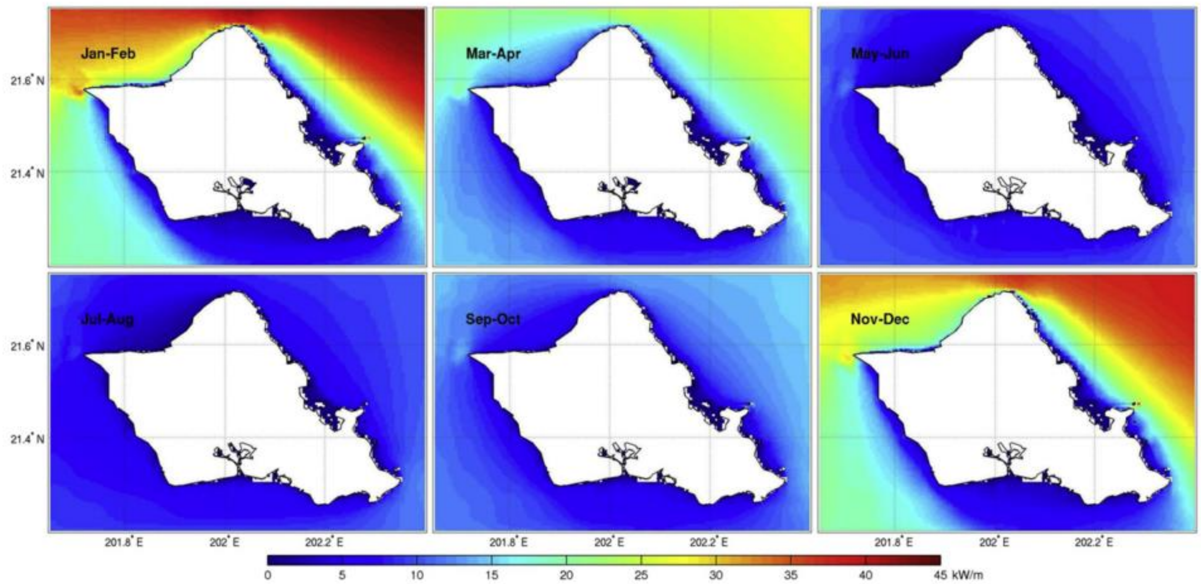


**Figure 5 - Bi-monthly median wave power for Oahu (Stopa et al. 2013 [6])**

As shown in Fig. 5, it can be seen that northern most tip of the island experiences the maximum annual wave power. This part of the island also experiences high energy very close to shore, which is an important factor when considering the steep drop off of water depth just a short distance offshore. Since the device will be submerged for shallow water, it must be placed close to shore before the water depth becomes too deep. However, the device will be operating past the surf zone, so it is important that it is not placed too close to shore where wave breaking may occur. The theoretical breaking limit is given by [7]:

$$\frac{H}{h} = 0.8$$

Where $H$ is the wave height and $h$ is the water depth. Therefore, the water depth in which a 5-meter wave may begin to break is:

$$h = \frac{5\,m}{0.8} = 6.25\,m$$

The device should be installed deeper than this value to ensure there is no wave breaking, which would lead to energy dissipation. Also, the device needs to be deep enough so that normal activities can proceed as usual on the surface such as boating and shipping. However, the deeper the device is submerged, the less wave energy it will be able to convert to electricity. Also, maintenance will become increasingly more difficult and costly the deeper the device is submerged. A 7 meter depth is initially assumed for calculations, however, this depth will be adjusted as further analysis is performed on the device.

### *Bathymetry*

The bathymetry for the northern point of Oahu is shown in Figure 6. From this figure, it can be seen that the bathymetry near Kaneakua Cove is relatively smooth and not as steep when compared to other parts of the island.

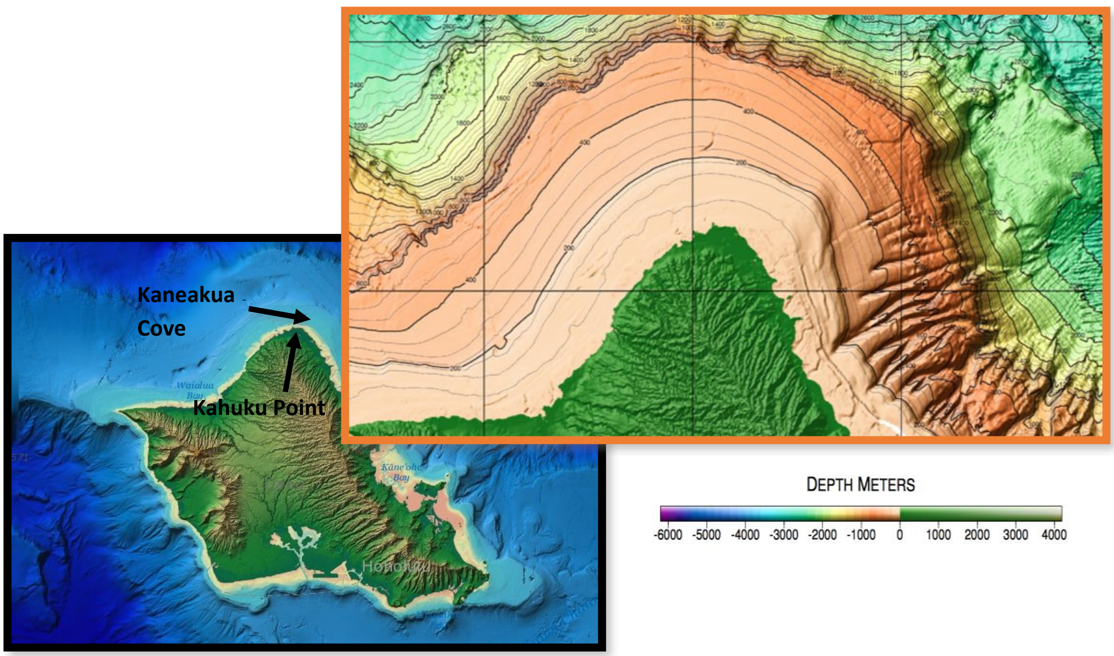


**Figure 6 - Bathymetric map of Oahu (NOAA Bathymetric Data Viewer)**

The bathymetry is map will be used to determine the distance offshore that the device will need to be placed in order to be submerged at the desired depth. Also, this gradual bathymetry allows for implementation of an array of Poseidon devices since they will all be operating in similar water depths.

## Location Conclusion

The Kaneakua Cove in the North-East point in Oahu will be susceptible to the large northwest swells during the winter months as well as wind waves brought on by the trade winds throughout the year. The slight easterly position from Kahuku Point will be more prone to shorter period waves due to the trades, which increases the power output of the device. A 3-D rendering of the site can be seen Figure 7.

Figure 7 – 3-D rendering of Kaneakua Cove (Google Maps)

## 3. Power Production

The method of calculating power output is based on a power matrix specific to the WEC and an occurrence matrix specific to the location that the WEC is placed. These matrices are indexed by a range of significant wave heights and wave energy periods for the rows and columns respectively. Each entry in the power matrix is known as an 'energy bin' and is calculated using the physical concepts of the work energy principle:

$$P_{ij} = \frac{dE_{ij}}{dt} = \left(F * \frac{ds}{dt}\right)_{ij} = (F * v)_{ij}$$

Where P is the power output, E is the mechanical energy, F is force on the plate, and v is the heave velocity of the plate. The matrix indices, *i* and *j,* represent the row and column related to a particular energy bin.

For WECs that have already been designed, power matrices are supplied by the manufacturer, but since Poseidon is a new device, the power matrix must be calculated. For preliminary results, the forces are calculated via a linear wave theory diffraction problem. Using these forces, the velocity of the plate is found by solving the equation of motion. As the project progresses, the nonlinear solution will be found, however the linear solution will provide a reasonable preliminary estimate of the power output by this device. The power matrix for the pressure differential device is shown in Table 1.

Since wave parameters fluctuate constantly throughout the year, an occurrence matrix is necessary to obtain an accurate power output estimation. The occurrence matrix is constructed of bins that express the yearly percentage that each wave occurs. The average power output is calculated by:

$$P_E = \frac{1}{N}\sum_{i=1}^{n_T}\sum_{j=1}^{n_H} p_{ij}P_{ij}$$

Where $P_E$ is the average electric power output, $N$ is the total number of entries in the matrices, $p_{ij}$ is the percentage corresponding to the bin defined by row $i$ and column $j$, and $P_{ij}$ is the power in the same energy bin [8].

**Table 1 - Power matrix for Poseidon at 7 m submergence depth [MW]**

| $H_s$ (m) | $T_e$ (s) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **5** | **5.5** | **6** | **6.5** | **7** | **7.5** | **8** | **8.5** | **9** | **9.5** | **10** | **10.5** | **11** | **11.5** | **12** | **12.5** | **13** |
| **0.5** | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1** | 11 | 9 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| **1.5** | 25 | 20 | 17 | 14 | 12 | 10 | 8 | 7 | 6 | 5 | 5 | 4 | 4 | 3 | 3 | 3 | 2 |
| **2** | 45 | 36 | 30 | 25 | 21 | 18 | 15 | 13 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 5 | 4 |
| **2.5** | 70 | 56 | 46 | 39 | 33 | 27 | 23 | 20 | 17 | 15 | 13 | 12 | 10 | 9 | 8 | 8 | 7 |
| **3** | 101 | 81 | 67 | 56 | 47 | 40 | 34 | 29 | 25 | 22 | 19 | 17 | 15 | 13 | 12 | 11 | 10 |
| **3.5** | 138 | 110 | 91 | 76 | 64 | 54 | 46 | 39 | 34 | 30 | 26 | 23 | 21 | 18 | 16 | 15 | 13 |
| **4** | 180 | 144 | 119 | 99 | 83 | 70 | 60 | 51 | 44 | 39 | 34 | 30 | 27 | 24 | 21 | 19 | 17 |
| **4.5** | 228 | 182 | 150 | 126 | 106 | 89 | 76 | 65 | 56 | 49 | 43 | 38 | 34 | 30 | 27 | 24 | 22 |
| **5** | 281 | 225 | 185 | 155 | 130 | 110 | 93 | 80 | 69 | 61 | 53 | 47 | 42 | 37 | 33 | 30 | 22 |

**Table 2 - Occurrence matrix for selected site**

| $H_s$ (m) | $T_e$ (s) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **5** | **5.5** | **6** | **6.5** | **7** | **7.5** | **8** | **8.5** | **9** | **9.5** | **10** | **10.5** | **11** | **11.5** | **12** | **12.5** | **13** |
| **0.5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1.5** | 0 | 0 | 0 | 0.25 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2** | 0 | 0 | 0 | 0 | 0.08 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2.5** | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 | 0.08 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **3.5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **4.5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The entries that are highlighted in green in the above tables are the bins that are relevant to the wave data at the site location that we chose.  Since the location only experiences these particular waves, all outlying bins will be zero in the occurrence matrix (Table 2).

Power output is generally expressed in units of kilowatt-hours per year, which can be obtained by multiplying the average power output by 8,760 hours per year. The calculated power output for this device is 156 MW-hr/year.

# 2. Alternative Evaluations

## Technical Feasibility

Three different wave energy converters are considered for use in the site location chosen. These are Pelamis, Oyster, and a novel wave energy device referred to as a pressure differential WEC.

### Alternative 1: Pelamis

The Pelamis is comprised of several cylindrical members that are connected end-to-end and float on the surface, as seen in Figure 8. As waves pass by, they cause the device to move in a snake-like manner, which can be used to extract energy. Special generators located at the joints are used to convert the mechanical energy corresponding to the relative motion of each section.

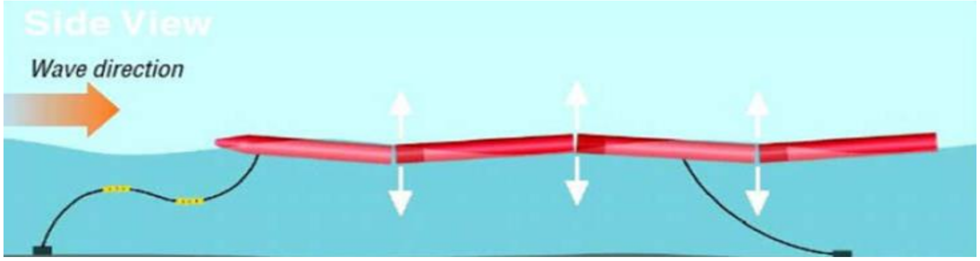


**Figure 8 – Pelamis (www.c2es.org)**

An advantage of this device is that it has a relatively good power output for the price. Being located on the surface allows for easier maintenance than if it were submerged. However, being located on the surface is a huge disadvantage because of susceptibility to damage by wave breaking and is very unsightly.  Other disadvantages are associated with this type of device, such as being able to only operate effectively in a small range of wave types. The incident wave length is very specific to the length of each Pelamis section. If the wavelength is too long the entire Pelamis will tend to move together as one, rather than having each member move relative to each other. Also, the incident wave rays must be nearly parallel to the longitudinal axis of Pelamis, otherwise a similar phenomenon can occur [9].

### Alternative 2: Oyster

The Oyster, which can be seen in Figure 9, is essentially a massive hydraulic ram that uses wave energy to pump water to a nearby hydroelectric plant. This WEC consists of a large flap that is hinged on the seafloor and allowed to rotate when encountered by a wave. The flap is connected to a large piston that is used to pump water to the nearby plant.

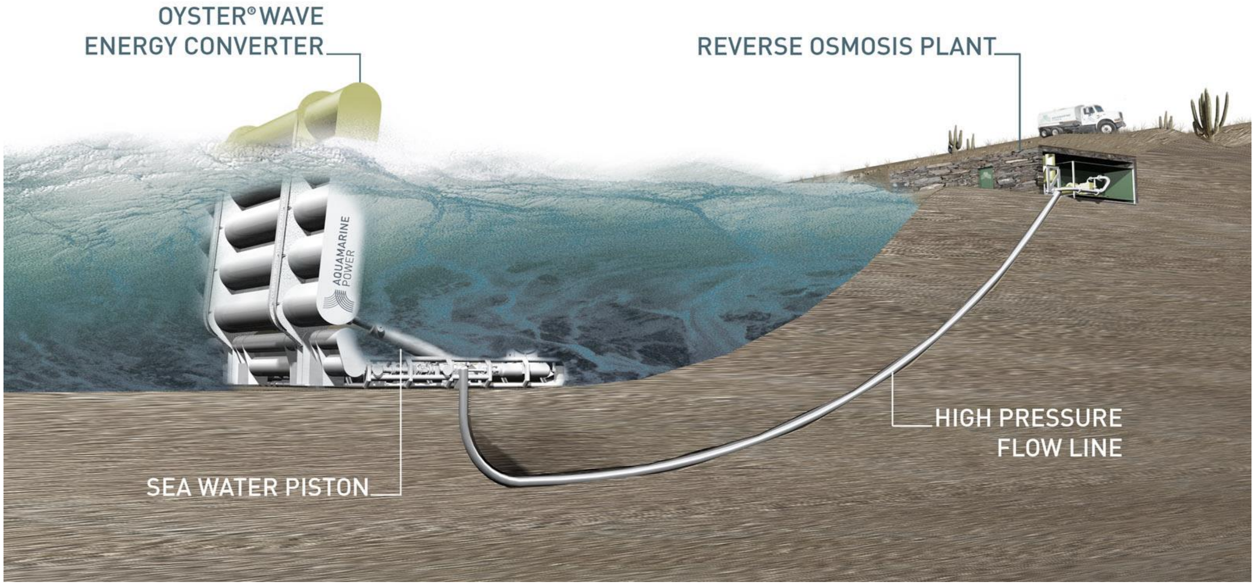


**Figure 9 - Oyster WEC connected to nearby hydroelectric plant (www.powerelectronics.com)**

Since the device spans from the seafloor to the surface, it is able to harness the energy contained in the all parts of the water column. Disadvantages related to this device are similar to Pelamis in the case that waves need to be travelling in a specific direction in order to efficiently harness the wave's energy. In addition to Pelamis, part of the device is located at the water surface. WECs that lie on the surface are undesired due to their unsightliness and the difficulty they introduce to ship traffic.

## Alternative 3: Poseidon

Poseidon is a new WEC that has yet to be produced. The device consists of a horizontally submerged plate that is restricted to heave-oscillation when shallow-water waves propagate over it. The plate can be connected to a number of different devices to convert its mechanical energy to electrical energy, such as a piston, rotor, or a linear induction generator. The major advantage of this device is in its simplicity. In addition, since the entire device is completely submerged, the issues of unsightliness, damage due to wave breaking, and ship traffic are avoidable. These factors allow for easy expansion of a single device into a field of devices spanning an area of the seafloor. Also, the energy harnessing capabilities of this device are less dependent of wave direction. A major disadvantage to a submerged device, however, is that available wave energy decreases as submergence depth increases. The preliminary design of Poseidon was shown in Fig. 1.

Table 3 - Alternative comparison

| Device | Advantages | Disadvantages |
|---|---|---|
| Pelamis | • High power output<br>• Easy installation | • Located on the surface<br>• Very large<br>• Complicated design |
| Oyster | • Few moving parts<br>• Hydroelectric plant located onshore is easy to maintain | • Parts located on the surface<br>• Must have hydroelectric plant |
| Poseidon | • Completely submerged<br>• Simple design<br>• Ability to employ a field of devices | • Lower power output<br>• More difficult maintenance |

# 3. Economic Analysis

## General Costs

The general costs to be considered in this economic analysis are those that remain constant for all three alternative WECs proposed. A project life of 20 years is analyzed for each of the alternatives, this time period is selected based on prior reports that suggest a project life of 20 years for the Pelamis and Oyster WECs [10], [11]. It is assumed that this is a conservative estimate for the life cycle of the Poseidon as well, due to the decreased likelihood of damage in comparison with the two other alternatives. Since the alternatives are to be analyzed at the same site location, it is assumed that the cost of electricity ($/kW-hr) will be constant amongst all devices at $0.33/kW-hr [12]. The discount rate considered will also be constant at 3% as it is assumed that the rate will be constant among the devices as they are used for the same purpose [11]. And the insurance rate is assumed constant at 2% of the capital cost of each WEC, which reflects a quote for a similar WEC project in America [13]. Another assumption that should be noted is that all WEC alternatives are able to transmit 100% of the energy that is absorbed, which is not to be confused with the capacity of the devices which is the ratio of energy actually produced by the WEC to the maximum production rate of the WEC. Therefore the alternatives are being compared strictly on the basis of energy output and potential cost of a single WEC, connected to an onshore power plant grid, in the proposed site location on the northeastern coast of Oahu over a life of 20 years. Specific costs estimated and assumed will be addressed in the following paragraphs, and full spreadsheet calculations for each WEC are referenced in Appendix A.

## Pelamis Wave Energy Converter

Initial capital (IC) costs and O&M costs of the Pelamis WEC were obtained in the “Offshore Wave Power Feasibility Demonstration Project” which offers an upper and lower limit for the initial cost of a single demonstration Pelamis WEC in Hawaii, the average between the two limits is the initial cost assumed in this report [14]. The total initial cost estimated based on said limits is $4.63M for a single Pelamis, and the initial cost breakdown, seen in Table 4, is based on the percentage of cost attributed to each parameter of the device [14]. The annual operation and maintenance (O&M) costs were based off of a general quote for 180 Pelamis devices located in Hawaii, and if the cost relationship between O&M and number of WEC units is assumed to be linear it can be found by simply dividing the total estimation by the number of devices [14]. The annual O&M cost for a single Pelamis is then estimated at $61K, which is a generous estimate of cost since the O&M cost on a bulk number of units would presumably be less cost per unit than a single unit. The O&M costs combined with the insurance cost (2% of IC), result in overall annual payments of $159K.

**Table 4 - Initial Cost Breakdown of Pelamis WEC**

| INITIAL COST BREAKDOWN OF PELAMIS | |
|---|---|
| **PARAMETER** | **COST** |
| **Concrete Structural Sections** | $939,120.00 |
| **Installation** | $243,744 |
| **Facilities** | $243,744 |
| **Construction Management** | $404,950 |
| **Subsea Cables** | $119,168 |
| **Mooring** | $404,950 |
| **Power Conversion Modules** | $2,275,000 |
| **TOTAL ESTIMATED INITIAL COST:** | $4,630,675 |

These costs, in comparison with the calculated energy output of the Pelamis at 1,530 MW-hr/year, result in a net present value (NPV) of approximately $4.9M and an initial rate of return (IRR) of 13%. However certain assumptions were made while calculating energy production values that skew production rates in favor of the Pelamis. One consideration that was not taken into account is the wave direction, the calculations assume that the wave direction is incident to the WEC devices such that optimal power production is achieved by the Pelamis. In ordinary conditions, direction of wave propagation is likely to change throughout the year, which would decrease the actual energy production rate of a Pelamis WEC. Another consideration that is not taken into account is the likelihood of damage to the WEC, which is a surface dwelling device. Current O&M procedures on the Pelamis require that the significant wave height $H_s$ be less than two meters in order to detach the Pelamis system and tow the device in for maintenance, and at our current site location this offers a very narrow window of opportunity for maintenance [11]. The structural integrity of the Pelamis during storm conditions would pose economic concerns, the WECs would either have to be moved before or replaced after large storms and either alternative would result in considerable cost that is not evaluated in this report. Even with these considerations taken into account, the Pelamis is the most economically competitive alternative to our proposed WEC.

## Oyster Wave Energy Converter

The Oyster WEC has considerably larger capital costs than the other WECs considered in this report due to the large scale of the structure, with an estimated initial cost of nearly $8.9M estimated in the "*Yakutat Conceptual Design, Performance, Cost and Economic Wave Power Feasibility Study"* which estimates cost of a single Oyster WEC in Yakutat, Alaska [10]. Due to the high capital cost and relative immaturity of the Oyster project, accurate cost estimates are currently unavailable so the feasibility study breaks down a rough cost using a weight breakdown of the structure supplied by the WEC manufacturer Aquamarine©, and the appropriate steel cost per ton was used to assume the initial cost [10]. This initial cost is then assumed to be relatively accurate in the selected site location of Oahu, at a similar depth. The study then breaks down the cost of O&M of a single WEC by parts & labor as well as an annualized cost of a device overhaul every 5 years throughout the life of the project. These O&M costs were assumed to be consistent to our site location during this evaluation and totaled $195K, the insurance rate assumed for all WECs is applied at 1.5% of the capital cost and due to large capital, the insurance rates total over $177K yearly thus a total annual cost of $373K is assumed. On top of the significantly higher costs estimated for the Oyster WEC, is the insignificant power production of the device. The estimated power production from the Oyster only amounted to approximately 1432.3MW-hr/year, which is not enough to offset the enormous capital cost. The Oyster project never "broke-even" with an internal rate of return at -2% and a net present value around -$3.38M, which is enough to turn away any investor. Therefore the Oyster is not considered an economically viable alternative at our particular site location based on the WEC power matrix and wave characteristics. Potentially the Oyster could cut O&M costs by pumping a fluid other than seawater in a closed loop system to reduce internal corrosion of the device. [2] If the Oyster WEC project consisted of multiple devices in a wave farm scheme, the capital cost would be less intensive, but this is true with any of the WEC alternatives as well and in order to remain consistent in this economic comparison all considerations are for a single WEC device. The Oyster would have similar drawbacks to the Pelamis if the consideration of wave direction is taken into account when calculating wave energy (although less magnified due to proximity to shore), and thus resulting in a lower energy production rate than estimated making it even less economically viable.

## Poseidon Wave Energy Converter

The WEC proposed in this preliminary report is the Poseidon, a conceptual prototype in the midst of development. The Poseidon is in its infancy in terms of design, so the economic analysis of this WEC will consist of a rough initial cost estimate based upon known materials needed for construction, evaluation of the general cost breakdown of WECs, and comparisons to existing WEC projects and an initial cost breakdown is seen in Table 5. Where the material cost was estimated based upon the approximated size of the Poseidon, with an oscillating plate that is made from a high strength reinforced fiber plastic at about 0.9 cubic meters in volume (3x3x0.1 m), and approximately 2,000 kg of marine grade A36 steel for the structure, the cost of the materials is applied for an overall estimation [15], [16]. The direct drive linear generators used to transfer the mechanical energy of the oscillations to electric energy help to simplify the mechanical operation of the system, this simplicity results in a lower overall initial cost as well as a potentially lower O&M cost [9]. The annual operation costs include O&M, insurance costs, and an annualized overhaul cost, these are calculated as percentages of the total initial cost (i.e. insurance cost=2% of initial costs). The values assigned to the percentage of cost for O&M and an annualized overhaul are based off of general WEC cost breakdowns for known projects [17], [14], [11], [18].

Table 5: Initial Cost Breakdown of Poseidon WEC

| INITIAL COST BREAKDOWN OF POSEIDON | | | |
|---|---|---|---|
| **PARAMETER** | **EVALUATION** | **TOTAL NEEDED** | **COST** |
| **Reinforced fiber plastic:** | 27 $/kg | 1550 kg/m^3 *(0.9 m^3) | $ 37,665 |
| **Marine grade A-36 steel:** | 4.93 $/kg | 2000 kg | $ 9,860 |
| **Direct Drive Linear Generator:** | Material Breakdown | | $ 25,040 |
| **Subsea Cabling (approx 1 km):** | 53200 Euro/km | 1 km | $ 59,584 |
| **Installation:** | | | $ 40,000 |
| **Mooring:** | 10% IC (Dalton) | | $ 16,379 |
| **Construction Management:** | 9% IC (Dalton) | | $ 16,215.10 |
| **TOTAL IC COST:** | | $ 204,742.94 | |

The annual operational expenses are broken down in Table 6, where the O&M cost is calculated at 5% of the total capital, this value is fairly conservative based upon the general consensus of known WEC cost breakdowns, this value is expected to decrease with further research due to the inherent simplicity of the design as well as the reduced exposure to wave force that the Poseidon will experience due to the submerged state of the device. The overhaul cost, estimated at every 10 years of the life of the project, is estimated at a conservative 20% of the initial cost and is annualized over the life of the project so that it is included in the annual operational expenditures (OPEX).

Table 6: Annual Operational Expenses of Poseidon

| OPEX COST BREAKDOWN OF POSEIDON | | |
| --- | --- | --- |
| **PARAMETER** | **EVALUATION** | **COST** |
| **Operations and Maintenance** | 3% of total IC | $ 6,142.29 |
| **Insurance Cost** | 2% of total IC | $ 4,094.86 |
| **Annualized Overhaul** | 20% IC/# years | $ 2,047.43 |
| **TOTAL OPEX COST PER YEAR:** | | $ 12,284.58 |

The energy output of the Poseidon was calculated using the current industry standard for calculation of WEC energy output at a specific location, by the combination of a power matrix (based on WEC ability to convert available wave energy during specific combinations of significant wave height $H_s$ and the period of energy $T_e$) and a characteristic matrix based upon wave data ($H_s$ & $T_e$) at a particular location [19]. The power matrix for the Poseidon had to be developed unlike the alternative WECs with an established power matrix, and due to the infancy of the Poseidon project the energy output is a rough, yet presumably conservative, estimation at this preliminary stage. The value obtained for energy output is approximately 156 MW-hr/year, and this will be refined in future reports upon further development of the specifics involved with the design.

## Economic Evaluation Conclusions

The preliminary results conclude that the Poseidon WEC has a strong potential to be a viable source of renewable wave energy and according to the cost analysis performed the Poseidon has the highest rate of return and best break-even period of all WECs analyzed as seen in Table 7. With a NPV of over $690K and an IRR of 26%, the Poseidon has clear economic advantages over the alternatives due to the simplicity of the design, which allows for lower cost of O&M and capital expenses alike. The internal rate of return is larger than all other alternatives, and the Poseidon is expected to break even between year 3 and 4, which is the most attractive of the alternatives for potential investors. Further potential economic advantages of the Poseidon include energy production independent from wave direction, decreased likelihood of damage to the WEC, a submerged state that does not interfere with potential tourism and a potential for higher energy transmission rates due to its close proximity to shore. All of these advantages have a direct relation to economic opportunity that is outside the scope of this preliminary report, but will be addressed upon further development of the WEC Poseidon. Of the two alternatives addressed, the Pelamis WEC was the only alternative that turned out to generate a profit. With an increased number of units in a wave farm scheme, the cost of capital could decrease significantly but this may also be offset by the technical and economical disadvantages of the Pelamis that happen to be of the same nature as the advantages previously listed for the Poseidon. The Oyster WEC never returns a profit, and is in the “red” throughout the entire lifetime of the project. Although the cost of capital calculated for the Oyster could potentially decrease in the future and with more units, it is apparent that at this point in time this WEC is not an economically viable alternative. Upon completion of the preliminary economic analysis, it is recommended that the Poseidon should continue in the development of the design in order to construct a prototype for field-testing purposes.

**Table 7: Alternative Economic Comparison**

| | Alternate #1: The Oyster | Alternate #2: The Pelamis | Proposed Device: The Poseidon |
|---|---|---|---|
| **NPV** | $ -3,383,604.69 | $ 4,903,197.37 | $ 690,700.54 |
| **IRR** | -2% | 13% | 26% |
| **Break-Even Period** | NEVER | Year 8 | Year 4 |

## 4. Environmental Considerations

In 2007 the Energy Act went into effect by government officials to provide the Bureau of Ocean Energy Management the authority to create guidelines for renewable ocean energy devices [20]. Around the Hawaiian Islands lies a vast array of different species of sea life and ecosystems. Section 633(b) of the Energy Independence and Security Act of 2007 called for a report to be provided to Congress following specific guidelines that were categorized into four main topics: The potential environmental impacts of marine and hydrokinetic energy technologies, the options to prevent these adverse environmental impacts, the potential role of monitoring and adaptive management, and the necessary components of an adaptive management program [21]. Although there are 3 different alternatives to analyze, the wave energy devices will include many similar characteristics that will inevitably have an effect on the surrounding environment that must be analyzed. The main elements to be analyzed will include: change of natural current flow properties, change in sediment transportation, disturbance of benthic organisms, noise caused during installation and operation, generation of electromagnetic fields (EMF), toxicity levels of paints, lubricants, and antifouling coatings, influence of migration path changes to sea life, and the influence of the moving parts to the surrounding environment. Around the Oahu island in particular, a migration of humpback whales from Alaska make their way to the Hawaiian Islands to mate and give birth during the months of December through May [22]. A total of around 7,000 humpback whales will be making this migratory journey to Hawaii which means the impacts of a wave energy converter must be minimal in regards to the whale's migration and mating pattern. In January 2003, the very first wave energy project environmental assessment was performed on the North shore of Oahu by Global Energy Partners, LLC. The assessment was over a two-year period taking into account the environmental impact of six wave energy converter buoys and their installation and operational impacts to North Shorelines environment. The conclusions based by topic are as follows:

Marine Biological Resources. It is stated in the report that minor biological impacts may occur upon the cable route, but no biological habitats of concern have been identified in this area.

Terrestrial biological Resources**.** There are no federally listed endangered or threatened terrestrial species that occur at North Shore.

Shoreline Consideration. The wave energy converter would have no effect in shifting/altering the current or wave directions. Sediment transportation and shoreline erosion would not be an issue cause by the wave energy device.

Noise. It is stated that the noise caused by the installation and drilling for the wave energy device will be no different for fish and mammals than that of ship common ship traffic.

Public Recreation. It has been concluded that there are no inherent recreational impacts within the 500-yard buffer zone.

Public Safety. It has been concluded that there are no inherent public safety risks within the 500-yard buffer zone of the wave energy converter.

# 5. Task Descriptions

## Project Introduction

### Task 1 – Purpose

**Estimated start/finish dates:** 09/01/15 – 9/2/15
**Duration:** 10 hours
**Task leader(s):** Josh Wagner, Jordan Wagner, Clark Groom, Jason Thies
**Description:**
As the planet's the oil supply continues to decrease with increasing energy demand, the world's ocean waves could prove to be a viable renewable and clean energy resource. The purpose of this project is to design a device that will convert the massive amount of mechanical energy that is stored in ocean waves into electricity. Most existing wave energy converters (WEC's) operate on the water's surface, which introduces an array of problems such as increased maintenance, shipping complications, and visually unappealing structures. Therefore, a completely submerged device that is fixed to the seafloor is of particular interest. The device will consist of a horizontal plate, which will oscillate in the heave direction due to shallow water wave forces. The plate oscillation will power a generator, which will output usable electricity that is to be transported and connected to the local power grid. To complete this task in an efficient manor, we will abide by our project flow chart to optimize all aspects of the device.

### Task 2 – Literature Review

**Estimated start/finish dates:** 09/01/15 – 12/14/15
**Duration:** 50 hours
**Task leader(s):** Josh Wagner, Jordan Wagner, Clark Groom, Jason Thies
**Description:**
The goal of this task is to perform expansive search for previously discovered information on all relevant areas of the project. This information will come from research project results found in reliable technical journals such as *Ocean and Resources Engineering, Applied Ocean Research, and Renewable and Sustainable Energy Reviews*. The main literature topics of interest include wave energy converters, hydrodynamics of oscillating plates, global and local wave information, subsea cabling, and electric generators. Additionally, literature pertaining to other alternative energy resources, such as offshore wind energy, will be investigated for any information that can be applied to wave energy harvesting. All papers found from the literature review will be stored on Mendeley, which is an online cloud system that will allow all group members to have access to the discovered papers.
**Resources:** Mendeley, peer-reviewed papers and reports

### Task 3 – Decide Alternatives

**Estimated start/finish dates:** 09/14/15 – 9/21/15
**Duration:** 10 hours
**Task leader(s):** Jordan Wagner, Jason Thies
**Description:**
The goal of this task is to determine two WEC designs aside from the proposed design that would be most feasible in converting wave energy into electricity. The two alternatives that are chosen for the analysis will be the Pelamis and Oyster wave energy converters (O'Connell, M). This will allow us to compare two previously designed devices to our entirely new design. The two alternative WEC's will also be chosen from already implemented devices so that actual data can be obtained on the device's feasibility rather than just speculation. If the two alternatives are found to be less advantageous than the proposed design, which we expect, the proposed device will be designed so that the shortcomings of the alternatives are minimized.
**Resources:** Literature (B Drew et al. 2009)

## Site Location Selection

### Task 4 – Site Alternative Analysis (Wave Resources)

**Estimated start/finish dates:** 09/14/15 – 9/28/15
**Duration:** 10 hours
**Task leader(s):** Josh Wagner
**Description:**
The goal of this task is to determine three possible locations where the WEC will operate. These three locations will be chosen based on two criteria; wave resources and wave energy demand. Wave resources vary greatly around the world; therefore, it is extremely important to choose a site location with favorable wave resources throughout the year. An annual global wave study will be performed in order to determine regions of the world that meet this criterion. A WAVEWATCH III hind cast model is used to determine the global annual wave data including significant wave height, wave period, and wave power. Consistent significant wave height will be the main priority for ranking a location's wave resources. However, preliminary studies suggest that a shorter period with a higher wave height would increase the proposed device's energy output, therefore period will also be considered in the site location.
**Resources:** Literature (Randi A. Arinaga, Kwok Fai Cheung 2012)

### Task 5 – Site Alternative Analysis (Demand for Wave Energy)

**Estimated start/finish dates:** 09/27/15 – 9/28/15
**Duration:** 5 hours
**Task leader(s):** Josh Wagner
**Description:**
In addition to wave resources, a location's demand for wave energy is necessary for the success of the project. Therefore, the goal of this task is to determine which of the three site locations has the most need for wave energy development and the necessary governmental and private sector support for such a project. In order to accomplish this, each location will be evaluated to determine government programs, laws/agreement, and past projects that have been implemented on the Hawaiian Islands such as *Azura that* would suggest a strong possibility of government subsidies (which is discussed in task 6). In addition, the potentiality of private sector investments will be assessed by examining past and current projects that have or had private sector backing. These projects are not limited to wave energy devices; all clean energy projects will be used in the assessment.
**Resources:** Literature (Barnes et al. 2013, Clement et al 2002, Silva et al 2013)

## Laws and Regulations

### Task 6 – Compliance with Energy Act of 2005

**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 2 hours
**Task leader(s):** Clark Groom
**Description:**
The Energy Policy Act of 2005 is a comprehensive national energy policy that provides incentives to traditional energy production as well as for new, more efficient production technologies. The sections in the Energy Act of 2005 that will be related to the Poseidon wave energy converting device are: Sec. 201 - Inventory of Renewable Resources, sec. 202 - Renewable Energy Production Incentive, sec.203 - Federal Purchase Requirement, Sec. 209 - Rural and Remote Community Electrification Grants, Insular Areas Energy Security – Comparison for the least dependent on imported fossil fuels, Sec. 931 - Renewable Energy Demonstration Grants, Sec. 1703 – Eligible Projects, Sec. 1835 - Renewable Energy on Federal Land and Sec. 388 – Lease Grants for Outer Continental Shelf (OCS) Region. These policies will be investigated further according to the design specifications of Poseidon.
**Resources:** Ocean and Offshore Renewable Energy Policy (Alternative Energy News), Energy Act of 2005 (109th Congress Report)

### Task 7 – Compliance with Bureau of Ocean Energy Management

**Estimated start/finish dates:** 09/01/15 – 12/15/15

**Duration:** 2 hours

**Task leader(s):** Clark Groom

**Description:**

The Bureau of Ocean Energy Management (BOEM) is an agency within the United States Department of the Interior, established in 2010 by Secretarial Order. BOEM promotes energy independence, environmental protection and economic development through responsible, science-based management of offshore conventional and renewable energy and marine mineral resources. The framework provided by the (BOEM) will be used as the road map from start to finish that is governed by all relevant regulations for ocean energy projects which are: The Energy Act of 2005, National Environmental Policy Act of 1970 (NEPA), Clean Air Act of 1970 (CAA, reauthorized in 1990), Coastal Zone Management Act of 1972 (CZMA, reauthorized in 1990), Clean Water Act of 1977 (CWA), Marine Mammals Protection Act of 1972 (MMPA), Endangered Species Act of 1973 (ESA)

**Resources:** Bureau of Ocean Energy Management Regulatory Framework (BOEM)

## Class Document Management

### Task 8 – Weekly Meetings

**Estimated start/finish dates:** 9/01/15 – 5/03/16

**Duration:** N/A

**Task leader(s):** All

**Description:**

Throughout this task, all relevant regulations and codes will be further investigated to insure that all requirements are met throughout the design process.

Many assignments will be due for both Capstone I and Capstone II classes throughout the project. Proper management is essential to making sure that all assignments are turned in by the due dates. This includes having completed drafts revised at least one week before the due date. Also, group members should communicate clearly and effectively on all aspects of the project, and responsible group members for any specific task should be decided. The goal of this objective is to meet all required due dates for the class to ensure success of the project.

**Resources:** Microsoft Project

## Bathymetry and Metocean Data

### Task 9 – Bathymetric Data

**Estimated start/finish dates:** 11/9/15 – 11/16/15
**Duration:** 6 hours
**Task leader(s):** Josh Wagner
**Description:**
Bathymetric data is necessary to determine whether the sea floor at the chosen site is suitable for the device to operate. The criteria for a suitable bathymetry includes no steep drop offs that would increase chances of landslides, no sudden and extreme seafloor elevation spikes that would result in wave breaking, or any seafloor shapes that would cause extreme complications with the installation or operation of the device. In addition, bathymetry that is able to support a farm containing multiple WEC's is desired. Such bathymetric characteristics include long, gradual slopes that would allow for most of the devices to operate at relatively similar water depths. Also, bathymetry information will be used to determine the exact location of the device given the desired water depth. For example, the distance from the shore the device will need to be installed to achieve this water depth. Bathymetric data for the location will be gathered using bathymetric maps specific to the site location.
**Resources:** NOAA (http://maps.ngdc.noaa.gov/viewers/bathymetry)

### Task 10 – Wave Data

**Estimated start/finish dates:** 11/9/15 – 11/16/15
**Duration:** 5 hours
**Task leader(s):** Josh Wagner
**Description:**
Wave statistics is the most important data that needs to be gathered for the hydrodynamic analysis of the project. Annual wave heights and periods are crucial to determining the power output of the device. Therefore, the goal of this task is to create statistical wave data and spectral distributions gathered from year round wave information specific to the site location that will be used in the hydrodynamic analysis of the device. At this point, global wave data was already gathered in the Task 4, however higher-resolution local wave data will now be needed for the selected site. First, wave data will be gathered from buoys that are located in proximity to the site. In addition to buoy data, a SWAN model nested in WAVEWATCH III allows for a high-resolution, annual wave model for the site location. The SWAN is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. The SWAN model as well as buoy data, includes bi-monthly average significant wave heights, wave periods, and wave power at much higher resolution than.
**Resources:** Literature (Stopa, Filipot, Li et al. 2013), National Data Buoy Center – NOAA

**Task 11 – Current Data**
**Estimated start/finish dates:** 11/16/15 – 11/18/15
**Duration:** 5 hours
**Task leader(s):** Josh Wagner
**Description:**
The local currents are important factors when determining the forces on the piles of the structure, as well as determining the frictional force the plate must overcome. Therefore, annual current data at the site must be collected in order to complete the structural and hydrodynamic analysis. This information will be found from current sensors placed in the area of the Northern Point of Oahu and mathematical models that are used to approximate the current data. Depending on the sensor's depth, the current profile will be determined over the height of the structure using a current power law.
**Resources:** Current Data – NOAA, DNV-RP-C205 (4.1)

## Feasibility Study

**Task 12 – Technical Alternative Analysis**
**Estimated start/finish dates:** 09/10/2015 – 10/05/2015
**Duration:** 10 hours
**Task leader(s):** Jordan Wagner
**Description:**
The technical alternative analysis is needed to compare three wave energy converters on the basis of their functionality in the sea state of the chosen site location. The physical functionality of the WEC, limitations of the design, and potential performance of each of the three WEC alternatives will be addressed at the chosen site location. A technical feasibility analysis of the proposed Poseidon WEC and the two alternatives, the Pelamis and the Oyster WEC, is imperative in the overall evaluation of the WECs to ensure that they can be implemented at the proposed site location. A literature review will be conducted for information on the two alternative WECs for comparison the Pelamis, and the Oyster WEC (Falcão 2010). It is expected that the literature review will yield sufficient peer-reviewed articles regarding the Pelamis and Oyster WECs, as they are currently some of the most developed WEC projects on the market. Information regarding the newly proposed Poseidon WEC will be mostly theoretical, as the design has not yet been fully developed. Therefore the initial technical feasibility analysis of the Poseidon WEC will be rough, and is subject to change upon further development of the WEC project. This task will be revisited once all design specifications have been completed to the Poseidon WEC.
**Resources:** Literature (Falcão 2010)

**Task 13 – Alternative Cost Analysis**
**Estimated start/finish dates:** 09/10/2015 – 10/05/2015
**Duration:** 10 hours
**Task leader(s):** Jason Thies
**Description:**
The economic feasibility of the alternatives is based upon a cost analysis where the proposed Poseidon WEC and the two existing WECs, the Pelamis and Oyster, will be compared side by side in order to establish the most economically viable option. The information needed is annual energy production and cost of each of the alternatives, including capital cost and operation & maintenance expenses. This information will be found by doing a literature review of the alternatives in order to find a way to calculate power production in the sea state of our location and to find a cost breakdown of the current WECs. The information needed for the Poseidon WEC includes an estimation of material cost, as well as a rough calculation for power output in the chosen location. Once information regarding the energy production, and cost breakdown of each WEC is found, a cost analysis will be performed to calculate and compare the net present value (NPV), internal rate of return (IRR), and revenue generated by each WEC. The cost analysis will be the grounds for determining the potential WEC to be developed at the chosen site location for the rest of the scope of the project. This task will be revisited once all design specifications have been completed to the Poseidon WEC.
**Resources:** Literature (Carter 2005)

**Task 14 – Break-Even Analysis**
**Estimated start/finish dates:** 09/10/2015 – 10/05/2015
**Duration:** 5 hours
**Task leader(s):** Jason Thies
**Description:**
A break-even analysis will be performed in conjunction with the cost analysis, as an extension to the overall feasibility analysis of the alternatives. The break-even analysis will verify the results of the cost analysis and will represent the results in the format of a chart, which will be displayed in the presentation for easy viewing. The break-even chart is helpful to quickly determine the time period that it takes for the profit from energy production to outweigh the cost of each WEC hence the term "break-even". These break-even periods are crucial for investors to know when they will begin to get a return on their money. The information that will be needed for the cost analysis is sufficient to perform the break-even analysis, so the literature review in the previous task will be used to provide information for the break-even analysis as well. The chart will be generated using this information and Microsoft Excel software. This task will be revisited once all design specifications have been completed to the Poseidon WEC.
**Resources:** Microsoft Excel

### Task 15 – Environmental Analysis of Alternatives

**Estimated start/finish dates:** 09/10/2015 – 10/05/2015
**Duration:** 3 hours
**Task leader(s):** Clark Groom
**Description:**
An environmental analysis will be conducted in order to ensure that the proposed WEC will have a minimal negative impact on the native environment. Global and local environmental regulations will be conducted in accordance to the Bureau of Ocean Energy Management to ensure that the proposed project will not violate any regulations upon installation or operation. The Bureau of Ocean Energy Management is in charge of both the management of the local and global environmental impacts from the Poseidon WEC. The global impact potential from the WEC includes a potential reduction in fossil fuel use, thereby reducing carbon emissions and positively impacting the world's environment (Bedard 2004). The local impact refers more to the impact of the WEC on the surround site location, and a local assessment will be made to verify that the proposed WEC device will not disrupt local sea-life or negatively impact the surrounding area in any way. A literature review will be conducted in order to find relevant, peer-reviewed sources on the local environmental laws, as well as on the impact of carbon emission reduction.
**Resources:** Literature (Bedard 2004), (BOEM) Bureau of Ocean Energy Management

## Design of Device

### Task 16 – Materials Study

**Estimated start/finish dates:** 01/19/16 – 2/01/16
**Duration:** 5 hours
**Task leader(s):** Clark Groom
**Description:**
The material analysis will be conducted in accordance with DNV-OSS-312. A study will be conducted to decide the optimal material to use for the device based on cost and performance. The desired material will need to be rigid and durable enough to withstand the cyclic loading states that it will encounter. Since both mass and width of the plate will be major factors in plate motion, a detailed material study will be crucial to the success of the project. The goal will be to find a material that, based on thickness requirements, will not be abundantly positively or negatively buoyant. Such a material will allow for easy buoyancy modifications, which may be necessary according to the hydrodynamic analysis.
**Resources:** Literature (Falcão 2010)

**Task 17 – Preliminary Device Dimensions**
**Estimated start/finish dates:** 01/19/16 – 2/01/16
**Duration:** 5 hours
**Task leader(s):** Clark Groom
**Description:**
The device dimensions and design will abide by all codes in the AISC manual.
The dimensions of the structure will be chosen in pursuance of structural integrity when subject to extended periods of cyclic loading states. The diameter, height, and distance between piles will be chosen in order to provide sufficient resistance to fatigue, bending moments, and shear. Preliminary plate dimensions will also be chosen, however these will be modified based on the parametric studies that will be conducted during the hydrodynamic analysis to obtain maximum efficiency of the system. The goal will be to choose device dimensions that will allow for a structurally sound device, which will be confirmed later with a detailed structural analysis.
**Resources:** AISC manual

**Task 18 – Frame/Plate Connections**
**Estimated start/finish dates:** 01/25/16 – 3/01/16
**Duration:** 6 hours
**Task leader(s):** Jason Thies
**Description:**
The connections between the frame and the plate will be designed in order to minimize friction, which could greatly influence plate motion. Horizontal wave forces will push the plate against the frame, effectively increasing the friction in the system. The goal will be to design a durable connection that will reduce the frictional forces between the frame and oscillating plate. Several different designs are possible to achieve this goal which include: Roller, journal , and fluid bearings.
**Resources:** Company (Flow Solutions, Inc.)

## Drawings

**Task 19 – 3-D Animated Drawing**
**Estimated start/finish dates:** 02/01/16 – 2/15/16
**Duration:** 10 hours
**Task leader(s):** Josh Wagner
**Description:**
An animated schematic of the prototype is necessary when trying to explain the device to anyone who is not familiar with the project. A 3-D animated drawing will be created using a parametric modeler, such as Creo or Rhino. While dimensions are needed to create an accurate representation, this particular schematic will be used almost exclusively as a visual aide. Therefore, exact device dimensions, though desired, will not be a requirement for this task. The goal will be to create an aesthetically pleasing animation that will

illustrate the concept of the device to a person who has no prior knowledge in the field of wave energy converters.
**Resources:** Parametric modeler such as Creo or Rhino

### Task 20 – Technical Drawings

**Estimated start/finish dates:** 02/01/16 – 3/11/16
**Duration:** 10 hours
**Task leader(s):** Jordan Wagner
**Description:**
Detailed technical drawings will be created that incorporate the exact layout of the device. Several drawings will be created using AutoCAD that represent the structure, energy transformation devices, and electrical components. Exact dimensions are going to be required for this step, as these will be the drawings used when constructing the device. The goal is to create a set of design drawings that provide all of the technical details needed for anyone trying to build the device.
**Resources:** AutoCAD

## Hydrostatic Analysis

### Task 21 – Plate Buoyancy Calculations

**Estimated start/finish dates:** 03/11/16 – 3/31/16
**Duration:** 3 hours
**Task leader(s):** Clark Groom
**Description:**
The buoyancy of the plate will be analyzed based on the preliminary dimensions chosen in Task 18. The plate will need to sufficiently buoyant so that the wave forces will be able to induce motion, so an optimal plate thickness will be found to satisfy this requirement. Since plate dimensions are crucial factors influencing motion, the exact plate dimensions will be based on the hydrodynamic study. Therefore, it may be necessary to repeat this step until optimal plate dimensions are found. The goal will be to analyze the hydrostatics of the plate in order to make sure that the desired buoyancy is achieved. The theory that will be applied for the hand calculations will be Archimedes principle.
**Resources:** Hand calculations, HydroD

### Task 22 – Frame Buoyancy Calculations

**Estimated start/finish dates:** 03/11/16 – 3/31/16
**Duration:** 3 hours
**Task leader(s):** Clark Groom
**Description:**
The structural frame will also be analyzed to ensure the desired buoyancy is achieved. The buoyancy of the frame can affect the integrity of the structure by adding unnecessary stress states on the system. A negatively buoyant frame is desired so that device will easily

remain on the seafloor without inducing unnecessary stresses in the anchoring system. Many problems can arise if the structure wants to float, so particular attention will be paid to having the system negatively buoyant. The goal is to analyze the hydrostatics of the frame in order to verify that the desired conditions are met. The theory that will be applied for the hand calculations will be Archimedes principle.
**Resources:** Hand calculations, HydroD

## Hydrodynamic Analysis

### Task 23 – The Green-Naghdi Solution

**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 150 hours
**Task leader(s):** Josh Wagner, Jordan Wagner
**Description:**
The wave-induced motion of the plate will be analyzed using the Level 1 Green-Naghdi (GN) equations. A FORTRAN subroutine will be added to an existing program that provides the GN forces on the plate. The subroutine will numerically solve the equation of motion based on these forces using the Euler forward method. If it is determined that this method introduces too much numerical error, a higher order method can be used, such as a higher order Runge-Kutta method (Hayatdavoodi, Ertekin 2015). The goal is to determine the motion of the plate so that the theoretical power output can be calculated. It is assumed in this task that only vertical wave forces affect the heave motion of the plate, however the horizontal forces will be analyzed later to determine friction in the system.
**Resources:** FORTRAN programming language, Literature (Hayatdavoodi, Ertekin 2015)

### Task 24 – Linear Solution

**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 30 hours
**Task leader(s):** Josh Wagner
**Description:**
If time and resources allow, plate motion will be analyzed with more simplified solutions for comparison. The linear solution will be found using Airy wave theory to solve the equations of motion. Because the presence of the plate alters the wave, the problem must be solved as a diffraction problem. A FORTRAN code that gives the diffracted forces on the plate will be modified to numerically solve the same way as in Task 24. The added mass and damping of the plate will need to be accounted for in order to obtain accurate results. The goal of this task is to obtain the linear solution of this problem. Also, comparisons with Potential Theory and Navier-Stokes Equation will be performed.
**Resources:** FORTRAN programming language, Literature (Patarapanich 1984)

### Task 25 – Potential Flow Solution

**Estimated start/finish dates:** 03/11/16 – 03/31/16

**Duration:** 15 hours

**Task leader(s):** Jordan Wagner

**Description:**

The problem will be solved using a potential flow solution, which can utilize SESAM's HydroD package. A panel model will be created in GeniE and imported into HydroD for hydrodynamic analyses. A process in HydroD, known as Wadam, can run hydrodynamics on the plate based on potential flow. HydroD uses a finite element method which integrates pressures in each cell over the entire surface. The results from HydroD will provide another source of comparison to the Green-Naghdi theory. Added mass and damping coefficients obtained from this method can also be compared to those used in the linear solution.

**Resources:** Genie, HydroD

### Task 26 – Computational Fluid Dynamics

**Estimated start/finish dates:** 09/01/15 – 04/01/16

**Duration:** 150 hours

**Task leader(s):** Jordan Wagner

**Description:**

Computational fluid dynamics (CFD) will be utilized to help solve the problem. CFD is a very accurate, yet involved, method for solving fluid flow problems. The plate will be constructed in a CFD program known as OpenFoam. A dynamic mesh will need to be created over the plate in order to analyze the flow when the plate is in motion. In order to analyze wave induced forces in OpenFoam, a plugin known as Waves2Foam will be used. A major advantage of using CFD is the ability to obtain results even when the plate is very close to the surface, which produces wave breaking. As wave theories do not apply for this case, using CFD will be extremely beneficial for analyzing plate motion at any location in the fluid domain.

**Resources:** OpenFoam, Waves2Foam

### Task 27 – Effect of Friction on Plate Motion

**Estimated start/finish dates:** 04/08/16 – 04/15/16

**Duration:** 10 hours

**Task leader(s):** Josh Wagner

**Description:**

The effect of friction on plate motion will be analyzed using the Green-Naghdi solution. The same code that is used in Task 24 will be used to find the horizontal wave induced forces, which will influence the friction in the system. The coefficient of friction for the frame/plate connection will be found. With the force and friction coefficient known, the friction forces in the system can easily be calculated. A subroutine will be written to

incorporate these forces into the Green-Naghdi code. The goal is to determine the overall effect friction will have on plate motion.
**Resources:** FORTRAN programming language, (Hayatdavoodi, Ertekin 2015)

### Task 28 – Effect of Generator on Plate Motion

**Estimated start/finish dates:** 04/08/16 – 04/15/16
**Duration:** 5 hours
**Task leader(s):** Josh Wagner, Jason Thies
**Description:**
In order to convert the mechanical energy of the plate into electrical energy, an energy conversion device must be implemented. Devices such as pistons, rotors, and linear induction generators are typically used for this purpose. The device will have a major influence on plate motion, which makes a detailed analysis necessary for finding the optimal type and number of devices needed. Because each device exerts a force opposite of the plate motion, these forces will be written into a subroutine in the same manner as in Task 27. The goal of this task is to determine the effect of the power transformation device on plate motion.
**Resources:** FORTRAN programming language, (Hayatdavoodi, Ertekin 2015)

### Task 29 – Parametric Analysis

**Estimated start/finish dates:** 04/08/16 – 04/15/16
**Duration:** 15 hours
**Task leader(s):** Jordan Wagner, Josh Wagner
**Description:**
A parametric analysis will be performed in order to find the optimal plate dimensions for maximum power output. Because plate motion is majorly affected by both plate and wave characteristics, a parametric analysis is needed to compare a wide range of options. The GN code will be used as the main platform for the analysis due to the ease of quickly changing parameters. As CFD is extremely computationally and time expensive, it cannot be used to perform a parametric analysis. The goal of this task is to determine the exact optimal dimensions of the plate in order to maximize power output.
**Resources:** Fortan programming language

### Task 30 – Analysis of Device Field

**Estimated start/finish dates:** 04/15/16 – 04/30/16
**Duration:** 10 hours
**Task leader(s):** Jordan Wagner
**Description:**
All hydrodynamic analysis has been based on a single device, however a field of devices will most likely need to be implemented in order to extract enough usable power. Because the presence of one device might affect how others behave, an analysis will be conducted. Since this device hasn't been implemented yet, the information on this topic is scarce, so a very

thorough literature search will need to be conducted. The goal is to determine the best placement of devices in order to minimize the effect one device has on another. Most likely the optimal arrangement of devices is in a line along the crest of the waves (normal to wave ray); this will be examined further in this task.
**Resources:** Literature (TBD)

### Task 31 – Forces on Frame

**Estimated start/finish dates:** 04/01/16 – 04/08/16
**Duration:** 10 hours
**Task leader(s):** Jordan Wagner
**Description:**
The hydrodynamic forces on the frame will be analyzed to ensure structural integrity. Since the frame will be composed of cylindrical piles, Morison's equation will be used to compute the forces on the structure. A Matlab code can easily be written to calculate and plot the Morison forces and moments. The results will be used in the mooring and structural analyses later. Special attention needs to be paid to verifying that Morison's equation is applicable in this situation based on the pile diameter and wavelength. While Morison's equation is extremely empirical and not very accurate in a lot of cases, it will at least provide the expected forces on the structure within an order of magnitude. Morison's Equation can provide rough estimates for the inertial and drag forces experienced on the frame. DNV-RP-C208 codes will be followed.
**Resources:** Matlab, DNV

## Structural Analysis

### Task 32 – FEM Frame Analysis

**Estimated start/finish dates:** 02/15/16 – 02/26/16
**Duration:** 10 hours
**Task leader(s):** Josh Wagner, Jordan Wagner
**Description:**
The structural analysis of the frame will be performed, in which the goal is to ensure that the structure will not be compromised as a result of external forces from waves, current, or buoyancy. Therefore, global or local structural failure will have significant impact on the device's operation, so it must be determined that the frame is sufficient in resisting the external forces acting on it. In order to achieve this goal, a finite element analysis will be performed on the structural frame, which will use the external forces induced by the factors previously stated. First, the structure must be modeled in the chosen FEM software and then discretized into finite elements. The 100 year storm period of return will be applied to ensure that Poseidon can withstand extreme storm conditions. The forces will have already been determined in the previous task, so they can then be added to Algor FEM software following DNV-RP-C208. All relevant DNV codes will be used to determine safety

factors and limit states for such a structure, and the FEM results will be compared to these codes to ensure that the stresses in the frame and piles will not cause structural failure.
**Resources:** ALGOR FEM Software, Sestra, DNV-RP-C208 (2.1)

### Task 33 – FEM Plate Analysis

**Estimated start/finish dates:** 02/26/16 – 03/4/16
**Duration:** 10 hours
**Task leader(s):** Josh Wagner, Jordan Wagner
**Description:**
The plate's frame connectors are crucial to the performance of the WEC, so it is imperative that connections remain in full working order. Therefore, a FEM analysis of the plate's connections will be performed in order to ensure that the strength of the plate's connections to the frame is effective in resisting the external forces acting on them. The method will be performed similarly to the previous task in which the connections will be modeled in a FEM software and then previously determined external forces will be applied. In addition to the connections, the integrity of the plate itself will be ensured using the same approach. The stresses found through the finite element analysis will be ensured to meet the limit states defined by DNV-RP-C208 with safety factors applied.
**Resources:** ALGOR FEA Software, Sestra, DNV-RP-C208 (2.1)

### Task 34 – Seafloor Anchoring

**Estimated start/finish dates:** 03/7/16 – 03/10/16
**Duration:** 8 hours
**Task leader(s):** Josh Wagner
**Description:**
The attachments that fix the device to the seafloor must be designed to ensure that the structure stays anchored to the seafloor and is effective in resisting external loads. In order to design this anchoring, similar anchoring systems will be researched for various types of offshore structures. The possible anchoring systems include driven piles or gravity based systems. The system chosen will be the one that proves to be most effective in fixing the structure to the sea floor while remaining economically feasible. Once the anchoring system is designed, the integrity of the system will be ensured using appropriate hand calculations and software. Codes pertaining to sea floor anchoring of fixed offshore wind turbines will be followed for anchoring design in order to properly determine whether the anchoring is sufficient.
**Resources:** ALGOR FEA Software, GeniE, DNV-OS-J301(4.1), ACI, ASME

## Mooring

### Task 35 – Hand Calculations

**Estimated start/finish dates:** 03/21/16 – 03/23/16
**Duration:** 7 hours
**Task leader(s):** Josh Wagner
**Description:**
It may be determined that mooring is required to keep the piles fixed effectively. Before any calculations are performed, the mooring arrangement must be designed. Mooring arrangements for various offshore structures will be researched to find any designs that could be used as a starting place for design. The mooring must be designed to provide adequate load resistance, not interfere with the device's performance, and must remain economically feasible. After the mooring arrangement is designed, hand calculations will be performed in order to ensure the integrity of the mooring lines. An iterative process will be used to determine the most economically feasible mooring. DNV codes will be used with the hand calculations to determine whether the mooring is adequate
**Resources:** DNV-OS-E304 (2.1)

### Task 36 – OrcaFlex

**Estimated start/finish dates:** 03/23/16 – 04/1/16
**Duration:** 7 hours
**Task leader(s):** Josh Wagner
**Description:**
OrcaFlex is a leading software package used for dynamic analysis in the offshore industry. It is especially useful for mooring analysis. The software will be used to determine the required mooring forces for the device. The designed mooring arrangement will be inputted into OrcaFlex and analysis of various wave heights and periods will be performed. The mooring forces in the lines will be gathered from the software and compared to the hand calculations. Ten year max wave heights will be used as a worst case scenario because of the low safety risk.
**Resources:** OrcaFlex Software

## Installation

### Task 37 – Installation Process

**Estimated start/finish dates:** 02/22/16 – 02/26/16
**Duration:** 5 hours
**Task leader(s):** Clark Groom
**Description:**
The procedures for installing the device in the field will be determined based on safety and cost efficiency. The first step will be determining the transportation of materials to the site,

which should easily be achieved with a barge. Next, the process of unloading the piles and fixing to the seafloor will be determined. The mooring and plate attachment procedures will finally be constructed. Since the device is located in shallow water, the installation process should be able to be performed with diver and shallow water equipment. In addition to installing the device itself, much consideration needs to be taken into developing the process for installing the underwater power grid. Finally, the best season for installation is a major factor. According to wave patterns in this location, the summer months will be the best time for installation due to the decreased significant wave heights. The main objective will be to construct a set of procedures for installation that is both safe and cost effective.
**Resources:** Literature (Falcao 2010)

### Task 38 – Installation Analysis

**Estimated start/finish dates:** 02/22/16 – 05/26/16

**Duration:** 5 hours

**Task leader(s):** Clark Groom, Jason Thies

**Description:**

An economic analysis of the procedures developed in the previous task will be performed. The cost of each major step will need to be determined, such as barge rental, underwater welding, pile placement, and other miscellaneous tasks required to complete the installation. These cost estimates will be obtained from literature survey and contacting relevant companies. The main objective will be to make sure that budget conditions are met during the installation phase of the project. If it is determined that the designed installation procedure is not economically feasible, a new procedure must be developed and reanalyzed.
**Resources:** Literature (Falcao 2010)

## Local Environmental Analysis

### Task 39 – Effects of Moving Parts

**Estimated start/finish dates:** 09/01/15 – 12/15/15

**Duration:** 5 hours

**Task leader(s):** Clark Groom

**Description:**

The moving parts will be evalutated using the OCS Alternative Energy Final Programmatic Environmental Impact Statement (EIS) Guide. Section 5.3.8.4.1 in the (EIS) guide will be followed for the considerations for Collision and Entanglement. The scoped mammal of possible concern that seasonally inhabits the waters of Kahuku Point located at the northern most tip of Honolulu is the humpback whale. In accordance with 5.3.8.6 of the (EIS) guide, Research will be conducted on the Humpback Whales migration pattern around Kahuku Point to take the required mitigation measures to ensure that no congregation, mating, or feeding areas are affected. Entanglement and Collision potential will be reduced through the use of sonic pingers. The sonic pingers will be used as a mitigation method to generate frequencies that cause marine mammals to avoid the cables and moving parts of the Poseidon Wave Energy converter.

**Resources:** OCS Alternative Energy Final Programmatic Environmental Impact Statement Guide (BOEM)

### Task 40 – Noise of Installation Analysis

**Estimated start/finish dates:** 09/01/15 – 12/15/15

**Duration:** 3 hours

**Task leader(s):** Clark Groom

**Description:**

Section 5.3.8.3.2 of the (EIS) guide will be used for the analysis on the effects of Construction Noise. Noise generated during mooring of wave energy devices could disturb marine mammals that may be present in the vicinity of the construction area. The data collected in the humpback whale migration research will be used to determine the optimal time of year for installation and the required mitigation to be taken to prevent any disturbances to local marine mammals by noise.

**Resources:** OCS Alternative Energy Final Programmatic Environmental Impact Statement Guide (BOEM)

### Task 41 – Analysis of Local Clean Energy Benefits

**Estimated start/finish dates:** 09/01/15 – 12/15/15

**Duration:** 3 hours

**Task leader(s):** Clark Groom

**Description:**

The Poseidon WEC will be aiding in the reduction of the Hawaiian Island's dependency on fossil fuels. We will compare the environmental impacts of the different energy alternatives to provide adequate proof that if we continue using the same extraction methods, devastating environmental disasters could be in store for our future. The goal will be to calculate Poseidon's effect on the reduction of dependency that Hawaii has on nonrenewable energy resources.

**Resources:** Hawaiian Energy Facts and Figures (Hawaiian State Energy Office)

## Global Environmental Analysis

### Task 42 – Analysis of Global Clean Energy Benefits

**Estimated start/finish dates:** 09/01/15 – 12/15/15

**Duration:** 3 hours

**Task leader(s):** Clark Groom

**Description:**

The Poseidon WEC will be aiding in the reduction of global warming emissions that will ultimately prevent the receding of the ozone layer. The effects on air quality and improved environmental health will be discussed and expounded on greatly. This will be the major selling point on the global environmental impact. By helping reduce greenhouse gases and emissions, not only will our global population health and air quality increase, but the well-

being of Planet Earth itself will be preserved. Also, the risks involved for extracting this type of energy is astronomically lower than extracting fossil fuels, e.g. oil spills.
**Resources:** Literature (Falcao 2010)

## Wave Tank Testing

### Task 43 – Model Similitude Calculations

**Estimated start/finish dates:** 02/01/16 – 02/15/16

**Duration:** 10 hours

**Task leader(s):** Josh Wagner

**Description:**

If time and resources allow, a model will be developed for wave tank testing. In order to have an accurate model test, dimensionless parameters such as Reynolds number need to be similar for both prototype and model. Calculations for the model plate dimensions will be made to provide correct similitude. Also, correct parameters need to be applied for the generated wave for an accurate test. The goal of this task it to create a model that can be used in wave tank experiments to further prove that the supporting theory applies.
**Resources:** Wave tank, Literature (Carter 2011)

### Task 44 – Model Construction

**Estimated start/finish dates:** 02/15/16 – 02/22/16

**Duration:** 15 hours

**Task leader(s):** Josh Wagner

**Description:**

With the desired model dimensions known, the model can be constructed. A major aspect to a successful experiment will be the simplicity of the model. Complicating the model by trying to make an exact replica of the prototype could easily result in erroneous results. The goal is to analyze general relationships between certain waves and plate motion. There are multiple options for construction of the model, which will be decided on at a later date. The objective will be to construct a simple model that is capable of producing reliable results in wave tank testing.
**Resources:** Wave tank, Matlab

### Task 45 – Testing

**Estimated start/finish dates:** 02/22/16 – 05/01/16

**Duration:** 50 hours

**Task leader(s):** Josh Wagner, Jordan Wagner

**Description:**

Wave tank testing will performed on the previously constructed model. The model will be subject to a wide range of different waves with varying parameters. Along with other measuring devices, a high speed camera and a Matlab tracker can be used to track the motion of plate. From this test, the parameters that cause maximum plate velocity will be examined. It is desired to perform the experiments as simple as possible. Determining

general trends between response and wave parameters is the goal of this task, rather than obtaining extremely precise numeric values.
**Resources:** Wave tank, high speed camera, measuring devices, Matlab

## Maintenance

### Task 46 – Marine Growth Prevention/Removal

**Estimated start/finish dates:** 11/15/2015 – 01/30/2016
**Duration:** 3 hours
**Task leader(s):** Jason Thies
**Description:**
It is very important to prevent and/or regularly remove any marine growth on the proposed Poseidon wave energy converter because of the moving parts involved with the design. If marine growth is allowed to accumulate on the wave energy converter, the motion of the device will be inhibited by the marine growth and the wave energy converter will see an increase in friction which will almost certainly cause an increase in mechanical energy loss thus resulting in electrical energy loss and a decrease in overall annual energy output. A literature review will be conducted in order to investigate the current industry methodology used for marine growth prevention in order to assess viable options to prevent marine growth on the proposed Poseidon WEC. The most economical option available to completely prevent marine growth on the moving parts of the WEC will be chosen and factored into the operation and maintenance costs throughout the life of the proposed project.
**Resources:** Literature (Fevag 2012)

### Task 47 – Lubrication

**Estimated start/finish dates:** 11/15/2015 – 01/30/2016
**Duration:** 3 hours
**Task leader(s):** Jason Thies
**Description:**
The moving parts associated with the proposed Poseidon wave energy converter, including the generator, will need to maintain constant lubrication to prevent friction from causing mechanical energy loss. In this step lubricants will be investigated in conjunction with the type of guide system used for translational motion. The type of connection between the translating plate and the frame will be investigated in this step and roller connections such as bearings will likely be focused on. A literature analysis will be conducted to investigate general practice for lubrication of generators and subsea structures, particularly subsea structures with moving components such as other wave energy converter projects. The most viable option for subsea lubrication will be determined and factored into the overall maintenance and operational expenses. The lubrication procedure will be incorporated into the regular maintenance plan associated with the wave energy converter.
**Resources:** Literature (TBD)

### Task 48 – Corrosion Prevention

**Estimated start/finish dates:** 11/15/2015 – 01/30/2016
**Duration:** 3 hours
**Task leader(s):** Jason Thies
**Description:**

Corrosion prevention is imperative for the Poseidon WEC as it is completely submerged in seawater. A literature review will be performed in order to assess the current industry standards for corrosion prevention of underwater structures. Potential strategies that will be investigated for corrosion prevention include, but are not limited to, using sacrificial anodes, coating the exposed surfaces of WEC, and use of a non-corrodible material for construction of the WEC. Corrosion prevention on the overall structure of the WEC, as well as on the generator will be of concern, particularly all moving parts and any conductive or magnetic surface. Once solutions for the corrosion prevention are found, cost of each of the methods including additional future maintenance costs will be assessed to make the proper decision on corrosion prevention measures.
**Resources:** Literature (Baxter 2013), DNV RP F103-B401

### Task 49 – Electrical Component Maintenance

**Estimated start/finish dates:** 11/15/2015 – 01/30/2016
**Duration:** 3 hours
**Task leader(s):** Jason Thies
**Description:**

The electrical components associated with the wave energy converter Poseidon will be subject to maintenance in order to maintain their integrity in the subsea conditions. The necessary electrical components foreseen for the completion of the Poseidon wave energy converter include, but are not limited to, the linear direct drive generator, a power electronic converter, and subsea cables. The linear direct drive generator has the possibility of being composed of materials such as magnets, iron, and copper which will need to be sealed or coated in order to prevent corrosion, regular maintenance will be needed to ensure proper sealing and/or coating of these metals. The subsea cables will potentially be placed along the seabed, and it will be necessary to ensure that they are secure and protected from potential damage. It is assumed that the subsea cables will be sealed so that water will be kept out, and it will be necessary to check these cables periodically to ensure proper sealing. The location of the power electronic converter will predicate the level of maintenance involved for the converter, as subsea and on shore locations are both possibilities for the converter. The information needed to assess the electrical component maintenance will be found through a literature review of peer-reviewed sources relevant to wave energy converter power takeoff systems and generators in order to develop a maintenance plan for the electrical components. The most viable option for maintenance will be implemented into the maintenance course of action and the cost will be factored into the economic analysis.
**Resources:** Literature (Falcao 2010)

### Task 50 – Maintenance Course of Action

**Estimated start/finish dates:** 11/15/2015 – 01/30/2016
**Duration:** 4 hours
**Task leader(s):** Jason Thies
**Description:**
The overall maintenance course of action will be determined by determining the individual maintenance plans from tasks 47-50. The maintenance requirements involving lubrication, electrical components, removal/prevention of marine growth and corrosion, will be assessed along with any other necessary maintenance of the wave energy converter. The maintenance tasks will be scheduled so that they may coincide with each other and have a minimal overall cost. The most economically viable method will be the chosen maintenance course of action throughout the life of the Poseidon project. Keeping the maintenance cost low will be a key factor in the overall economic analysis of the Poseidon wave energy converter project.
**Resources:** Literature (Falcao 2011)

## Energy Conversion

### Task 51 – Power Matrix from Linear Solution

**Estimated start/finish dates:** 10/01/15 – 10/30/15
**Duration:** 8 hours
**Task leader(s):** Josh Wagner, Jordan Wagner
**Description:**
A matrix that contains the theoretical power output based on significant wave height and period will be constructed. This will be achieved by solving a linear wave theory diffraction problem to find forces and velocities of the plate. With these parameters known, the power output can be calculated using the work-energy principle. As particular waves do not happen throughout an entire year, an occurrence matrix will be constructed. This matrix will consist of the probability that each entry in the power matrix will occur. Incorporating the occurrence matrix with the power matrix, a relatively accurate yearly power output animation will be found. The diffraction problem with be solved by writing a subroutine to numerically solve a preexisting Fortran code. The objective is to determine reliable power output estimations so that an economic study can be performed.
**Resources:** Fortran programming language, Literature (Patarapanich 1984)

### Task 52 – Power Matrix from GN Solution

**Estimated start/finish dates:** 10/01/15 – 1/19/16
**Duration:** 8 hours
**Task leader(s):** Josh Wagner, Jordan Wagner
**Description:**
A more accurate power matrix will be constructed using the GN solution. A similar subroutine will be used to solve the equation of motions for the plate using the given

forces. The power output is calculated the same way by means of the work-energy principle. The same occurrence in the previous task will be used, as the yearly probability of each wave occurring does not change. Using this nonlinear solution, very accurate results can be obtained for maximum power output. By inspecting the power matrix desired wave parameters can be found, which will affect the location selection for device placement. The goal of this task is to determine a more accurate power output than the linear solution.
**Resources:** Fortran programming language, Literature (Hayatdavoodi, Ertekin 2015)

### Task 53 – Power Takeoff Alternative Analysis

**Estimated start/finish dates:** 11/07/2015 – 01/30/2016
**Duration:** 15 hours
**Task leader(s):** Jason Thies
**Description:**
An analysis will be performed on the alternative power takeoff systems used throughout the wave energy community. The potential power takeoff systems that are expected to be analyzed include, but are not limited to, direct drive, hydraulic, limited and direct mechanical linkage systems. Each of these systems will be assessed to determine the proper power takeoff system that should be used with the particular proposed wave energy converter Poseidon. Using the correct power takeoff system is absolutely imperative in order to have a wave energy converter that is operating at the highest capacity possible. The power takeoff systems will be analyzed both technically and economically to determine the best power takeoff system for the Poseidon. It will be necessary to have a general idea of the velocity, force, and amplitude of oscillation regarding the oscillating plate of the Poseidon in order to properly make an assessment on the best power takeoff system to use.
**Resources:** Literature (Baker 2003, Bostrom 2011)

### Task 54 – Translator Analysis

**Estimated start/finish dates:** 11/07/2015 – 01/30/2016
**Duration:** 15 hours
**Task leader(s):** Jason Thies
**Description:**
The translator is basically a linear rotor, and is the only moving part in all direct drive generators. It will be imperative to find the amplitude and velocity of motion of the translator, as well as the mass of the translator and the system, in order to properly assess the machine topology needed for the linear direct drive machine and also to assess the size and cost of said machine. Proper knowledge of the translator motion will be used in the equation of motion in order to determine the motion of the system. The translator motion, size, and material property are all imperative to the overall energy production of the wave

energy converter, therefore this task is paramount in the grand scheme of the overall project.
**Resources:** Literature (Baker 2003)

### Task 55 – Linear Direct Drive Generator Alternative Analysis
**Estimated start/finish dates:** 11/07/2015 – 01/30/2016
**Duration:** 50 hours
**Task leader(s):** Jason Thies
**Description:**
A literature review will be performed to understand, and compare the alternative linear direct drive generators that are currently available and to make a decision on the generator most suited for the Poseidon WEC, according to Baker 2003. The alternative generator options will be assessed in order to find the generator most suited for our particular wave energy converter the Poseidon. The weight, size, and cost of the generator as well as the potential energy production will all be imperative in deciding the correct generator for the Poseidon. The weight and size of the generator is based solely on the product of the force acting on the translator and velocity of displacement. A review over existing machine topologies in combination with known values of velocity and displacement of the translator should yield sufficient information in order to make a decision on the correct machine topology to use, and the resulting weight and size of such a linear generator. Existing wave energy converter projects with direct drive linear generators such as the Archimedes Wave Swing will be helpful in making an assessment on the criteria for evaluating the proper generator for the Poseidon wave energy converter. A technical and economic feasibility analysis will be performed to determine the generator type to be used.
**Resources:** Literature (Baker 2003)

## Energy Transportation

### Task 56 – Power Storage Study
**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 3 hours
**Task leader(s):** Clark Groom
**Description:**
The subsea power storage unit that will be used is a subsea distribution unit designed by Siemens. This distribution box will be used as the main subsea energy storage unit before it is transferred through the subsea cabling to the local power grid. The power storage unit will also include ROV mating connections for the use of ROV maintenance and inspection.
**Resources:** Literature

### Task 57 – Subsea Cabling

**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 3 hours
**Task leader(s):** Clark Groom
**Description:**
The Anguila Subsea Distribution System concept was developed in 1993 and is the leading system for distribution of electrical power and signals. The cabling consists of many advanced technical advantages such as the double barrel intrusion protection for ultimate water prevention and double electrical barriers to insure no electricity is transposed through the cable barriers. The cables are designed to be handled by ROV's so they can be installed just as the subsea power storage units are. The most economic cable path of the cabling to the grid connection must be determined. Bathymetry data will be used to avoid any problematic seafloor features such as steep drop offs, coral reefs, areas prone to landslides or any other features that could be hazardous to the cabling.
**Resources:** Literature (Siemens), DNV-RP-J301 (3.2.5, 4.8.1)

### Task 58 – Subsea Junction Boxes

**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 2 hours
**Task leader(s):** Clark Groom
**Description:**
If time allows, the subsea junction boxes will be designed as part of the electrical grid for Poseidon. The subsea distribution box has the ability to act as an electrical storage device, and a subsea junction box to provide the proper cabling location and power distribution from the farm of devices. This box will be the guide and meeting location for the cabling of the entire wave energy farm. Once all power is transmitted to the junction box from the different devices, it is then mass transported to the local power grid.
**Resources:** Literature (Union of Concerned Scientist)

## Marketing

### Task 59 – Global Marketing

**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 2 hours
**Task leader(s):** Clark Groom
**Description:**
The global wave and tidal energy market was worth $25 million in 2013. It is expected to grow at compound annual growth rate of 64.1% from 2014 to 2020, eventually reaching a value of $10.1 billion in 2020. The report estimates the installed capacity of the global wave and tidal energy market to reach 3712 MW by 2020, growing at a compound annual growth rate of 34.5% from 2014 to 2020. In order to capitalize on this increasing market, the

device will be designed to work in all parts of the world with the necessary wave resources, not only for the single proposed location. Therefore, the project will be marketed for governmental and private purchase or investments around the world.
**Resources:** Literature (Transparency Market Research)

**Task 60 – Conventions/Expos**
**Estimated start/finish dates:** 09/01/15 – 12/15/15
**Duration:** 5 hours
**Task leader(s):** Clark Groom
**Description:**
The Odyssea group will attend relevant conventions and expos in order to advertise the project. These conventions will be crucial in gathering the necessary backing the project must have to be implemented and will introduce the project to potential buyers. The topics of the desired conventions and expos will include renewable energy, offshore energy, oceanography, and ocean sciences.
**Resources:** RenewableEnergyWorld.com, GreenPowerConferences.com, www.OTCnet.org

## Conclusion

After comparing all three alternatives, the Poseidon wave energy converter was deemed to be the most economically and technically feasible design. For the economic analysis, Poseidon had the lowest initial cost with the fastest break-even period compared to Pelamis and the Oyster. Also, Poseidon being a completely submerged device provides several major advantages over WECs that break the surface. The North Shore of Oahu was found to be the optimal location providing the desired wave resources for maximum energy extraction.

The main tasks required to accomplish the project consists of a detailed hydrodynamic analysis, a power conversion analysis, and a structural analysis. While these tasks will require the most attention, a number of other tasks will also need to be fulfilled to ensure completion of the project. The total manpower estimated to complete the project will be 841 hours, which will be divided amongst the group. As there are many tasks to be completed, time management will be a crucial factor in determining the success of the project.

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# Appendix A:

| Pelamis Wave Energy Converter | | | | LOCATION: | Northeast Shore of Oahu | | | | |
|---|---|---|---|---|---|---|---|---|---|
| YEAR | AVERAGE ENERGY PRODUCTION (kWhr/yr) | GOVERNMENT SUBSIDIES ($0.189/kWhr) | ANNUAL GROSS INCOME | OPEX COST | COST | CASH FLOW | PRESENT VALUE | INTERNAL RATE OF RETURN | |
| 0 | | | | | $ 4,550,000.00 | | | | |
| 1 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 616,896.46 | | -86% |
| 2 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 598,928.60 | | -33% |
| 3 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 581,484.08 | | -33% |
| 4 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 564,547.65 | | -20% |
| 5 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 548,104.51 | | -11% |
| 6 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 532,140.30 | | -5% |
| 7 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 516,641.07 | | -1% |
| 8 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 501,593.27 | | 3% |
| 9 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 486,983.76 | | 5% |
| 10 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 472,799.77 | | 7% |
| 11 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 459,028.90 | | 8% |
| 12 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 445,659.13 | | 9% |
| 13 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 432,678.76 | | 10% |
| 14 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 420,076.47 | | 11% |
| 15 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 407,841.23 | | 11% |
| 16 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 395,962.36 | | 12% |
| 17 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 384,429.48 | | 12% |
| 18 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 373,232.50 | | 12% |
| 19 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 362,361.65 | | 12% |
| 20 | 1530000 | $ 289,170 | $ 794,070.00 | $ 158,666.65 | $ 158,666.65 | $ 635,403.35 | $ 351,807.43 | | 12% |
| | | | | | | | | | |
| GROSS NET INCOME: | | | $ 15,881,400.00 | | | NPV: | $ 4,903,197.37 | IRR: | 13% |

| Oyster Wave Energy Converter | | | | | LOCATION: | Northeast Shore of Oahu | | | |
|---|---|---|---|---|---|---|---|---|---|
| YEAR | AVERAGE ENERGY PRODUCTION (kWhr/yr) | GOVERNMENT SUBSIDIES ($0.189/kWhr) | ANNUAL GROSS INCOME | OPEX | COST | CASH FLOW | PRESENT VALUE | INTERNAL RATE OF RETURN | |
| 0 | | | | | $ 8,890,200.00 | | | | |
| 1 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 359,349.22 | | -96% |
| 2 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 348,882.74 | | -77% |
| 3 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 338,721.11 | | -60% |
| 4 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 328,855.44 | | -46% |
| 5 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 319,277.13 | | -37% |
| 6 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 309,977.80 | | -29% |
| 7 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 300,949.32 | | -24% |
| 8 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 292,183.80 | | -20% |
| 9 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 283,673.60 | | -16% |
| 10 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 275,411.26 | | -13% |
| 11 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 267,389.57 | | -11% |
| 12 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 259,601.52 | | -9% |
| 13 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 252,040.32 | | -8% |
| 14 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 244,699.34 | | -6% |
| 15 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 237,572.17 | | -5% |
| 16 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 230,652.59 | | -4% |
| 17 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 223,934.56 | | -4% |
| 18 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 217,412.19 | | -3% |
| 19 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 211,079.80 | | -2% |
| 20 | 1432300 | $ 270,704.70 | $ 743,363.70 | $ 373,234.00 | $ 373,234.00 | $ 370,129.70 | $ 204,931.84 | | -2% |
| | | | | | | | | | |
| | TOTAL GROSS INCOME: | | $ 14,867,274.00 | | | NPV: | -$ 3,383,604.69 | IRR: | -2% |

| Poseidon Wave Energy Converter | | | | LOCATION: Northeastern Shore of Oahu | | | | |
|---|---|---|---|---|---|---|---|---|
| YEAR | AVERAGE ENERGY PRODUCTION (kWhr/yr) | GOVERNMENT SUBSIDIES ($0.189/kWhr) | ANNUAL GROSS INCOME | OPEX COST | TOTAL COST | CASH FLOW | PRESENT VALUE | INTERNAL ROR |
| 0 | | | | | $234,535 | | | |
| 1 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 60,378.99 | -73% |
| 2 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 58,620.38 | -34% |
| 3 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 56,912.99 | -11% |
| 4 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 55,255.33 | 2% |
| 5 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 53,645.95 | 10% |
| 6 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 52,083.45 | 15% |
| 7 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 50,566.45 | 18% |
| 8 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 49,093.64 | 21% |
| 9 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 47,663.73 | 22% |
| 10 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 46,275.47 | 23% |
| 11 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 44,927.64 | 24% |
| 12 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 43,619.07 | 25% |
| 13 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 42,348.61 | 25% |
| 14 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 41,115.15 | 25% |
| 15 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 39,917.62 | 26% |
| 16 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 38,754.97 | 26% |
| 17 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 37,626.19 | 26% |
| 18 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 36,530.28 | 26% |
| 19 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 35,466.29 | 26% |
| 20 | 155979.1 | $ 29,480.05 | $ 80,953.15 | $18,762.80 | $18,762.80 | $ 62,190.36 | $ 34,433.29 | 26% |
| | | | | | | | | |
| | | TOTAL GROSS INCOME: | $ 1,619,063.06 | | | NPV= | $ 690,700.54 | IRR= 26% |

# Appendix B:

**Report Responsibilities**

| | |
|---|---|
| **Executive Summary:** | Jordan Wagner/Josh Wagner |
| **Introduction:** | Clark Groom/Jordan Wagner |
| **Site Location:** | Josh Wagner |
| **Power Production:** | Jordan Wagner/Josh Wagner |
| **Alternative Analysis:** | Jason Thies |
| **Environmental Considerations:** | Clark Groom |

**Task Descriptions:**

| No. | Task Name |
|---|---|
| | **Begin Project** |
| 1 | Purpose |
| 2 | Literature review |
| 3 | Decide alternatives |
| | **Location Information** |
| 4 | 3-Site alternative analysis |
| 5 | Demand for clean energy |
| | **Laws and Regulations** |
| 6 | Compliance of Energy Act of 2005 |
| 7 | Compliance of B.O.E.M Guidelines |
| 8 | Compliance of Pacific O.C.S region |
| | **Bathymetry and MetOcean Data** |
| 9 | Low-res bathymetric data |
| 10 | High-res bathymetry data |
| 11 | Wave data |
| 12 | Current data |
| | **Feasibility Report** |
| 13 | Technical alternative analysis |
| 14 | Alternative cost analysis |
| 15 | Alternative break-even analysis |
| 16 | Enviornmental analysis |
| | **Design of Device** |
| 17 | Materials study |
| 18 | Device dimensions |
| 19 | Rail/plate connections |

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| **Josh** |
| **Clark** |
| **Jason** |
| **Jordan** |

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| | **Computer Modeling** |
| 20 | 3-D animated drawing |
| 21 | Technical drawing |
| | **Hydrostatic Analysis** |
| 22 | Plate buoyancy calculations |
| 23 | Frame buoyancy calculations |
| | **Hydrodynamic Analysis** |
| 24 | Green-Naghdi solution |
| 25 | Linear solution |
| 26 | Potential flow analysis (SESAM) |
| 27 | Computational fluid dynamics |
| 28 | Effect of friction on plate motion |
| 29 | Effect of generator on plate motion |
| 30 | Parametric analysis |
| 31 | Analysis of expanding to field of devices |
| 32 | Forces on frame (Morrison's Eq.) |
| | **Structural Analysis** |
| 33 | FEA frame analysis |
| 34 | FEA plate analysis |
| 35 | Seafloor anchoring |
| | **Mooring** |
| 36 | Hand calculations |
| 37 | Orca-Flex |
| | **Installation** |
| 38 | Installation process |
| 39 | Installation analysis |
| | **Local Environmental Analysis** |
| 40 | Effects of moving parts |
| 41 | Noise of installation analysis |
| 42 | Local benefits analysis |
| | **Global Environmental Analysis** |
| 43 | Global benefit analysis |
| | **Testing** |
| 44 | Model simultude calculations |
| 45 | Model construction |

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| **Josh** |
| **Clark** |
| **Jason** |
| **Jordan** |

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|---|---|
| 46 | Wave tank testing |
| | **Maintenance** |
| 47 | Marine growth prevention/removal |
| 48 | Lubrication |
| 49 | Corrosion prevention |
| 50 | Electrical component maintenance |
| 51 | Maintenance course of action |
| | **Energy Conversion** |
| 52 | Power matrix from linear solution |
| 53 | Power matrix from GN solution |
| 54 | Power Takeoff Alternative Analysis |
| 55 | Translator Analysis |
| 56 | Direct Drive Linear Generator Analysis |
| | **Energy Transportation** |
| 57 | Power storage study |
| 58 | Subsea cabling |
| 59 | Subsea junction boxes |
| | **Marketing** |
| 60 | Global marketing |
| 61 | Conventions/Expos |

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| **Josh** |
| **Clark** |
| **Jason** |
| **Jordan** |