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Wave and Tidal Energy in New York: Sustainable Hydroelectricity for the Grid

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Wave and Tidal Energy in New York: Sustainable Hydroelectricity for the Grid

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Abstract:

As humanity continues to exceed the ecological carrying capacity of the earth in its use of nonrenewable energy sources, it is imperative to find and shift to alternative renewable energy sources that can sustain human civilization. The ocean based phenomenon of tides, current, and waves are a way in which that source of energy can be obtained and broadened for human consumption. Oceanic energy can serve not only as a means to provide cleaner energy, but also improve the economy and the land based environment. The natural sciences and social sciences are examined within the quantitative data present. The natural sciences present within the data are not limited to the wave and tidal/current electrical generation within a given body of water, the quality of electrical transfer from generation to the grid, and the potential for impact on the water quality and marine life in the area. On the other hand, the quantitative data of the social sciences is reflective within the number of current wave and tidal/current renewable energy programs and those under planning, in relation to the political policies and civilian interests. The three disciplines that I explore include environmental politics, environmental geography and oceanography, and environmental engineering. I specifically target the environmental geography of the state of New York's continental shelf and its surrounding coastal zone. As for environmental politics, I examine coastal state and federal politics, laws, regulations, and civilian incentives/disincentives. In regards to environmental engineering, I discuss the relative technology currently being used within the field of obtaining ocean wave and tidal/current energy and the significance of certain grades of material within an oceanic environment. I utilize the Roosevelt Island Tidal Energy program as a case study to indicate the significance and necessary expansion for further use of offshore renewable energy within New York territorial waters. My policy recommendations focus on the benefits that offshore renewable energy may provide given a combination of funding, and maritime geographic and ecological consideration.

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Introduction: Why Oceanic Hydroelectricity ...?

Although it is clear in the United States today that there needs to be a widely available source of sustainable energy for consumption, there aren't substantial movements to utilize every aspect of potential energy at hand. The ability of hydro kinetics in the form of tidal/current and wave energy is an available source for many mega-coastal cities across the seaboard of the United States to not only install, but furthermore expand in usage. The installation of many of coastal modules within the world have led to a combination of economic and energy production growth, however; there have been simultaneous concerns for what affect the construction of such modules may have on not only costs and maritime traffic, but also the marine life that would have to bear with further human intrusion. These causes are founded on the basis that there may be irreparable damage to both human and animal life. In spite of the many of these perceptions, many present modules in the United States and abroad have been established with relatively low labor costs and have generated electricity to the grid with minimal impact to the environment.

Though the installation of hydro-kinetic systems would seem to be heavily dependent on the initial financial costs involved, the systems and their placement are by and large an investment in location and its associated theoretical energy levels. The initial costs for any technological piece are within the research and development or in its installation are a significant numerical assessment that may drive public and private support and/or investment within the United States or nations abroad, however; the numerical costs associated with such segments may drive this initial backing in any different direction. Hence, in the relation of differing nations' energy capabilities and investment in hydro-kinetic technology, a number of them would have to weigh the initial costs of the systems against the theoretical return of wave and/or tidal/current energy against what alternative energy measures may instead be utilized. Against what initial scientific assessment on energy values may find, there is a risk for investors to pursue hydro-kinetics due to the not only the changing political and legal framework of the United States and other nations, but also the engineering opportunities and potential

hazards that may result in an initial outcome turn-over.

The political history and legality within the specific context of the United States and its relationship with wave and tidal/current-kinetic technological is more or less a representation of the bureaucratic system of the government within a scientific framework. Similar to most components within bureaucratic systems, hydro-kinetic technology fits into numerous different regulatory categories in regards to the location in which a system will be situated in, the land-line connection via which the system will connect to, and the quantity of units which will encompass the entirety of a system. Absent within the tangled development of rules and regulations are the probable interest groups that may influence the legality and implementation of the unit systems. Though the current legal structure of the United States isn't a healthy system for a large-scale implementation of hydro-kinetic systems to be undergone, the stream-lining of the engineering capabilities and public recognition of the efficiencies of the technology is a significant step to be taken for its progress.

In order to fully understand the scope of what oceanic hydroelectricity would yield from tidal dissipation in American waters, I will explore not only the political factors associated with tidal module construction, maintenance, and energy distribution, but also geographic capabilities and potential future technological investment. I will specifically utilize the turbines by Roosevelt Island as a case study example for the potential growth of New York's geographic maritime capabilities.

Throughout the course of this thesis paper, I will look at not only a series of the experiences that hydro-kinetics have had in wave and tidal/current-kinetic operation, but also present an outlook for where the technology is currently going. In Chapter 1, I will look at both theoretical and experimental qualitative and quantitative data on current, in-progress of being built, planned, and potential wave and tidal/current-kinetic modules. After that, in Chapter 2 I will evaluate the hydro-kinetic capabilities in New York City Harbor, utilizing Roosevelt Island as a case study example for the type and quality of grade tidal/current-kinetic modules currently available, and as a means to indicate the level of energy capable of being transferred to the grid in a reliable and safe manner. Next in Chapter 3, I examine the

current market standard for various types of wave and tidal/current-kinetic modules and their efficiencies, as well as the progress being made to increase efficiency against the cost of production and maintenance. Then in Chapter 4, I will look at the history of wave and tidal/current-modules in regards to politics; with focus ranging from general legislative history and present issues to public and private investment interests. Finally, in the Conclusion, I construct several different policy recommendations from fields of the previous chapters; of which will generate a degree of support for hydrokinetic energy as a strong source for alternative coastal energy consumption.

Running the Numbers on Maritime Energy

The production of energy within any context is usually attributed to a mid-to-high cost reward with medium-to-low energy gain. The use of fossil fuels is relatively an expensive source of energy; both in the input costs of production and distribution, with further exterior costs in output and renewal, let alone the limited supply that roughly took 400 million years to form. In comparison, oceanic energy is a stable, if a sometimes slightly unpredictable source of potential energy that varies from offshore to shore based variations.

Though there are variations of energy output across the 70% of the world's surface that the ocean takes up, there are consistencies within energy output. The energy from a wave is determined by wind speed, the duration in which the water is exposed to wind, the distance over which the wave is exposed to wind, the depth of the water that the wave occurs in, and topography of sea bed. According to the International Energy Agency, the total world resource of wave-kinetic energy is about 8,000-80,000 Twh/year¹. According to the Electric Research Power Institute, the coastline of the United States would be able to provide roughly 2,100 terawatts per hour/year; which current projects utilize only 15% of in the production of 250 to 260 terawatts per hour/year². Theoretical accounts of the values for optimal point in which wave-kinetic energy is economically and practically viable for extraction is held to be

¹. MacDonald, Mott. *Offshore Renewable Energy*. New York: *Earthscan* (2012): 6.

². MacDonald, M., 9.

between 145 and 2,000 Twh/year (Figure 1.1)³, however; the Carbon Trust organization considers the range of 2,000 to 4,000 Twh/year to be a more economically practical measure for an adequate financial trade-off⁴.

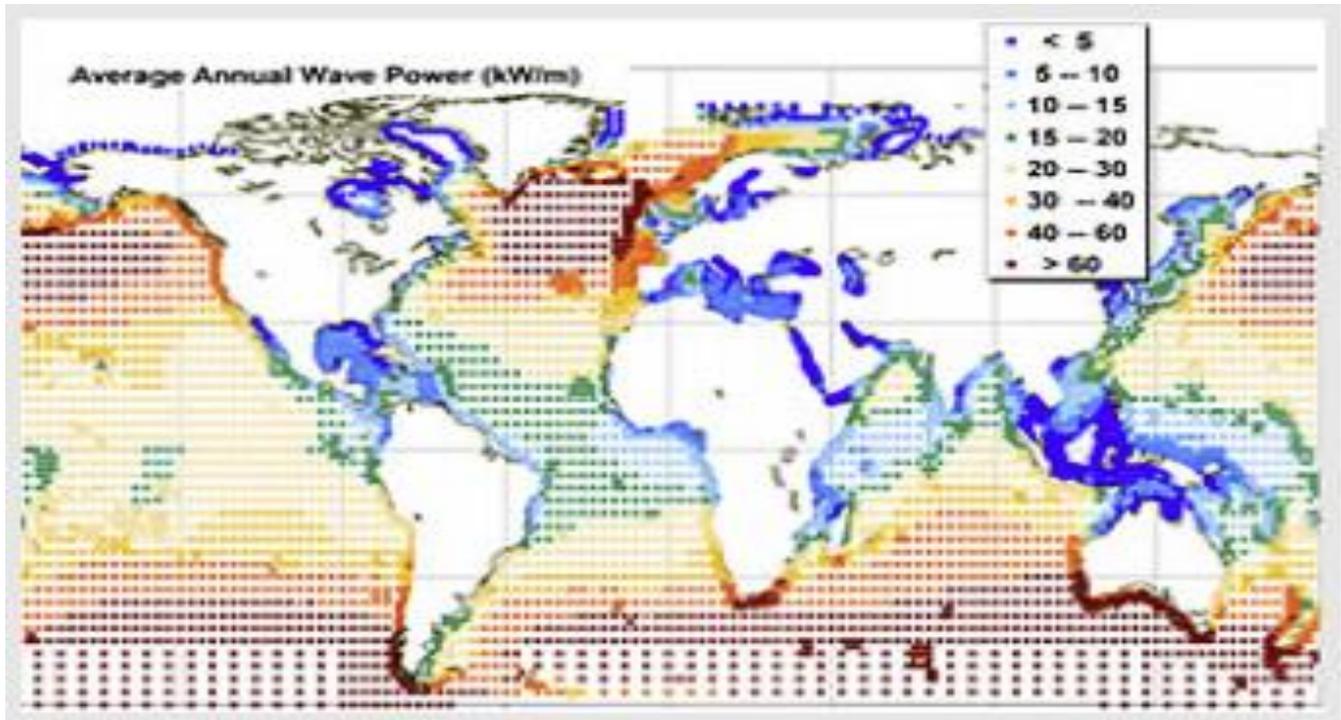


Figure 1.1

On the other hand, the theoretical world resource of tidal/current energy is about 365 Twh/year and tidal currents about 800 Twh/yr; an indication of the joint benefits of modules of both modes of operation⁵. The degree of change in potential energy in the ocean has the more substantial sources between the latitudes of 40° and 60° (on either side of the equator), versus the more moderate sources between 10° and 30°, and almost nonexistent swells that occur in/around the polar caps⁶. The substantial wave sources between the latitudes of 40° and 60° versus those seen between 10° and 30° is by and large due to the condition that the prevailing global winds in both the Northern and Southern Hemisphere run from the west to the east; which is significant in the consideration that wind is the

³ <http://www.crses.sun.ac.za/images/pages/ocean/01.png>

⁴ MacDonald, Mott. *Offshore Renewable Energy*. New York: Earthscan (2012): 6.

⁵ MacDonald, M., 7.

⁶ Beatley, Timothy, and David J. Brower. *Coastal Zone Management*. 2nd ed. N.p.: Island, 2002. Print.

primary factor beyond the creation of waves⁷. In association with the west to east prevailing winds, there is a strong seasonal variability for the size and power of waves, such as: the summer waves in Oregon being on average 10kW/meter crest length versus the waves in the winter which are on average 50kW/mcl⁸. Of the mean wave power potential across the coastal United States, though the density does vary from coast to coast, the latitude range more or less is an accurate measure via which to gauge energy. The potential wave density in Southern Alaska was considered to be about 1,250 terawatts an hour over the course of a year, whereas Washington, Oregon, and the California coast were seen to be able to generate about 440 terawatts per hour over a year, whilst in Northern Hawaii the foreseen value was given to be 300 terawatts an hour over year; however, the western seaboard of the United States in the New England to mid-Atlantic coastline was considered to be only about 110 terawatts an hour over a year⁹; of which either California or Oregon alone is more than the numerical amount that was generated from U.S. annual hydroelectric production in 2003 (270 TWh)¹⁰. If only a quarter of that potential energy was extracted via today's tidal/current-kinetic system efficiencies that range up to 80%, then 420 terawatts of energy would be produced per hour in a year. Though tidal/current energy does differ in terms of the atypical flow that is seen in wave generation, potential sites across the United States coastline do indicate a similar pattern in terms of power density and energy transfer over a surface area. The tidal/current power density for Anchorage in Alaska was 1.6kW/m² and a site energy flux of about 1.0TWh/year, whereas Tacoma Narrows in Washington had a power density of 1.7kW/m² and a site energy flux of 0.93TWh/yr, versus the eastern shore site of Muskeget Channel off of Marthas Vineyard, Massachusetts; which had a power density of 0.9kW/m² and a site energy flux of 0.12TWh/yr¹¹. However, in order to be able to extract the potential energy from these sites, the cost

⁷. McArthur, S., and Brekken, T. (2010). Ocean Wave Power Data Generation for Grid Integration Studies. *Department of Electrical Engineering and Computer Science, Oregon State University.*

⁸. McArthur, S., and Brekken, T. (2010). Ocean Wave Power Data Generation for Grid Integration Studies. *Department of Electrical Engineering and Computer Science, Oregon State University.*

⁹. MacDonald, Mott. *Offshore Renewable Energy*. New York: Earthscan (2012): 275.

¹⁰. McArthur, S., and Brekken, T. (2010). Ocean Wave Power Data Generation for Grid Integration Studies. *Department of Electrical Engineering and Computer Science, Oregon State University.*

¹¹. MacDonald, M., 276.

trade-offs for being able to determine whether or not the potential energy is worth the total amount of financial investment into hydro-kinetic systems; otherwise, public opinion and markets would yield to the probable cheaper option.

Despite the costs that are inherent to most energy productions, many of the costs of wave and current/tidal modules are relatively inexpensive. The 2012 cost to build a single wave energy converter was roughly upwards of no more than \$13,700.69, of which may have been up to an additional \$6,531.00 to install¹². According to the Electrical Power Research Institute, a fully operation utility-scale wave power plant that has up to 100 megawatt total install capacity would have a cost/energy trade-off of about 10 cents per kWh; which at 2010 was 2 to 3 times the cost/energy trade-offs of hydroelectric, coal, or wind farms¹³. The probable reason behind such an initial high cost per energy trade-off would be due to the lack of competitiveness for these large-scale projects, which is assumed to theoretically reach 3 to 4 cents per kWh when the total world capacity reached 10,000 Mw¹⁴. The costs for the construction of a 2012 tidal module were upwards of \$12,150.00, with an additional cost of up to \$6,000 to install¹⁵. The level of costs to build and install the different modules for tide and wave are variable in the degree of how deep the units are, how close to shoreline the units are, and how much energy the unit is programmed to be able to generate.

The quantitative data of hydro-kinetic systems within the United States is vastly different to that of other nations, in terms of not only the number of hydro-kinetic systems that are operable, but also the variance at which the technology can be pursued in relation to the context of the coastal conditions of a nation. As of 2012, within the United States there were fewer than five hydro-kinetic systems in operation, however; there were a number of potential sites that were underway in either being assessed,

¹². MacDonald, Mott. *Offshore Renewable Energy*. New York: Earthscan (2012): 60-68.

¹³. McArthur, S., and Brekken, T. (2010). *Ocean Wave Power Data Generation for Grid Integration Studies*. *Department of Electrical Engineering and Computer Science, Oregon State University*.

¹⁴. McArthur, S., and Brekken, T. (2010). *Ocean Wave Power Data Generation for Grid Integration Studies*. *Department of Electrical Engineering and Computer Science, Oregon State University*.

¹⁵. MacDonald, M., 60-68.

zoned, or under legal review for operation¹⁶. The number of sites and potential systems within the United States can be attributed to the previously mentioned theoretical values associated with coastal conditions. On the other hand, by 2008 Portugal only had three near-shore 750kW devices located off of its coastline; of which saw the material of these devices wash up on it when these devices ultimately failed due to a number of technical issues and poor funding¹⁷. The poor funding was by and large a result of public opinion intermixed with political and scientific observation of the unsuitable conditions within Portuguese waters for adequate capital investment versus energy trade-off¹⁸. However, in the case of the United Kingdom and Ireland there have been a number of investments into hydro-kinetic project operation since as early as 2000¹⁹. The early investment and projection of hydro-kinetic operation sites by the UK and Irish may be considered a definitive probable outcome due to the tidal/current features that are present within their respective territorial waters.

The rationale for hydrokinetic energy through both wave and tidal/current modules can be heavily attributable to the data which supports not only significant theoretical amounts of energy, but also the experimental outcomes which have more or less supported the theoretical values. Though there is an evident variation among the values of potential hydrokinetic energy throughout the world, the outstanding dispense of the potential variation between wave and tidal/current theoretical energy more than makes up for the lack of one of them within a coastal location. A case for the installation of hydrokinetic modules may be examined through the study that was undergone by Roosevelt Island, New York City, which utilized both qualitative and quantitative data as a means to rationalize the benefits and costs of the overall project.

¹⁶. MacDonald, Mott. Offshore Renewable Energy. New York: Earthscan (2012): 276.

¹⁷. MacDonald, M., 280.

¹⁸. MacDonald, M., 286

¹⁹. MacDonald, M., 246-249 and 258-266.

New York City Hydro-Kinetic Energy Capabilities:

The effectiveness of tide and wave modules in generating electricity are both largely factor of their placement. The theory of linear waves holds that waves generated out in deep water will create a long swell. Regardless of the theory, however; many deep water sections are prone to irregularities and the occurrence of rogue waves. Hence, both tide and wave modules are more or less prone to be placed in a zone of nearshore currents²⁰. Despite the placement of Verdant Power's demonstration of tidal/current-kinetic turbine system units in the East River of New York State next to Roosevelt Island and eventual installation of these units post demonstration is situated within a zone of nearshore currents, the benefit for such installation may be considered to be adherent to the natural capabilities and optimal trade-off opportunities that reside within the location.

Prior to any discussion of installation of hydro-kinetic turbines in the East River, there had to be an assessment as to the cost/benefits that would theoretically exist if such an installation were to occur. The pre-meditated projection of such a project was undergone with the intention of testing the theoretical hydro-kinetic potential of 500-1,000 MW that existed within the New York areas of Long Island and Niagara River²¹. In order for the assessment to commence, the New York State Energy Research and Development Authority contracted and sponsored the energy company Verdant Power; to set up a series of demonstrations of turbine systems within the East River. The money that was utilized for the project annual assessment was obtained via sales of New York State electric and gas utilities, public benefits, voluntary annual contributions from NY Power Authority and the Long Island Power Authority, as well as a few corporate donations²². However, the full ownership of assessment and of any project outcome of the time would that of the contracted Verdant Power.

In order to assess the efficiency levels of energy that would be able to generated within the East

²⁰. Beatley, Timothy, and David J. Brower. *Coastal Zone Management*. 2nd ed. N.p.: Island, 2002. Print.

²¹. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

²². www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

River, Verdant Power initiated a three demonstration phase system through which the company would be able to determine the optimal range of energy that could be generated versus the costs that would be required to install and maintain.



Figure 1.2

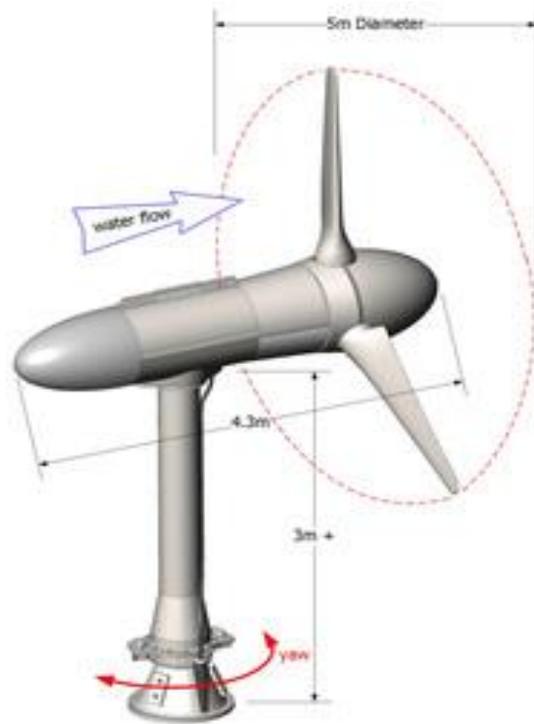


Figure 1.3

The demonstration project went from December 2006 through January 2007 with initially only two turbines off of Roosevelt Island (Figure 1.2)²³; of which worked 100% of its fully bidirectional operation hours over 155 tidal changes²⁴. Though the initial demonstration showed that there were water-to-wire efficiencies of about 40%, about 10 megawatts per hour of energy ended up being delivered to two test buildings on Roosevelt Island. The 2nd demonstration period ran from February 2006 through July 2007 with six turbines being run; logging about 7,128 hours of operation and delivering up to 45 megawatts per hour to the two test buildings on Roosevelt Island²⁵. The 3rd

²³. http://www.naturalhistorymag.com/sites/default/files/imagecache/large/media/2014/01/east_river_looking_south_jpg_54977.jpg

²⁴. www.nysersda.ny.gov/.../roosevelt-island-energy.pdf

²⁵. www.nysersda.ny.gov/.../roosevelt-island-energy.pdf

demonstration by Verdant Power ran from July 2007 to early October 2008 with six newly designed Gen 5 turbine rotors (Figure 1.3)²⁶ in operation for roughly 1,000 hours of grid-connection; which saw 12 megawatts per hour delivered²⁷. Though there were six turbines, five of them were utilized to obtain energy from the East River, while the sixth turbine system was used as a test indicator for a number of different technological components that Verdant Power was trying. The phase 2-3 demonstrations had turbine peak efficiencies of 38-44%; which had been a relative theoretical expectation with the water current speeds that ran between 3 to 7 feet per second in the East River by Roosevelt Island²⁸. Despite the numerical turn-out of energy that the six (albeit the one test turbine in phase 3) turbines from the demonstrations were able to generate, the key process of the demonstration may arguably have been to assess the interactions that such hydro-kinetic technology may have on the immediate environment and marine life within the East River.

In the initial assessment of the project within the East River, the understanding that in order to receive permit grants and an operation license under state and federal based rules and regulations was held that the project had be aware of its environmental impact. Hence, in the initial project permit grants that were given to Verdant Power via the Federal Energy Regulatory Commission, the company had to provide a series of environmental and monitoring reports to the condition of East River whilst the turbines were in and operational²⁹. The parameters of the turbines themselves were first observed in terms of any potential impact or interference that may occur at a micro-scale (5 meters), meso-scale (60 meters) and a macro-scale (the 1st encounter of probable influence)³⁰. The observation of interference was done under the potential risk that the turbines may create in the form of alterations of current and wave strengths and directions within the East River, alterations of sediment transportation and deposition, alteration of habitats, noise pollution from either construction and/or turbine operation, the generation of electromagnetic fields (EMF); which might disrupt marine wildlife, potential toxicity

²⁶. <http://www.verdantpower.com/uploads/2/4/7/6/24768638/3248742.jpg?188>

²⁷. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

²⁸. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

²⁹. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

³⁰. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

from paints and lubricants in or on the turbines, the alteration of animal movement/migrations, and the chance of there being strikes from the turbines' blades³¹. Within the impact report given within primarily the last 2 phases of the demonstration, the studies indicated that by and large there were not significant impacts on either marine life or the environment of the East River or greater New York City water area³². Within this impact study was a stationary netting test that was undergone to verify if there were any strikes or injuries to fish during the turbine operation; with the theoretical idea that a net within the flow of a turbine would capture any or a portion of fish that were either dead or injured from the turbines. Though the fish study was undergone during the seasonal fish period of October to early December to indicate whether or not there was high mortality rate among fish, the initial netting didn't yield any significant numbers³³. Further indicated within the impact study was the testing of blade strike probability on various fish that were considered to utilize the East River or the surrounding area. Within the more prominent native species of fish in the area, the short-nose sturgeon was considered to have a blade strike probability of 0.008%; the fish has an average length of 88 cm., the Atlantic herring had a probability of 0.03%; with an average size of 20 cm., the Atlantic butterfish had a probability of 0.03%; with an average size of 0.03%, the black sea bass had a probability of 0.03%, with an average size of 25 cm., and the Atlantic mackerel had a 0.04% probability; at 30 cm³⁴. Hence, among the five most prominent native fish within the area there seemed to be little to no probability of being struck by one of the blades of the turbines. Another feature within this impact study was the observation of bird activity, on whether or not the turbines would disrupt the feeding and diving activities of birds. The impact report indicated that there was no relatively large difference between pre-and-post turbine operation in regards to bird activity; primarily due to the number of birds observed on either stage of

³¹. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

³². www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

³³. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

³⁴. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

the project's development and the consideration that the East River section by Roosevelt Island isn't perceived as a migratory pathway for birds because of the limited natural environment within the area³⁵. Also indicated within the impact study was the affect that the turbines may have on native populations of loggerhead turtle, Kemp's Ridley turtle, green turtle, and harbor seal species within the area. Despite the assumption that larger marine life may be affected by the turbines, there were no indications of large marine life being seen within the netting or observed injured/dead within the area due to turbine strikes³⁶. The assumption to such an outcome was due to the probable outcome that large marine organisms didn't utilize the East River for migratory movement, but instead used the coast instead; due to the better foraging options and limited invasive human interaction. Though the impact report indicated a pre-and-post operation account of the impact that turbines had on the area, due to the legality of the operation Verdant Power has to maintain an environmental monitoring program to satisfy federal, state, and independent agencies legal rules and regulations and opinions on the matter.

When the program was first initiated by the New York State Energy Research and Development Authority and contracted out to Verdant Power for its implementation, the program had to go through a series of federal, state, and local agencies and interest groups. The primary federal actors in question were the Department of Environmental Protection, the Federal Energy Regulatory Commission; which initiated Verdant Power's Pilot License Application in 2010, and the U.S. Coast Guard; the U.S. Coast Guard approved a buoyed exclusion zone to recreational and commercial activity along the east side of the Roosevelt island for the project to occur safely, whilst those on the state and city level included the Department of City Planning, the Economic Development Corporation and the New York Rivers United³⁷. The only outspoken non-U.S. government affiliated group that indicated a large interest into the matter of the implementation of turbines into the East River was the Native American tribal group

³⁵. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

³⁶. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

³⁷. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

the Delaware Nation³⁸. Albeit the position that the Delaware Nation may have had on the development of hydro-kinetic turbines in the East River, the majority of the other actors involved with the project seemed more concerned with a large-scale commercial implementation following the demonstration instead of the actual demonstration of the 3+ machines. The reason for such a claim can be attributed to the dialogue that was articulated among the different actors that was heavily focused on issues and matters associated with the process of the National Environmental Policy Act³⁹. Regardless of the issues or concerns that these actors may have had, the Federal Regulatory Commission agreed to issue Verdant Power to install up to 30 turbines in the East River channel in 2012, as long as the company continued to demonstrate the cost effectiveness, environmental capability, and technological reliability of the turbines⁴⁰. The agreement that the Federal Energy Regulatory Commission made with Verdant power via the implementation of these 30 turbines was the 1st tidal energy project to be issued a license within the United States. Though Verdant Power currently maintains its license capabilities, under the legal framework of its agreement with the Federal Energy Regulatory Commission, the company has to maintain the credibility of its technology against any overall cost trade-offs that might be implemented against its holdings in the East River.

The hydro-kinetic technology used by Verdant Power is that of similar technology that may be seen within wind-turbine systems; however, the hydro-kinetic technology of Verdant Power may be applied to sites ranging from marine shallows to near-shore to high velocity river sites. The Kinetic Hydropower System (KHPS) that Verdant Power initially implemented in its assessment tests is that of a module that had a rotor with 3 fixed blades that would rotate at 40 revolutions per minute, a sealed nacelle; which is essentially the outer casting of the turbine, a pylon and passive yaw mechanism designed to allow the turbine to self-rotate in its current placed conditions, an enclosed generator and

³⁸. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

³⁹. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

⁴⁰. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

drivetrain within the nacelle, and a mounting system for which the device would be placed on when on the bed of the East River⁴¹. An underwater, low-voltage cable would be attached from the generator in the nacelle to a control building; which would then transfer the energy to the two test buildings used for the assessment⁴². The technological progress within the three phases of the demonstration saw proof of a wire to wire system, in which roughly 70 megawatts per hour of energy was transferred at rotor efficiencies ranging from 41% to 52%; over a course of an estimated 9,000 total hours of fully turbine bidirectional operation⁴³. In the 2006-2008 development phase off of Roosevelt Island, Verdant Power connected its Generation 4 KHPS turbines; which were a 5 meter diameter rotor design⁴⁴. However, in 2011 Verdant Power established its Commercial Class KHPS (Generation 5) turbines into the East River for grid-connection⁴⁵. The Generation 5 hydro-kinetic turbines are considered by Verdant Power to be highly reliable and cost-effective due to its technological components of composite fiber reinforced polymer blades, its casting connection between the pylon and nacelle, its integrated gearbox and drivetrain, its failsafe brake system; which not only limits the rotation rate, but also is auto-controlled to that the rotors are also released when they are able to generate electricity, and the non-toxic coating and lubricant system that the turbines now use; silicone and eco-speed based material⁴⁶. The capabilities of Verdant Power's Generation 5 hydro-kinetic system are one of only a few possible engineering capabilities that may be utilized within the East River.

Though the process undergone at Roosevelt Island was theoretically longer than it may have been initialized, the quality of the returns in both energy and safety has more or less removed the negativity behind the delays which the project has seen. The quality of the hydrokinetic system that Verdant Power has utilized up to this point in time off of Roosevelt Island is one of the many different

⁴¹. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

⁴². www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

⁴³. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

⁴⁴. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

⁴⁵. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

⁴⁶. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

engineering options that is currently available for wave and/or tidal/current kinetic usage, and is capable of being substituted for any number of these alternative modules and/or module components.

Engineering Capabilities and Advancement:

Though the capabilities of the two different hydro-kinetic systems of wave and current are by and large similar on the grounds of their technological components, the way in which they obtain energy and convert it to the grid varies substantially. The current marketable component of a wave energy system typically consists of a wave power absorber, a turbine, a generator, and power electronic interfaces. The connection of these devices to the grid varies on the length of the system from the shore and at what depth level it is set-up at. Furthermore, the grid-connection itself plays out in multiple ways in terms of the functionality of hydro-kinetic system.

A hydro-kinetic wave based device contains different numerous based components, each of which has variation interchangeable elements that may be used for differing energy efficiencies, cost trade-offs, or simply a geographic based decision. As previously stated, a typical ocean wave energy harvesting system consists of a wave power absorber, a turbine, a generator, and power electronic interfaces⁴⁷. In a basic movement to energy; the absorber captures the kinetic energy of the wave, which may be either conveyed then to the system's turbine(s) or it directly to driving the generator(s)⁴⁸. Regardless if the generator is a linear or a rotational type, the generator would then produce a variable frequency and amplitude AC voltage, which would then be rectified to DC; due to DC transmission efficiencies within a salt-based environment⁴⁹. Prior to the connection to the grid, this transmission goes through DC/DC converter or a transformer for voltage regulation⁵⁰. Once voltage synchronization occurs via an inverter and output terminals, the energy is then transferred onto the grid. Despite the

⁴⁷. Khaligh, Alireza and Omer C. Onar. *Solar, Wind, and Ocean Energy Conversion Systems*. Boca Raton: Taylor & Francis Group, (2010): 223.

⁴⁸. Khaligh, A. and Omer, C., 223.

⁴⁹. Khaligh, A. and Omer, C., 223.

⁵⁰. Khaligh, A. and Omer, C., 224.

basic pattern of absorption to grid connection, there are numerous other variations that exist within the framework of wave-kinetic energy.

Foremost among the opportunities for wave-kinetic energy are the different typologies that exist for both offshore and nearshore devices. As was previously stated a floating body typically acts as a wave point absorber, whilst another body is fixed to the ocean floor. However, in the case where variation is needed or desired; there are three primary typologies for capturing wave energy offshore; each of which has an atypical buoy that has the geometrical shape of a cylinder or something that is close to it. The geometrical shape is suited for the task of the shell of the device purely based on the relationship that its shape has to its perceived movement. However in some cases the shape of the shell may be slightly different in order to take advantage of wave capabilities. In the case of a salter cam typology (Figure 1.4)⁵¹ “nodding duck” the outer shell is designed in the form of a tear-drop shape, whilst within the outer shell is a fixed cylinder⁵².

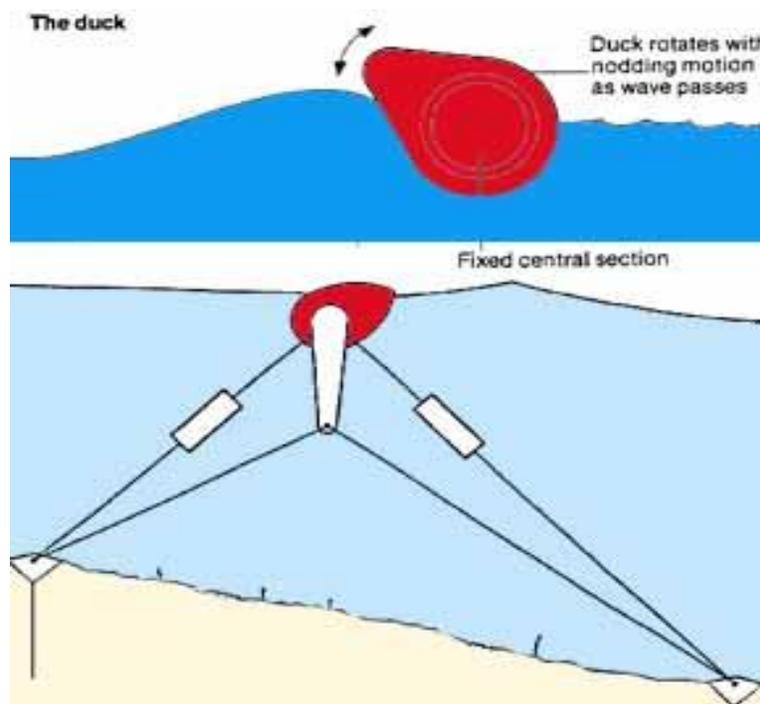


Figure 1.4

⁵¹. http://www.marketoracle.co.uk/images/Kitley_17_5_07_image002.jpg

⁵². Khaligh, Alireza and Omer, C. Onar. *Solar, Wind, and Ocean Energy Conversion Systems*. Boca Raton: Taylor & Francis Group, (2010): 231.

When waves occur around the nodding duck device, the outer shell will roll around the fixed cylinder within it; transforming its kinetic energy into electrical energy. The process occurs in the manner that the outer shell's rotation around the cylinder converts the wave energy into hydraulic fluid, which then runs through a hydraulic motor and is converted into rotational mechanical energy, and then finally converted into electricity via a generator. On the other hand, there are air-driven turbines (Figure 1.5)⁵³, which deals primarily with the conversion of pressurized air as the active agent in energy production instead of the wave itself⁵⁴.

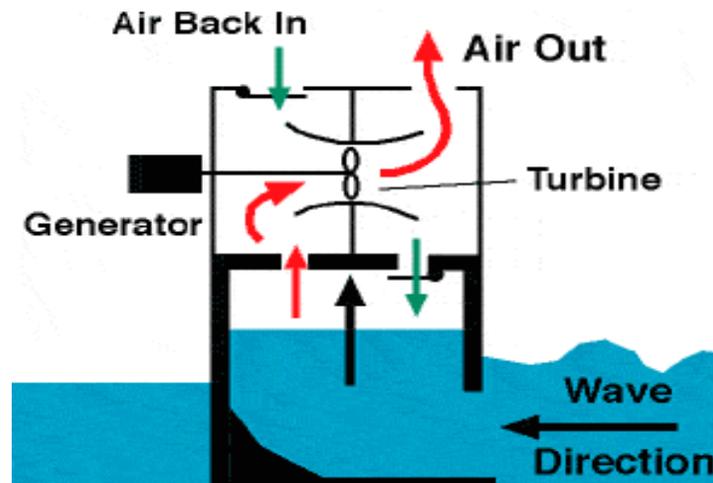


Figure 1.5

The air-driven turbine is essentially a floating buoy that contains an air chamber and an air-driver generator inside of it. When a wave makes contacts with the buoy it results in an increase in the water level within the chamber section of the buoy, which results in the application of pressure to the air within air chamber section of the buoy. In the course of being pressurized, the air begins to apply force to the turbine and eventually rotates it. The final piece is the transformation of mechanical energy from the turbine to the generator, which produces the electricity. All in all, the air-driven turbine is a complex design relative to the salter cam. Lastly, the fixed strator and directly driven PM linear

⁵³. <http://interdisciplinaryenergystudy.wiki.lovett.org/file/view/wave.gif/203879590/wave.gif>

⁵⁴. Khaligh, A. and Omer, C., 233.



generator-based buoy (Figure 1.6)⁵⁵ is a buoy system that is designed to pull a generator, whilst it moves vertically with the waves⁵⁶.

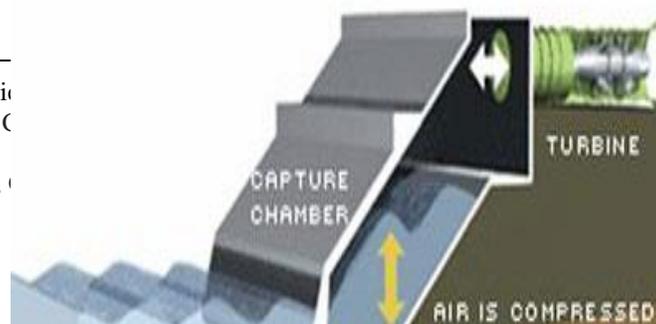
Figure 1.6

In the course of a wave movement, the buoy will follow in its motion (up-and-down); which in turn pulls an attachment-line that is connected to a pillar and strator on the seabed. During this movement on the pillar and strator end of the attachment there is movement from a piston; which is being pulled from the attachment-line, which in turn pulls a generator. On the other hand, the nearshore options for different typologies vary substantially in terms of both efficiency and cost-energy trade-off. These nearshore turbine systems are established in either on-shore to within the surf-zone of waves. In order to increase the potential wave energy within nearshore zones, there are multiple methods for which can be utilized to have regularly sustaining energy via nearshore turbines, such as: the channeling of waves into a catch basin to use and rotate a turbine; which due to the necessity to build a reservoir to collect the water is expensive, and the choice-installation of building in areas of regular high sustaining series of waves⁵⁷. Similar to offshore, nearshore turbine options include an air-driven turbine system known

⁵⁵. <http://citeseerx.ist.psu.edu/viewdoc/...>

⁵⁶. Khaligh, Alireza and Omer, C. G. (2010): 255.

⁵⁷. Khaligh, Alireza and Omer, C. G. (2010): 233.



Boca Raton: Taylor & Francis

Boca Raton: Taylor &

as an oscillating water column (Figure 1.7)⁵⁸; which generates electricity from the wave-driven rise and fall of water in a pipe⁵⁹.

Figure 1.7

The oscillating water column is relatively costly and complex in design for a system due to it being based on or close to the shoreline, which entails a number of probable fluctuations in wave series and structural integrity challenges. Similar to offshore, nearshore also have wave power absorbers which essentially absorbs the wave and converts it to mechanical energy in the same manner that would occur in offshore wave power absorbers⁶⁰. Some of the current market turbines that are available for nearshore activity are seemingly distinct in the manner that they utilize a form of air pressure and/or turbine blade technology that is closely associated with that typically seen on wind turbines. The “Well’s” Air Turbine is a low-pressure air turbine system which is utilized more or less on shore mounted structures; is capable of two-way direction airflow⁶¹. Though the “Well’s” turbine eliminates the need for valve systems to rectify airflow, the turbine necessitates the building of a shoreline based structure; which alone is expensive and a potential environmental impact. An alternative to the “Well’s”

⁵⁸. http://www.sciencebuddies.org/Files/4073/5/Energy_img062.jpg

⁵⁹. Khaligh, A. and Omer, C., 233.

⁶⁰. Khaligh, Alireza and Omer, C. Onar. Solar, Wind, and Ocean Energy Conversion Systems. Boca Raton: Taylor & Francis Group, (2010): 234-236.

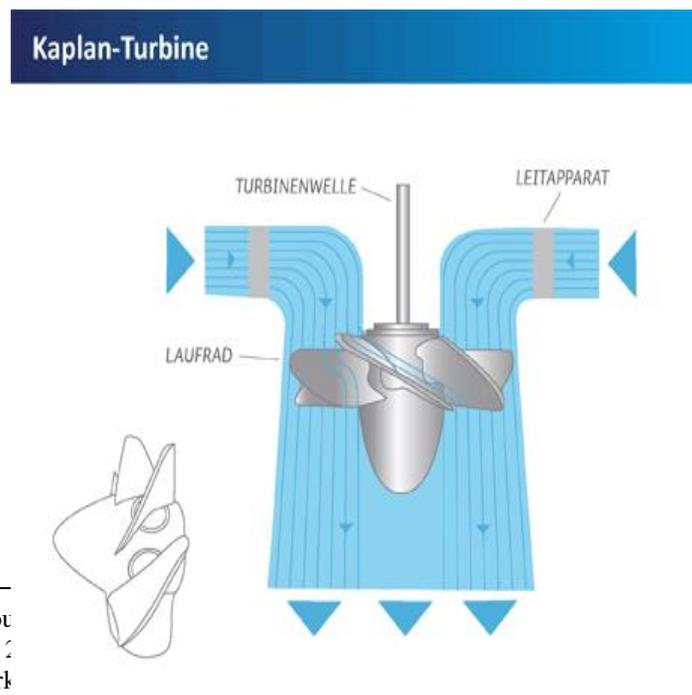
⁶¹. Khaligh, A. and Omer, C., 237.

turbine is the nearshore Self-Pitched-Controlled Blade Turbine (Figure 1.8)⁶²; which utilizes a series of rotated blades to transform wave energy into mechanical energy⁶³.



Figure 1.8

Though the blades are capable of operating at a higher torque rate and higher operating efficiency via a lower rotation speed, the trade-off of the design is the apparent cost of the initial installation and subsequent maintenance. Lastly, the Kaplan Turbines for wave energy conversion are propeller-like water turbines that are suitable for both current and wave applications (Figure 1.9)⁶⁴.



⁶². <http://d2n4wb9orp1vta.clou>

⁶³. Khaligh, A. and Omer, C., 2

⁶⁴. <http://www.landeskraftwerk>

Figure 1.9

Due to the ability to have adjustable angles for speed regulation and torque control, Kaplan Turbines have roughly 90% efficiency in wave-to-electrical energy transformation⁶⁵.

Another significant variation of typology that exists with these devices is that of the generator that is utilized to convert the wave-based energy into electrical-based energy. Though the generators used vary in application, they generally are of either a synchronous or induction generator class⁶⁶. The various types of the two classes that are currently developed and market available are as follows. A wave-activated linear generator system that resides within the frame of a buoy; the buoy supports a rectangle wire loop and two permanent magnets at both ends⁶⁷. Generation occurs in a wave-activated linear generator system through current in the conductor; due to the moving conductor relative to the magnetic force. The benefits of this generator type are the lack of rotation and potential fouling that would occur; lowering down potential maintenance costs. Another generator type that is available to be utilized is the linear, synchronous, longitudinal-flux PM generator; which converts wave energy to electrical energy via direct drive of vertical (up and down motion) that is associated with the previously mentioned fixed strator and directly driven PM linear generator-based buoy⁶⁸. Though the amplitude and frequency of this generator system may vary, the variations can be reduced via the input connection of a series of arrays to the generator. An alternative would be the three-phase synchronous generator for ocean wave applications that is generally utilized in the location of power plants that would observe constant wave series⁶⁹. The downside of these generator types is their ability to stress and break down

⁶⁵. Khaligh, Alireza and Omer C. Onar. *Solar, Wind, and Ocean Energy Conversion Systems*. Boca Raton: Taylor & Francis Group, (2010): 241.

⁶⁶. Khaligh, A. and Omer, C., 249.

⁶⁷. Khaligh, Alireza and Omer C. Onar. *Solar, Wind, and Ocean Energy Conversion Systems*. Boca Raton: Taylor & Francis Group, (2010): 249-250.

⁶⁸. Khaligh, A. and Omer, C., 255-260.

⁶⁹. Khaligh, A. and Omer, C., 260-266.

easily from their mechanical materials and heat loss, and the expense that is needed to install and maintain them.

Despite the variation of whether a module system is relatively nearshore versus offshore, a number of the means for which grid connection occurs are seemingly similar in terms of design and safety precautions. In the context of energy efficiency, any device that has a transmission line that is between 50 km to 100 km is considered cost effective⁷⁰. Though dependent on whether it is shore to nearshore or offshore, the transmission line design that is generally utilized for grid connection is as previously mentioned a DC voltage based transmission. In a typical frame of the transfer of generated energy to grid, the energy that is outputted by a generator needs to be conditioned (stable) before it can be connected to a grid network or to stand alone units⁷¹. The conditioning can occur through the interface between linear or synchronous generator applications and a number of different means, such as: the establishment of various farm structure-like wave-kinetic systems; to help reduce power fluctuations due to the different periods and wave heights experienced by each device, the utilization of capacitor tanks; to act as short term energy buffer storage devices, the utilization of a six-pulse insulated gate bipolar transistor inverter between the generator and grid system; to synchronize the output voltage to the quantities present on the grid, and/or the use of a low-pass LC filtering network; which would act as a means to suppress the higher frequency components of the inverter output voltage prior to grid connection⁷². The connection of these devices to the grid varies on the length of the system from the shore and at what depth level it is set-up at. The benefits of a these grid-centered components of wave-kinetic devices is that when they are part of a group of systems within a given area, the placement of individual wave energy converters would not only reduce any extreme variations in the generation of electricity, but also reduce the need for the energy storage systems on the device. Once

⁷⁰. MacDonald, Mott. *Offshore Renewable Energy*. New York: Earthscan, 2012. Print.

⁷¹. Khaligh, A. and Omer, C., 282.

⁷². Khaligh, Alireza and Omer C. Onar. *Solar, Wind, and Ocean Energy Conversion Systems*. Boca Raton: Taylor & Francis Group, (2010): 282-283.

the energy is stable and in synchronization with the frequency of the grid, the energy can then be transferred over to the grid.

On the other hand are tidal energy devices which can act either in shore and/or on the Outer Continental Shelf, and can operate at any depth with operating variations. The current/tidal-kinetic devices are typically installed for the benefit that they are relatively regular and predictable, and therefore can be stationed in the most beneficial area. Traditional exploitation of current/tidal-kinetic energy has been the construction of a barrage (wall), to make a basin between it and the land⁷³. Water would rush in through a series of gates during the peak flow of water, and then recede back during the eventual lull; which would generate energy as it passed across either a wheel or blade-like system on its way out. Though the system was traditional, it had a severe negative impact on the environment in regards to sediment deposition and habitat destruction, and was also costly to install and maintain. However, this traditional notion has progressed into the development of tidal fence-like system that is set-up between the entrances of ocean channels and generates electricity via the push of water through the turbine system in the fence⁷⁴. Though considerably lower on its impact to the environment, the tidal fence still is a probable intrusion to maritime and large mammal traffic that would get potentially caught up in the fence or have to deliberately avoid it. Hence, the markets for current/tidal-kinetic device systems are much more elaborative and complex in comparison to its previously mentioned counterparts in wave-kinetic systems.

These system devices are more or less constructed around the natural pattern that tide/current acts on. As previously mentioned, the traditional systems that utilized tidal/current power used this natural pattern of the ebb and flow of the water to its advantage⁷⁵. In the context of ebb generation, the basin behind the wall would be filled by the incoming tide through a side gate in the structure of the wall, which would then be closed when the water reached its peak level. When the tide moved out, the

⁷³. Khaligh, A. and Omer, C., 169

⁷⁴. Khaligh, Alireza and Omer C. Onar. *Solar, Wind, and Ocean Energy Conversion Systems*. Boca Raton: Taylor & Francis Group, (2010): 169.

⁷⁵. Khaligh, A. and Omer, C., 174-177.

turbine (or wheel) gate on the wall structure would be opened; which would lead the water to rotate the turbine as it passed through. On another level, there was generation via the flooding of basins; where the turbine gates were closed until sufficient head was created on the ocean side and then opened. In order to benefit both ends of the traditional generation methods, two-way generation were designed in which to take advantage of both ebb and flood techniques. Though the two-way generation allows for the utilization of both methods to obtain sources of energy, the system doesn't give a significant trade-off in the regards to energy efficiency versus the cost, ecological impact, and potential maritime hazard that are connected to it. An off-shoot solution to the tidal/current dilemma involved within the traditional techniques was the implementation of the concept of an offshore based tidal lagoon; in which water would run through a man-made free-standing system within the ocean and generate electricity as it passed through the structure. Though the tidal lagoon does alleviate some of the more problematic issues involved within the traditional techniques used to harvest tidal/current energy, there isn't a substantial amount of support for it, due to maintenance costs and potential hazards to oceanic wildlife⁷⁶. Therefore, the markets for efficient methods for nearshore tidal/current-kinetic options are highly more probable to not only be developed, but also implemented.

In the context of the typologies of turbine shapes and designs utilized in tidal/current-kinetic devices there are a number of different options that take advantage of different location placement and trade-offs between cost and effectiveness. In respect to the make of a turbine, there are generally three types for turbines that are utilized, such as: the 3-5 bladed bulb turbine; which has the essential components of a turbine bearing, shaft seal box, and generator, the rim turbine^{*}; which is likewise designed with essential components, but has the rim of the generator attached directly to the edges of the turbine closest to its blades, and the tubular turbine; which also has all of previously mentioned components, but has its generator directly on top of a barrage and the turbine's blades are connected to

⁷⁶. Khaligh, Alireza and Omer C. Onar. Solar, Wind, and Ocean Energy Conversion Systems. Boca Raton: Taylor & Francis Group, (2010): 176-177.

^{**}Though the maintenance of the rim turbine is better in comparison to that of the bulb turbine, there are generally noted issues involved between the sealing used on the rim between the blades and the generator.

the generator via a relatively long-shaft^{**77}. In these typical types of tidal/current-kinetic devices is a number of control methods via which the ocean energy is able to be transferred from the blades to the turbine in an efficient capacity. The methods range from a number of speed controls; which act as the primary movers and conduits for the transformation between the various forms of energy⁷⁸. Within these conduits are a number of dynamics that assist in the energy transformation, such as: rotor dynamics; which calculate the rotor speed in-between the electromagnetic torque and the mechanical torque of a device's blades and its turbine, and turbine dynamics; which in association with conduit dynamics essentially helps designate the rotation of the turbine in regards to the relationship between the pressure of the blades to the flow of energy to the turbine. Though there are a number of current turbine systems that are developed and marketable, and generally incorporate elements of the bulb, rim, and long-shaft turbine systems, they all vary more or less vary due to their intended range of efficiency and targeted location of operation. The horizontal axis turbine is essentially a system in which the blades fixated on a shaft in the direction of presumed optimal flow of the current⁷⁹. A classic example of a current market based horizontal axis turbine that is in use would those utilized by Marine Current Turbine's Seaflow and Seagen Turbines (which is now owned by Atlantis Resources Ltd.)⁸⁰. The Atlantis Resources Ltd. turbine SeaGen was considered to be the world's first commercially available tidal/current energy based turbine. The SeaGen is a turbine system that has a swiveled motor arm that is set on a fixed steel pile 2.1 m in diameter; which is designed to be tall enough to keep above its ideal water depth designation between 20-30 meters⁸¹. The blades of the turbine are designed to be able to be physically raised up and down on the swiveled motor arm, to enable easy access for maintenance

**** Though the long-shaft gives ample room for the placement of a gearbox, the trade-off was the generally noted aspect of there being issues with vibrations and general safety with the shaft piece.

⁷⁷. Khaligh, A. and Omer C., 179.

⁷⁸. Khaligh, A. and Omer, C., 180-192.

⁷⁹. Khaligh, Alireza and Omer, C. Onar. Solar, Wind, and Ocean Energy Conversion Systems. Boca Raton: Taylor & Francis Group, (2010): 192.

⁸⁰. Khaligh, A. and Omer, C. 193.

⁸¹. Khaligh, A. and Omer, C. 193

and/or repairs. The optimal speed at which SeaGen would operate in would be coastal speeds between 4 and 5.5 mph; which would theoretically aim to generate roughly 300kW per SeaGen system; which is roughly the same amount that a 98.5 ft. wind turbine would generate⁸². On the other hand there is the vertical axis system turbine, which is designed to be able to harness bidirectional tidal flow; the vertical access to set up perpendicular to the flow of the water⁸³. Though this bidirectional tidal system permits flow from either direction, the system requires a complex and costly two-way directional generator to be able to be set-up for multi-directional water flow. A classic example of a vertical axis system turbine that is being currently utilized for commercial usage is those made by Blue Energy Inc.⁸⁴. These turbines systems are set-up so that there are four fixed hydro-foil blades that are connected to a rotor, which in turn drives an electrical generator; of which utilizes a control gearbox that is set-up above the water. The theoretical expectation of a single Blue Energy Inc. turbine is roughly 200 kW of power, of which would be transmitted from the unit to the grid via a submersible DC cable. Another commercially available tidal/current-kinetic turbine in the market is the linear lift based system; which is a hydroplane with a variable pitch on a pivoted arm⁸⁵. The linear lift based turbine obtains energy via the exertion of force against the hydroplane via the movement of the water against it. A class available options for the linear lift based turbine system are those offered by Engineering Businesses Ltd.; called the Stingray⁸⁶. The Stingray module has a hydroplane that is placed in the relative direction to the ongoing, or dominant, direction of current. The current causes the supporting arm to swing back and forth, which causes the hydraulic cylinders within the system to extend and retract; which drives a hydraulic motor that in turn connects to an electrical generator.

⁸². Khaligh, A. and Omer, C., 193.

⁸³. Khaligh, A., and Omer, C., 197.

⁸⁴. Khaligh, A. and Omer, C., 198.

⁸⁵. Khaligh, Alireza and Omer, C. Onar. Solar, Wind, and Ocean Energy Conversion Systems. Boca Raton: Taylor & Francis Group, (2010): 198-199.

⁸⁶. Khaligh, A, and Omer, C., 199.

Though the generator and gearbox components within these turbine systems vary for their respective applications, their placement within the devices are more or less essential components to not only the direct energy transfer of the systems, but also the efficiency by which the systems can become optimal in terms of cost-effectiveness. For tidal/current systems, the typically two generator types that are by and large utilized by the turbine modules are either synchronous or asynchronous type generators⁸⁷. The synchronous generators are by and large the more efficient and developer choice-option of the two generator types in regards to the notion that 97% of hydro-kinetic energy from tidal/current systems from 2010 utilized them; and that their energy efficiencies varied between 75-90%. On the other hand asynchronous generators are considerably more rugged in comparison to synchronous generators in terms of energy efficiencies and design, but are set lower in terms of capital cost. Unlike the previous components within turbine systems, the gearboxes that are used within them are by and large similar for every single turbine. However, the placement of a gearbox between the turbine shaft and the generator shaft is done so for the purpose of the handling the load of the rotor⁸⁸. The gearbox is designed to take a typical velocity range of 5-30 rpm that a tidal/current-kinetic system may present. On the chance that a gearbox isn't present within one of the previously mentioned turbine systems, the rotor of the turbine would theoretically experience low rotational speeds; and probably lead to a failure of the system. However, they're specifically designed gears-less generator systems, such as: the low-speed high-torque synchronous generators currently under development to be implemented within turbine systems; which would prevent energy loss and simplify maintenance⁸⁹. Before the transfer of energy from the generator to the consumer, there are a series of technological processes via which the energy needs to go through prior to going to the grid.

The flow of energy from the generator to the grid is a variable methodology via which the energy needs to not only be stable, but also be in synch with the energy level variation that is currently

⁸⁷. Khaligh, A. and Omer, C., 199-204.

⁸⁸. Khaligh, A. and Omer, C., 205.

⁸⁹. Khaligh, Alireza and Omer C. Onar. Solar, Wind, and Ocean Energy Conversion Systems. Boca Raton: Taylor & Francis Group, (2010): 205.

present within the grid. As previously mentioned, the tide/current-kinetic turbines normally generate an amount of energy that has a flow rate variation that results in significant variations of speed and output; which prior to grid connection needs to have its voltage and frequency of energy synchronized to that of the grid level. Atypical of most of the generated energy is the consideration that energy has an AC voltage, and needs to be converted into DC power via three phase bridge rectifiers followed then by a DC/AC converter⁹⁰. The necessity for the initial conversion to DC has been already addressed in regards to the efficiency of DC voltage through an oceanic environment versus AC voltage; however, the converter back to AC is primarily due to the grid-operation on AC voltage⁹¹. In the case where intermittencies may occur through either maintenance, a default in transmission line or damage to one of the units, power will not be generated; in which case alternative measures can be utilized to supply adequate power supply. Though other electrical sources may be utilized to supply power to the grid, an energy storage system can be connected in a parallel system to the output stage of the generator or output of a conversion stage; and be able to supply the stored energy to the grid⁹². However, in the case of an overload or under-voltage within the grid, the tidal/current power generation system are more often than not in a stable state due to their stand-alone island-like connection that they have in relation to the grid; the units aren't fed by the grid, but feed it. Despite the probable unlikelihood of tidal/current-kinetic devices being affected by extreme variations of voltage in the grid, most of the previously indicated market turbine companies place detection circuit systems between the inverter and the grid to indicate any abnormalities⁹³. However, in lieu of being able to station these components and any of the models at one's own discretion, there is a series of environmental impact reports that need to be filed on how the technology of these devices may affect the status of the environment that they will be placed in.

⁹⁰. Khaligh, A. and Omer, C., 211.

⁹¹. Lynn, Paul A. *Electricity from Wave and Tide*. N.p.: John Wiley & Sons, (2012): 130-141.

⁹². Khaligh, A. and Omer, C., 212-215.

⁹³. Khaligh, Alireza and Omer C. Onar. *Solar, Wind, and Ocean Energy Conversion Systems*. Boca Raton: Taylor & Francis Group, (2010): 216-217.

The environmental impact report for any technological component that is placed into an environmental context, is more or less a write-up of a series of preliminary and operational tests (similar to those undergone by Verdant Power in **Chapter 2**) that takes into account all of the possible issues that said technology may create within its environmental context, and possible means to mitigate those issues. Though it has been previously noted that wave and tidal/current kinetic modules do not create any emissions along the lines of fossil fuels, there are potential hazards that can originate in installation, general maintenance, and operation, all during which the environment can be exposed to a number of different pollutants. Though there are a number of different hazards depending on whether or not the hydro-kinetic module is a single unit, part of a small array of single units, or even part of a farm, the general impact in engineering is relatively similar across the ground in regards to the effects on abiotic features, geology and water/air quality; biotic, the terrestrial ecology, fish and aquatic mammals, and birds; and socio-economic features, which range from nearby available resources to the landscape/seascape of the project site⁹⁴. As was previously stated, the general environmental hazards of these devices can involve a range of different toxins, all of which can be substituted for cleaner and more efficient features. However, the different non-technological mitigation methods that may be utilized to lessen the impact on the environment from these devices is somewhat flawed, due to the aspect that they are all more or less trade-offs in general impact⁹⁵. The chose to implement a hydro-kinetic system in a less-sensitive human and/or animal area is in itself a trade-off which may be seen in the case of Verdant Power and Roosevelt Island. In this situation the studies indicated that there was not a substantial amount of marine traffic going through that section of the New York City's water system and section of the water-way had been blocked off from human-marine ship traffic. Though the efficiency of the devices here may not have been in the most efficient location, the position was one that would see the lease amount of interference. Another mitigation method would be the constraint in operational hours and/or speed of a turbine of a hydro-kinetic system. The focus within this mitigation

⁹⁴. Cruz, Joao, ed. *Ocean Wave Energy*. Berlin: Springer Series, (2008): 402.

⁹⁵. Cruz, J., 416.

method is threefold, in the context of the trade-offs among energy efficiency, human involvement, and marine/environmental impact. In the reduction of operational hours and/or turbine speed there would be a lesser degree of energy being harvested from said unit(s), but, on the other hand there would be a lesser chance of probable environmental damage to marine life. However in the case of Roosevelt Island, it was already determined through the case studies that were done that there was not a significant impact from the turbines on marine and/or bird life. Another aspect through operational reduction would be the cause for potential noise pollution that may be emitted from the unit(s) and/or power sources, which may disrupt human or animal activity. In the case of the turbines off of Roosevelt Island by Manhattan, the aspect of noise pollution being a factor in any form of disrupting human or animal activities would seem highly improbable. The general non-technological mitigation methods for hydro-kinetic modules would seem to be highly specific to the site, and would need to be conditioned to fit any actual hazards that would be present within the current context of the environment. On the other hand there are a number of different mitigation methods that may be utilized in association with the main technological hub of these units. Aside from the environmentally safe alternative material options that were seen in Verdant Power's Gen5 turbines, there are probable technological elements that would be able to dissuade biotic interaction with the unit(s). The most ideal component that was previously discussed within this chapter would be the utilization of the electromagnetic field within some of the types of turbines to prevent animal activity near within a certain radius of the project. Though the field would disrupt marine and bird activity within a certain radius of the unit(s), the hypothetical return would be the reduction of the already fairly few animal casualties from these turbine systems (See **Chapter 2**, Roosevelt Island blade probabilities and case studies). Yet again, any technological mitigation methods aside from safer material would have to cater to the conditions of the specific sites that a hydro-kinetic system would be looking to be placed in.

The technological capabilities of wave and tidal/current kinetic modules present an efficient method through which energy can be obtained and transferred into a grid system. Though the

cost/efficiency of the modules would seem to favor wave-kinetic modules over tidal/current-kinetic modules, the general range of placement that tidal/current modules have against wave-kinetic modules would seem to make up for initial negative investment. Though these hydro-kinetic system types vary on their overall energy transfer to the grid, the overall efficiency and output would seem to put them as being more technologically viable than wind systems for obtaining energy for coastal usage. Aside from any initial maintenance struggle that may be present with dealing with an underwater energy system, there are a number of different historic political actions that have yielded a number of various walls through which hydro-kinetic companies have needed to go through in order to further progress the technology.

History of Politics on Maritime Energy:

Despite the inherent benefits that exist with investing in hydro-kinetic energy, there are many diverse opinions towards the future growth of these modules in United States waters. Among the current benefits that reside for these projections are tax credits, state-level renewable portfolio standards, and government issued grants for small businesses. On the other hand, the issues of permits for certain projects have rested on the basis of environmental and maritime affects that such projects may lead to.

Prior to the present discussion of hydro-kinetic modules in the ocean, the development of these oceanographic sources of energy had to bear through a numerous obstacles in order to reach its current stage. In the early 1940s, oceanic hydro-kinetic technology found its first implementation by Japanese inventor Yoshio Masuda; who designed an electric module power system on buoys for the sole purpose of maritime navigation⁹⁶. Despite the benefits inherent within these self-powered buoys, the US national energy policy didn't seemingly recognize them or that of other domestic sources of renewable energy until international events prompted the matter to be discussed. The international crisis in

⁹⁶. Lynn, Paul A. *Electricity from Wave and Tide*. N.p.: John Wiley & Sons, (2012): 20.

question was the OPEC's oil embargo in 1973, which drove the Carter administration to seek out alternatives within the form of wind and solar power, however; there were few supporters of any large-scale wave machine installations until a 1974 journal article in *Nature* was published by a Professor Stephen Salter⁹⁷. Professor Salter's article re-examined the possibilities of energy conversion from hydro-kinetic movement and the sufficiency by which such power may be connected to grid based systems. Though not a solely reliable for the eventual contributions of others, the article is credited to have spurred the growth of hydro-kinetics in the form of the development of the contouring raft; invented by Christopher Cockerell, and the Norwegian Tapchan system⁹⁸. Through a combination of Salter's article, the OPEC crisis, and these hydro-kinetic inventions, political involvement in furthering hydro-kinetic development may be considered as being sought after for the prime purpose of having a low-impact source of energy, but also the flexibility, seemingly low-cost involvement for a trade-off in the form of investment, and the engineering similarities between these early hydro-kinetic inventions and other renewable-energy based inventions. However, moderate political forces in opposition to further hydro-kinetic development may indicate the necessity for such capital funds to be diverted to cover the costs for any growth of these systems; in the form of subsidies, grants, tax-breaks, and/or the direct funding of government owned-and-operated hydro-kinetic systems, the financial logistics of there being readily accessible connection via the grid, and sufficient planning and maintenance procedures.

In the development of oceanographic projects, most if not all projects fall under the guidelines of permitting, licensing, and allocation of sea right requirements that are heavily embodied within the bureaucratic system. Due to the emergence of an environmental conscious within the public sector of American politics in the early 1970s which was translated into numerous pro-environmental legislative acts, the government followed through at the instigation of the 1969 Stratton Report on developing a

⁹⁷. Lynn, P., 20.

⁹⁸. Lynn, P., 21-22.

national and state based coastal zone management system⁹⁹. Through the Stratton Report, the federal government sought to have states achieve a balance between environmental and industrial pursuits; which was never fully defined in terms of amount of balance necessary, via the encouragement of grant-based programs and the passing of the Coastal Zone Management Act¹⁰⁰. The Coastal Zone Management Act by and large is a declaration that coastal resources should be utilized and managed for the benefit of the nation, be it if that resource is organic or of inorganic; ie. wave and current based sources of energy. The responsibility for managing this and other coastal environmental sustainable projects were scattered across a number of different agencies within the government, with the primary agency being the Office of Ocean and Coastal Resources Management; a subdivision of the National Oceanic and Atmospheric Administration¹⁰¹. Though the Office of Ocean and Coastal Resources Management bears the sole responsibility of implementing the Coastal Zone Management Act, their authority is severely limited in regards to being almost entirely dependent on the initiative of state based management programs to carry out the dual based notions of conservation and development; on the sole basis of grant based finances.

In regards to state based implementation of the Coastal Zone Management Act and their access to and conservation of coastal based resources, the jurisdiction of the state is by and large seemingly in hand with federal interests more so than environmental pursuits. In the case of offshore developments, the legal recognition for which states may act is within is a 3 nautical mile distance of the shoreline; as dictated by the Submerged Lands Act of 2002¹⁰². The Submerged Lands Act may be considered both as a means of the federal government to protect and manage the flow of potential offshore resources, but also as a probable measure against states from intruding into contention with neighboring nations. Prior to any development within state waters, there are a series of permits that are required (as outlined with Verdant Power's project on Roosevelt Island, NY). The permits and regulatory body behind a wave

⁹⁹. Beatley, Timothy, and David J. Brower. *Coastal Zone Management*. 2nd ed. N.p.: Island, (2002): 102.

¹⁰⁰. Beatley, 102-106.

¹⁰¹. Beatley, 91-94.

¹⁰². MacDonald, Mott. *Offshore Renewable Energy*. New York: Earthscan, (2012): 276.

hydro-kinetic module being able to be constructed within a 3 mile distance from a state's shore is the Federal Energy Regulatory Commission; hence, even if a state wants to develop some form of a hydro-kinetic unit or even a drilling platform within its navigable waters, it needs to get the permit license through a federal based organization¹⁰³. On the other hand, a state would need to receive a permit for a tidal based system via the US Army Corps of Engineers prior to construction⁷. Similarly, the political departments that are responsible for what wave module projects are permitted outside of the 3 mile nautical limit on the Outer Continental Shelf varies. On the one hand there is the Department of the Interior's Minerals Management Service which is a regulatory body due to the Energy Policy Act of 2005, whereas on the other hand the Federal Energy Regulatory Commission also has the regulatory power to issue and revoke permits for Outer Continental Shelf wave projects⁷. Tidal based energy modules that require permits beyond the 3 nautical mile barrier of state lines can be issued via the Federal Energy Regulatory Commission¹⁰⁴. Furthering the division between which regulatory bodies are responsible for the implementation of permits and supervision is the action of the National Ocean Council; which has also begun to act as a regulatory body for both within the territorial areas of the Outer Continental Shelf and state water lines⁷. Another regulatory body, which can hamper the growth of hydro-kinetic development, is the National Marine Fisheries Service; which has the authority and responsibility for the protection of essential fish habitats¹⁰⁵. Similar to any Environmental Impact Report, the work of the National Marine Fisheries Service holds that any development cannot interfere with the health and production of the essentials of federally managed species' marine habitat. Hence, in total there are only a few agencies like the Office of Ocean and Coastal Resources Management which are responsible for an unmarked balance between environmental and development projects within state lines, whilst there exists a number of other bodies crisscrossed against one another for regulatory authority for both state and non-state lines in dealing with both tidal and wave based energy sources.

¹⁰³. MacDonald, 276.

¹⁰⁴. MacDonald, 275.

¹⁰⁵. www.nyserda.ny.gov/.../roosevelt-island-energy.pdf

Aside from the initial dilemma that exists within the patchwork of regulatory bodies, the federal government has promoted a number of different means via which may enable hydro-kinetic projects to progress. Prior to the recent United States fiscal crisis, there were tax credits given by the government to only a few sources of renewable energy; of which hadn't been extended to wave, tidal/current, and ocean thermal energy. It wasn't until the 2008 that these sources of energy were listed as eligible means of technology for tax credits via one of the clauses within the Emergency Economic Stabilization Act¹⁰⁶. Within this clause it stated that systems that were to be constructed by 2013 would receive a \$1.1 tax credit per kilowatt hour produced and only for systems that would procure over 150kW. Hence, if a company, such as Verdant Power, was capable of navigating the various bureaucratic regulatory bodies in place, they would assume to have access to further incentives to construct these hydro-kinetic systems. Furthering development, the previously mentioned Office of Ocean and Coastal Resources Management is capable of awarding up to \$100,000 for small business projects within states; in order to incentivize that state to meet both conservation and developmental obligations¹⁰⁷. Similar to most grant-based funding, small-businesses may further make a case for additional funding based on the theoretical outcome that such hydro-kinetic or other project may provide. Furthermore, the United States has set aside roughly \$50 million annually from 2008 to 2012 for the sole purpose of the creation of a national ocean energy research center; which will further progress the research and development of hydro-kinetic possibilities¹⁰⁸. In the future of hydro-kinetic possibilities, both President Barack Obama and the U.S. Department of the Environment have issued calls for a both initiatives of 25% renewable power by 2025 and the deployment of up to 37 gigawatts of power via marine and hydro-kinetic sources by 2050¹⁰⁹. The collective total of potential interest within expanding renewable energy sources would seem to exist within the political body, and with specific strength to furthering the potentials of hydro-kinetic power. However, like most collective factors within government operations, there is

¹⁰⁶. MacDonald, Mott. *Offshore Renewable Energy*. New York: Earthscan, (2012): 277.

¹⁰⁷. MacDonald, M., 277.

¹⁰⁸. MacDonald, Mott. *Offshore Renewable Energy*. New York: Earthscan, (2012): 277.

¹⁰⁹. MacDonald, M., 277.

room for both the movement for hydro-kinetic power and other sources of renewable-energy to be removed from any further federal action via a range of possibilities, from lobbyists to the international market of fossil fuels being intentionally placed lower than the construction/maintenance costs of renewable based technology.

The historical decision-making progress of the utilization of hydro-kinetic sources of energy has been one that is not only fraught with indecision, but also one that has been heavily weighed with bureaucratic issues. Though there is presently a market available and incentivized for hydro-kinetic module operation, the overall system in place is not friendly for companies or investors to navigate through in order to implement this aspect of renewable energy. However, there is United States government based interest for the pursuit of alternative measures of energy for not only the ability to remove the reliance on foreign based energy and socio-environmental dangerous practices, but also as a means to curb the rate of emissions and climate change. In the overall scope of progress for renewable energy to deter climate change there would seem to a level of irony within the political and policy-making fields of renewable energy against more efficient levels of hydro-kinetic energy. Within the context of there being an increase in sea levels through the advancement of climate change, the hypothetical energy quality of wave and tidal/current kinetic would seem to increase relative to the amount of water that would be shifting across the surface of the earth. Hence, the viability of further renewable-energy hydro-kinetic opportunity that may potentially exist within the context of the rise of sea levels, if there is no clear-cut political action against the continued progress of climate change. Regardless of the theoretical energy potential that may exist with the rise in ocean levels, the present wave and tidal/current kinetic levels present an adequate means through which sufficient means of energy can be obtained and transferred to the grid, of which can be further enhanced on a non-climate change basis through several different policy based recommendations.

Conclusion: Policy Recommendations for Solving the Problem

All in all the establishment of hydro-kinetic energy systems in the United States is a relatively new phenomenon that has yet to be exploited to its full potential due to not only a vast number of governmental regulations, but also a lack of financial investment and public appeal. In a broad observation that current maritime geographic information provides on water energy capabilities, the notion of developing further wave and tide devices would seem to be highly acceptable.

Considering the current consideration of where the political standpoint is of whom is in charge of issuing permits and controlling the management of these devices in both electrical output and maintenance, policy recommendation should lay at the establishment of definitive streamlined parties at both the federal and state level. The current position of the Office of Ocean and Coastal Resources Management as having little to no authority as the primary enforcer of the Coastal Zone Management Act is something that doesn't seem to be initially able to be changed. Aside from the agency being able to grant money to state based projects that indicate a balance in the conservation of state coastal resources and development, there is little to no initiative for states to adhere to an almost equilibrium status. This lack of initiative is significant in the manner that coastal states can choose to or opt out of the option to develop hydro-kinetic systems along their coast; which in itself was part of the initial dilemma in regards to the introduction of the other numerous organizations and agencies that may have perceived a hydro-kinetic system as an environmental imbalance on the coast and halted the initial work that was started by the Office of Ocean and Coastal Resources Management. In light that states wouldn't seemingly back the intrusion of another strong, federally environmental-based authority intruding into state resource matters, the Office of Ocean and Coastal Resources Management should be cut and duties absorbed into that of the Environmental Protection Agency; of which as was seen in the Roosevelt Island Case, already present as a federal actor. In regards to the parties that permit,

license, and regulate the implementation and monitoring of the hydro-kinetic systems it would seem in the best interest to hold any territorial water more than 3 miles under that of the joint-authority of the Department of the Interior's Minerals Management Service and the FERC, whilst the FERC should be the sole actor within the 3 mile radius of state waters. The reason behind such action is primarily for the prevention of other agencies from ruling in on permit and license allocation, as well as implementing the rules and regulations of development. In the prevention of such intrusion, an adequate approach for companies to pursue the construction and operation of hydro-kinetic establishments can be undergone without counter permits and licenses being further needed. A further function within this streamlined association with a number of different agencies would be the necessity to maintain the current level of environmental assessments, but under the regulation guidance of either the Department of the Interior's Minerals Management Service or the FERC. Further in line with the responsibility of hydro-kinetic system implementation would be an accurate zoning under the guidance of one of two of previously mentioned agencies, in order to work with maritime traffic routes and other presently based coastal resources/projects.

Though there is a responsibility of hydro-kinetic systems to be implemented in environmentally assessed areas, there is also a significant responsibility among present and future hydro-kinetic companies to be able to implement not only the most optimal trade-off between cost/energy, but also to design systems that are reasonably safe. In an ideal market policy maneuver, companies would be incentivized to provide the most efficient wave and/or tidal/current module systems to either another party or to implement themselves through either receiving heavy subsidization and/or energy tax breaks. However, as was stated within the section **Running the Numbers on Maritime Energy**, there is a present market value among hydro-kinetic cost per energy that is seemingly, overwhelmingly large in comparison to that of other renewable and non-renewable energy sources. Hence, an early carry policy would need to be implemented in order to incentivize the large-scale build-up of hydro-kinetic systems, so that companies wouldn't perceive the risk to be overbearing. Once the market for the energy was

stabilized, then the early carry policy would be able to be somewhat relaxed, but with the probable subsidies given out to companies that would pursue a research and development goal of more energy cost-effective methods. On the other hand is the necessity for the system modules to be safe for not only the environment, but for grid-connection and for consumer product consumption. In a simultaneous comparison to the ideal world of company efficiency, the implementation of companies to construct and implement their system modules with the necessary safety and non-hazardous features would receive a form of financial incentive. However, with the trade-off between costs per energy presently against hydro-kinetic energy, it would seem plausible that companies wouldn't by and large desire to utilize quality raw materials and technological drive unless the projected long-term return from either the energy output and/or the policy subsidized money and/or tax breaks provided some manner of positive gain. Hence, the vitality of their being a policy oriented towards reversing the cost per energy that is delaying large-scale hydro-kinetic system implementation.

The implementation of a tidal/current system off of Roosevelt Island in the East River is an ideal scenario in which both actors in and not in the government and the cost per energy scenarios may be addressed within the framework of policy recommendation. The reduction of actors within the assumed rules and regulations of hydro-kinetic systems to that of the designated Federal Energy Regulatory Commission and that of the New York State Energy Research and Development Authority; in conjunction with New York City energy planners, would've enable a streamlined process for assessment and implementation without probable delay. Though Verdant Power did upgrade the quality of its turbines since the initial two turbines went in for the 1st phase of the demonstration, the present cost per energy of hydro-kinetic systems has probably yielded a negative outcome for the company, albeit as was previously mentioned the company did receive a stipend from NYSERDA to continue operation.

Though there are a number of obstacles that are clearly present against the further growth of wave and tidal/current-kinetic system modules, but there are a number of plausible policy oriented

directions in which a number of such obstacles may be overcome. The theoretical and experimental data that has been conducted for hydro-kinetic technology indicates the overwhelming potential that the modules have for generating electricity from a renewable energy source. In summation it would seem that the future of renewable energy should heavily consider the utilization of wave and tidal/current-kinetic systems; albeit if only policy influence would create a healthy market to incentive development.

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