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Abstract approved:

Annette von Jouanne

Wind energy is a cornerstone to the world of renewables. It is widely used in many parts of the world as a clean and effective form of power generation. However, wind power has a number of drawbacks, which limits its use in many regions. Solar power has been used not only for small electronic devices, but as a power generating addition to some homes. The output of solar power is not as substantial as wind energy, but it is much easier to deal with, and simple to construct. Wave power has emerged with great promise in the last few years. This new power has immense room to grow, and could possibly be more stable and reliable than wind power, with potentially less environmental impact than hydroelectric power. Wave energy has the potential to generate more power for less cost than most forms of renewables. Wave energy can be a major contributor to the Oregon power grid in the near future, and with increased support for the technology growing, it may have a strong impact on the world's energy problems.

Key Words: Wave Energy, Wind Energy, Solar Power, renewables, Wave Park

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The Introduction of Renewable Wave Energy to the Existing Power Grid

by

William Arthur Ruthruff

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

William Arthur Ruthruff, Author

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William Arthur Ruthruff

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1 – Introduction

Much of the focus in 2006 and previous years has been centered on the generation and consumption of energy. A great deal of this focus has been in regards to the latter of these two. We see in the news almost daily some advertisement attempting to sell some new energy saving device. Be it the new hybrid-electric vehicle from Toyota advertising a 60 MPG car, or a washing machine that is energy star compliant. One of the biggest indicators of our energy costs is hidden in the price of gasoline. This is one of the reasons why fuel efficient and hybrid electric vehicles have gained such praise. We see these as the answer to our problems, and that by consuming less fuel we will save money, and the earth.

The misnomer in this is that we are still consuming a non-renewable source of fuel; in this case, oil. This is oil that we primarily import from an increasingly unstable region of the world, and as this supply of oil becomes less assured as an import, we see the end result manifested as higher energy prices. In the United States, the national energy profile is predominantly non-renewable resources, such as coal, natural gas, and petroleum. Both coal and petroleum are non-renewable, and polluting. As with any resource that is finite, as supply dwindles and demand grows, prices will rise.

Energy Type	Percent of Production
Coal	23%
Natural Gas	23%
Petroleum	40%
Nuclear	8%
Renewables	6%
Biomass	46%
Hydroelectric	45%
Geothermal	6%
Wind	2%
Solar	1%

Table 1 – National Energy Profile [9]

All of this has given incredible focus on the idea of renewable energy as a form of production. We see renewable energy almost every day, be it in a calculator powered by a small photovoltaic cell, or even the lighting around us being comprised of electricity that was generated from a renewable source. In Oregon we are very fortunate to have a great deal of energy produced from hydroelectric power. This provides us with cheap and "renewable" energy. We are very careful to attempt to balance the energy needs of the region with the environmental effects of damming a river.

Wind power has been advancing with the aid of European countries, where energy costs are much higher than they are in the United States. The advancement in wind power in Oregon is evident in the wind farms that have been developed along the state line between Oregon and Washington, as well as smaller farms in eastern Oregon. Wind power is gaining popularity due to the research producing lower cost per watt from wind power, as well as the rising cost of conventional forms of electrical generation. It is predicted by as soon as 2020 that the cost of renewable energy will be on par with conventional electrical generation. [3]

Renewable energy generation is much different than coal or oil generation. These are typically a large plant that does nothing but produce electricity from this fuel at a controllable rate. Renewable energy is different in that it typically is comprised of many different parts. Renewable energy is an all encompassing term that can refer to any form of energy that can be reused, or does not require a fuel as an input. This includes, but is not limited to, wind, hydroelectric, photovoltaic, and wave energy. In all these instances, no one form of renewable energy is going to replace a major contributor of energy such as coal, but the more efficient these all become, and the more they are funded, we will see a larger contribution to our national energy grid from these forms of generation. As research into renewable energy sources continues, we are bound to find more ways to generate energy. As we discover more ways of generating energy from renewable sources local to our regions, we will lessen our dependency on importing energy and allow for a more stable energy market.

Wave energy is emerging as a viable form of renewable energy generation based on research at Oregon State University. As with any new technology, the question arises with just how best to introduce it into the current market. In this case, we have a brand new form of energy that will need to be placed where there is no established infrastructure for transporting the generated power to the grid. In addition, the actual capacity of these generators must be integrated into the supply of power that we currently consume. Consumers pay for electricity at the conventional rate. Typically, with renewable energy being more expensive than conventional generation, consumers must elect to pay for the form of generation. Wave energy, much like wind power, must be marketed to the public so that they will want to purchase it. Wave energy's survival will

depend on its ability to sell itself to consumers. If the public can be sold on wave energy, then it will continue to advance and will become one of the major players in renewable energy generation.

2 - Wind Power

The Stateline wind farm, located on Vansycle Ridge on the Washington-Oregon border is a prime example of what developers would look for in locations to build a wind farm. The average speed is 16 to 18 mph, which is around the ideal speed for most wind turbines to generate maximum power. Phase I of the Klondike wind farm, located in Sherman County, Oregon, is a section of 16 wind turbines that generate 24 MW of electricity. This project was expanded into another 75 MW of electric power in 2005. [2]

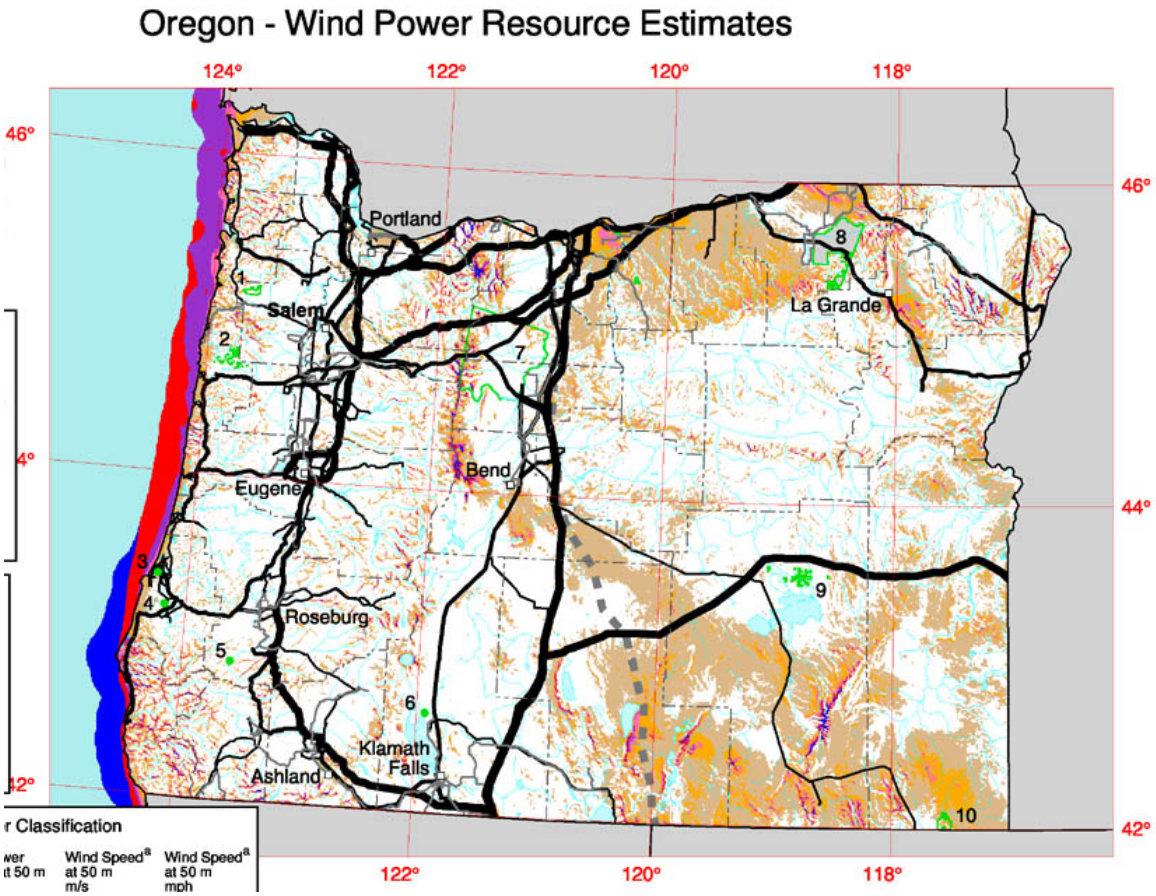

Figure 1 – Wind Power Resource Estimates for Oregon [5]

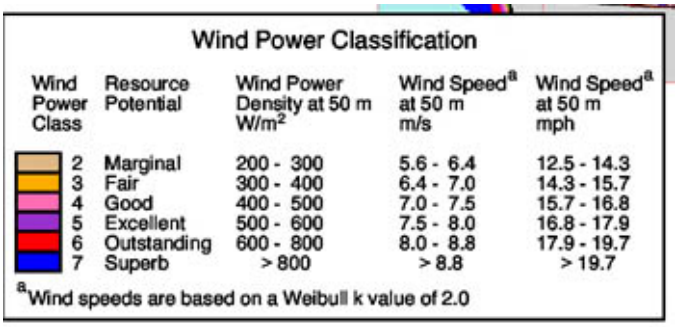

Figure 2 – Legend for Wind Power Resource Estimates for Oregon [5]

New projects are planned to expand the wind power capacity in the Northwest. Washington State is expected to produce an additional 229 MW of available power is currently underway. [1] With new expansions planned, wind power will have a substantial growth over the next few years.

2.1 – Benefits of Wind Power

The benefits to the community were great. By placing wind power, the Klondike project generated an additional $321,205 in property tax revenue for the county. The project is expected to continue to generate an additional $250,000 in property taxes each year for the project's 20 to 30 year lifetime. The farmers who allowed these wind turbines lost only 7 acres of land from their overall production value, but gained annual royalty payments between $2,000 and $4,000 for each turbine that is placed on their property. They do not have to maintain the turbines in any way, and it provides an additional form of steady income for the farmers. This is particularly important in the winter months when many farmers are unable to work their land. They are still generating an income in these winter months to help hold them over until next spring. [6]

2.2 – Limitations on Wind Power

Even with all these benefits to wind power, there are limitations on its usefulness to the public. One issue, which may be considered minor by many, is the aesthetics of the surrounding area. For all its benefits, the wind turbine is not a subtle thing. The larger turbines used for projects can get upwards of 400 feet tall. Since the locations of these turbines are placed where there are high winds, typically along ridge lines and peaks, the placement of a wind turbine can be a very conspicuous addition to the landscape. Additions like wind turbines can hinder a view of a ridgeline, and lower the property value of real estate in the area. Placement of these turbines becomes fairly crucial, not just for maximum power generation, but also for the beauty of the surrounding area, something many in the public hold at a higher value than power generation.

Wind power also suffers from a capacity problem much like hydroelectric power. Hydroelectric power has been limited mostly by a lack of locations to build dams. Most of the waterways along the Columbia River in Oregon are essentially full on dam capacity. Wind power will eventually run into the same problem in Oregon, as there are a limited amount of good locations to place wind turbines that will still be effective power generators. Right now we are seeing an explosive growth in wind power projects, but the finite number of locations for these projects will limit the total number of wind power projects that can be placed in not only Oregon, but the rest of the country and the world.

2.3 – Connecting Wind Power to the Grid

Connecting wind energy to the grid is not as simple as plugging a cord into an outlet. A number of issues stem from attaching a new wind turbine onto the grid. Typically turbines are placed in more rural areas where the wind is better for generation. These areas also have a comparatively lower demand for power, and do not have the infrastructure to transmit a great deal of additional power. If a wind farm is going to be built, considerations as to how the power is to be transmitted to other regions. New lines may have to be placed if current methods of power transportations are not adequate to move the additional power. [4]

The output of wind turbines vary as much as the wind varies. This creates an output voltage fluctuation which is not good for the power grid. Many pieces of more sensitive electrical equipment have protection devices that trip to prevent damage, while other processes require constant voltage with very little allowed variation. Wind energy would not be good for a process such as this, or to even be introduced onto the grid, without some form of correction. The voltage fluctuation can be easily remedied by rectifying the voltage to DC, then converting it back to AC. However this introduces more cost into the system as well as the problem with harmonics. Whenever electricity is converted to AC through power electronics, the issues of introducing harmonics arises. These harmonics are potentially damaging, causing overheating or malfunctioning of equipment. The harmonics can be filtered out, although for an added cost to the system.

Typically a wind turbine is attached to the grid through an AC induction generator. The induction generator provides a number of advantages over other forms of generators. They are fairly cheap, they cannot be overloaded, and have less mechanical

parts to wear out. The only drawbacks to the generator type is there is no on board active voltage regulation, but this can be easily remedied at a later substation. The substation will provide the majority of the services needed to clean up the wind power so it is ready to be placed onto the grid. It is a simpler and more cost effective solution to have all the conversion done in a central location rather than on each individual device.

3 – Solar Power

Solar power in Oregon is not as prolific as it is in other states such as California. Oregon is not a state known for its sunshine, however, solar does play a part in the overall energy configuration. The term solar power is generally used to describe photovoltaic, or PV, solar energy. This form of solar power takes sunlight onto PV cells and converts it into electrical energy. Solar panels in the home are usually placed on the roof, which allow for the most sunlight to be collected without obstructions. Solar cells convert photons to electrons and output a DC current, however it is typically on a much smaller order than that of a solar turbine. While the process is simpler in terms of conversion than wind power due to the fact that a DC current is being generated, it requires many more solar panels to produce greater amounts of energy.

3.1 – Limitations of Solar Power

The solar panels have issues with the semiconductors becoming damaged. There are no mechanical moving parts to the solar panels, which provide a certain amount of resilience to them. However, the semiconductors used to produce the electrical current do have the possibility of being damaged from excess heat. This thermal damage can affect the ability of the panels to produce electrical current. Photovoltaic solar panels are a passive form of generating power that requires no mechanical moving parts. While simpler to connect and set up, they do not produce as great of an output as a wind turbine would.

3.2 – Connecting Solar Power to the Grid

Connecting these solar arrays to the grid requires them to be linked up and converted into AC. This requires no generator, but has the same considerations regarding harmonics introduced onto the system from the AC conversion process. Like wind power, the solar power will be redirected to a substation where the majority of the power conversion will be done. This provides a centralized location where all the power can be prepared for the grid. It is a great deal simpler than connecting wind turbines to the power grind due to the lack of an AC to DC conversion process. Solar panels output a DC voltage, which needs to be inverted to AC and interfaced to the grid using a power electronic inverter and filtering

4 – Wave Energy

The idea of using ocean waves to generate power is not exclusive to Oregon. Researchers in Great Britain are several years ahead of the United States, with test facilities set up off the coast of Scotland. The Swedish and the Japanese have similar devices they are testing as well. But how to implement this idea on the Oregon coast is something that has been talked about, and ideas are underway. Implementing a new form of energy generation west of the Cascade mountain range is important for Oregon's energy map. With many of the wind turbines being placed in eastern Oregon, as well as the population of Oregon being concentrated in western Oregon, there is a need for 1,000 megawatts of power that must be transmitted from eastern Oregon. Major transmission lines are both costly, and introduce more losses into the system, driving up the cost of power. Ideally, the power should be generated locally to both cut down on the dependency on external sources of power, as well as driving down the costs of the power itself.

4.1 –Wave, Solar and Wind Power Differences

Renewable energy is much different from conventional sources of power in terms of the power that is actually generated. When a wind turbine is placed, there is little control over the actual output of that turbine. The wind dictates exactly how much power is outputted from the turbine. The same is true for wave energy. The ocean waves will dictate how much power is outputted by these generators. However, there are some important differences between ocean energy and wind energy. Ocean energy is much more predictable and steady, as opposed to wind energy which tends to be more sporadic

and impromptu. Ocean waves do not dissipate as fast as wind, which greatly increases their predictability. To determine the power generation 12 hours in the future, one only needs to look at the profile of the ocean wave an appropriate distance away from the generation point. This will give an excellent idea as to how much power will be generated in the future, and additional generation can be added or subtracted as needed. This gives ocean power a decisive advantage over wind power with regards to predictability of output power, something that is very controllable with a traditional coal or oil fired generation site.

4.2 – Placement Considerations for Wave Generators

The density of water is 1,000 times that of air. This means that a smaller area can generate more energy. This is important west of the Cascades, as both space and aesthetics are at a premium. One of the major drawbacks of wind power is the presence of a large wind turbine that is extremely visible and can disrupt the natural landscape of an area. While this may not seem like a major concern, for many the prospect of renewable power is not enough to make them agree to the placement of a large wind turbine in their back yard. The advantage ocean power has is that the buoys will be placed offshore, and have very little impact on the ocean landscape. At this time, the ideal distance appears to be about 2 miles offshore. Such a small device or even a number of these small devices placed so far offshore will do little to disrupt the beauty of the landscape. This also has implications for fishermen that would be sharing the water with these wave energy devices. The introduction of wave generators in the ocean could disrupt the routes of fishermen that would want to use the same area. By minimizing the

space these devices require, the impact they have on existing life in the ocean is also minimal, and is a great benefit is obtained at little cost. With a project such as this, it is important to realize that the end result of power generation is just as important as sharing the area with others who desire to use the same area.

4.3 – Benefits to the Community

Projects such as this are a great benefit to the community for the same reasons as wind power. The communities and people who allow forms of generation to be built in their area typically get increased revenues to the community. One major issue that has been affecting all communities not only in Oregon, but around the country, is decreased funding for public services. This has an impact on all aspects of the community, and most of them negative. By allowing forms of power generation to exist in the community, additional funding is always welcome, but the reservations usually come from the overall impact it has on the community itself. In the case of renewable energy sources, the impact is usually a minimum. With ocean energy, the impact is less than that of wind power, due to the lower profile of the generators compared to wind turbines or solar arrays. The only noticeable impact to the land-based community would be the on shore substation, something that would be built with any form of power generation. However, the impact on the fishing and crabbing industry is still under investigation, with goals to determine the lowest impact wave park sites.

4.4 – Potential of Wave Energy

"One buoy is expected to generate 100 kilowatts of power, on average. A network of 500 such buoys could power downtown Portland." [8] Facts such as this show the impact that wave power will have on the power grid. To make a claim that a new form of renewable energy easily has the potential to power the downtown business district of a major city such as Portland is a bold statement indeed. Ocean power is only limited by the number of buoys that can be placed. Unlike wind or solar power, wave power is a much more powerful and much more reliable form of power input. Solar power is limited by the amount of light that can reach a solar array; wind power is limited by the duration and speed of the input wind. Wave energy is steady, and runs at all hours of the day, year round. It is an extremely powerful resource that has yet to be tapped, and under the proper conditions could easily provide a great deal of energy that clean and reusable, just like solar and wind power, but on a much larger scale and a much more reliable set of circumstances.

4.5 – Implementation of Ocean Power

Implementing ocean power on the Oregon coast is a complex task. Currently there are plans to implement the first commercial wave park off the coast of Reedsport, Oregon. Reedsport offers a unique opportunity that utilizes all the aspects that ocean power has to offer. The placement of an abandoned lumber mill next to the ocean gives researchers an existing substation that can be dedicated to the newly generated power. With some assistance from the local utility and the community, Reedsport seems like the perfect place to start testing ocean power's capabilities.

The easement for the outflow pipe and the abandoned substation so close to the water is perhaps one of the most important features that the implementation of ocean power requires. The power that will be generated off the coast will have to be converted into useful power, and then tied into the grid. What this substation offers is a convenient means of doing that. When looking for new and suitable locations to set up a new array of ocean power generators, the location on land may be just as important as the off shore wave profile. Any future expansions of this project must take into consideration the conversion of the power into the grid. The most effective means of converting the power will be on land in bulk. This will allow the use of larger and more robust equipment and centralize the conversion process. In the end, a large substation on shore will most likely be required for all of these wave farms.

The profile of wave activity in Oregon closely mirrors that of power demands throughout the year. Wave activity is generally higher in the winter months where heaters are more active and lower in the summer months. The wave profile of future sites will need to match the power demands it will serve. The wave activity in the area that

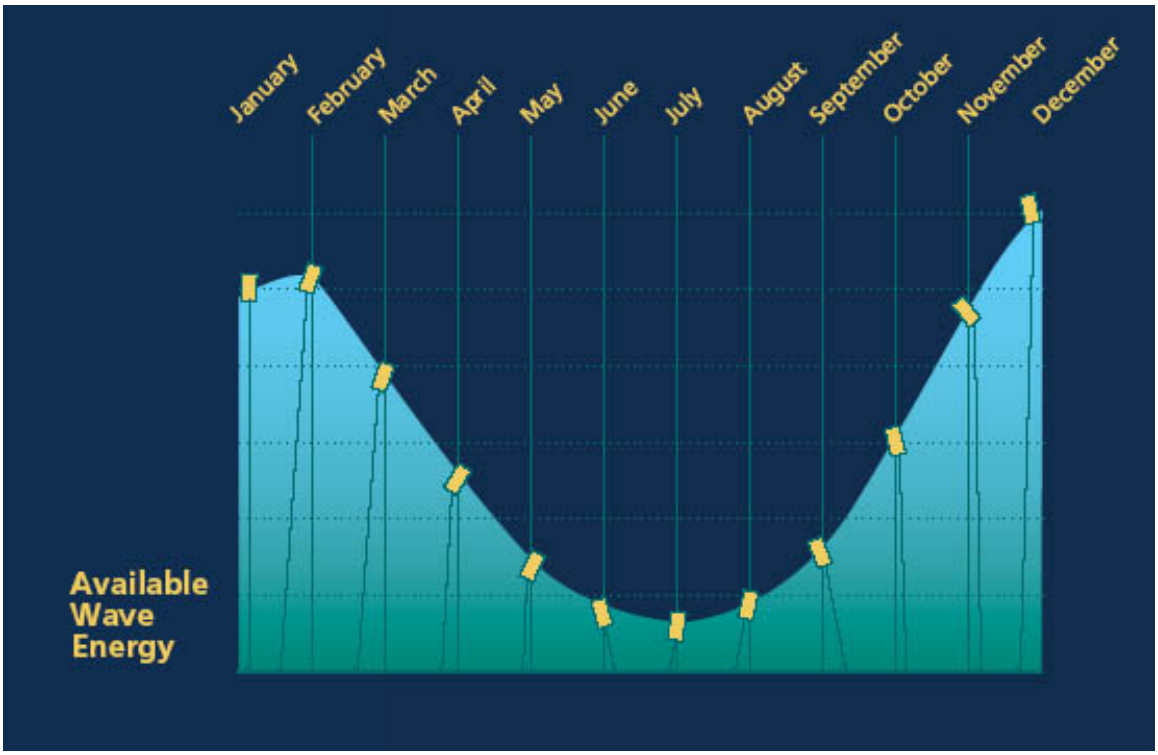

Figure 3 – Available Wave Energy in Oregon by Month [8]

will be used as a site for ocean power generators will have to be active enough to make it worthwhile to place generators. When implementing a wind farm, studies are done to determine the wind activity in the area to determine whether or not it would be effective to place a turbine. Similarly, the profile of ocean waves will need to be studied not just to determine if the wave activity is high enough, but also if there are any dangers such as tsunamis, hurricanes, or other offshore disturbances that could damage the equipment. Other offshore activities must be considered as well. Placing a grid of 500 generators in an area is going to change how that water is used by others, and may disrupt other commercial and recreational activities in the area. These generators may negatively impact the fishing routes of commercial fishermen, who have been hit hard in recent years due to dwindling fish populations. If the introduction of generators would hurt that

already damaged segment of the economy, it may not be worth it to place generators in that area.

The commercial sector of the community is not the only group of people that must be appeased. Placing any form of power generation in an area is as much political as it is scientific. While it is possible to find the perfect location for a wave farm, the internal politics of the community may prevent such a farm from being built. While the placement of power generation could provide a monetary compensation for the land used, this may not be enough for a community to fully support the addition of a substation, transmission lines, and off shore buoys. Looking for a community with the foresight and willingness to cooperate is a major component to a successful project. Fortunately, the community of Reedsport is willing to assist in this pilot, and the outcome may be enough to sway other communities to either allow or ask to be part of future expansions of the project.

The idea is that much of the generated power will be transmitted elsewhere for use. Once the power has been generated, and it has been converted to an appropriate form for consumption by the user, it will need to be transmitted to other parts of the state, such as the Willamette Valley, for consumption. As with any new form of power that is generated, this will introduce additional load onto the grid and the transmission lines. The current load of the lines will need to be analyzed to see if they can handle the additional load of the new generators. It may end up being that the generators will easily provide for the coastal cities, and power generated from the Willamette Valley will not have to be transmitted to the coast, allowing it to be consumed locally at a lower cost. The transmission lines that currently carry power to the coast may end up carrying power

from the coast to the Portland power grid. It is possible that by targeting these wave farms in specific costal cities where larger transmission lines are carrying a high load of power to lower the load going to the city, and save costs by generating the necessary power locally. It will always be cheaper to locally generate power than transmitting it over a great distance. The opportunity that these wave generators bring is not only generating power locally for the coast, but being able to transmit free power from the coast to areas where there is a higher amount of power consumption.

4.6 – Connecting Wave Energy to the Grid

Solar and wind power parallel wave energy in terms of production due to the fact that they both take multiple smaller sources of generation and combine them to create a large power contribution. The method of connecting wave energy to the grid is much the same as for these other two forms of power generation. Wave energy should utilize the same concept of generating the power on board, and converting it at a centralized substation. The power that is sent to the substation from the individual wave generators will need to be rectified to DC and converted to AC. This will also allow the power that is placed on the grid to be completely independent of the changes in wave frequency or amplitude.

To generate power, a linear generator is a very reliable and robust design for this application. By using a linear generator design with permanent magnets, the machine is extremely robust for a situation such as this and provides the kind of generation that is needed for this application. The power generated from this could be either 1 or 3 phase

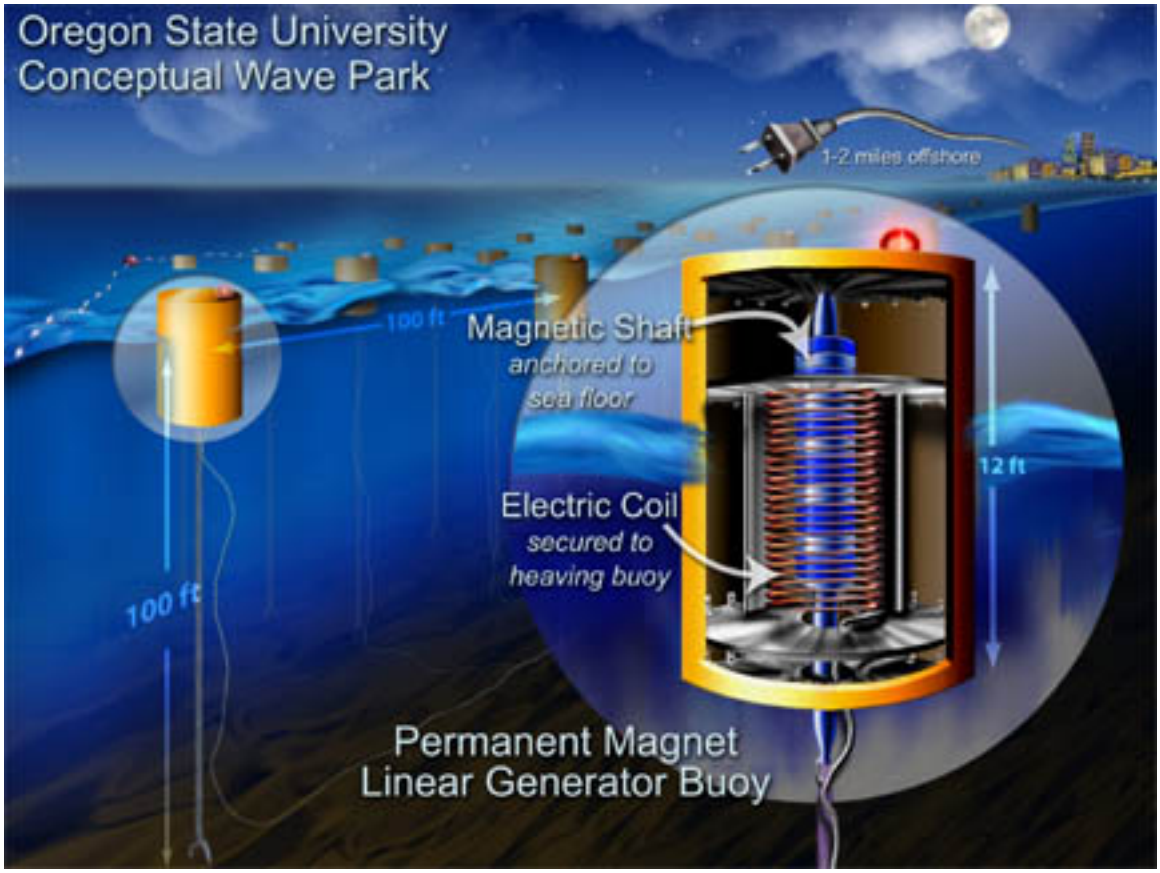

Figure 4 – Conceptual Wave Park [7]

power, which would provide a very good versatility to the design and widen its application uses for different regions and load requirements.

5 – Conclusion

Wave energy is an amazing technology in itself. Energy cannot be created from nothing, but in a certain respect, renewable energy generation tests that theory. Placing a turbine to harness the power of the wind mathematically is not creating energy from nothing, but there is no fuel consumed in the process. Setting out an array of solar panels to collect the sun's energy has an underlying equation to govern it, but the process itself does not consume any more of the sun than what would already be used. Placing a buoy in the ocean and allowing it to move freely seems like such a simple concept, yet it has amazing implications for the future of power generation. The waves will not be used up in this process, and there is such an amazing gain in energy with no fuel being consumed. Fuel in most respects is not only in short supply, but is also can be difficult to come by. A form of power generation such as this will be an amazing milestone in the future of power generation.

The implementation of it will only be limited by willingness to allow the buoys to be placed off shore. With such an amazing benefit in setting up these generators, it is difficult to believe that this will be a problem. The rights and usage of the water will always be an issue, same as land ownership rights are. But sharing the ocean much the same as we share the land is not a difficult task with a bit of planning. The placement of these buoys will need the same studies as the placement of any new construction, so that all aspects of the placement have been considered. The world's energy demands will not curtail anytime soon. It is with great foresight that projects such as this are researched, and implemented so that future energy crises can be avoided, and as methods of energy consumption become more efficient, generation methods that require fossil fuels as input

can be phased out as renewable energy sources step up and increase in their capacity to generate. Renewable energy sources have the greatest sustainability of any power generation method currently available. Any opportunity given to further the research and advancement of renewable power generation should be taken with the foresight that it will become a necessary part of tomorrow's society.

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