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Technology assessment of hydrokinetic energy: Run-of-river and in-stream tidal systems

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Technology Assessment of Hydrokinetic Energy: Run-of-River and In-Stream Tidal Systems

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Master of Science in Sustainable Environmental Resource Management / Master of Science in Integrated Science & Technology

University of Malta / James Madison University

2011
Technology Assessment of Hydrokinetic Energy: Run-of-River and In-Stream Tidal Systems

A dissertation presented in part fulfilment of the requirements for the Degree of Master of Science in Sustainable Environmental Resource Management

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August 2011

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This is an assessment of the emerging technology of hydrokinetic energy, specifically for current-based systems in rivers, streams or canals. The over reliance on fossil fuels for our power and energy needs is not only environmentally detrimental, but also unsustainable. By exploring means of electric power that emerge from existing technology, society can become less dependent upon non-renewable resources and move towards self-sustaining practices. I will begin with a US electricity overview, and then transition into a discussion about hydropower and its shift to hydrokinetic energy technology. After comparing both turbine and non-turbine hydrokinetic energy systems, the thesis then delves into specifics on turbine systems within rivers and tidal streams; non-turbine systems, although under development, are not being explored on a commercial scale and are outside the scope of this study. The diffusion of turbine-based hydrokinetic energy has been facilitated by different private companies and the government, and integrated within the energy system of the United States. Along with these facilitations, there have also been barriers that have halted various hydrokinetic projects. A technology assessment of specific hydrokinetic criteria is completed by the use of specific interview questions and companies that are in the hydrokinetic industry and willing to participate in the survey. These interviews were then evaluated based upon the company specific answers in order to determine future feasibility and pinpoint ways to better use hydrokinetic energy as a source of electricity.
Statement of Authenticity:

I hereby certify that this thesis contains no material that has been accepted for the award of any other degree in any university and to the best of the writer's knowledge and belief, it contains no material previously published by another person except when due reference is made in the text.

Andréa René Badger, August 2011
Dedication:

This thesis is dedicated to my family and friends who have supported me no matter what, without question, and who have all taught me that striving to attain my goals is the purpose of life. And also to those in the Inaugural SERM Class who shared this experience with me: thank you for being friends who became my family.
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I would also like to acknowledge the motivational people I have met throughout my journey around the world: you all hold a special place in my heart and mind, opening my eyes to experiences and adventures that I never thought possible. I shall meet up with you again on the next voyage.
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Chapter 1: Introduction

This thesis is a technology assessment of inland hydrokinetic energy technologies, a form of hydroelectric power production that offers a promising alternative to conventional hydropower. As a carbon-free source of electricity, hydrokinetic energy technology can be used to harness the free flow of water and produce electricity through turbines designed for implementation in tidal streams and rivers. Notably, hydrokinetic power will not obstruct waterways, a principal disadvantage of conventional hydroelectric power plants (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Hydrokinetic power is emerging as a feasible electric power alternative by drawing in the technological principles from other renewable technologies, such as wind and conventional hydropower, which has helped to bring this technology to market more rapidly (Khan, Bhuyan, Iqbal, & Quaicoe, 2009).

This thesis explores the potential commercial diffusion of hydrokinetic power and addresses economic, environmental, political, and technical considerations. The technology assessment of hydrokinetic technology for inland systems suggests that while all factors are important, the technology is extremely sensitive to the geophysical characteristics of particular locations; site specifics therefore dictate the ultimate technological, economic, and environmental feasibility of this technology around the United States. Nonetheless, hydrokinetic energy technologies could help provide electricity to selected areas of the United States where suitable inland sites are located.

The technology assessment presented here is the result of a literature review of the current status of hydrokinetic energy technologies as well as in-depth interviews with three companies that have deployed inland hydrokinetic power generation systems. To better understand the influence of location, as well as economic, environmental, and policy considerations, company interviews explored six categories of factors: (1) sites, (2) water resource attributes, (3) turbine technology, (4) policy and permitting, (5) environmental impacts, and (6) economics. Each category was discussed in depth during the interview, with a series of questions created to assess hydrokinetic energy technologies and the
future feasibility of this alternative power source in the United States. After the information was gained and consolidated, it was synthesized to show present knowledge about hydrokinetic power and the future of this alternative electricity. An exploration of inland hydrokinetic power is important to understand future options for renewable sources of electricity within the United States. Currently the United States is a large consumer of electricity compared to the rest of the world. Within the US, most of the electricity produced is based on non-renewable sources, approximately 89%, and has detrimental effects on the environment, including an increase in carbon dioxide emissions that contribute to the change in climates around the world (U.S. Energy Information Administration 2009). Existing sources of hydroelectric power are in limited locations around the US because of the sheer size of impoundment dams. Hydrokinetic power is a renewable source of electricity that is important to attain more knowledge in order to use, to divert from overusing the non-renewable electricity currently used, which has potential destructive effects.

Background on Hydrokinetic Power

The flow of water can be used to produce electricity for hydrokinetic power production. It uses the kinetic energy embedded within the natural movement of water to convert the motion to electricity. The flow of the water moves the device’s rotor, turning a shaft within the conversion device. The turn of the shaft moves the magnets within the generator, creating electromagnetism, allowing the electrons to move within thus converting to usable electric power. The basics of hydrokinetic power production are similar to those of conventional hydropower, but this technology uses ways of extracting the potential energy other than damming or diverting. Hydrokinetic power production differs from conventional methods mostly due to the configuration of the systems. Hydrokinetics use single turbines in a collective array to harness energy: there is no immobile dam infrastructure concreted in the environment.
Hydrokinetic power differs from conventional methods of producing electricity from water movement because of the specific devices and placement, however the basic principles of using movement to be converted into electricity stay the same. Water is 832 times denser than air; the tides, currents and free-flowing rivers represent an untapped and powerful clean energy source, and hydrokinetic energy extraction can be done with little to no known impacts or introduction of infrastructure on the surrounding environment.

United States Electric Power Needs

The United States is the largest consumer of energy in the world. Electricity generation in the US is significantly higher than other nations, producing a total of 4,344 terawatt hours (TWh) of electricity per year, 21.5% of the world total; China is the second largest electricity producer at 3,457 TWh, 17.1% of the world’s total (International Energy Agency, 2010). Total electricity consumption in the United States is projected to increase by 1,135 billion kilowatt hours (kWh) over the next 24 years at a rate of about 1.0% per year (U.S. Energy Information Administration, 2011). Per capita US electricity consumption is 13,647 kWh per year compared to 2,453 kWh per person in China (International Energy Agency, 2010).

Electricity in the United States is generated from a mix of sources including fossil fuels, renewable energy, and nuclear power. Sources constituting a larger portion of produced electricity in the US are dependent upon the availability, costs, and/or the amount of electricity able to be produced from each source. Figure 1 shows a pie chart that depicts the use of different sources for electricity within the United States.

The largest portion of electricity in the US is generated by coal, which constitutes almost half of total US electric power generation. Coal based electricity has impacts including emissions associated with this type of electricity and harmful influences on surrounding ecosystems and miners extracting this resource. Nuclear and natural gas are both readily available and combined equal almost as much electricity produced as coal. Unlike coal, natural gas is much cleaner during the
combustion process. Gas turbines are most commonly used during high demand peak use times, and in 2009 23% of the United States’ electricity was fueled by natural gas (U.S. Energy Information Administration, 2009).

Nuclear is dedicated solely to the production of base load electricity. Petroleum can be used for electricity, however the price of petroleum varies significantly day-to-day, which deters electricity production from this source. Very little petroleum is used for electricity production, approximately 1%, and usually this is to run intermediate turbines (U.S. Energy Information Administration, 2009).

Electricity generated from renewable sources, which represents 18% of all US electric power production, derives from hydropower, wind, solar, biomass, and geothermal energy. Hydropower produces the largest portion of renewable electricity, approximately 7% of US total electricity production (International Energy Agency, 2010). Biomass and municipal solid waste is about 1% of the total amount of renewable electricity generation and wind is approximately the same, about 1% of the total (U.S. Energy Information Administration, 2009). Solar and geothermal account for small portions of the total; all other renewable sources account for approximately 4% of the total US electricity production (U.S. Energy Information Administration, 2009). These numbers are represented in the ‘other renewables’ category in Figure 1.

Total renewable electric power generation is projected to increase by 14% from 2010 to 2035, at a rate of about 0.5% per year (U.S. Energy Information Administration, 2010). Of this 14% increase, wind power is projected to increase
approximately 2.8%, and biomass will be up 5.4%, both of which will share the largest growth (U.S. Energy Information Administration, 2010). The amount of electric power generated by renewable energy, excluding hydropower, is projected to be 3.6%. Wind is expected to be the fastest growing renewable sector representing one-third of the total renewable energy expansion, and with solar increasing about 3.1% per year (U.S. Energy Information Administration, 2011). The amount of hydroelectric power produced within the United States is expected to stay between 6.5% and 10% of total US electric power production. Large hydropower dams are no longer being constructed due to effects they produce on the environment and ecosystems, such as the changing of ecosystems and species as well as the sedimentation of the riverine systems, however, smaller options are still being developed which keeps hydropower a large portion of the renewable electricity sector (Sternberg 2010).

Within the United States there are programs that promote the use of renewable electricity generation in order to increase energy security. State renewable portfolio standard (RPS) programs create a market demand for renewable electricity and are polices that are set up within each state to produce a specific amount of electricity from renewable sources by a future point in time (U.S. Department of Energy, 2009). A certain percentage of electricity sales and megawatts (MW) must be from renewable sources within as little as 2 years, and up to 19 years, into the future, according to the information for the 24 states that currently have RPS programs in place (U.S. Department of Energy, 2009). Because of RPS programs throughout the United States, the generation of electricity from renewable sources will continue to increase, especially as more states create renewable portfolio standards. Programs like these publicize the need for electricity security and help to attain specific future goals of renewable electricity generation.

Federal government programs also influence the rates at which electricity is being pushed to be produced from renewable sources, which in turn increases national security, conserves natural resources, and meets regulatory requirements and goals. The Energy Policy Act of 2005 has specific requirements about the total
electricity consumed by the Federal Government that must come from renewable energy (U.S. Department of Energy, 2011). From 2011 to 2012, at least 5% of federal government electricity must come from a renewable source, and in the fiscal years following 2012 at least 7.5% of federal electricity consumption must be from renewable sources (U.S. Department of Energy, 2011).

Assuming there are no additional constraints on carbon emissions, coal will continue to remain the dominant source of electric power generation into the next quarter century (U.S. Energy Information Administration, 2011). This generation will increase by 25%, largely as a result of an increased use in the existing capacity of coal-fired power plants (U.S. Energy Information Administration, 2011). Natural gas continues to be a large portion of the electricity industry because of the current low prices and the boom in construction of natural gas fired power plants in 2000 (U.S. Energy Information Administration, 2011). Because of the continued reliance on coal, the carbon dioxide emissions will continue to be a problem, even if more constraints are placed on this industry.

Despite the continued reliance on coal, and the increased output of other renewable forms of electric power production by approximately 72% over the next 24 years, there is still a large need for hydropower (U.S. Energy Information Administration, 2011). The large impoundment dams that are currently in place will continue to generate electricity, and newer small hydropower will increase in use across the United States due to the inability to further implement larger forms of hydropower. Small hydropower is that which produces between 100KW and 30MW of electricity and is usually directly connected to the end user and not to the national grid (U.S. Department of Energy, 2008). In 2008, hydropower accounted for 718.02 TWh of electricity which will continue to increase by a total of 149.47 TWh’s by 2030 (Institute for Energy Research, 2011). This increase will provide more renewable electricity to end-users from hydrokinetic power technologies alongside small hydro and not from an expansion of the built infrastructure for conventional hydropower.
Electric Power Production and Carbon Dioxide Emissions

Currently, CO2 emissions in the United States are 18.38 tons of CO2 per capita (International Energy Agency, 2010). In 2008, the CO2 emissions from electricity generation were 2,359.1 million metric tons, a 30% increase from 1990, a 1.5% annual increase during this period (U.S. Energy Information Administration, 2009). Emissions from electric power generation decreased by approximately 2.1% in 2008, which can be attributed to a larger amount of electricity generated from non-carbon sources alongside the US’s economic downturn (U.S. Energy Information Administration, 2009).

With the expansion of renewables for electric power generation influenced by RPS laws in many States, and slowed growth in electricity demand, CO2 emissions directly related to electric power production is expected to grow by 18% from 2009 to 2035 (U.S. Energy Information Administation, 2011). As an increased amount of attention is given to emission reduction, diversifying the electric power sector and increasing the amount of renewable electricity generation could help curb CO2 emissions more quickly. By taking extra steps to reduce CO2, the growth of emissions from electric power generation has been projected to increase at a slower rate: 16% from 2009 to 2035, which is less than the total increase in US energy use (U.S. Energy Information Administation, 2011). Hydropower and hydrokinetic power provide opportunities for the United States to diversify its electric power generation portfolio to reduce CO2 emissions from energy use.

The Limitations of Conventional Hydropower and the Emergence of Hydrokinetic Systems

Conventional large impoundment hydroelectric power production has been curbed because of the impacts to the environment, including riverine ecosystems and fish species citations. The United States has not expanded generating capacity for large scale power dams since the 1980s because of the concerns over their negative impacts on river systems (PEW Center on Global Climate Change, 2009). New large
Hydropower dams are not considered a practical option for increasing hydropower generation because of the environmental impacts as well as the lack of available sites for development. The sheer size of the large impoundment dams creates a building hindrance as most rivers in the United States are either not large enough to withstand the construction of large-scale dams or they are important as navigable channels, deterring any built infrastructure. Conventional hydropower sites have simply been exhausted: either they have already been developed or they have been assessed and cannot be developed with the current built infrastructure technology (PEW Center on Global Climate Change, 2009). When building conventional hydropower methods to harness the energy embedded in water, it is very difficult to do so without impacting the environment negatively (PEW Center on Global Climate Change, 2009). Because of the impacts that could occur to the sedimentation of the riverine system, the ecosystems (including fish species), plant life, microbial communities, and the impact to other uses of the river, the negative impacts began to become a bigger issue and outweigh the positives of this type of cleaner electricity.

Hydrokinetic energy technologies can produce electricity from water movement without blocking the river or creating a physical barrier to fish species, which inevitably impacts those populations. These systems have worked off other electricity producing systems (such as conventional hydropower and wind power) to create a way that water can produce electricity with an infrastructure that does not require a dam or impoundment (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Hydrokinetic turbines can be placed in river systems around the United States and stay within the freshwater environment for a prolonged period of time; so the channel can thus be used to harness energy alongside other uses like recreation and shipping. Hydrokinetic energy technologies are emerging because of the shift towards more renewable sources of electricity and because it is possible to apply information from other electricity sectors and sources to make hydrokinetic power realized quickly (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Around the United States there are large numbers of rivers and streams where hydrokinetic power systems could be implemented to capture the flow, however these areas are all site-specific.
in terms of their technical, economic, and environmental feasibility for power
generation (Federal Energy Regulatory Commission, 2011). Each hydrokinetic site
needs to be assessed separately in order to make sure there will be little to no
impact on the surrounding areas, and reduce possible future impacts such as those
that came about from conventional impoundment hydropower.

The inception of hydrokinetic energy technologies is recent; therefore the
industry still has many unanswered questions. Most of the design concepts for
hydrokinetic turbines are in the research and development stage and have yet to
make it to a real-world setting to be tested (Khan, Bhuyan, Iqbal, & Quaicoe, 2009).
Some companies within this sector have begun to take their hydrokinetic devices
and place them within the natural environment; however, none of these systems are
fully demonstrated anywhere in the United States. There are projects currently
deployed in a much smaller capacity than the full potential. A total of 63 projects
that acquired a permit to demonstrate within the selected area around the United
States, and each of the projects is at various stages of development (Federal Energy
Regulatory Commission, 2010). Inland hydrokinetic technologies are going to be
available for a commercial setting most likely before offshore wave generation
because inland systems are protected from the harshness of the ocean climate
(Sternberg, 2010). Even though these inland systems will most likely be fully
commercialized prior to offshore generation, there are still uncertainties associated
with this technology.

There are many unknowns about the environmental impacts of hydrokinetic
power, an issue because of concerns over the environmental impacts associated
with conventional hydropower. Assessments of possible sites will help to curb the
potential for future impacts upon the environment from hydrokinetic power
production, alongside the already known effects of other waterpower sources.
Because there are a number of areas where hydrokinetic energy devices could
harness energy and produce electricity around the United States, finding the best-fit
areas is a difficult task. With so many design choices, it is tough at this nascent stage
to predict if one area is better for implementation than another without a full
assessment. Potential hydrokinetic power generation sites are being assessed
throughout the US and going through the federal regulatory review necessary to install these systems. Demonstrations and testing are necessary before widespread deployment can occur at suitable sites across the United States.

In the scientific literature, technical information about hydrokinetic energy, the technology, and resulting power production generally gives an overview of specific engineering issues associated with hydrokinetics. However, hydrokinetic energy is site-specific and must be discussed specifically based upon the location, where the technology must be carefully matched to site conditions; power generation systems thus will differ from location to location. Particular data gathered at possible implementation sites by companies who are researching, developing and eventually installing these devices, helps to build a better understanding of the future possibilities for hydrokinetic power: becoming the basis of the technology assessment within this thesis project.

Conclusion

The United States continues to increase electricity needs alongside the increasing population. The population growth rate is declining, however the population will continue to increase: approximately 50% in 2050 from the population in 1990 (U.S. Census Bureau, 2010). This consistent increase will have the same impact on electricity needs: constantly increase them. With greater electricity use, more carbon dioxide will be emitted into the atmosphere unless the electricity sector is diversified. With the help of State RPS programs, the US is currently undergoing diversification in electricity. These programs will continue to be important in promoting energy security as well as increasing the renewable sources used to decrease the issues associated with conventional electricity sources and their high carbon content (U.S. Department of Energy, 2009).

Hydropower, specifically small hydropower, can help to increase the amount of electricity without decreasing the quality of our air. Hydrokinetic electric power can also avoid the negative environmental impacts of conventional hydropower, including sedimentation issues, disruptions of fish species and their populations,
and localized climate change from the large impoundment reservoirs (Sternberg, 2010). Conventional hydropower is not a feasible way to further diversify the US electric power industry not only because of these negative effects, but also because of the lack of places around the United States that can support these immense dam infrastructures. Hydrokinetic power is much more promising because it is smaller, can be placed within a river current, and is more suitable to diverse geographic regions around the United States. Also, hydrokinetic electricity, when demonstrated at its full site potential, has the ability to produce a commercially viable amount of power. This is in contrast to smaller forms of conventional hydropower, which cannot be commercially deployed, and are directly connected to the end user (i.e. farms). By assessing the feasibility of hydrokinetic power at specific sites around the United States, it can be better understood and potentially become more readily available for future commercialization.
Chapter 2: Hydroelectricity’s Shift from Conventional to Hydrokinetic Technologies

Conventional hydropower is shifting from large-scale impoundment dam technology to hydrokinetic energy, a damless low- or no- head form of waterpower. Hydrokinetic energy technology is still in the early stages of development, and each pilot site is, in essence, experimental; devices, placement, and system types are therefore likely to differ between locations. The research on hydrokinetic devices draws, in part, on insights from wind energy systems because of the use of small turbines and the role of fluid mechanics in system design. Companies within the hydrokinetic industry continue to research and develop best-fit devices for capturing in-land hydrokinetic energy around the United States. By comparing conventional hydropower to its lesser-known hydrokinetic counterpart, we can see that electricity can come from “older” natural resources in new ways with new emerging technologies. By understanding past and current trends of the hydrokinetic energy technology sector, we are able to see how this industry can continue to develop and possibly become a significant commercial source of electricity.

Role of Hydropower as A Source of Electricity

Hydropower has historically played an important role in US electric power production. The first large hydropower plant in Niagara Falls, NY, was established in 1881 to power streetlights to the surrounding areas, and to this day generates and contributes to the power used in western New York (U.S. Department of Energy, 2008). The Niagara Falls station was so successful that it created a large market within the US for this new form of technology. The world’s first commercial hydroelectric power plant began operation in 1881, and by 1886 there were 45 water-powered electric plants in the United States and Canada (U.S. Department of Energy, 2008). Throughout the United States, dams were built in many river systems, diverting water from the original system and creating reservoirs to use the head (the difference in height between the water in the reservoirs and where the
water flows out of the dam) to artificially increase the kinetic energy from the water within the first decade of hydropower’s existence.

By 1889, 200 electric plants in the U.S. used waterpower to generate electricity (U.S. Department of Energy, 2008). The amount of hydroelectric power generation was 15% of total US generation in 1907, 25% by 1920, and nearly 40% by 1940 (U.S. Department of Energy, 2008). Hydropower capacity tripled again from 1940 to 1980, although the total share of electric power production accounted for by hydropower declined during this period due to the dramatically expanded capacity in coal- and nuclear-fired power plants (U.S. Department of Energy, 2008). Currently, 192 hydropower stations generate 282 TWh, or 7% of the total amount of electricity generated in the United States (International Energy Agency, 2011; International Energy Agency, 2005).

*Types of Hydropower*

The amount of electricity that can be harnessed from conventional hydroelectric power stations is dependent upon annual rainfall as well as the amount of runoff, both of which flow into the impoundment basins (or reservoirs) that most U.S. hydropower draws from (Sternberg, 2010). Hydropower is usually described or characterized by the output size of the power station (installed capacity as measured in kilowatts or megawatts) or by the category of hydropower (conventional, microhydro, or ultra-low head height and hydrokinetic) that the installed capacity falls into. Khan and others (2009) represent the difference between the types of hydropower in Figure 2. This figure reflects a technology classification scheme that is based upon hydropower potential, the working hydraulic head, and the hydraulic flow of a hydropower system (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Conventional hydropower projects use higher head when compared to other hydropower sources, such as unconventional low-head or hydrokinetic scheme projects. Micro-hydropower and unconventional systems have the ability to exploit lower head heights and/or lower flow rates in ways that larger systems cannot.
The size rating of power stations is relative to their total output, and conventional hydropower generation can be large, small, or micro, depending upon the total potential output. Large hydroelectric power stations have an installed capacity of 30MW or more, which includes all the large dam facilities associated with conventional hydroelectric production (Energy Efficiency and Renewable Energy, 2005; U.S. Department of Energy, 2006). These power stations need a large hydraulic head to produce electricity (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Small power stations can generate between 1MW and 30MW of electricity, and include forms of hydraulic systems for electricity production other than the conventional damming method. Low power stations are depicted as those stations generating 1MW or less, where small areas use the electricity and are directly connected to the source offsetting the amount of electricity needed from utilities (Energy Efficiency and Renewable Energy, 2005; U.S. Department of Energy, 2006). As seen from figure 2, these smaller power stations require less hydraulic head to produce electricity, but tend to operate at a higher flow rate (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). The number of hydro plants around the United States, of all sizes, is 2,378 (U.S.
Department of Energy, 2006). All of these hydropower stations, according to a 2006 feasibility study by the Department of Energy, generate approximately 35,432MWh, with 80% (of the total amount of hydropower) coming from the 192 large impoundment hydropower stations, such as Hoover Dam on the Colorado River and the Grand Coulee Dam on the Columbia River in Washington (U.S. Department of Energy, 2006). There are limited locations where large hydropower can be installed; however, the vast size of the dams and the large hydraulic head created from impoundment deliver an immense amount of energy as the water pushes through the turbines.

**Conventional Hydropower.** — Large impoundment, conventional hydropower is the largest portion of the renewable energy sector in the United States, representing 70% of all electricity generated from renewable resources (U.S. Department of Energy, 2011). Figure 3 depicts how a conventional impoundment hydroelectric plant works to use water and convert the potential energy into usable electricity.

![Figure 3: Conventional Hydroelectric Dam](http://www.civilengineergroup.com/negative-impacts-hydroelectric-dams.html)
The building of the dam’s infrastructure creates a reservoir from the blockage of flow. These reservoirs hold the potential energy of water, and when the water is released, it is thrust through a penstock/piping system. The pressure produces flow or kinetic energy from the original diverted water, spinning a turbine at a lower elevation. The difference between the height of the water in the reservoir and the water expelled through the turbines is called the head, which drives the energy. When the ‘falling water’ is thrust through the generator-connected turbines within the dam, its energy is converted from movement to electricity using the basic electrical generator properties. The force of kinetic energy that creates a mechanical motion of the generator is harnessed; an electrical conductor is moved with the spinning motion, and goes through a magnetic field causing a current of electrons to flow, which is the electricity that we use. This electricity is then connected to the power grid through power lines to be distributed to surrounding areas.

The ability to exploit more water resources for traditional, large-scale hydroelectric power plants around the United States is constrained because of the size of the impoundments, the lack of large river systems to further dam, and the social and environmental costs created by damming and large reservoir systems (Khan, Iqbal and Quaicoe, 2007). As a consequence, growth in the hydropower sector must take a new direction toward small hydro or hydrokinetic energy technology. Implementing these technologies would not require expensive or large-scale changes in the power distribution infrastructure or in electricity using equipment (U.S. Energy Information Administration, 2010).

**Small hydropower.** — Small hydropower is a smaller scale hydropower that has a greater geographic diversity because these systems require less space than conventional impoundment hydropower. These systems can generate between 10KW to 30 MW of electricity (U.S. Department of Energy, 2001). Usually small hydropower is used in the same way as large impoundment hydropower: a dam is built on a much smaller scale, and then turbines are used to generate electricity electromechanically. The diversion method of hydropower, where water is redirected away from the channel through a piping system using drops in terrain
elevation for head, is also considered small hydropower (U.S. Department of Energy, 2001). These are intermediate levels of hydropower: they are not as big as large impoundment dams, but they are still connected to the grid infrastructure for commercial power production.

**Micro hydropower.** — Micro hydropower is even smaller in capacity than small hydropower, and can generate up to 100 kilowatts (kW) of electricity from rivers and streams (U.S. Department of Energy, 2001). These systems are usually directly connected to end-users, such as farms, homes, and small commercial enterprises. Most of the systems used by home and small business owners would qualify as micro hydro systems; in fact, a 10 kW system generally can provide enough power for a large home, a small resort, or a hobby farm (U.S. Department of Energy, 2001).

**Hydrokinetic power systems.** — Both large and small-scale hydropower is changing from conventional impoundment dam systems to those that require no reservoir, impoundment, or penstock diversion. The penstock diversion method of conventional hydropower diverts water from the river, and turbines are used to capture flow without large dams that may impact the ecological environments within and surrounding the resource (U.S. Department of Energy, 2011). This diversion method is known as a 'run of river' scheme for conventional hydroelectric power systems (Energy Efficiency and Renewable Energy, 2005).

Hydrokinetic power is most similar to run-of-river systems, **but water is never diverted away from the river.** Hydrokinetic technology captures energy using the natural flow of the river instead of pushing water through a penstock to increase the pressure. Hydrokinetic energy technologies are not restricted to river systems; the potential extends to tidal and wave energy conversion as well. Hydrokinetic power systems are related to ultra low-head hydropower systems\(^1\): they are similar because neither use dams nor retain water to create hydraulic head; these systems use currents from the rivers or tidal streams to produce electricity.

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\(^1\) Ultra low-head hydropower systems are those that use currents of the natural river flow to produce small amounts of electricity. That electricity is not used for commercial use, but used by directly connecting it to the source, i.e. a barn close to the water. The electricity cannot be transported far and can usually only offset other sources of electricity.
The current moves the turbine blades, which then spin a rotor connected to a generator. In this manner there is no artificial or natural head; the system can be used in any area where there is flowing water, and these types of hydropower will not impact the environment like larger, conventional hydropower has in the past.

Ultra low-head hydropower, as seen previously in figure 2, derives more from the flow of the water and less by the amount of head within the area of implementation. The main difference, however, between ultra low-head and hydrokinetic power is that hydrokinetic creates a mix between large conventional hydropower as a commercial setting and that of a smaller hydropower collecting the natural flow of the river or stream. Hydrokinetic technologies are built to harness the natural flow, but are also intended to be commercial hydropower stations providing bulk power to the grid, not just small amounts of electricity to end-use, on-site facilities (which is what ultra low-head is primarily used for).

Hydrokinetic Energy Technology

Hydrokinetic energy is the result of the natural movement of water within different systems. Rivers, tides, and waves all have the potential for harnessing movement to capture and generate hydrokinetic power. Hydrokinetic energy sources are classified in different ways, including offshore and inland generation. Offshore generation harnesses wave power and tides from coastal bodies of water such as oceans and seas. Inland generation is composed of run-of-river and in-stream tidal energies, both are secluded from the intensity of offshore areas. There is great potential for harnessing energy within inland areas because (a) it is easier to deploy equipment in these environments compared to those offshore, and (b) are more closely related to hydroelectricity currently being produced by other types of hydropower plants since all of these are in-land systems, i.e. impoundment dams, diversion method, etcetera. Most of the research and development (R&D) for hydrokinetic energy has occurred in the last decade (Sternberg, 2010). Research on hydrokinetic energy is ongoing, and the most recent developments have created a better understanding for inland hydrokinetic systems.
Assessing inland hydrokinetic energy technologies, specifically run-of-river and in-stream tidal systems, can shed light on the feasibility of commercialization of these technologies and their contribution to diversification of the US electricity sector.

*Types of Inland Hydrokinetic Systems*

Inland hydrokinetic energy systems are categorized as either run-of-river or in-stream tidal systems. Run-of-river systems harness energy from the unidirectional flow of surface water and utilize ultra-low head height turbine systems. Although run-of-river systems exploit the potential energy from a differential head height in flowing water, they nonetheless differ from conventional hydropower. Run-of-river systems do not require the construction of impoundment dams, they do not divert water away from the natural system, and they can generate energy from much lower head heights than conventional hydropower systems (U.S. Department of Energy, 2011).

In-stream tidal systems are inland systems within saltwater bays or estuaries connected to the ocean. In-stream tidal systems must be able to harness flow from two directions (due to tidal flows) to convert the most kinetic energy possible into useable electricity (Bedard, Previsic, Hagerman, Casavant, & Tarbell, 2006). In-stream tidal systems capture tidal energy that moves into an inlet, which acts as channelized flow; such systems convert both the tidal energy and the natural in-stream flow of the inlet into electricity (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Note that there is a difference between marine (coastal) tidal systems and in-stream tidal systems; pure marine tidal systems are closely related to those of wave energy and will not be specifically discussed in this thesis. In-stream tidal locations are considered in-land locations because of the barriers to open marine water and the associated forces of tidal power.

In-stream tidal systems work much like run-of-river systems because of the channelized flow from which the electricity is harnessed; they can also be naturally occurring within the landscape or man-made. Either type of channel (natural or
engineered) helps to facilitate flow, creating the potential to generate electricity. The cyclical nature of tides (whether diurnal, mixed or semi-diurnal) facilitates the predictability of the electricity-generating potential at a given site.

**Types of Hydrokinetic Power Systems**

Hydrokinetic technologies use both turbine and non-turbine systems to generate electricity. Turbine systems and non-turbine systems can both harness energy from unidirectional water flow, although R&D has been conducted far more extensively on turbine-based systems (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Non-turbine systems include unconventional concepts and most are at a proof-of-concept or part-scale model stage, therefore needing more research, development, and demonstrations before being commercially deployed (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Turbine systems have been tested and used in various environments, such as (a) closed testing sites in natural rivers, (b) research testing in university laboratories and (c) open test sites within the real-world settings, thus increasing the feasibility of these systems for commercial deployment.

These are the main devices developed for inland systems and are shown in relation to one another in Figure 4. Most hydrokinetic turbine systems include Axial or Horizontal, Vertical, and Cross-flow (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). These are the main devices developed for inland systems and are shown in relation to one another in Figure 4. Most hydrokinetic turbine systems are
similar to wind turbines systems, which helped advance the technology faster than most new alternative energy sources (Wellinghoff, Pederson, & Morenoff, 2008).

Axial (or horizontal) turbines have a rotational axis parallel to the incoming water stream, as seen in Figure 6. The rotor for this device is parallel to the flow and has blades that turn perpendicularly to the water (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). When the rotational axis of the rotor is vertical to the water surface and at a right angle to the water stream, the turbine is a vertical axis turbine (Figure 5). Vertical axis turbines are used more often in Europe than in the US. Vertical axis turbines are those where the blades are connected to the rotor, and both are vertical. Cross-flow turbines are designed with a rotor that is parallel to the water surface, as in the horizontal configuration, but is also at a right angle to the incoming water stream. These turbines are a combination of vertical and horizontal axis turbines. (The vertical axis turbine is placed on its side so that the rotor is parallel to the water.) Different configurations of vertical and horizontal turbines are named and shown in Figures 5 & 6. These figures help visualize the difference between turbine types and orientations.

Figure 5: Types of Vertical Axis Turbines

(a) Squared Cage-Darrieus (b) H-Darrieus
(c) Darrieus (d) Gerlet (e) Savonius

This figure describes different device schemes of vertical axis turbines.


Figure 6: Types of Horizontal Axis Turbines

(a) Inclined axis (b) Rigid mooring
(c) Non-submerged Generator (d) Submerged Generator

This figure describes different device schemes of horizontal axis turbines.

**Relationship Between Site and Turbine Design**

The workings of hydrokinetic power systems, including the design/size of the turbines and placement within the environment, depend directly on the deployment site. Site characteristics will also determine the turbine system that best matches the environmental conditions and site specifics. Device design and site assessment depend upon each other in order to have the least amount of impact on the surrounding environment and harness the most energy. As Khan et al., state:

“...water velocity has a highly localized and site specific three-dimensional profile and rotor positions against such variations will dictate the amount of energy that can be effectively extracted” (Khan, Bhuyan, Iqbal, & Quaicoe, 2009).

This quote describes the differences between locations of hydrokinetic energy technology placement and how it is fully dependent upon the profile of the water resource and the device used. Because there are no standards for hydrokinetic turbines, and areas where large amounts of energy are present will have different features, which may or may not be conducive to implementation, each area needs to be assessed separately and all site-specific details need to be taken into consideration.

Engineering design adapts the turbine to the site selected for assessment. Companies consider different options regarding blade length and width, spacing, placement within the waterway, and power grid interconnection to create systems that harness as much energy as possible, fitting within the parameters of the site. The size of the turbine is directly related to the amount of potential hydrokinetic energy available. To achieve economies of scale, in-stream tidal turbine systems are being designed with larger capacities to capture more of the energy released by the tides, and can be up to several megawatts (MW), and river turbine capacities range from several to hundreds of kilowatts (kW) (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Physical size considerations are based on the site, including length and width of the turbine blades and the height of the structure, which correlates to the amount of
electricity the system can generate. Spacing of the deployed turbine units will depend directly on the available area at the site, taking into consideration depth of the water resource and cross-sectional area.

River turbines exploit the kinetic energy of water flowing in unidirectional motion; therefore turbines must have a generator that captures flow from one direction. These differ from in-stream tidal systems, which ebb and flow, creating a bi-directional flow of tidal channels. Turbines deployed within in-stream tidal areas need a yaw and pitch mechanism to capture the flow of the water coming in and receding afterward (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). The engineering and development of a multiple application turbine—with the ability to capture both types of inland hydrokinetic energy—could reduce engineering costs. A multiple application device can increase the use of hydrokinetic technology because once a site is assessed the turbine can be deployed essentially “off the shelf,” no matter the inland location.

System Configurations and Placement

Hydrokinetic conversion equipment can be placed in multi-unit arrays to transform energy; these ‘fields of turbines’ act like a wind farm would on land. Designs of these multi-unit arrays depend upon the site assessment, bathymetry, available area, and use conflicts, such as transporting goods or recreational activities (Bedard, Previsic, Hagerman, Casavant, & Tarbell, 2006; Swanson, 2008). Each of these aspects listed above provides information determining the size of the hydrokinetic turbine field. There is also a difference in size, directionality, and placement between river and in-stream tidal systems that needs consideration when assessing areas for feasible deployment (Bedard, Previsic, Hagerman, Casavant, & Tarbell, 2006).

Design considerations include the velocity of flow, the width of the channel, and the needed amount of electric power output for the system to be economically feasible in that area. Each of these factors impacts the design of the turbines, influencing aspects such as blade width and length and turbine placement and
spacing within the channel. Duct augmentation is now being considered for hydrokinetic turbines (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Ducts help to channelize flow by capturing more energy and by inducing pressure within a constrained area. Duct augmentation was first considered for wind turbines, with little to no impact on the operation of the turbines; however, with hydrokinetic turbines the density of the water helps to increase the effectiveness of a duct. Duct augmentation also helps to regulate the speed of the rotor, which also reduces design constraints because the upper ceiling on flow velocity is reduced (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). This additional technology for hydrokinetic turbines also eliminates the need for a yawing mechanism, simplifying in-stream devices (Meade, 2005). Both horizontal and vertical axis turbines have experimented with ducts, and ducts are used on 30-50% of the turbines being researched (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Nonetheless, the companies interviewed as part of this study did not discuss duct augmentation as a feature of their installations.

Conversion devices must consider structural strength as well as survivability of the device within the waterway (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Structural strength includes the flotation of the device and/or anchoring of the device within the environment. Survivability deals with maintenance of the parts and materials used to create these turbines. If parts and materials will not hold up in the water, or if there are serious maintenance problems, they must be addressed before small-scale or commercial deployment. Both survivability and structural strength dictate maintenance needs and the economic operational costs after device deployment. Turbine design, in sum, must consider all aspects possible, including survivability, structural strength, and the assessment of deployment sites.

Rivers and tidal streams differ in their physical structure and geography, which will dictate placement of devices within each type of channel. The placement of hydrokinetic conversion devices depends on the cross-section of the channel, length of the area available, and depth of the resource (Khan, Iqbal and Quaicoe, 2007). Within in-stream tidal and river systems, turbines may be placed on the sea floor or riverbed, floating within the channel, or mounted to a near surface structure.
already built in the deployment site (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Placement constraints include (a) power generation capacity, (b) technical aspects such as instrumentation, and (c) non-technical aspects such as competing uses for the area (e.g., shipping, fishing and recreational boating) (Swanson, 2008). Because the energy flux on the surface is higher than that of channel-bottom, competing uses of the water stream will essentially reduce the effective usable area for the hydrokinetic system (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Water velocity is site specific, however, the quantity of energy flux in a certain area is diverse and depends upon the distance from the shore and the channel geography. A three-dimensional profile of a river or tidal stream can provide a better understanding of the bathymetry and characteristics of an area, which will help to choose the best placement option.

Different mounting schemes are needed for the three areas of hydrokinetic system placement, seabed or riverbed, floating, and near surface. Each turbine device (shown in Figures 5 & 6) is used with a specific mounting system, which is usually dictated by how the device is engineered. Proper mounting increases energy extraction and reduces energy impacts from competing uses of the water. Three different mounting arrangements are used, which include Bottom Structure Mounted, Floating Structure Mounted, and Near Surface Structure Mounted (Figure 7) (Khan, Bhuyan, Iqbal, & Quaicoe, 2009).

**Figure 7: Mounting Schemes for Hydrokinetic Devices**

placement near the surface of the waterway, accessing the largest energy flux. The last type of mounting arrangement, Near Surface Structure Mounted (NSM), has a structure that would be near the surface of the water. This could use a cable, wire, or large pole to keep device in place. Instead of floating as with FSM, the structure would be solidly placed and immovable.

Each mounting scheme impacts the waterway differently. The BSM creates a pathway above with less impact on navigation channels. This would help alleviate social concerns held by stakeholders and area residents, because recreation and social activities are only mildly impacted by the device. To the user and provider, it is a win-win situation: the waterway would still be available to be used in conjunction with the new alternative energy device. FSM and NSM arrangements are both located in the larger energy flux, however they also have a greater impact on the day-to-day uses of the waterway. These two types of arrangements would be able to harness more energy, which is typically more economical. Aesthetics are important, and may cause stakeholders to oppose projects with an FSM or NSM system; BSM would best suit areas where visual disruption would deter the project since the energy would be harnessed without any visible infrastructure.

Vertical turbines, in most cases, are floating or near the surface of the water in contrast to horizontal turbines, which are more likely to be moored to the bed of the waterway. Rivers tend to have devices designed for floating or near-surface applications, in contrast to tidal turbines – more apt for placement on the channel bottom. The difference between the river and tidal stream placement tendencies reflects constraints imposed by competing sea users and design challenges associated with floating structures. Within a tidal stream, the floating concept may have concurrent issues with wave energy technologies: the strength of the systems tend be incapable of withstanding the harsher velocities and weather that are synonymous with offshore generation (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Because tidal streams are more secluded, these have a better chance of extracting energy and surviving the environments. With rivers there tends to be varying bathymetry making it more difficult to use the bottom structure mounted technique. All information about hydrokinetic energy technologies, including placement, siting,
and devices were taken into consideration when developing the interview questions used to create the technology assessment of hydrokinetics.

Technological Status of Hydrokinetic Power Systems

The future status of hydrokinetic power systems is dependent upon overcoming the barriers associated with this type of electricity. The technology developed for harnessing hydrokinetic energy and producing power is not proven or standardized, and most devices are still at a proof-of-concept or research and development stage (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Each assessed potential site and the pilot technology that is deployed there acts as an experimental hydrokinetic project to gain knowledge about how the technologies perform in real-world settings. Advancements in hydrokinetic technology has recently occurred most through axial/horizontal and vertical turbines, which is due to a higher number of precommercial deployments bringing these systems to the forefront (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). Hydrokinetics were originally developed for remote powering applications, and were configured with inclined or floating horizontal turbines (see Figure 6); vertical and horizontal axis turbines had long been considered the primary choice for harnessing hydrokinetic energy (Khan, Bhuyan, Iqbal, & Quaicoe, 2009).

Currently, the hydrokinetic research companies view existing technologies as solutions for a wide spectrum of applications. This represents a new trend in hydrokinetic research towards multiple use application devices. However, devices are still being engineered for various types of rivers, in-stream tidal systems, channels and dams, with the technology being tailored to suit resource-specific needs (Khan, Bhuyan, Iqbal, & Quaicoe, 2009). In the past non-turbine systems were a larger part of the research and development of hydrokinetics. These concepts, including an oscillating hydrofoil and piezoelectric conversion, are currently still less developed than turbine system devices. Figure 8 shows turbine systems at different stages of commercial development. This graphic illustrates that turbine systems, both vertical and horizontal, are the largest portion of this industry
at a total of 76%. The largest number of turbine systems are currently at the ‘part-system’ phase, which is a barrier within this industry because each project gains knowledge on what will facilitate the commercialization and what may hinder hydrokinetic energy’s ability to become feasible at a commercial level.

The development of hydrokinetic energy confronts specific barriers that may cause problems for the technology. Some of these hindrances include biofouling, cavitation, and uncertainties with duct augmentation. Duct augmentation can be more effective with water because water is denser than air, hence the reason why although duct augmentation was unproductive with wind turbine technology, it has been increasing in testing with hydrokinetic turbine systems.

Biofouling, when underwater devices become encrusted with barnacles and algae (for example), can interfere with turbine operations. The use of anti-biofouling agents can help mitigate this problem. Anti-biofouling coatings are applied to systems, deterring organisms from leeching onto equipment and creating issues within the workings of the turbine (Bedard, Previsic, Hagerman, Casavant, & Tarbell, 2006). The use of fluids and coatings increase the risk of chemical toxicity, however the fluids and coatings used for hydrokinetic devices have been tested on offshore oil platforms. There have been no risks of chemical toxicity with the real world testing of these turbines. The anti-corrosion and biofouling technology used
on those platforms has lasted for fifty years of use (Bedard, Previsic, Hagerman, Casavant, & Tarbell, 2006). Lastly, cavitation can occur when the spinning blades create bubbles within the water. These bubbles can affect the moving mechanisms of the devices as well as impact the surrounding ecosystems with pressure and oxygen changes (U.S. Department of Energy, 2005).

Commercialization of hydrokinetic power stations is still in the future, and relies upon further R&D on engineering, placement, and grid connection of these systems. Currently, pilot project sites are those closest to commercialization. Pilot projects are demonstration facilities that are to be utilized for a short period of time to conduct research and necessary studies. The power generated from these test projects is not transmitted into the national grid (Wellinghoff, Pederson, & Morenoff, 2008). These pilot projects will help estimate the economic feasibility of hydrokinetic power by acquiring data on operational costs, infrastructure costs, and maintenance and repair.

The United States Department of Energy (DOE) provides grants to hydrokinetic energy projects to help offset the costs and risks that come with the testing and production of new technologies. As of April 2009, the DOE allotted an investment of up to $12 million dollars over two fiscal years (2009-2011) to develop and test hydrokinetic energy conversion devices and perform site-specific environmental studies associated with the operation, installation and maintenance of these devices (Manomet Center for Conservation Sciences, 2009). In September 2010, DOE invested another $37 million dollars in the advancement of this technology, reinforcing the significance of hydrokinetic energy and acknowledging that R&D funding is one of the biggest barriers facing this technology (U.S. Department of Energy, 2010).

In April 2011, the Department of Energy allotted even more funds to promote hydrokinetic power technologies. Projects to receive funding from this $26.6 million will be in different areas: sustainable small hydropower was allotted $10.5 million over 3 years, and advanced hydropower system testing at a Bureau of Reclamation Facility is to receive $2.0 million over 3 years (U.S. Department of Energy, 2011). Research, development and testing of low- to no- head small
Hydropower are considered part of hydrokinetics, and companies researching can apply to receive some of these monies from the government.

While the federal government is facilitating this technology, the R&D resources devoted to hydrokinetic energy development do not cover the full funding. Future funding for hydrokinetic energy projects is projected to increase as the technology advances and becomes more commercially feasible. The Secretary of the U.S. Department of the Interior, Ken Salazar, summarizes the goals of the United States government for funding of hydrokinetic technologies:

“Supporting advanced, environmentally friendly hydropower will help bring our nation closer to reaching the Administration’s goal of meeting 80 percent of our energy needs with clean sources by 2035...These funding opportunities will help unlock innovative approaches to hydropower development that emphasize sustainable, clean power generation while reducing environmental impacts (U.S. Department of Energy, 2011).”

Hydrokinetic Energy Policies and Permitting

The Federal Energy Regulatory Commission (FERC) is the agency that regulates hydrokinetic energy, including the permitting and licensing of power projects around the United States. This agency has identified specific eligibility requirements for applying and receiving a permit, license, or exemption on any hydrokinetic project\(^2\). As the hydrokinetic energy industry has advanced and expanded, regulatory reforms have been introduced that have added options for companies and developers such as an expedited license, a conditioned license, or becoming a test project site. These regulatory reforms are being implemented to enable the industry to develop more rapidly.

\(^2\) All information on the policy and permitting of hydrokinetic energy technologies can be found at the Federal Energy Regulatory Commission website: hydropower industry – hydrokinetics.

FERC oversees three types of issuances, including a preliminary permit, a pilot project site, and a project license. A preliminary permit allows a company to have the first option of assessing the area, and eventually testing turbines and installing devices. Under a preliminary permit, the developer or company may not build on or change the site in any way; this is strictly a permit that allows firms to gain information and have priority to apply and receive a license for that area in the future (Wellinghoff, Pederson, & Morenoff, 2008). The application process is lengthy, and a granted permit requires written reports every 6 months for the 3-5 year duration of the permit. If a company does not have a preliminary permit from FERC, then another company has the right to apply for and then use that area, even if it has not tested and assessed the area first (Wellinghoff, Pederson, & Morenoff, 2008). This permit also requires that on-going environmental monitoring be completed and included within the semi-annual reports, however the type of environmental assessment is not specified in the regulations.

An area deemed as a pilot project site gives the company a longer period of time for testing and implementation of devices. A pilot project permit allows companies to install turbines, collect data, and connect to the distribution grid, while preliminary permits only allow testing of the devices and no actual connection and use through the electricity grid (Wellinghoff, Pederson, & Morenoff, 2008).

In order to use an area for a longer period, a company must apply for a license through FERC, which would allow a company to operate at a chosen site for 30-50 years. A preliminary permit is required before a license is granted, but a license will allow the company to install more turbines, connect to the grid, and test the technology in a commercial setting (Wellinghoff, Pederson, & Morenoff, 2008). An array of turbines can also be installed at the site, providing more information on the commercial feasibility of hydrokinetic power as well as the electric power output of the system.

Along with FERC’s regulations, other federal agencies and the states have their own policies that must be followed. Other potential regulatory entities and issues include the Army Corps of Engineer construction permits, water use permits from state agencies, and environmental impact assessments for state and federal
governments. There are an abundance of policies that must be followed at both state and federal level, and the company applying for federal permits must prove they are in compliance with state guidelines.

The regulations through FERC were first based on conventional hydropower and power stations with fuel-based electricity generation, therefore if FERC streamlines the permit process and creates policies directly related to hydrokinetics, it would create a better political environment for hydrokinetic power production (Wellinghoff, Pederson, & Morenoff, 2008). Streamlining would promote the viability of this electricity source. Policies have been recently modified to promote the use of hydrokinetic energy technology; however further streamlining the permitting process, such as tailoring policies directly towards hydrokinetic power instead of using policies for conventional hydropower, would create a better political environment for companies to pursue this technology.

Summary

Hydrokinetic energy technology has drawn on the innovations and limitations of other renewable power sources, such as wind and conventional hydropower, to create hydrokinetic systems that harness the natural flow of river and in-stream tidal waters. These dam-less hydrokinetic power systems use the natural flow of water, without the need for hydraulic head, to capture and produce electricity. Site-specific parameters, including water resource attributes, environmental impacts, and economics, will heavily influence turbine designs and placement to capture the most energy for electric power production. Information about sites is needed to understand placement locations, arrangements of turbines, positioning within the channel, size of turbine, and other particulars. Hydrokinetic devices are still in an early stage of development, and therefore each site where turbines are installed is seen as an experimental site. As a consequence, the technological barriers to the future commercialization of this technology include: a wide array of applications for hydrokinetic turbines and the immense differences between placement sites with the common denominator being large amounts of energy to be harnessed.
Federal policies are attempting to overcome these barriers by introducing further funding for hydrokinetic testing and connection and allowing for testing to occur with fewer restrictions. The increase in funding helps to offset the overall costs, which is the most important aspect of developing this technology because companies are still not allowed to receive monetary compensation even if they have connection to a utility grid. Preliminary permits still only allow for the assessment of a site and give preferential access to the assessed area. In order to pursue the area further, a license is needed, and through FERC, these licenses have become easier to obtain with the increase in research and development that has been done within this sector.

Hydrokinetic power production must adhere to federal policies alongside state specific permitting to further research, develop, and deploy in the future. Although policies can change and become more lenient with the amount of research and testing completed, certain regulatory protections will stay in place and most likely not change. Environmental assessments of the areas being used for hydrokinetic research, development, and possible implementation is needed to understand current impacts as well as future impacts of this technology. Protecting the environment is a main reason why hydrokinetics cannot just be developed, implemented and directly connected to the grid; making sure that future impacts will not negatively affect the surrounding areas is important. Federal policies can eventually promote hydrokinetic power production and connection, as long as hydrokinetics continue to track and assess the environments in which they implement this technology.
Chapter 3: Technology Assessment and Criteria

Technology assessments are a way of evaluating the feasibility of an emerging technology relative to a variety of criteria, such as economic costs, social and cultural acceptance, technological barriers, and environmental impacts. A technology assessment of hydrokinetic energy within the United States can provide information about the feasibility and future possibilities of this technology. By obtaining information directly from hydrokinetic energy technology companies, issues, problems, and opportunities can be highlighted that affect further implementation of inland hydrokinetic systems.

The technology assessment conducted here includes specific criteria about the development and impacts of hydrokinetic power as well as perceptions by companies operating pilot hydrokinetic power stations. Companies willing to be interviewed were contacted, and information from these interviews helped evaluate the hydrokinetic power sector and provided information about the future of the industry.

*Technology Assessment Overview*

Science and technology innovations continuously remake society, and vice versa. Technology assessments were first implemented to provide unbiased information to show possible positive and negative future impacts of technological advancements prior to an effect on the environment surrounding the technological innovation – which could be anything from environmental to health-related to science and technology itself. Assessments can inform and support natural science and engineering research and also provide a mechanism for observing, critiquing, and influencing social values as they become imbedded in innovation (Guston & Sarewitz, 2002). Technology assessments as a category of assessment encompass a wide array of social research methods that attempt to anticipate how research-based technologies will interact with social and environmental systems. Eijndhoven
(1997) identified eight basic social functions (or roles) of technology assessment; these are presented in Table 1.

Table 1: **Identified Functions of Technology Assessments**

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<td>1</td>
<td>Political and administrative attempts to obtain stronger influence in decision making by widening their sources of information in respect to scientific and technological developments</td>
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<td>2</td>
<td>Support short-term policies in the framework of current policies, suggesting explorations of alternatives, providing evaluations, and legitimating current policies</td>
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<td>3</td>
<td>Contributing to development of long-term policies</td>
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<td>4</td>
<td>Early warning of possible problematic or undesirable consequences of technology developments at the earliest possible stages</td>
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<td>5</td>
<td>Expanding knowledge and decision making about technology by giving support to societal groups to form strategies with respect to technological developments</td>
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<td>6</td>
<td>Tracking down, formulating, and developing desirable and useful technology applications for society</td>
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<td>7</td>
<td>Encourage the general public to accept the technology</td>
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<td>8</td>
<td>Promote scientists’ awareness of their social responsibility</td>
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(Eijndhoven, 1997, pg. 270)

All of these functions are not necessarily of concern for any given technology assessment. However, there are three major elements that must be considered in a technology assessment: the concern about the consequences of new technology, the need for assessments prior to large technological projects, and the demand for more involvement from stakeholders (Eijndhoven, 1997). Each of these criteria contributes to an assessment that provides (in principle) unbiased information to stakeholders about the possible impacts of a new technology. Joe Coates discussed technology assessments at the opening session of the first European technology assessment conference in 1987 and stated:

*Technology Assessments are a “bridge between experts and the public forum, the translator of technical information into public language for debate and decision.”* (Eijndhoven, 1997)
The basis for a technology assessment is thus taking information about technological advancements and providing knowledge for the public to consider regarding decisions about the development of a technology. In order for a technology to influence society in a positive way, it must ideally be embedded into the social actions of the public. The provision of information to the public is an underlying aspect of a technology assessment, they are not just used for policy creation and understanding future impacts.

A type of technology assessment closely related to the one presented in this thesis is called a constructive technology assessment. Technology evolves in close interaction with societal systems, and assessments can only be made when anticipation, reflection and learning take place within the development process, resulting in better technologies, with more positive effects and fewer negative impacts (Eijndhoven, 1997). Technology assessments can impact the technological development process, with the capability to influence and shape how a technology is developed. By understanding how technology is connected to society (and vice versa) and assessing technologies at an early stage, technology development could change, thus increasing the potential for positive impacts and decreasing the potential for negative ones.

Hydrokinetic Power Technology Assessment Criteria:

Information about and from the companies that are utilizing hydrokinetic energy technologies can help to frame our understanding of the diverse placement of these devices in the environment. The technology assessment did not delve into specifics of the companies themselves, but focused on six primary categories of information: (1) the site, (2) the water resources located within the area, (3) the technology, and (4) the policy/permitting process, (5) environmental impacts, (6) economics. Each of these categories reflect site specific details about the technology; even though there may be similarities across sites (especially with the permitting and licensing processes), because hydrokinetic energy is a new technology with non-standard
designs, the technology assessment criteria are still grounded in site-specific conditions. Each of these categories is summarized below.

(1) Site – The recurring theme throughout all of the discussions on hydrokinetics is that this energy technology is site specific. Not only is looking at the geophysical characteristics of a site necessary for the placement of hydrokinetic devices, but the city or village where implementation has occurred reflects the diversity of places where hydrokinetics can be used. The reason for choosing a defined area for a company is important, giving insight into what makes an area attractive for hydrokinetic energy technologies.

The installed capacity of the power generation equipment helps to develop a sense of the total amount of energy available for extraction from a site. Current installed capacities, or the number of devices currently deployed, were also explored in addition to the total number of devices that could eventually be deployed within the available area.

(2) Water Resources – The water resources are the basis of why certain sites are chosen for further assessment rather than others. The velocity of the water in the area of deployment is directly proportional to the amount of energy that can be captured. Also, the devices used at the sites are usually chosen based upon the velocity and the amount of area available for placement. The cross-sectional area helps to model the space that can be utilized for turbines; this helps estimate research deployments and full capacity deployments within each site. Cross-sectional area is a determining factor of whether a site will be able to handle the amount of turbines needed to offset the amount of electricity use in surrounding populations.

Energy flux is explored specifically as well because it is higher on the surface and can impact the mounting scheme used at a site. Energy flux should be taken into consideration when choosing a turbine for different locations; however, companies may have based their site selection upon the device they engineer and will inevitably use. Either way, the placement area and the turbines that are used
are dependent upon one another significantly. When assessing the specifics of the water resources, an overall question of "why here?" is the best way to understand location choice. Why are the water resources within the area good for hydrokinetic technology deployment? Although findings appear to be based on the opinion of the interviewee, these will most likely reflect the results of tests that determined velocity and the amount of energy that can be extracted without detrimental effects upon the environment.

(3) **Technology** – Questions about the technology used within the chosen area will help to understand what turbines are best for specific sites and if those devices are similar ones used in other hydrokinetic areas. The technology can also dictate the site that is chosen; if the company manufactures a specific technology and they want to use that particular device, an area will be chosen that can handle the turbine(s). The type of hydrokinetic energy that is harnessed at the site will also have an impact upon the type of device that can be used, therefore it is important to note if the water system is free-flow or tidal stream. The devices chosen for the area may be more heavily influenced by the geophysical properties of a site, or sites may be selected based on their best match to a company’s own technology.

The device’s efficiency is also an important aspect of the technology and the technology assessment, since it influences economic feasibility. If the efficiency of the device is very low, then even if the resource has a huge potential for energy capture, the device negates the resource and will produce less electricity than needed or possible.

(4) **Permitting/Licensing and Policy** – Hydrokinetic energy technology is a new technology that does not have much of a policy history or regulatory precedent. Because new precedents are being set, the process to receive deployment permit or license is long. The current status of the permits, licenses and policies surrounding each site may have similarities, because hydrokinetic energy is a new and growing technology. However, differences will occur depending upon the resource location and the devices installed. All information on hydrokinetic energy technology is site
specific, the permit and licensing processes will depend upon site location and may be tweaked for different assessment and deployment areas. Therefore specific licensing and permitting processes set in place by the FERC may change on a site-to-site basis and can affect the overall feasibility of a project.

(5) Environmental Impacts – Protecting the environment when the addition of new technology occurs is an important aspect. Questions arising about environmental impacts of the technology and the assessments being completed for the sites where hydrokinetic power production schemes may be implemented is extremely important: keeping track of positives and negatives and keeping the environment safe from any detrimental effects. Most of the questions regarding environmental impacts were broad and could be answered with the provision of public assessments conducted by the companies, or could not be answered completely due to the lack of data gathered for that topic currently. Those that are pursuing hydrokinetic power technologies and do not have specific environmental impacts recorded, are conducting continuous monitoring throughout the assessment site(s).

(6) Economics – The economics behind hydrokinetic electricity is important to understand because it will influence the eventual cost to the end-user. If the costs of researching and developing this technology outweigh the revenue that the industry may make per kWh, then it would not be economically beneficial to pursue this type of electricity generation. However, offsetting non-renewable electricity sources will increase energy security, and is a benefit to our society overall. The eventual cost to consumers may have to be offset by some economic cost-lowering techniques in order to expand this electricity type, however once on the market, it is possible that this type of electricity would be less expensive and comparable to the cost of conventional hydropower. Questions arise about the economics and costs associated with developing and implementing hydrokinetic energy technologies, and therefore must be discussed within the technology assessment in order to get a full view of the technology.
The technology assessment conducted here explores these six categories to identify real or potential barriers that hinder the diffusion of hydrokinetic technology as well as factors that have facilitated the technology. The issue is whether the development of this technology is so site-specific that general conclusions about barriers and opportunities cannot be drawn. However, this research shows that a number of general findings about this technology are possible. The sections below detail the methodology for conducting the assessment.

**Methodology**

This technology assessment is based on research of publicly available resources as well as interviews with companies involved in the hydrokinetic power industry. Companies best suited for interviews were identified based on their actual deployment or testing of in-land hydrokinetic power systems in the U.S. Information about the companies was collected directly from company websites. These websites provided information about how the companies were formed and their missions regarding the feasibility of hydrokinetic energy technologies.

The interviews and questions were designed to gain information about specific sites where hydrokinetic energy plants have been installed around the United States. By synthesizing answers of the interviews into an assessment, it identifies characteristics that must be present at locations of hydrokinetic energy extraction as well as factors that may not be as critical to implementation.

Annual reports and other public documents were also explored to obtain information about hydrokinetic installations. Finally, some critical information may be missing because of the proprietary nature of these technology projects, and the concerns companies may have about publishing or sharing such insights. Thus this assessment may not be as fully developed as otherwise, leaving some questions unanswered.
Interview Questions

Interview questions were designed to obtain information about the six assessment criteria discussed previously: (1) sites, (2) water resources, (3) technology and devices, and (4) policy and permitting, (5) environmental impacts, and (6) economics. The last two criterion discussed within the assessment were developed, included within the interview and are very important aspects of this technology, however the emergent status of the sector indicates that much of the information regarding these sections is unavailable. The economics of hydrokinetics was also explored in terms of its comparability to the electric power fuels currently used by the company in other applications. The interviews conducted contained the following questions and criteria:

Name (of interviewee):

Organization/Company Name:

- Do you have an annual report or other public document about your company’s hydrokinetic technologies? May I have a copy?
- As we explore the questions below, please make sure to indicate which, if any, of your answers involve business confidential information.

Site Specific:

- What is the location of the Hydrokinetic Technology site? (If there is more than one, please answer each question for each specific site)
- Why was this site chosen?
- How do you characterize the water flow at the site? What is the amount of primary energy of this site?
- What is the installed capacity of turbines at this site?
- What is the capacity factor at the site for a turbine?

Water Resource specifics:

- What is the velocity of water resource in specific area of assessment/deployment?
- What is the cross-sectional area of site?
• What is the energy flux of the specific site?
• Why are the water resources within the area good for the deployment of a hydrokinetic device?

Technology specifics:
• What type of hydrokinetic energy is being used?
• What specific device is being tested or deployed in this area?
• Why was this device chosen?
• What is the efficiency of the conversion device? (The amount of production vs. the amount used when connected)

Permit/Policy specifics:
• Describe the current status of the licenses and permits for this site.
• Describe the process that the site went through in order to gain licenses and permits as well as assessing/deploying in this site.
• What barriers/problems have hindered the diffusion of this technology in this site?
• What has facilitated this technology within this site?

Additional Information:
• What kind of environmental impact assessment did you have to do on this site? Do you have a public report of the environmental impact assessment?
• Describe the economics of hydrokinetics compared to other electric power generation (cost of construction, charge per kW/h, etc.).

The questions and statements above are each important to the discussion of the present state of hydrokinetic energy technology. The commercial feasibility of hydrokinetics is still not fully understood, however, knowledge gained by the technology assessment will help create a better understanding about hydrokinetic technology and its role in the future of electricity.

Interview Process
The process of interviewing companies for the technology assessment began with a list of companies conducting R&D on hydrokinetic energy technologies. These companies were on a master list of all hydropower firms created by FERC (Federal Energy Regulatory Commission, 2011). There are 109 companies conducting R&D on hydrokinetics in the United States, which includes those trying to implement offshore generation (Energy Efficiency and Renewable Energy, 2010). The FERC list includes all projects at all different stages of development; therefore some of the companies had no actual technology device or FERC permit; the companies are simply somehow working on hydrokinetic energy technology.

The FERC master list was narrowed to companies with sites strictly dedicated to free-flow river currents and in-stream tidal systems. The companies that were assessing sites or deploying turbines in rivers and tidal streams were then contacted by email and asked to participate in the technology assessment. A total of ten companies were contacted; of those ten, three of the companies agreed to participate in the interview process.

Each company received the interview questions prior to the phone interview that was conducted and were asked if they were willing to participate. The three companies willing to participate in the interview process, either by a direct phone interview or by answering the questions and returning the answers by email were Alaska Power & Telephone, Verdant Power, and UEK Systems. These companies answered most of the interview questions; however, some questions were not answered because of company policy or because the company did not have the answer to specific questions. Many of the companies unwilling to be interviewed were reluctant to provide information about their hydrokinetic energy R&D because of the increased competitiveness within this sector. The companies that did participate were aware that all information provided during the interview would be recorded and then evaluated for this thesis. Because the information would be public, prior to the start of each interview I stated that if, for any reason, there were questions the company did not want answered publicly, they should decline to answer.
Alaska Power & Telephone

Alaska Power and Telephone Company (AP&T) is a noted, progressive utility, providing service to remote places and improving infrastructure throughout the state of Alaska. AP&T has supplied low-cost, reliable electric power and communication services to rural Alaska for 39 years (Alaska Power and Telephone, “Alaska Power…”, 2011). This company is employee-owned and community-minded. Many of the people working at AP&T are lifetime Alaskans, and current or retired employees own over three quarters of the company’s equity. Terrain, geography, and weather are challenges that AP&T must overcome as they provide service to communities located above the Arctic Circle, deep in the Wrangell Mountains, and throughout the islands of southeast Alaska (Alaska Power and Telephone, “Welcome”, 2011). These are some of the most remote locations in Alaska, and AP&T’s goal is to modernize more of the state and its utility infrastructure.

Alaska Power and Telephone Company is a utility company and is therefore not strictly based on hydroelectric generation; however, the company has more hydroelectric projects on line, under construction, or in planning than any other investor owned utility in Alaska (Alaska Power and Telephone, “Alaska Power…”, 2011). The continued quest to harness renewable resources is a mix of modern technology, environmental priorities, and the ability to tackle complicated engineering problems. This company helps to integrate modern technology within rural and remote locations, increasing the connectedness of Alaska as a whole, and improving the modern amenities (Alaska Power and Telephone, “Alaska Power…”, 2011). AP&T works with an integrated set of stakeholders to provide the best electricity and other utilities possible. They work with landowners, federal and state managements, resource agencies, consumers and local governments to offer safe, reliable, and reasonably priced utilities (Alaska Power and Telephone, “Alaska Power…”, 2011).
In Alaska, they are dependent upon diesel fuel in many of their remote locations because of the useable infrastructure in place (Alaska Power and Telephone, “Alaska Power…”, 2011). However, the ability to engineer better alternatives, such as hydrokinetic projects, may reduce dependence upon fossil fuels and possibly provide electricity from renewable sources for rural and remote locations.

Verdant Power, Inc

Verdant Power is a New York City based company, specifically specializing in marine renewable energy and is considered to be a world leader in this sector. This company began in 2000 as technology developers, and partnered with utility industry veterans to advance the construction and operation of electricity generation facilities, specifically hydropower (Verdant Power, “Who we are”, 2009). The cross over between developers and utilities helped bring about the turbines engineered through Verdant Power. These turbines are not only being tested within the United States, but all around the world, connecting communities to renewable resources for electricity (Verdant Power, “What we do”, 2009). Verdant Power Systems employ underwater turbines to generate clean energy from the currents of tides, river, and manmade channels, depending upon location, and these systems are invisible from the shoreline.

Verdant Power’s mission statement is “[Verdant Power]...helps build sustainable communities around the world,” and in order to comply with this mission statement, the company is based on four core values: integrity, care, collaboration and creativity (Verdant Power, “Mission & Values”, 2009). These core values come through in the work that the company does: designing turbines as well as assessing and implementing hydrokinetic technologies for real world use. Verdant Power approaches the products and services they provide with a commitment to relationships built within outside communities (Verdant Power, “Mission & Values”, 2009). Verdant assumes responsibility for the earth’s resources, and care implies that there will be continuous learning and development in the
enterprise and communities. Collaborations are built to be deep and effective between the company, customers and stakeholders. Verdant power creatively applies their experience and insights in designing to deliver their products and services. These core values are important to understand Verdant Power’s ability to integrate their technologies in the real world.

**UEK Systems**

Philippe Vauthier, the founder, innovator, and visionary of the company, started UEK in 1981. UEK is based upon the turbine technology created and patented called the underwater electric kite, hence the name UEK (UEK, Underwater Electric Kite, “History”, 2010). This company is strictly based on engineering and designing ways to harness river, tidal, and ocean currents to provide electricity generated by hydrokinetic turbines. UEK headquarters is in Maryland, however much of the research is done at universities around the United States (UEK, Underwater Electric Kite, “Welcome”, 2010). The company’s prototype turbine has been designed and tested since the inception of the company. This patented turbine is the reason for the creation of the company, and therefore the underwater electric kite will be deployed at any site used for hydrokinetic energy capture (UEK, Underwater Electric Kite, “History”, 2010). Information about UEK available on the website is dedicated primarily to the underwater electric kite turbine, which indicates that the turbine describes the company and its promise to further research and development to increase the feasibility of capturing flow and generating electricity.

**Summary**

This technology assessment is based on six key criteria (site, water resources, technology, policy, environmental impacts, and economics) and explores these criteria with publicly available resources as well as company interviews. The methodology of the technology assessment is straightforward; companies to be interviewed were chosen based on the information from a master list provided by
the Federal Energy Regulatory Commission. Information on the companies interviewed was gathered to understand their diverse locations and gain some background information about their involvement with this technology. Questions were designed to assess the overall feasibility of this technology, especially given its site-specific design and operational context and to identify barriers and opportunities related to the further development and commercialization of inland hydrokinetic systems.
Chapter 4: Analysis and Findings

The technology assessment of hydrokinetic energy takes into consideration that technological advancements impact society. It is important that the information contained within the assessment be available for the public to understand the changes made in this sector, from conventional hydropower to hydrokinetic electricity systems, as well as indicate the needs for the technology to become a feasible source for electricity as the sector develops and grows. I assessed the need for hydrokinetic energy technologies and the connection between conventional sources of hydropower moving toward a new type of technology. Companies that are developing ways to use the free-flow of rivers and tides within tidal stream areas are at a nascent status, however they are rapidly growing in number as well as gaining information to feasibly extract energy and produce electricity for practical use. It is necessary to understand how site specific this technology is, as well as specifics about the assessment site, including: water resources, proximity to users, and the device technologies that are best suited for deployment sites. The criteria looked at for this technology assessment began with very common questions that are the basis of any new technology: environment, economics, barriers and facilitators, and impact on the surrounding populations. These concepts were then developed into interview questions specific to the hydrokinetic energy technology sector, to gain as much knowledge of the current situation on hydrokinetic devices and deployment as possible.

Hydrokinetic energy technology site placement is very diverse. Because of the ability to use a variety of different environments for free-flow and tidal stream devices, the technology assessment was carried out to help compact the amount of information on hydrokinetics. Also, by creating concise information, it is possible to view the important facts about placement, inevitably helping to depict more possible sites for this technology in the future of hydrokinetic technology, and assess the feasibility of hydrokinetics as a source of electricity. In order to perform the technology assessment, I developed a process to identify impacts between society and the technology. That then evolved into interview questions used to
collect information from companies currently researching, developing, and implementing hydrokinetic energy technologies, to see how the companies plan to proceed with the technology and increasing awareness about hydrokinetic power. The information attained during the interview questions was compiled into one spreadsheet providing a basis for the synthesis of statistics about hydrokinetic energy technology. The technology assessment needed to be evaluated after all information was combined, and after reviewing the findings, a more in-depth overview of present hydrokinetic energy and its future as an electricity source can be seen.

*Technology Assessment Specific to Hydrokinetic Energy Technologies*

The criteria for this technology assessment emerged from common questions about the feasibility of any new technology: potential environmental impacts, economic costs and benefits, technical and market barriers and facilitators, and impact on the surrounding communities. These criteria were then developed into interview questions specific to the hydrokinetic energy technology sector to gain as much knowledge of the current situation on hydrokinetic devices and deployment as possible from the three companies that were interviewed.

Hydrokinetic energy technology site placement is very diverse. Because of the ability to use a variety of different environments for free-flow and tidal stream devices, the interviews with companies were carried out to help consolidate the information on hydrokinetics. Interviews were conducted with companies currently researching, developing, and implementing hydrokinetic energy technologies to see how the companies plan to proceed with the technology and increase awareness about hydrokinetic power.

The information collected from the interviews sheds light on opportunities, obstacles, and barriers regarding the adoption of hydrokinetic energy technologies. Answers to the interview questions were synthesized by assembling them into a spreadsheet by question and category. By combining all the information attained from the interview process, the answers provided information for the six categories:
Sites, Water Resource Attributes, Turbine Technology, Policy and Permitting, Environmental Impacts, and Economics. These categories provide a logical grouping of the technology factors and discussions pertaining to the overall feasibility of this new alternative electricity source. In the discussion below, results of the interviews were synthesized to avoid revealing potentially confidential information about the companies.

Sites

The sites for which information was gathered have commonalities, suggesting that there are certain requirements for the deployment of hydrokinetic energy technologies regardless of location. The locations of possible hydrokinetic power stations around the United States differ in many ways, however they are all near an end-user community load. These loads represent remote locations or more populated areas where the hydrokinetic electricity could alleviate peak use or offset the generation from fossil fuel power. In either scenario, with the siting locations in close proximity to the end users, the cost of grid connection and needed infrastructure would be lessened. With hydrokinetic power sites, locations may be an obstacle or barrier. The most productive sites may be in extreme remote locations where generating electricity would not be cost-effective, because end-users would not be available to use the electricity produced or costs for connecting to and transmitting through the bulk power grid would not be profitable. Proximity to a community load, with a site large enough to provide a suitable amount of electricity to impact the surrounding community, increases the feasibility of hydrokinetic power. Sites that not only provide an adequate amount of electricity, but are also close to a user load, increase the feasibility of hydrokinetics around the United States.
**Water Resource Attributes**

In addition to proximity to loads, other attributes were also present at each site: high water velocity and deep river or stream depth. Hydrokinetic energy technologies must be located in areas with certain characteristics in order for the technology to operate effectively. Water velocity is extremely important when discussing run-of-the-river and in-stream tidal systems for hydrokinetic power. The larger the velocity of the water resource, the more energy can be extracted, increasing cost-effectiveness. One company stated that, technically, smaller velocities do have the capability to produce electricity from hydrokinetic turbines, but the lowest velocity that must be present to spin an installed turbine is 1 m/s. Therefore, any rivers or streams that have a velocity of at least 1 m/s potentially have the ability to generate electricity from hydrokinetic devices. When synthesizing the water velocity information across all three companies, the minimum average flow at these sites is above 2.0 m/s, suggesting that most hydrokinetics require a water velocity above 2.0 m/s to potentially be feasible from a cost and power output perspective.

Another key water resource attribute is the cross-sectional area of the resource. The greater the cross-sectional area, the more turbines can be installed, increasing total electricity generation. The cross-sectional area includes depth and width; the water needs to be deep enough to accommodate the turbines to prevent interference with other resource users, such as navigation, and the water velocity needs to be adequate enough to capture energy impacting electricity in surrounding areas. Width, in accordance with the cross-sectional area, allows the use of more turbines; increasing the space in which they can be installed and in return increasing the amount of electricity that can be produced. However, cross-sectional area is more important that basic width and depth because it takes into consideration both aspects at the same time, therefore being able to describe the water resource much more accurately.

The water resource must also be available for a prolonged period of time throughout the year to install and test hydrokinetic turbines in real-world settings.
Remote areas that freeze through the winter months may make it difficult to complete research in order to install and monitor devices. With the inability for year round testing and monitoring, certain water resources may prolong the implementation of hydrokinetics. This may or may not deter from testing and installing the technologies in harsher climates, because these water resources may have an abundance of other qualities possibly providing large amounts of generated electricity if turbines were installed.

_Turbine Technology_

The turbines used for the capture of the water’s flow in this technology assessment are all free-flow, run-of-the-river systems or in-stream tidal systems. Regardless of site and placement, turbines that can harness the energy from the water in free-flow or in-stream tidal systems work in similar ways; the water spins the turbines, which moves within the generator, converting mechanical energy of the device into electrical energy.

The devices currently being tested and installed by the companies interviewed for the technology assessment have structural differences. One specific device is manufactured with 3 blades, similar to a wind turbine. These turbines have a horizontal axis and are single turbines mounted on the bottom of the stream system by gravity-based pylons, not drilled into the riverbed. Another device discussed within the interviews is constructed of two single turbines deployed side-by-side making an 8ft by 16ft square turbine. These will most likely be mounted in a near shore mounting scheme in order to decrease the disturbance of the navigable channels. Some companies deploying hydrokinetic devices engineer and manufacture their own turbines, which is why companies chose those specific models to implement. The site for those companies is chosen based on the turbine and its ability to work within that area. In opposition, other companies choose a location first and the device used was applicable to the project constraints: meeting the schedule and amount of money that was willing to be paid. In these cases, companies contract out the responsibility of engineering the turbine. By focusing
upon the site and installation instead of manufacturing, certain sites could be implemented and connected to the grid faster due to more attention on the implementation process and less on engineering the devices. This could be proven in the future; however, it is interesting to contrast the companies creating their own devices and those that contract through other companies.

The efficiency of the turbines tested and installed gives insight into the amount of energy harnessed and eventually converted into useable electricity. The efficiency of hydrokinetic turbines ranges from 30% upwards to approximately 60%. These numbers may be theoretical, depending upon the how the devices were tested: in actual sites where the current is harnessed or in a closed testing site to see how well turbines may work in a real-world setting. This information suggests that each type of turbine would be able to convert an average of 45% of the water flow into electricity, which is currently more than solar and wind technologies.

Choosing a device to potentially harness a large amount of the flow within the project site is crucial for hydrokinetic power. The turbines themselves are not an obstacle or barrier for attaining hydrokinetic power because the engineering and testing would promote the use of such turbines. A barrier would likely be the cost of in-house engineering and/or the cost of contracting out that responsibility.

Policy and Permitting

The permits and policies governing the hydrokinetic energy sector began with those already in place for conventional hydroelectricity as well as those permits needed for conventional electric power stations. FERC currently oversees the use of hydrokinetic energy technologies. As discussed in chapter 2, many companies apply for preliminary permits for specific areas giving them sole right to do what they want with that site, which is in conjunction with the companies interviewed to assess the technology. With a permit for an area, those companies have the first option to test, deploy, and install turbines. Without a permit, another company can step in, attain a permit and use the area prior to the first company. One company that was interviewed chose to pursue a pilot project license, which gives them a
longer period of testing and implementation. These pilot projects allow companies the right to install turbines and collect data from actual use and grid connection, while preliminary permits only allow turbines to be tested, not directly connected to the grid. In addition to a longer testing period and the right to connect to the distribution grid, companies that have applied for a pilot project license can also install more turbines within the licensed area, furthering the abilities of a hydrokinetic power station. Most companies deploying hydrokinetic turbines have filed through FERC to attain a preliminary permit, guaranteeing their company has the right to use the areas they had researched (Federal Energy Regulatory Commission, 2011).

Each of the companies interviewed have hydrokinetic sites located in different areas of the United States, and are governed by different policies and permits needed for the implementation of hydrokinetic energy technology. Each state in the US has its own regulations concerning the environment; therefore, each site would go through State dependent channels in order to become operational. The specific permits that should be applied for and may be required for a hydrokinetic power station are dependent upon the State in which the site lies. State permits and policies that the interviewees obtained were: Army Corps of Engineers permits, water use permits, submerged land use permits, habitat permit or a review of the environment, and all needed to be in place before a permit application to FERC is completed. All the information necessary for the permits is shared with FERC during the application of the preliminary permit. Each site will need State permits because each site has state policies and regulations that must be followed, prior to obtaining the federal permits. Within the companies interviewed, all of the sites being used have completed the necessary State permits in order to complete further permit and policies needed for implementation of hydrokinetic power production technologies.

The permitting process is seemingly different between companies because the process must take site specifics into consideration. Besides the differences, each company still gravitated to the same course of action: applying for a preliminary permit and then choosing to go from there, in which ever direction they felt best for
their company. With information gathered from the interviews, if FERC streamlines their permit process, and creates policies directly for hydrokinetics, then it would help to promote hydrokinetic energy as a viable source for electricity. These regulations that hydrokinetic energy technologies must follow are dated and certain portions are unrelated to this type of electricity generation. By creating policies that apply only to hydrokinetics, instead of using those that are connected to other conventional methods of waterpower, it will make it easier for companies to invest their money and time into this renewable source. The policies surrounding hydrokinetics creates problems with moving forward with this technology and being able to use the produced electricity to, at the least, offset current electricity production.

*Environmental Impacts:*

The environmental impacts of hydrokinetic energy technology and its implementation in real-world settings are still uncertain. It is understood that large conventional hydropower has larger and longer lasting impacts than those that are known to come from hydrokinetic energy technologies, however, environmental monitoring is a necessity to make sure that future impacts do not occur (Sternberg, 2008; Sternberg, 2010).

Currently, full environmental impact assessments surrounding the areas of implementation are not required as discussed by the interviewees; monitoring in and around the river or stream is being conducted through the companies that may implement in the future. Monitoring of the environment in these areas is being conducted by the companies themselves to make sure that the impacts to the environment are not negative or detrimental in any way. Environmental monitoring is separate from a full environmental impact assessment because it is based on a day-to-day analysis and is ongoing. With the full EIA, the environment is assessed in the greatest detail possible for a period of time and then a conclusion about the area is made: whether or not the site has the abilities needed for the technology, or if any impacts are occurring with the level of development that was already completed.
Currently, the monitoring and the data collected must be supplied to FERC through the permit and/or license applications for hydrokinetic sites. Some companies have currently completed full reviews of the environment completely unaware of the type of monitoring needed. According to one company interviewed, millions of dollars were spent to conduct research to make sure that hydrokinetic energy is safe for the environment prior to implementation, because at that time no one knew how to perform an EIS in an area with this technology. By pinpointing exact environmental monitoring techniques that should be used, the amount of money spent on environmental impact assessments can be reduced, providing funds to dedicate to other aspects of hydrokinetics. Environmental assessments would evaluate the water resource and the surrounding areas to make sure any infrastructure for hydrokinetic power stations would have little to no impact on land and aquatic species. One company discovered certain species on the site’s shore, therefore monitoring in all areas of the site are needed to reduce any possible impacts. Each demonstration of hydrokinetic turbines has monitored the environment to show possible impacts, and currently there have not been significant impacts to the hydrokinetic sites (Khan, Bhuyan, Iqbal, & Quaicoe, 2009; Wellinghoff, Pederson, & Morenoff, 2008).

**Economics:**

Because hydrokinetics as an alternative energy source is still becoming established, the costs and benefits surrounding this technology are not fully understood. According to the interviews, the economics need to take into consideration not only the cost of installation and implementation for grid-connected electricity, but also the cost of contracting engineers for the turbines, manufacturing turbines, transportation of equipment to the hydrokinetic sites, and the barges and infrastructure needed for installation. Interviewees indicated that this technology would be more expensive in remote areas due to more limited infrastructure (roads, distribution lines, substations, and so forth) to promote the installation. If there is an established road infrastructure surrounding hydrokinetic sites, then it would not
impact the costs of installation, even if the sites are isolated from larger populations. If companies manufacture their own turbines for the use in their permitted sites, then those companies would not need to pay out or contract the use of turbines through another company, however, they do need to bear the costs of engineering the devices.

Most companies that are developing the technology for hydrokinetic electricity do not disclose costs, most likely because the costs and benefits have not yet been concluded because of the infancy of hydrokinetic power. In order for hydrokinetic electricity to be feasible in the future, there will need to be cost lowering techniques, because this will not be a viable source unless the end cost to consumers is marginal to the cost of other sources of electricity. Information on the specifics of techniques that may be used for lowering costs were not mentioned within the interviews, but exploring different options and possibilities will be crucial to the eventual connection of this electricity to end-users.

The length of time for feasibly using hydrokinetic energy technologies depends upon the creation of policies tailored directly towards this technology, as well as the compensation that companies may receive for their efforts in alternative energy. The companies interviewed have all tested turbines in the natural environments, and could feasibly harness energy, convert it to electricity, and use it to power surrounding areas, but capital is needed in order to continue. Monetary funds through the Federal Government are set aside for researching ways to offset the use of fossil fuels, and therefore companies can apply to receive grants and capital for hydrokinetics. This, however, would only provide certain companies the ability to continue researching this technology. The regulations associated with FERC permits do not currently allow for monetary compensation for the electricity produced by hydrokinetic turbines (Wellinghoff, Pederson, & Morenoff, 2008). In order to be monetarily compensated, companies must obtain a license to further research and commercialize, then possibly gain capital from their work. Verdant Power is currently connected to the grid, but must pay for the amount of electricity that they are offsetting the utility company within their area (Verdant Power, 2009). This company’s efforts are presently powering a grocery store and parking garage
for free in order to gain more knowledge about how turbines work when connected to the grid. Of the companies that were interviewed, none of them are receiving any compensation for their research efforts; however, an increase in competition and data collection from hydrokinetics commercialization is not far into the future.

*Barriers of Hydrokinetic Energy Technology due to Conventional Hydropower*

Conventional hydroelectric power generation has created barriers for hydrokinetic energy technologies because of the negative impacts that it has had on the environment previously. Hydrokinetic energy technology does not and will not impact the natural world in the same ways that conventional hydroelectric power has, however, the stigma surrounding the negative impacts parallel hydrokinetic energy because both sources use water resources. Because conventional methods have used dams, reservoirs, and artificially created head to increase the amount of energy captured from the natural environment, it has lead to impacts that cannot be reversed. Fish that feed in one area and spawn in another could not retreat back to their spawning grounds, lowering the population of these species. Dam infrastructure placed within the rivers to extract energy modified the flow of the water. Because of these changes the ecological environments established for decades were altered, transforming the species of fish and vegetation that were once thriving in those areas around the United States to different species. The infrastructure also impacted the sedimentation of the river systems. Altering the sedimentation patterns of rivers changes these systems ecologically, impacting species and possibly changing the river flows. Sedimentation also helps control the flooding of areas; river systems have a natural ability to achieve this. When methods of conventional hydropower were implemented, the infrastructure changed the system’s ability to work the same as before. Reservoirs of sitting water used for hydroelectric energy create a festering pool for bacteria and disease, which could impact the populations surrounding the power stations.

The impacts of hydrokinetic energy technologies would not be equivalent to those changes occurring with the conventional generation of electricity from water.
Hydrokinetic power would not need large amounts of infrastructure that would impact the flow of the water, species, or the natural sedimentation that takes place. The devices used for hydrokinetic electricity generation are smaller than built dams, and are placed in rows and columns, spread out for natural flow to occur in between, harnessing part of the natural flow of the water but keeping the original river system intact. Companies are aware that navigation channels are needed in areas where energy could be captured; therefore, the river systems will keep their navigable abilities without obstruction by having the turbines placed below the boats that use the channel, or beside the area needed for use. On-going environmental monitoring is a necessity to detect current or possible future changes in the natural environment, therefore any effects caused by this technology would be acknowledged at a faster rate than ever before. Continuous monitoring helps to gain information about any impacts that the turbines may have. Currently, the impacts known about hydrokinetic energy technology are minimal, and do not coincide with those impacts of conventional hydropower, due to the differences in installation and implementation of these within river systems.

The main concern about installing turbines within river and tidal stream systems are those impacts to fish species. It has been stated by Verdant Power that most fish species within the area leave the turbines alone, limiting injury and mortality rates (Verdant Power, 2009). To make sure that these impacts continue to be negligible, the turbines should be placed away from feeding or spawning areas so the species within the systems will not be impacted. Also, study plans should be developed so that the aspects for that specific site are monitored, but permits and policies should dictate monitoring that should happen at each site, streamlining more of the process. Fish studies, environmental monitoring, discussion of cavitation throughout the site, and land species studies should be put together, monitored, and shared with FERC. Research happens in order to obtain permits and follow policies at the state and federal levels, but the future of hydrokinetic energy technologies and implementing power stations will be based on future findings after the initial installation and data collection.
Conclusion

Information gained within the interviews were compiled to provide conclusions about the current state of the technology and to give insight in the future of hydrokinetic energy technology. Hydrokinetic energy technology must be in close proximity to the end-users of the electricity, whether in remote locations or in largely populated areas. The amount of electricity that can be generated is directly impacted by the water resource attributes including velocity and water area available for installation. The area available within a site dictates the amount of turbines that can be installed in order to harness the energy from the velocity of the river or tidal stream. The higher the velocity, then the turbines can extract more of the energy contained within the resource. The devices themselves are related directly to the companies that are manufacturing or selling their engineered designs. Each turbine is used because it works well within the area chosen, either because the site is best fit for the turbine or vice versa. The devices themselves will only be installed if they can extract enough energy to be beneficial for the populations in close proximity to the resource. There are permits that must be obtained through each state as well as the federal government to then further the development of hydrokinetic energy technology in specific areas. Companies that have applied for permits or licenses follow similar paths in order to receive them, however the policies are still based upon older conventional hydropower methods, which can hinder the ability of companies to fill out the applications correctly, slowing down the process of being awarded a permit or license. The environmental impacts and economics surrounding hydrokinetic energy technologies are not completely understood because hydrokinetic energy technology is still developing. The companies that are applying for permits and licenses are monitoring the environmental impacts, and full EIA have yet to be required. Economically, specific costs were not disclosed, but cost-lowering techniques such as subsidizing this industry could help to alleviate the difference with the costs of other electricity sources so that when hydrokinetic power can be brought to the end-users, it can compete with other electricity sources.
Overall, the benefits surrounding hydrokinetic energy technologies are seen more and more when further data collection has occurred. The renewability and ease of grid connection could help to promote the use of this electricity source in the near future. Barriers may impede the ability of hydrokinetics to be implemented and used as a viable electricity source. The barriers to implementation and those facilitators that will help to push the commercialization of hydrokinetic energy technologies will be discussed in depth in the next chapter along with a synthesis of the technology assessment. There is an opportunity for this technology to produce renewable electricity for populations in areas with specifics that promote hydrokinetic turbine installation. Increasing public awareness of renewables could encourage the use of hydrokinetics and give support to further projects.
Chapter 5: The Feasibility of Hydrokinetic Energy

The key finding of this technology review is that hydrokinetic energy technology is site specific making it difficult to generalize. Information provided for this industry is vague and general. Interviews with companies directly involved in hydrokinetics provide some insight; however, we are still left with a great deal of uncertainty about the commercial potential of this technology. Analyzing the current barriers can provide insight into the changes that need to be made for the industry to move forward. Discussing the facilitators that push hydrokinetics further towards commercialization is important in understanding how the sector has progressed. By combining the information from the interviews and technology assessment of hydrokinetic energy and connecting this current data with that collected and presented by other feasibility studies, it can give a better overview of the future of hydrokinetics in relation to current and future sites for these systems.

*Analysis of Barriers Hindering Hydrokinetic Energy Technology*

The infancy of the technology and the location of different projects create barriers that companies must overcome. Once a site is established and a permit is obtained, the location can actually be used for assessment and possible implementation, which will help facilitate the technology. Because hydrokinetic technology is in a nascent status, there have been little to no regulations dictating aspects of hydrokinetic energy since most of the regulations still deal directly with conventional hydropower. This makes obtaining a permit or license difficult because some clauses may or may not apply to hydrokinetic energy schemes or assessments. New policies dedicated strictly to hydrokinetic energy are needed to create a better environment to set this industry in motion; specifically to replace sections that cannot possibly pertain to hydrokinetic power production like those associated with the building of large infrastructure and dams.

Besides the infancy of the industry and the policies and regulations associated with hydrokinetics, the use of the water resource can also create a
Within the water resource, large amounts of barge traffic may impede installation of hydrokinetic turbines. Specific devices engineered for sites of hydrokinetic electricity help overcome barge traffic within the location, because turbines can be placed in areas that can benefit both the electricity generation alongside the current uses of the waterway.

Currently, research on hydrokinetic energy technology implies that there are limited environmental impacts, and that this electricity source could be feasible depending upon the potential energy at the site and nearest community load.

An increased number of companies that vie for sites and develop devices has intensified the competition within this sector. Competition has justified hydrokinetics as a viable alternative for electricity, but also created an indirect regulatory bottleneck effect within the industry; competition can create a bottleneck when there is a lack of regulation in which many companies will compete within a similar sector. Because of competition, companies are unwilling to disclose information to each other, resulting in longer durations for R&D and implementation. The feasibility of hydrokinetics is based on the ability of companies to produce efficient devices that can be grid connected for an end use. If companies are reluctant to share research, the timeline for feasibility of hydrokinetic electricity will be lengthened. Companies are trying to accrue capital to keep researching and developing sites and devices, however, each company is working towards one common good: producing electricity from the flow of water by using open water turbines instead of damming river systems. By working towards this common goal, and if there is recognition of past pros and cons, moving forward with all the information currently known about this industry, hydrokinetic technologies can become a reality and produce positive outcomes.

Facilitators Pushing Hydrokinetic Energy Technology Toward Commercialization

There are aspects that are bringing hydrokinetic power systems into the forefront and helping to create a pathway to commercialization. These facilitators are
important to understand the progression of the industry and what may be helping instead of hindering.

There has recently been an increase in the number of locations applying for permits as well as companies willing to pursue this hydrokinetic power. By increasing the number of companies, this increases the amount of research, development, and overall data for this technology, facilitating this sector further. Other facilitators that help to push hydrokinetic energy technologies towards commercialization include the accessibility of site, if the location is remote but ideal, the willingness of companies to pursue the best locations, road infrastructure surrounding the location, accessibility to grid connection and proximity to end-users.

Hydrokinetic technologies have dealt with a growing period: increasing the amount of research and companies wanting to engage in hydrokinetic technology. This growing period has helped to push hydrokinetics rapidly, overcoming broken turbines and other mishaps in engineering to create the best devices to harness and convert water flow to electricity, increasing overall feasibility. Local support for this electricity promotes hydrokinetics in many areas around the United States. If the population surrounding the chosen sites is informed and supports hydrokinetic power it will create a better environment for implementation, grid connection, and use. By using the natural facilitation surrounding the industry and pursuing any other options that will increase the ability for commercialization and implementation of this industry, hydrokinetic power systems will be used in the near future.

Specifics needed for Hydrokinetic Electricity concluded from the Technology Assessment

By comparing and contrasting the sites where hydrokinetic energy technologies are being deployed and researched, it is necessary to conclude that there are certain aspects needed for turbines to harness and produce useable electricity. The velocity of the river or tidal stream needs to be at least 2.0 m/s based on the technology
assessment, even though less velocity could still spin the blades and move the rotor. No matter which turbine is engineered and used the flow must be great enough to be captured by the device. Also, the depth of the resource at the installation site must be deep enough to install the device. A turbine is selected because the installation company engineers it or because it fits the criteria for the site selected. The placement of the turbine within the resource is decided based upon best water flow, depth, and external factors: navigation and recreational uses. Depth of the river or stream is an important aspect because it gives companies more options for device placement. These two site-specific characteristics, velocity, width, and depth, are the controlling factors for hydrokinetic technology implementation. Sites around the United States are chosen based upon the depth and velocity of the resource before considering other features. After the process of selecting a site, other factors can be looked at more specifically including: grid connection, end-users in surrounding population, and environmental aspects.

Feasible areas for hydrokinetic energy to have the most impact would be those that could replace the current electricity based on fossil fuels. Small remote locations can replace the entire community load with renewable electricity. Larger areas may not be able to completely replace their current electricity with the amount that hydrokinetic energy technologies could provide, however, offsetting non-renewable sources with alternative electricity would provide better energy security. The electricity produced from this technology may be viewed negatively due to the lack of exposure about the workings, benefits, and the ability to offset current electricity use, but this could change by increasing public knowledge of hydrokinetic power.

The need for streamlined policies and permitting processes for the hydrokinetic energy sector are vital for this source to become feasible in the future. Policies surrounding hydrokinetic energy technologies are based on policies in place for conventional dammed hydropower. Those that were not specifically geared towards the implementation of this technology creates confusion, because companies must try to comply with policies which they cannot satisfy in all aspects. Regulations from state and federal agencies do not contain information on some
aspects of hydrokinetics and cannot pertain to all aspects of hydrokinetic energy technology, which has stunted this sector's ability to grow. Policies directly relating to the research, development, site selection, and installation of hydrokinetic technologies should be created to make it easier for hydrokinetics to harmonize with regulations, and be implemented in the natural environment. It is important to tailor federal and state policies directly to hydrokinetic energy technology, which will promote research, possibly increase installation, and decrease possible environmental impacts. By increasing the amount of research and information that is collected about hydrokinetics, policies, permitting, and licensing can be rewritten to include more specific details about aspects pertaining to hydrokinetic technologies such as: where turbines can be placed, placement options with the littlest impacts to the area, aspects of the water resource being used and how to mitigate possible changes, environmental monitoring needed for each specific site, and the impact to the bordering public and the amount of control that they may have as stakeholders in pursuing this technology.

Current and Potential Sites

Broad generalizations about hydrokinetic energy technologies are inevitable because the information available on this subject is non-specific. The lack of accessible concrete data detailing the ability of hydrokinetic energy turbines to capture water flow generates a vague overview of the feasibility of this technology. However, by creating a technology assessment and interacting directly with companies applying hydrokinetic practices, the future feasibility of this alternative energy source is much more positive. The technologies that are currently implemented depict that the technology is a viable way to capture energy and convert it into electricity. The sites around the United States that are being researched are at different phases of development; those further along in the process have deployed turbines currently producing electricity that could be used by society. Further research will indicate whether hydrokinetics would be an economical alternative to help offset the use of fossil fuels.
The Federal Energy Regulatory Commission has created maps of hydrokinetic energy sites around the United States. These sites can be seen in Figures 9 and 10, with those areas that currently have permits for hydrokinetic sites and those that have applied for permits and the permits are pending.

Figure 9: Issued Hydrokinetic Preliminary Permits

Figure 10: Pending Hydrokinetic Preliminary Permits

The issued permits for hydrokinetic energy, tidal and river systems, allows for 8818.071MW of total harnessed energy. The importance of these numbers is the potential that hydrokinetic energy has in the future. The 6.71GW of potential energy captured reinforces the feasibility of hydrokinetic electricity as a viable and smart energy option. One of the main barriers is that issued permits have not allowed for each site to deploy turbines because assessments are still underway.

Pending permits are those that have been applied for, but sites have not yet received a permit. The amount of energy from tidal and river systems for pending permits through FERC equals approximately 17.69GW, including areas on or east of the Mississippi River, and locations in Alaska as well. This amount of energy is dedicated directly to those sites that have applied, but not yet received a permit from FERC. Therefore, the total amount of energy is much higher than this total.

The companies that were interviewed for the technology assessment are all located on Figure 9: Issued Preliminary Permits. The first company is located on the Alaskan Canadian border right in the middle of the state. This company is focused on run-of-river, or inland hydrokinetic energy. The second company is developing in-stream tidal systems, called tidal within the figures, and is located in New York City, New York. The last interviewed company is researching on the Mississippi River in Louisiana, which is where most of the permitted areas are located. The companies are located within vastly different areas and climates within the United States, which creates an understanding that wherever the needed site and resource attributes are, a company can extract useable electricity. According to both figures (9 & 10), there are many more areas where inland systems are being researched and tested than those within tidal streams. The number of protected tidal streams is much lower than the total number of usable running rivers within the United States. The tidal streams must be researched more because the devices must be able to capture both the ebb and flow, not just one direction. Also, inland or run-of-river concepts are more closely related to wind power, this way the unidirectionality of the running water can use concepts from the wind energy sector, which is a much more developed area.
In terms of spatial analysis of this pending permit map, a lot of these permits were applied for or obtained along the Ohio and Mississippi Rivers. This implies that the Ohio and Mississippi are both accessible, near to end-users, have high enough velocity, and have available area for turbines to be placed. Because there are so many specifics about hydrokinetic energy technologies and placement that is site dependent, once it was understood that the Ohio and Mississippi Rivers were a prime example of hydrokinetic sites, many companies began to apply for permits to then perform research and determine if a license can be obtained and proceed with the future installations.

The sites that have filed applications through FERC have a potential that totals 24.40GW. The amount of energy within the United States in rivers and tidal streams is astounding. According to a study done by the DOE in 2006, the potential is more or less 70.0GW around the US, and the possibility to capture this energy would impact electricity use in a positive way (U.S. Department of Energy, 2006). There are, however, many other possible sites without a permit or that have not applied for a permit within the US that could be used for hydrokinetic power capture. The Department of Energy compiled a study that depicted areas around the United States with hydropower potential. Low power unconventional hydropower is comparable to hydrokinetic projects. Areas where low power unconventional and micro-hydropower could be located should be assessed for placement of hydrokinetics, and exploited with hydrokinetic power possibilities. Many of the areas, seen in Figure 11, have the potential for low-grade hydropower similar to areas of hydrokinetic power implementation.
Potential sites around the United States are particularly gathered in the Pacific Northwest, the States east of the Mississippi River, and Alaska (not shown here). This coincides with the locations of the largest river systems around the United States. The permitting of projects also coincides with the greatest potential of the Ohio and Mississippi rivers. The northeast, northwest and a few states in between including California, Colorado, and Utah have the greatest undeveloped resources for waterpower (U.S. Department of Energy, 2006). Hydrokinetic sites being researched are those that have the potential for becoming commercial sized, and therefore areas with large amounts of running water and tidal streams may not be focused on hydrokinetics, such as the pacific northwest, where they produce a large portion of the total hydropower currently in use. This is not to say that commercial hydrokinetic power will not eventually spread to other areas besides the current areas that are permitted, but those permitted areas in figures 9 and 10 are in areas where there is not only potential, but the availability of enough area in order for a commercial project to be located there.

Figure 11: Existing Hydro Plants and Feasible Projects in the US
Final Summary of Feasibility

Around the United States, only areas that can be developed for hydrokinetic energy technologies that will positively impact the electricity produced and impact the adjacent communities will be fully developed. Whether it is proximate to large load centers or near small remote locations, the areas around the US that are being researched will begin to exploit the resource for as much electricity as possible. The locations around the United States with potential (relative to the DOE study) will eventually become areas where permits may be applied for to develop more areas for implementation. Specifically, remote locations are going to be important for the current state of hydrokinetics: to help develop turbines, deploy the devices without any impact to populations, connect to the grid with little offset to the original amount of electricity, and to provide alternative electricity in areas that are dependent upon fuels for their electricity. Remote areas have a more urgent need for hydrokinetic technology and may have fewer stakeholders to input; these projects may have the ability to come online more quickly than those larger projects. Because these areas may be difficult to get to possible larger initial costs in researching these areas will ensue, but hydrokinetic energy technologies could be implemented more quickly because the end-users are close to the resource.

Harnessing the flow of water and converting that energy into usable electricity has the possibility to replace fossil fuel electricity generation in some areas, and offset electricity in other areas. With the research and development that has been done, the next step is to connect the turbines installed to a grid, which only one company has been able to do, to research the effects and the amount of electricity that could be feasibly generated in areas around the United States. Connection to the grid currently cannot provide monetary funds to the company, and they must pay the amount of electricity that is offset by the project. Because of these regulations, many companies want to make sure that their research is solid prior to moving forward because of the extra costs that this will incur. The phase of development that hydrokinetic energy technology is at currently, gives way to the future: grid connection and end-use electricity.
The more information gained from hydrokinetics will help to push this electricity source further into commercialization. With the immense amount of water resources in the United States, we have the ability to be on the forefront of this industry worldwide. The technology assessment provides further information promoting knowledge within society and across the different hydrokinetic energy companies. Awareness will support the future of this technology as a course of electricity.

In sum, the feasibility of hydrokinetic energy technology appears to depend on the specific site, turbine technology and its status, environmental impacts, cost, and policy and permitting. Site specific attributes affect feasibility because if the velocity, width, and depth are not enough to extract energy or for the technology to be installed, then the area will not be able to provide power from hydrokinetic technology. The area must have a velocity large enough to extract along with having the depth and width to install the devices, specifically the cross-sectional area in relation to the dimensions of the turbine being used. The turbine technology must be efficient, survive the climates in which they are placed, and be able to use the flow in either one direction or two depending upon the site specifics: run-of-river or tidal stream. The status of the devices currently depends on the company which implements and the company that manufactures the turbine, which can be the same or can be different. These companies can create hydrokinetic devices that can ebb and flow as well as extract unidirectional flow, therefore producing a turbine that can be used in a vast number of areas that have been assessed helping to promote this electricity. The feasibility is also dependent upon the policies and permits surrounding the industry. By creating a better political environment for this technology, it can be easily pursued. This political environment can produce an increase in grants and subsidies available for hydrokinetic energy technology to offset the costs directly associated with the research and further development of hydrokinetics for the companies, more research can be completed which will also promote this industry. If more research is done, there is a better chance for further understanding the impacts of this technology in natural settings, therefore decreasing the negative effects on the environment. By lowering costs to
companies, the more resources are available to then decrease the impacts on the environment, which will make this renewable electricity a resource that the United States populations want to use. The technology assessment helped to increase knowledge and understand how to decrease barriers while creating a better political environment for hydrokinetic energy extraction to become a prominent source of electricity. Research will be ongoing and further questions may be answered as the industry becomes more evolved and willing to share more details than presented within this assessment.
Bibliography:


