

River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska



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Executive Summary

This report outlines the status of hydrokinetic power generation technology, the expected trajectory of improvement over the next five years, and recommended actions the state can take to accelerate this technology field. The report is based on numerous sources as well as data collected by ACEP over the past year at a hydrokinetic research site in Nenana, Alaska.

Turbines placed directly in river, ocean, or tidal current generate hydrokinetic power from the kinetic energy of moving water (current). The available hydrokinetic power is a function of the density of the water and the speed of the current cubed. The minimum current required to operate a hydrokinetic device is typically 2–4 knots (1–2 m/s), but optimal currents are in the 5–7 knot (1.5–3.5 m/s) range.

The Alaska region contains about 40% of the total U.S. river energy resource, 90% of the total U.S. tidal energy resource, and 40% of the U.S. continental shelf wave energy resource. Hydrokinetic turbines have frequently been discussed as an option for generating power in communities located along Alaska's major river systems, and for tidal energy applications in Cook Inlet and coastal Southeast Alaska.

Studies by the Electric Power Research Institute indicate that hydrokinetic turbines are a viable method of generating power in Alaska. Electrical costs would range from \$0.11/kWh for tidal energy in Knik Arm to about \$0.68/kWh for energy from rivers near remote communities. All costs are in 2010 dollars. Ongoing studies to characterize the hydrokinetic potential of Alaskan river and tidal currents will provide improved information needed for future hydrokinetic demonstration projects.

At present, two hydrokinetic turbines have been tested in Alaska (a 5 kW turbine at Ruby during 2008, 2009, and 2010, and a 25 kW turbine at Eagle in 2010). The Eagle deployment was grid-connected, and if tests are successful, it will be converted to full commercial operation. Additional demonstration projects are planned for Cook Inlet, the Tanana River, and the Kvichak River, with other interested communities developing turbine deployment concepts.

Challenges to developing a commercial hydrokinetic industry in Alaska include determining the technological, operational, and economic viability of hydrokinetic turbines, meeting permitting requirements, and gaining stakeholder acceptance. Hydrokinetic technology can be affected by debris, sediment, frazil, and surface ice; river dynamics (turbulence, current velocity, channel stability); and the interaction of turbine operations with fish and marine mammals and their habitat. The question of turbine-operation impacts on the aquatic environment is one of the major issues that will determine stakeholder and permitting agency views toward this new technology. The 2010 hydrokinetic turbine demonstrations conducted at Ruby and Eagle were significantly adversely affected by in-river debris floating on the surface and neutrally buoyant debris. These experiences indicate that developing technology to mitigate debris problems will need to be a high priority for practical hydrokinetic power production.

River and marine hydrokinetic technology (RMHT)—an emerging technology—is at a similar stage as wind power generation technology was 15 to 20 years ago. For RMHT to move from the emerging stage to the practical commercial stage requires support similar to that provided to wind technology development during its nascent years. Financial support is needed for research to develop technology and further an understanding of the river and marine environments that will host RMHT. Data and modeling tools will be required to describe the interactions between RMHT and aquatic environments. Engagement through dialogue with all relevant stakeholders is needed at the earliest stages of project development in order to produce reasonable approaches to permitting and to develop Alaska-based expertise that is integrated with the national scene.

Alaska is well positioned to facilitate RMHT as it transitions from emerging to developed technology over the next five to ten years, by building on current and planned national and state structures. These structures include the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE, formerly the Minerals Management Service), the Department of Energy, and the Denali Commission, as well as Alaska state funding support for renewable energy projects and development of emerging technologies and research.

The one area where existing efforts and funding is lagging is the development of a science-based understanding of how fish and marine mammals will interact with RMHT. Issues of fish and marine mammals have a large stakeholder base related to ecological stewardship, economics, culture, and lifestyle that significantly affect agency views about permit requirements. Agencies have indicated repeatedly that they want to know how hydrokinetic technology will affect aquatic habitats and biology.

Five years ago, hydrokinetic technology consisted primarily of ideas in papers and studies. During the interceding five years, these concepts have been developed into actual devices and demonstration projects. Over the next five-year period, it is probable that permit requirements for demonstration projects will be well defined, several demonstration projects will be underway or completed, and initial commercial operations will have begun. Such progress assumes a continuation of the current state of high interest and activity in the development of RMHT and a continuation of support for the technology from agencies and stakeholders.

Introduction

Turbines placed directly in river, ocean, or tidal current generate hydrokinetic power from the kinetic energy of moving water (current). The available hydrokinetic power depends on the speed of the river, ocean, or tidal current and is a function of the density of the water and the speed of the current cubed. In order to operate, hydrokinetic devices require a minimum current and water depth. The minimum current required to operate a hydrokinetic device is typically 2–4 knots (1–2 m/s), but may be as low as 1 knot (0.5 m/s), depending on the particular technology approach. Optimum currents are in the 5–7 knot (1.5–3.5 m/s) range. Water depth is an important factor in determining the total energy that can be extracted from a site, since the cross-sectional area over which a turbine can extract energy is dependent on adequate water level above the installed device. Hydrokinetic devices are ideally installed at locations that have relatively steady flow throughout the year and are not prone to serious flood events, turbulence, or extended periods of low water level.

In Alaska's riverine environments, water flow can fluctuate dramatically on a seasonal basis depending primarily on the rate of seasonal snow and glacier ice melt. Tidal currents change direction and current velocities vary depending on local geography and bathymetry and the gravitational influence of the moon and sun. Ocean currents are a continuous directed flow of ocean water up to thousands of miles long. Surface ocean currents are restricted to the upper 300 m (1000 ft) or so and are largely wind driven. Deep ocean currents are driven by density and temperature gradients. Ocean passages in the Aleutian Islands have been identified as areas with significant ocean current hydrokinetic energy potential (Figure 1).

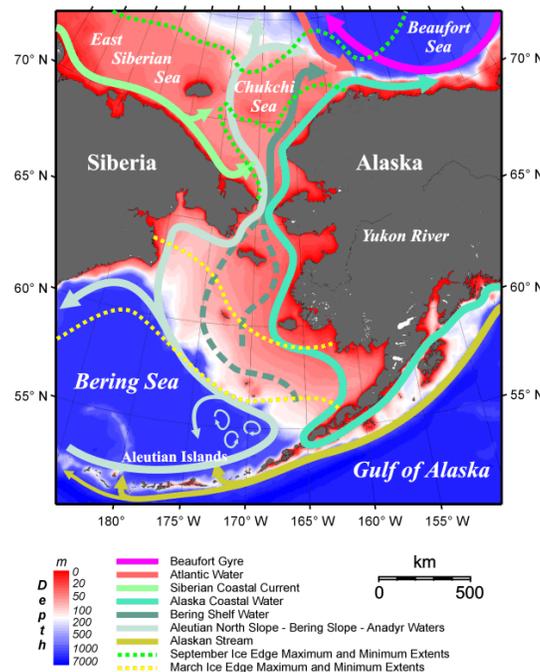


Figure 1. Alaskan ocean currents (<http://www.ims.uaf.edu/NPRBdrifters/bering%20chukchi%20map.png>)

The Alaska region hydrokinetic potential is significant, with about 40% of the total U.S. river energy resource, 90% of the total U.S. tidal energy resource, and 40% of the U.S. continental shelf wave energy resource (Miller et al., 1986; Previsic, 2007; Bedard et al., 2009). Hydrokinetic turbines have frequently been discussed as an option for generating power in communities located along Alaska's major river

systems, and for tidal energy applications. Many inland communities in Alaska that are particularly affected by high energy costs (paying more than three times the U.S. average) are situated along navigable waterways that could host hydrokinetic installations. Several resource assessment studies have been completed or are in the process of being completed, most in collaboration with or funded by the Alaska Energy Authority (AEA) (Polagye and Bedard, 2006; Polagye and Previsic, 2006; Previsic, 2008; Previsic and Bedard, 2008; Previsic and Bedard, 2009; Alaska Energy Authority, 2009) (Figures 2–4).

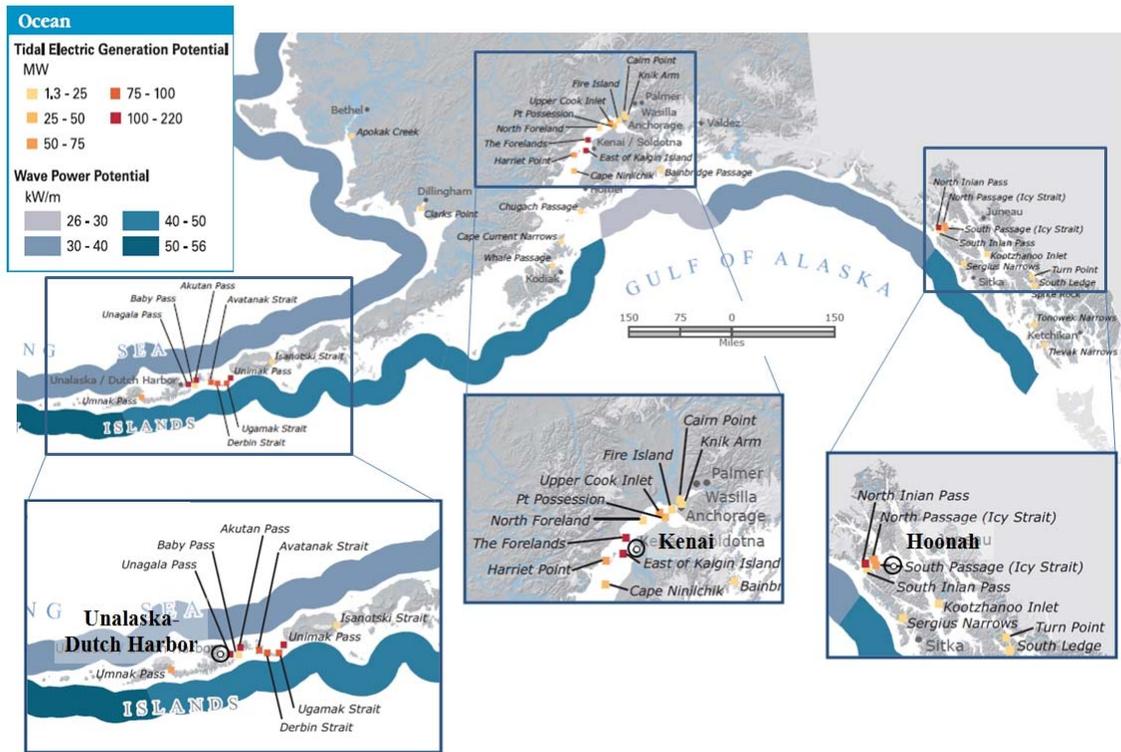


Figure 2. Southeast Alaska map of tidal energy resources (Alaska Energy Authority, 2009)

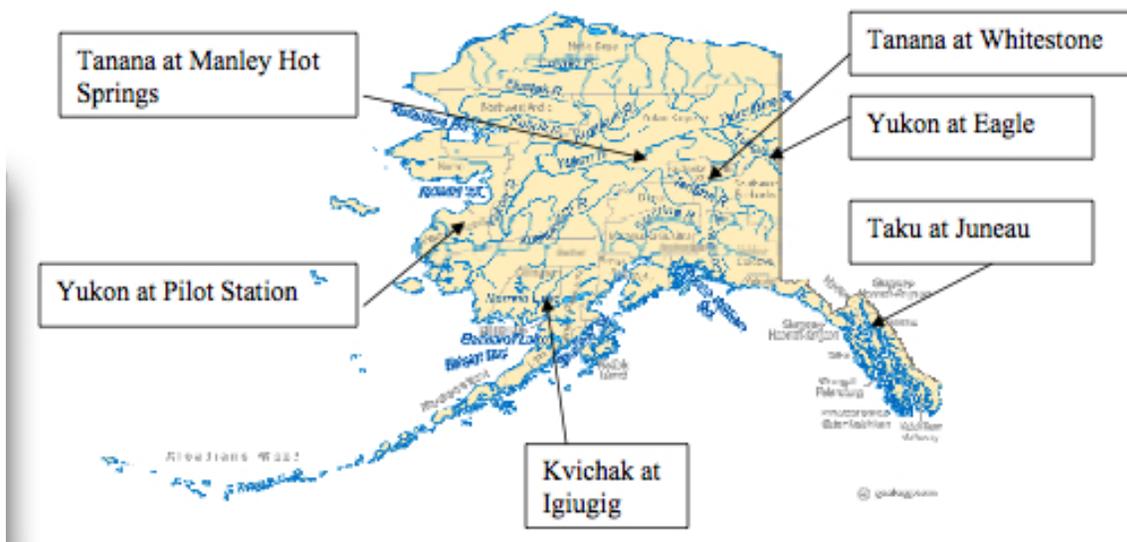


Figure 3. Map of Alaska rivers, identifying several sites studied for their river hydrokinetic potential (Previsic and Bedard, 2008)

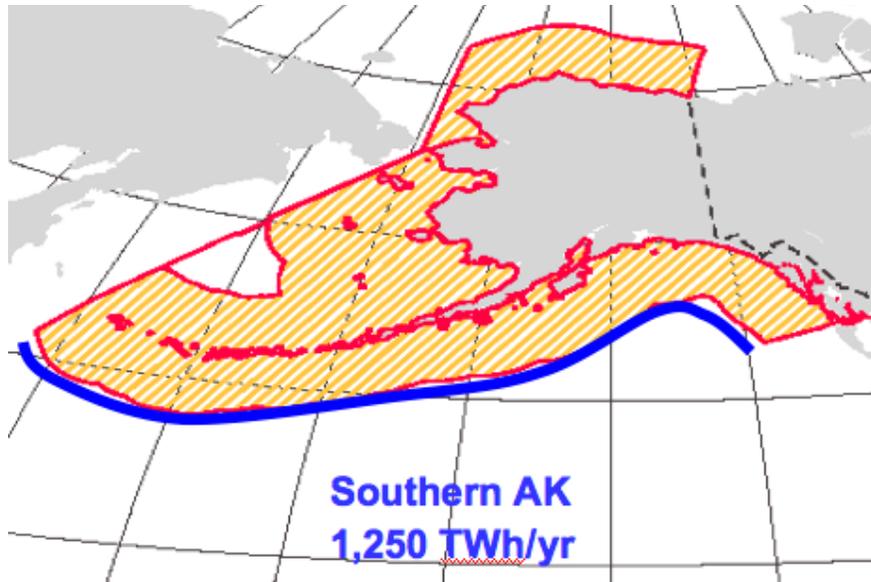


Figure 4. Map of the Alaska outer continental shelf indicating regions of wave energy

As of 2010, hydrokinetic devices are generally considered pre-commercial (Khan and Bhuyan, 2009). In recent congressional testimony, Roger Bedard (Electric Power Research Institute) commented, “The time period for a MHK [marine hydrokinetic] technology to progress from a conceptual level to deployment of a long-term full-scale prototype tested in the ocean is typically on the order of 5 to 10 years. The technology is still in its emerging stage; like where wind technology was approximately 15 to 20 years ago” (Marine Hydrokinetic Technologies, 2009). Since the late 1970s, when commercial wind projects in the U.S. were first realized, the efficiency and reliability of wind turbines have increased while the capital cost of wind turbines has decreased (EERE, 2008a). The cost of wind-generated electricity has dropped by as much as 80% in the past thirty years (Figure 5), from as much as 30 cents per kilowatt hour in some areas in 1980 to less than 5 cents per kilowatt hour in 2009 (AWEA, 2009).

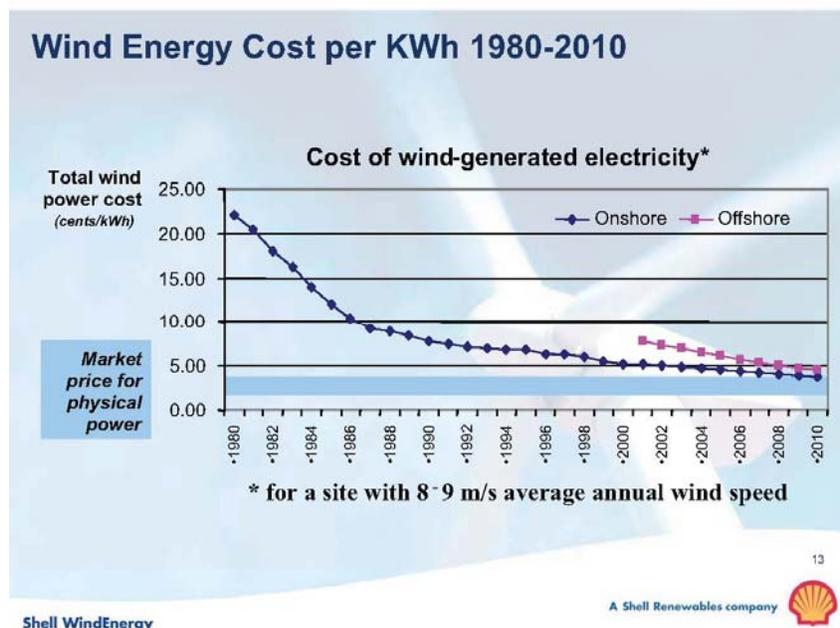


Figure 5. Wind energy cost per kWh 1980–2010 (Poulson, 2003)

As a technology becomes more mature, cost decreases may be achieved through learning-by-doing; research, development, and demonstration innovations; improved communication between involved parties; product standardization; and the redesign and scale alteration of a product (Junginger et al., 2005). In economics, this concept is referred to as an experience curve, which “analyzes cost development of a product or technology as a function of cumulative production” (Junginger et al., 2005, p. 133). Experience curves have been applied to other energy technologies, including photovoltaic panels, combined-cycle gas turbines, and carbon sequestration technologies (Junginger et al., 2005). It is reasonable to assume that hydrokinetic turbines will follow a similar experience curve as that of wind technologies, with decreasing costs as cumulative production increases.

The first hydrokinetic device deployed on a river system in the U.S. was deployed in Ruby, Alaska, in 2008 for one month (Figure 6), and briefly redeployed in 2009 and 2010 (a 5 kW New Energy EnCurrent turbine). A 25 kW New Energy EnCurrent turbine was briefly installed in the Yukon River at Eagle during the summer of 2010. Both turbine deployments experienced problems with in-river debris.



Figure 6. New Energy EnCurrent Turbine (on left) and deployed in the Yukon River (pictures courtesy of New Energy Corporation and Tom Ravens)

The only grid-connected in-current river hydrokinetic project operating in the U.S. is a Hydro Green Energy turbine installed behind an existing hydroelectric dam turbine near Hastings, Minnesota. This turbine is installed in the engineered waterway of the dam and is used to capture the energy that remains in the water current as it exits the dam (Neville, 2009). The dam filters out sediment and debris, making the installation site relatively benign when compared with installations in uncontrolled river or tidal currents where debris, sediment, and the river or marine environments impact turbine operations. All other hydrokinetic projects (current and wave) are at various stages of technology development, prototype testing, or demonstration. No full-scale commercial systems utilizing hydrokinetic turbines have yet been deployed.

Hydrokinetic technologies are still in the developmental phase, making it difficult to conduct accurate economic analysis for proposed installations. Once more devices are built and deployed, specific estimates for costs can be made. Although preliminary, economic analyses for several proposed hydrokinetic projects in Alaska have been conducted by the Electric Power Research Institute (see Table 1).

Study Location	Power Production (kW)	Capital Cost (2010 \$)	Cost per kWh (2010 \$)	Annual O&M Costs (2010 \$)
Igiugig	40 kW	\$315K	\$0.68	\$12.6K
Eagle	60 kW	\$283K	\$0.68	\$6.8K
Whitestone	590 kW	\$1.9M	\$0.19	\$135K
Knik Arm	17,000 kW	\$123M	\$0.11	\$4.5M
Yakutat	5,200 kW	\$48M	\$0.28	\$1.4M

The Electric Power Research Institute (EPRI) studied hypothetical in-river hydrokinetic installations at Igiugig, Eagle, and Whitestone (Previsic, 2008). All costs in the studies have been updated to 2010 dollars. The Igiugig study proposed a 40 kW installation, which would produce 207 MWh per year of electricity that would sell for \$0.68/kWh. The capital cost for installation would be about \$315,000, with an annual operations and maintenance cost of roughly \$12,600. This translates to about \$7,900 per installed kW. The EPRI study of a 60 kW installation at Eagle on the Yukon River states a capital cost of about \$283,000 or about \$6,000 per installed kW, with an annual operations and maintenance cost of about \$6,800. In total, the installation would generate 107 MWh per year of electricity that would sell for \$0.68/kWh. The EPRI conducted a study for a 590 kW hydrokinetic installation in Whitestone on the Tanana River. The installation's capital cost is an estimated \$1.9 million or about \$3,300 per kW, with annual operations and maintenance costs of roughly \$135,000. The installation would produce 1,325 MWh of electricity per year that would sell for \$0.19/kWh.

A study on in-stream tidal power was conducted by EPRI for Knik Arm in Cook Inlet (Polagye and Previsic, 2006). All costs have been adjusted to 2010 dollars. The study concluded that a commercial installation of an array of devices would extract an average of 17 MW of electricity from the tide. The estimated capital cost of the array is \$123 million, or about \$2,500 per installed kW, with an annual operations and maintenance cost of \$4.5 million. The cost of electricity for utility generation would be \$0.11/kWh.

The EPRI conducted a wave-power feasibility study for Yakutat to assess the technical aspects, cost, and economics of a potential wave-energy conversion project at the site (Previsic and Bedard, 2009). All costs are in 2010 dollars. A 5.2 MW plant composed of an array of eight Oyster wave-energy conversion devices has an estimated capital cost of about \$48 million, or \$8,900 per installed kW, and an annual operation and maintenance cost of \$1.4 million. The cost of electricity from the plant is an estimated \$0.28/kWh.

Significant engineering and environmental issues must be resolved before commercial projects can be realized in Alaska and elsewhere. In Alaska, evidence indicates that it may not be possible in many locations to deploy hydrokinetic turbines year-around due to low wintertime current velocities and the possible accumulation of frazil ice on turbine components. Frazil ice is ice that grows within the water column during freeze-up of rivers and open ocean environments (see the section on challenges to development). Staff at the Federal Regulatory Energy Commission (FERC) have identified a number of concerns about hydrokinetic turbines related to water turbulence, corrosion, anchoring systems, fluid leaks (e.g., hydraulic fluids), underwater transmission line effects, and installation and maintenance problems (Wellinghoff et al., 2008). In addition to these more or less technical issues, there is also concern from stakeholders and regulatory agencies over potential ecological effects related to marine mammals and to marine and river fish (Boehlert et al., 2007; Polagye et al., 2010).

The remainder of this report outlines the status of hydrokinetic technology, challenges facing development of commercial projects in Alaska, the expected trajectory of improvement over the next five years, and recommended actions the state could take to accelerate this technology field. This report focuses on river and tidal current hydrokinetic power technology, which is where most of the development focus is presently directed in Alaska.

Hydrokinetic Technology Status

The regulatory environment

An important factor in determining the success or failure of realizing the potential of hydrokinetic energy is the regulatory framework that governs hydrokinetic systems. Long time frames to achieve regulatory approvals can result in a lack of investment in hydrokinetic systems with consequent retardation of needed technology development. The FERC has a leading role in regulating hydrokinetic (and other) energy through the Federal Power Act (FPA) authorization. Permits from the FERC give an individual firm the exclusive right to study and eventually utilize the hydrokinetic potential of a reach of river or marine region for which the permit applies. Figure 7 shows the locations of FERC permits for Alaskan projects. The FERC permitting process is traditionally difficult for hydrokinetic projects because they are currently lumped together with major hydroelectric dam projects, although FERC is streamlining the process (Wellinghoff et al., 2008; Union of Concerned Scientists, 2009).



Figure 7. Locations of active FERC permits in Alaska as of July 2010 (Miles, 2010)

In addition to the FERC's regulatory role, other federal and state agencies provide input and their own regulatory function, depending on a particular project's proposed location (see Table 2). For projects located in ocean waters beyond the three-mile limit that defines state coastal waters, a project may require approvals from several federal agencies to meet regulatory requirements. In addition to the FERC, the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) may regulate hydrokinetic projects by issuing leases. The U.S. Fish and Wildlife Service (FWS), the National Marine Fisheries Service (NMFS), and/or the U.S. Army Corps of Engineers (USACE) may also require authorizations, depending on the nature of a particular project.

Within state waters, a project may need authorizations from both state and federal agencies to accommodate federal laws related to the Clean Water Act, the Coastal Zone Management Act, and relevant state regulations. Hydrokinetic projects on inland waterways require approvals from appropriate

state and federal agencies. In Alaska, the USACE, the Alaska Department of Fish and Game (ADF&G), and the Alaska Department of Natural Resources (ADNR) have regulatory oversight. Input from other stakeholders (e.g., FWS, NMFS, and local communities and groups) are taken into account during the permitting process (Wellington et al., 2008).

Agency	Regulatory Authority
Federal Energy Regulatory Commission (FERC)	In-water electric power generation (federal & state waters)
U.S. Army Corps of Engineers (USACE)	Land use and navigable waterways (federal & state waters)
Alaska Dept. of Fish and Game (ADF&G)	Fish and habitat (state waters)
Alaska Dept. of Natural Resources (ADNR)	Land use (state lands)
NOAA National Marine Fisheries Service (NMFS)	Fish, marine mammal, and habitat conservation (federal waters)
U.S. Fish and Wildlife Service (FWS)	Fish (federal waters)
U.S. Dept. of the Interior Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)	Regulation and leasing (federal waters)

The FERC has issued 143 hydrokinetic preliminary permits for potential hydrokinetic projects in the U.S. Of the 143 permits issued by FERC, 28 are tidal projects, 13 are wave projects, and 102 are inland projects. A majority of the inland permits are for projects on the lower Mississippi River, a largely untapped source of hydrokinetic power (FERC, 2010). According to FERC, there are currently seven issued hydrokinetic preliminary permits for Alaska, of which three are preliminary inland permits and four are tidal preliminary permits.

Hydrokinetic river and tidal current technology types

River and tidal current hydrokinetic devices typically use vertical or horizontal axis turbines similar to those developed for wind generation. Vertically oriented turbines are generally of the Darrius or Gorlov type that “typically have two or more blades mounted along a vertical shaft to form a rotor; the kinetic motion of the water current creates lift on the blades causing the rotor to turn driving a mechanical generator” (EERE, 2008b) (Figure 8). The rotor turns in the same direction irrespective of the direction of current flow, such that the turbine can operate in either river or tidal current environments. Horizontal axis turbines are typically of three types: the Darrius/Gorlov type (Figure 8), a fan blade type (Figure 9), or a propeller blade type (Figure 10).

A variety of hydrokinetic devices are under various stages of development and include utilizing a reverse Archimedes screw mechanism, oscillating hydrofoil motions (Figure 11), vortex-induced vibrations (Figure 12), traditional underflow water wheel technology (Figure 13), and other novel methods (EERE, 2008b; Bernitsas et al., 2008; Hasz Consulting, 2010). The underflow turbine was specifically designed to address problems associated with operating turbines in debris- and sediment-filled rivers in Alaska. An oscillating hydrofoil is “similar to an airplane wing, but in water; yaw control systems adjusts their angle relative to the water stream, creating lift and drag forces that cause device oscillation; mechanical energy from this oscillation feeds into a power conversion system” (EERE, 2008b).

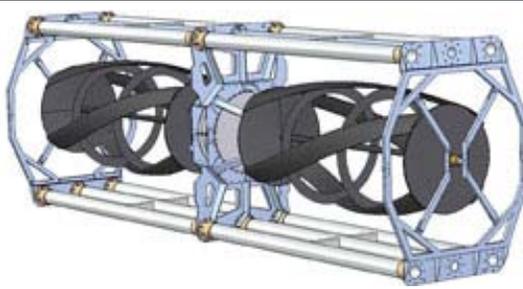


Figure 8. Horizontal axis cross-flow turbine
(picture courtesy of ORPC)



Figure 9. Open-Centre Turbine fan blade
(photo courtesy of OpenHydro)



Figure 10. Propeller blade horizontal axis turbine (photo courtesy of Verdent Power)

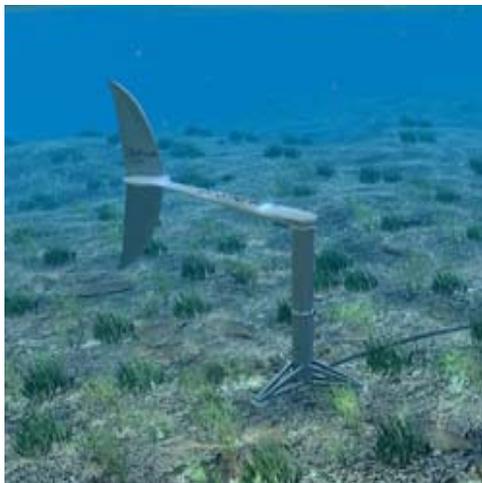


Figure 11. The bioSTREAM oscillating hydrofoil
(photo copyrighted by BioPower Systems Pty. Ltd.,
www.biopowersystems.com)

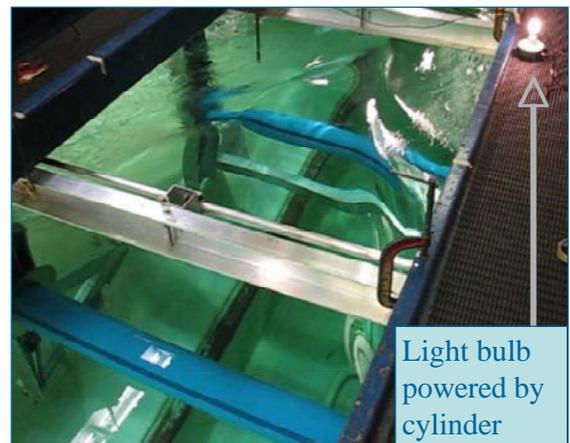
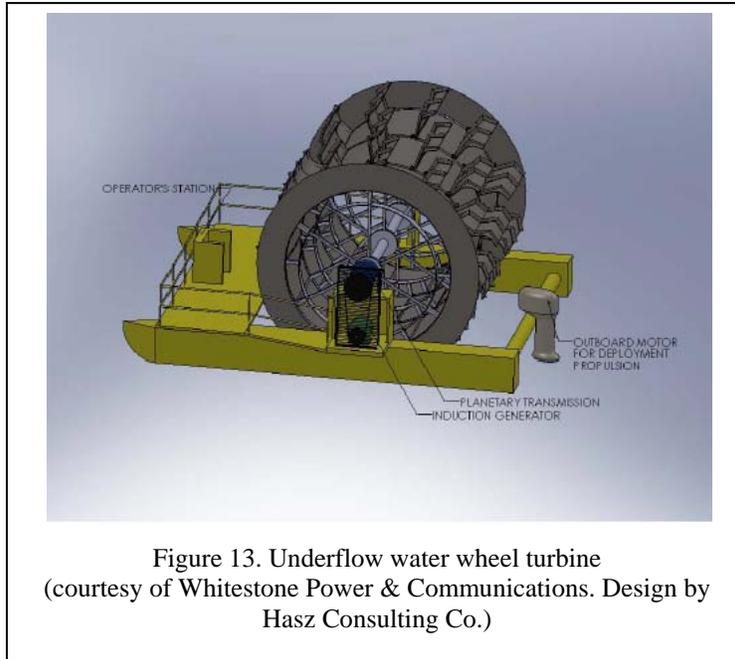


Figure 12. VIVACE vortex-induced vibration hydrokinetic turbine (picture courtesy of G. Simiao, Vortex Hydro Energy, and M.M. Bernitsas, U. Michigan)



Tables 3–5 list river and tidal current hydrokinetic turbine manufacturers and their stage of technology development.

Table 3. Vertical axis turbine companies and turbine technology stage of development				
Company	Location	Device	Stage of Technology	Capacity
Blue Energy	Canada	Blue Energy Ocean Turbine	Scale model sea trials	250 kW
C-Energy	Netherlands	Wave Rotor	Scale model sea trials	30 kW
Lucid Energy Technologies LLP	Goshen, IN	Gorlov Helical Turbine	Scale model sea trials	20 kW
New Energy Corporation Inc.	Canada	EnCurrent Turbine	Full scale prototype	5–250 kW
Ponte di Archimede International S.P.A.	Italy	Enermar	Scale model sea trials	25 kW
Sea Power International AB	Sweden	EXIM	Scale model sea trials	48–72 kW

Company	Location	Device	Stage of Technology	Capacity
Atlantis Resources Corporation	UK	Nereus	Scale model sea trials	150 kW
Clean Current Power Systems	Canada	Clean Current tidal turbine generator	Full scale prototype	65 kW
Free Flow Power	Gloucester, MA	SmarTurbine Generator	Scale model tank testing	10 kW
Free Flow 69	UK	Osprey	Scale model sea trials	1 kW
Hammerfest Strom UK	UK	Tidal Stream Turbine	Full scale prototype	300 kW
HydroCoil Power, Inc.	Wynnewood, PA	HydroCoil	Scale model sea trials	20–40 kW
Hydro Green Energy	Huston, TX	Hydro+	Commercial	35 kW
Maine Current Turbines	UK	SeaGen	Full scale prototype	300 kW–1.2 MW
Natural Currents Energy Services	Highland, NY	RED HAWK Tidal Turbine	Scale model sea trials	125 kW
Ocean Flow Energy	UK	Evopod	Scale model sea trials	1 kW
Ocean Renewable Power Company	Fall River, MA	ORPC Turbine Generating Unit	Scale model sea trials	32 kW
OpenHydro	Ireland	Open-Centre Turbine	Full scale prototype	250 kW–1 MW
Robert Gordon University	UK	Sea Snail	Full scale prototype	150 kW
SMD Hydrovision	UK	TidEl	Scale model tank testing	500 kW
Swanturbine Ltd.	UK	Swanturbine	Scale model sea trials	330 kW
Tidal Energy Pty. Ltd.	Australia	Davidson-Hill Venturi Turbine	Scale model sea trials	Unavailable
Tidal Generation Ltd.	UK	DEEP-Gen	Full scale prototype	500 kW
Tidal Steam	UK	Triton	Scale model tank testing	10 MW
Tocado Tidal Energy Ltd.	Netherlands	Tocado Aqua 2800	Full scale prototype	32 kW
University of Strathclyde	UK	Contra-Rotating Marine Turbine(CoRMaT)	Scale model sea trials	30 kW
Verdant Power	New York, NY	Free Flow System	Full scale prototype	35 kW–1 MW

Company	Location	Device	Stage of Technology	Capacity
BioPower Systems Pty. Ltd.	Australia	bioStream	Detailed design	250 kW
Pulse Generation Ltd.	UK	Pulse Hydrofoil	Scale model tank testing	100 kW
VIVACE	US	Vortex induced vibration	Scale model tow tank testing. Test deployment in the St. Claire river – 2010	Unavailable
Underflow water wheel	US, Alaska	Underflow waterwheel	Conceptual	Unavailable

Hydrokinetic Projects in Alaska

Several funded projects in Alaska are underway to better define the hydrokinetic potential of Alaska’s inland rivers, to evaluate the performance of specific turbine technology in Alaska’s river environments, and to prepare for river and tidal demonstration projects. These projects, listed in Table 6, are described in the following paragraphs.

Location	Manufacturer	Device
Ruby (Yukon River)	New Energy	5 kW EnCurrent Power Generation Systems
Cook Inlet	ORPC	(4) 250 kW TidGen TGU [2012] (4) 500 kW OGen TGU [2013] (4) 500 kW OGen TGU [2014]
Eagle (Yukon River)	New Energy	25 kW EnCurrent Power Generation Systems
Igiugig (Kvichak River)	EPRI study/ AEA renewable energy fund grant	Feasibility and Planning stage
Nenana (Tanana River)	ORPC	30 kW RiverGen TGU
Whitestone (Tanana River)	Whitestone Power & Communications	Underflow waterwheel turbine (recently awarded a DOD technology maturation grant)

Ruby hydrokinetic project

In the summer of 2008, a 5 kW in-stream hydrokinetic generator developed by New Energy Corporation was installed in the Yukon River at Ruby, Alaska, for a test period of one month. The project was designed to harness electricity from the free-flowing Yukon River and test the viability of using a hydrokinetic generator to offset the high-cost diesel fuel used to power the community's electrical grid. The pontoon barge holding the turbine was anchored to cliffs approximately 200 m downstream of the main Ruby slip. The project had a budget of \$65,000, which covered the generator, the pontoon barge onto which the generator was mounted, the transmission cable, the anchoring equipment, and a V-shaped debris boom attached to the front of the boat to protect the generator from debris floating down the river (Bryson, 2009). The turbine worked as anticipated, but slow current at the river’s edge prevented much electricity from being generated. The turbine was deployed again in the summer of 2009 and anchored to concrete blocks 800 ft offshore in an area of swifter current. While the diversion system was effective, it required regular cleaning, as entrapped floating and submerged debris adversely affected turbine performance. Power transmission between the turbine and shore became a significant challenge, and the power cable that was deployed only sent power to shore for four days before being worn through along the riverbed. The turbine was left in the river through the rest of the summer with an Acoustic Doppler Current Profiler taking measurements on river speed. In the summer of 2010, the anchor lines set during the previous summer were retrieved and a power cable that was more protected and better anchored was laid between the turbine and the shore. Using a 435 hp barge from a local barge line, the cable was dragged from shore through the water to anchor buoys mid-channel. Unfortunately, the wide stretch of river (900 m across) and the resources available prevented adjustment of the cable after the initial placement. Further attempts to reposition the cable failed due to its extreme weight. In addition, a number of high-water events throughout the summer brought unusual amounts of debris downriver, which continued to prevent long-term deployment of the turbine barge, even though the debris boom was redesigned twice to better enable it to shed debris (Figure 14). The turbine barge and power cable were successfully pulled from the river in mid-September 2010, and the cable was re-spooled using heavy equipment. The anchor lines were attached to three-eighths inch cable and laid on the river bottom; then the cable was played out to shore and attached to a sturdy anchor ready for retrieval in the spring.



Figure 14. Debris pile on a 5 kW turbine barge at Ruby, Alaska

Cook Inlet project

A subsidiary of Ocean Renewable Power Company, ORPC, Alaska LLC (ORPC), has applied for a FERC preliminary permit and filed a draft pilot project licensing application to install and test a series of power systems in Cook Inlet near Fire Island. Cook Inlet has the second highest tidal range in North America after the Bay of Fundy in Canada. The strong tidal resource makes Cook Inlet attractive for tidal energy development (ORPC, 2010). In the summer of 2009, ORPC conducted in-depth marine geophysical work at the site including bathymetry, side scan sonar, sub-bottom characterization, and extensive current velocity surveys. Additionally, ORPC conducted a pre-deployment fish and marine mammal study, and began a visual observation program to assess the frequency of occurrence and use of the proposed deployment area by Cook Inlet beluga whales, which are on the Endangered Species list. ORPC will continue this study through 2012, using state-of-the-art passive hydro-acoustic monitoring technology to further characterize usage patterns of the area and assess any effects of the tidal energy project on the distribution of these whales. Studies to determine the prevalence of debris, sediment, and ice (during winter) will be conducted in the future. In August 2010, ORPC conducted performance testing of their Beta TidGen™ Turbine Generator Unit at flow speeds of slightly more than 2.5 m/s (5 knots), demonstrating that the turbine produced power within design performance tolerances (Figure 15).

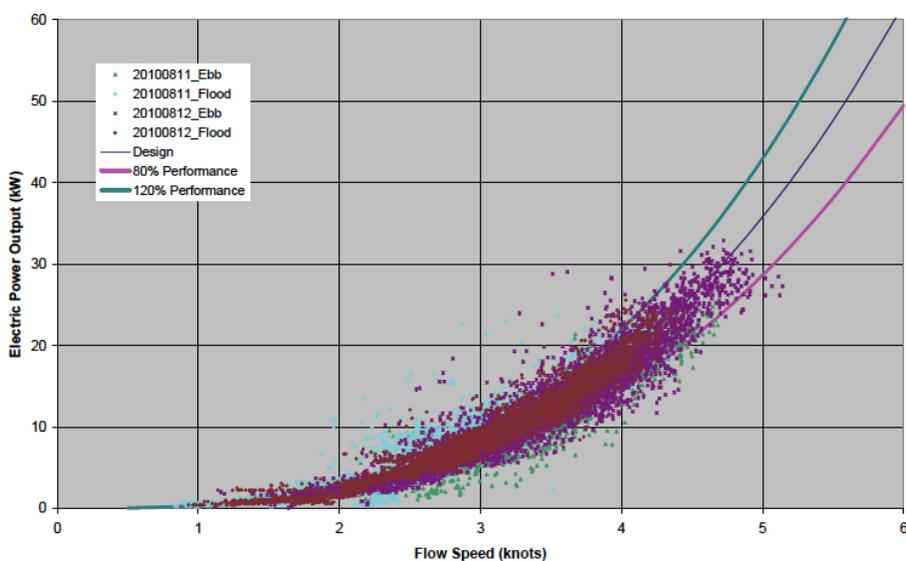


Figure 15. Electric power versus tidal flow velocity for the ORPC TidGen™ turbine shown in Figure 8 (ORPC, 2010).

Eagle hydrokinetic turbine project

The Alaska Power and Telephone Company (AP&T) received a grant from the Denali Commission in 2007 to install a hydrokinetic turbine in the upper Yukon River near Eagle, Alaska, as part of a pilot study to determine the viability of the new technology. The pilot project includes fish studies to determine the turbine's impact on local species and migrating salmon. If the five-year pilot project proves feasible and economical, AP&T may install additional turbines to meet the utility's full load requirement. The project's 25 kW New Energy Corp. EnCurrent turbine generator was installed in late spring 2010, and operating systems were commissioned. The turbine was in service until early July, when it was damaged during a period of very heavy debris drift on the river. The debris on the river surface piled up in front of the turbine barge, and large submerged, neutrally buoyant debris damaged the barge's mooring equipment. The turbine was removed from service, and the turbine barge was moved to shore for repair. Heavy rains in the region damaged the Taylor Highway and delayed efforts to repair and redeploy the turbine. After repairs in early August, the turbine barge was redeployed, and the turbine generator was placed back into service supplying power to the grid at Eagle (Figure 16). The generating and power-conversion equipment performed well. Turbine operation was halted again after another heavy drift event in mid-August, which damaged the generator power cable. The turbine was removed from service, but the barge was maintained on the mooring until late September, at which time all equipment was removed from the river, winterized, and placed in storage at the community's diesel power plant. Plans are to redeploy the turbine in spring 2011.



Figure 16. New Energy 25 kW hydrokinetic electric turbine on the Yukon River at Eagle, Alaska (August 2010).

Igiugig project

Igiugig, a small community of less than 60 people in southwest Alaska, is located at the mouth of the Kvichak River near Lake Iliamna. The village's position downriver from Lake Iliamna reduces summer/winter variability in the flow of the river. A study conducted by EPRI (Previsic, 2008) indicated that installation of a hydrokinetic turbine could help reduce the community's dependence on fossil fuels. The river where the hydrokinetic device would be deployed remains ice-free throughout the winter. Nonetheless, the device would need to be removed during spring breakup because of ice chunks that float downriver from Lake Iliamna. The town currently operates three diesel generators with capacities of 60 to 100 kW. Load patterns range from 40 to 95 kW, peaking during the cold winter months. Igiugig is in the

initial stages of implementing a plan to develop hydrokinetic turbine power-generation capability, working with the AEA through an Alaska Renewable Energy Fund grant. A preliminary FERC permit has been granted, and baseline studies are planned for 2011. The specific hydrokinetic technology has not yet been determined, but plans are in place to install a turbine in 2012.

Nenana project

ORPC, Alaska LLC has a Denali Commission grant to demonstrate its hydrokinetic RivGen™ Turbine Generator Unit (TGU) in the Tanana River at Nenana, Alaska. The full RivGen™ Power System will include the TGU, bottom support frame, debris-diversion system, and power electronics to interconnect the system into isolated micro-grids. Other participants in this project include the Alaska Hydrokinetic Energy Test Center (AHERC) at the University of Alaska Fairbanks (UAF), the National Renewable Energy Laboratory (NREL), the City of Nenana, and the Nenana Native Council. AHERC is characterizing the environment of the Tanana River, helping with debris description and foundation design in preparation for turbine installation, which is scheduled for 2012. AHERC will conduct studies to determine the impact of the turbine once it is installed. Additionally, river debris, ice, and/or silt, which could possibly damage a hydrokinetic device, are being studied.

Notable Hydrokinetic Projects beyond Alaska

Hydro Green Energy: Hastings, Minnesota, Project

Hydro Green Energy installed the first FERC-licensed commercial grid-connected hydrokinetic project in the U.S. The project began operation in January 2009 with the installation of a 100 kW hydrokinetic turbine in the Mississippi River near Hastings, Minnesota. The hydrokinetic turbine, which is installed behind an existing hydroelectric turbine, generates electricity by capturing the energy that remains in the water current upon exiting the dam. One benefit of installing the hydrokinetic turbine downriver from a dam is the filtration of river debris by the existing dam, which otherwise could damage the hydrokinetic turbine. There are plans to install a second 100 kW turbine at the site (Neville, 2009).

Clean Current: Race Rocks Tidal Energy Project

The Race Rocks Tidal Energy Project was undertaken as a means of offsetting diesel-generated electricity at the Race Rocks Ecological Reserve on the Strait of Juan de Fuca in Canada. A 65 kW Clean Current Tidal Turbine Generator (TTG) was installed from July to September 2006. Performance of the device was tested over a two-month period, before it was connected to the battery-storage system at the reserve. The device was in operation for five months and extracted power in water flows up to 6.6 knots. However, the device was removed in May 2007 because of unacceptable performance of its water-lubricated bearing system. In October 2008, the device was redeployed after the bearing system was replaced (Clean Current Power Systems Incorporated, 2008).

Verdant Power: Roosevelt Island Tidal Energy Project

Verdant Power is operating the Roosevelt Island Tidal Energy (RITE) project in New York City's East River. The project has been carried out in three phases. Prototype testing was conducted in phase one, which ran from 2002 to 2006. During phase two—the demonstration phase that ran from 2006 to 2008—Verdant operated an array of six full-scale 5 m diameter rotors. During phase two, the array produced 70 MWh over 9,000 turbine hours of operation. The project is currently in phase three, which began in 2009 and will continue until 2012. During this phase, Verdant plans to expand the scale of the project to 1 MW by increasing the number of turbines in operation to 30, if the proper permit can be attained from FERC (Verdant Power, 2009a).

Verdant Power: Cornwall Ontario River Energy Project

Verdant Power is operating the Cornwall Ontario River Energy Project (CORE) on the St. Lawrence River near Cornwall, Ontario. The project utilizes three-blade, horizontal-axis turbines to extract energy from the currents of the St. Lawrence River. The project is currently in the first of two phases. Phase one, the demonstration pilot, began in 2007 and will continue until 2011. During this phase, resource analysis, pilot permitting, and test deployments will be undertaken. During phase two, a commercial build-out will take place from 2011 to 2013, which entails securing commercial permits, installing turbines with a combined capacity of 5 MW (with future capacity additions up to 15 MW), and commercial sale of electricity to the local grid (Verdant Power, 2009b)

The European Marine Energy Center Ltd (EMEC, 2010)

The European Marine Energy Center (EMEC) Ltd. is a multi-berth testing facility for wave and tidal hydrokinetic devices. EMEC is located in Orkney, Scotland, because of the area's strong wave and tidal resources and because Orkney is the most northerly town connected to the UK grid. The wave testing site is located at Billia Croo, Mainland Orkney, and the tidal testing site is located at the Fall of Warness, off the island of Eday. At the center, manufacturers of wave and tidal energy conversion devices are able to test full-scale grid-connected prototypes. Services offered by EMEC include assessments of device energy-conversion efficiency, structural integrity, and survivability in a marine environment. Additionally, EMEC offers assistance with regulatory issues, grid connection, monitoring of weather and marine conditions, harbor access, and engineering, office, and data support. Devices tested at EMEC's wave site include Pelamis Wave Power's 750 and Aquamarine Power's Oyster. OpenHydro's Open Centre Turbine was tested at the tidal testing site.

The Fundy Ocean Research Center for Energy (FORCE, 2010)

The Fundy Ocean Research Center for Energy (FORCE) is located at the Minas Passage of Bay of Fundy, off the coast of Nova Scotia, Canada. The Bay of Fundy has the world's largest tidal range, which makes it the ideal testing site for tidal energy devices. FORCE owns and operates a grid-connected testing and demonstration facility with three berths. The facility will be connected to a grid that serves both eastern Canada and the United States. FORCE offers shared infrastructure, insurance, environmental monitoring, and resource research. The companies that have or are currently testing their devices at the FORCE facility include OpenHydro, Marine Current Turbines, and Clean Current Power (FORCE, 2010).

Alaskan Hydrokinetic Power Resource Evaluation Projects

The first step in developing hydrokinetic power resources requires knowledge of how much hydrokinetic energy is potentially available, where it is located, and how local site conditions affect turbine installations, operations, and maintenance. Two projects through the AEA are underway to characterize potential hydrokinetic power for several rivers in Alaska, and a Department of Energy (DOE) study is being conducted to characterize the hydrokinetic potential of rivers and constructed waterways throughout the U.S. including Alaska. The AEA recently published results from an assessment of Alaska's coastal tidal hydrokinetic potential (Alaska Energy Authority, 2009).

With funding from the AEA, the University of Alaska Anchorage (UAA) is conducting a two-year hydrokinetic energy assessment of major rivers in Alaska. It is expected that the project will be extended for a third year. In year one, UAA visited 17 sites on the Yukon and Kuskokwim Rivers including Bethel, Lower Kalskag, Upper Kalskag, Aniak, Chuathbaluk, Napaimute, Galena, Koyukuk, Nulato, Kaltag, Grayling, Anvik, Holy Cross, Marshall, Pilot Station, St. Mary's, and Mountain Village. In year two, UAA visited 10 sites on the Kuskokwim, Susitna, and Copper Rivers including Whitestone, Tanacross, Gakona, Copper Center, Chitina, Teller, Stony River, Sleetmute, Red Devil, and Crooked Creek. Based on data collected and nearby USGS gage data, hydraulic and hydrologic models are being developed and hydrokinetic energy potential is being assessed. Preliminary findings indicate that nearly all of the sites

have sufficient velocity to allow power generation. The sites farthest upstream have the highest velocities and, therefore, the highest hydrokinetic power density. In Pilot Station (on the Yukon River), for example, preliminary results indicate that the river could supply between 300 and 400 Watts per square meter of river cross-section. During 2011, UAA plans to study five to ten additional sites including additional sites on the upper Yukon. UAA is also doing modeling to estimate the impacts of hydrokinetic devices on river velocity, water level, and sediment transport.

In the spring of 2010, UAA, UAF, and NREL began a collaborative project led by EPRI and funded by DOE to conduct a nationwide hydrokinetic assessment. In April 2010, the AEA hosted a meeting of national hydrology “experts,” who provided guidance on what methodology to use in conducting the assessment. In the first year of the study, the team made use of NHDPlus to obtain estimates of average velocity and discharge at major river junctions of the U.S. (“NHDPlus” is an extension of the National Hydrologic Database [NHD] that includes DEM and river slope data.) The team determined that the top ten river sections, in terms of gross power potential, are found on the Mississippi, Columbia, and Yukon Rivers. Hydrologists are now working with the Corps of Engineers to gather additional river cross-section data in order to provide higher resolution power-density estimates of these major sources of hydrokinetic energy. In the second year, the practical limits of power availability will be assessed, accounting for issues such as navigational uses of the rivers and impacts of hydrokinetic devices on river flow.

In December 2010, UAA and the Ocean Renewable Power Corporation (ORPC) will be receiving a DOE grant to do abrasion testing of critical components (bearings and seals) of hydrokinetic devices. The research team will construct a laboratory flume at UAA to test bearings and seals under sedimentary, flow, and loading conditions that reflect the expected conditions at the ORPC field site in Cook Inlet. The team is currently designing the flume apparatus and expects to begin testing in January 2011.

In partnership with ORPC, UAF has undertaken detailed characterization of a reach of the Tanana River near Nenana, Alaska, in preparation for a second-stage planned deployment of ORPC’s RivGen™ TGU demonstration project in 2012. The river’s characterization includes an examination of the site’s available year-round hydrokinetic energy potential as well as the river environment, since it may affect the turbine installation. Aspects of the river environment of interest include river dynamics and channel stability, sediment transport, debris flow, ice interactions, and fish. An analysis of modeling and of measurements made in August 2009 indicates that in the main channel of the reach of river at the study site, the current velocity maximum was about 6 knots (3 m/s) with an average velocity of about 4 knots (2 m/s). The amount of available specific power per square meter ranged from 1900–6500 W/m² with most of the river reach exceeding 2600 W/m². Analysis of turbulence data indicates that the river channel is stable in the upper part of the reach and appears to be migrating from the left to the right shore at the downstream end of the test site river reach. Recent findings indicate that the riverbed at Nenana has a large amount of bed-load sediment transport ranging from sand size to cobble size, as a general function of current velocity. Analysis of river morphology and hydrodynamics just below the railroad bridge indicates that the reach of river just below the river may be most suitable for deployment of a TGU, and additional characterization work is underway to confirm these findings.

Challenges to Development of a Viable Alaskan Hydrokinetic Power Industry

Developing a vibrant hydrokinetic commercial industry involves determining the technological, operational, and economic viability of hydrokinetic turbines, meeting permitting requirements, and gaining stakeholder acceptance.

Technological and economic viability is a function of a specific manufacturer’s technology and power-generation costs in target markets, and is not a topic of this report. Operational viability is affected by the ability of a given hydrokinetic turbine technology and its support systems to operate in the river or tidal

environment of interest. For rivers in Alaska, this means operating in turbulent currents and specific discharges that vary seasonally; it also means interaction with sediment, floating and submerged debris (Figures 17), ice during freeze-up (Figure 18) and breakup, and local and migrating fish and marine mammal populations. High-velocity currents, specific power density, and specific discharge are localized in a river channel. Such channels have riverbeds and banks of sediment, gravel, and cobbles that may migrate, causing the high-specific discharge flow to shift away from an installed turbine (Figure 19).

Debris exists at all depths in Alaskan rivers because of the presence of trees, branches, and twigs with different degrees of absorbed water, and rocks and soil. At Ruby, efforts to protect the turbine from floating driftwood using a simple A-frame prow were successful during earlier trials. However, debris floating beneath the river surface snagged on the turbine's floating platform anchor chain, causing a decrease in current velocity immediately in front of the turbine, with an associated reduction in electrical output as the accumulated debris increased (Bryson, 2009). More severe debris problems plagued the Ruby deployment (Figure 14) and the Eagle project turbine deployments during 2010. Alaskan rivers carry debris throughout the open-water season, and more debris often enters rivers as stage increases; however, the relationship between river stage and debris size, amount, and distribution throughout the water column is not well understood or characterized. For large rivers, such as the Yukon, the relationship between debris and river stage is even more complex, as tributaries with high local stage may dump large amounts of debris into the main channel with little noticeable change in stage of the main river. Such information is needed to determine how debris will interact with turbines and to develop debris-mitigation methods.

The potential hydrokinetic energy of Alaskan rivers is highest during the period of open water and greatly reduced during winter months when the rivers are covered by ice. For example, open-water season for the Tanana River is nominally from sometime in May until sometime in October, with mean river discharge ranging from about 708 to 1700 m³/s (25,000 to 60,000 ft³/s). During winter months, mean discharge decreases to a low of about 200 m³/s (7000 ft³/s) (Langley, 2006) (Figure 20). These figures correspond to main channel current velocities that can exceed 3 m/s during open water and drop to less than 0.8 m/s during winter. This seasonal difference is significant to the operation of turbines, since most turbines require current velocities of about 3 knots (1.5 m/s) to operate viably.

A first consideration for turbines installed below the water surface in winter is whether low currents are sufficient to overcome turbine internal resistance to motion; another consideration is whether the turbine is economically viable to operate, since low current velocities produce very small amounts of power. One possible reason to operate a turbine throughout the winter is to capture energy at the transition between ice-covered and open-water seasons during freeze-up in the fall and just after breakup in the spring. Capturing energy at this transition might increase the period of high-current power conversion by as much as 1 or 1½ months—energy that might otherwise be lost by the time taken to deploy and remove a turbine each season (Figure 20). A challenge for turbines installed underwater is that of operating during the initial freeze-up period, when the river is in a super-cooled state and frazil ice crystals form throughout the water column, adhering to turbines or other objects in the water (Figures 18 and 21). A second challenge is to ensure that the location of a submerged turbine is not prone to ice jams during spring breakup. Susceptible locations can generally be determined by examining past ice jam occurrences, since they tend to be caused by local constrictions in the river or by changes in flow direction.



Figure 17. Log debris island impacting (upper left) and carrying off (upper right and lower left) a fish wheel on the Tanana River near Nanana, Alaska, on August 1, 2008, and depositing it against a bridge pier (lower right) (courtesy of Stephen Lord)

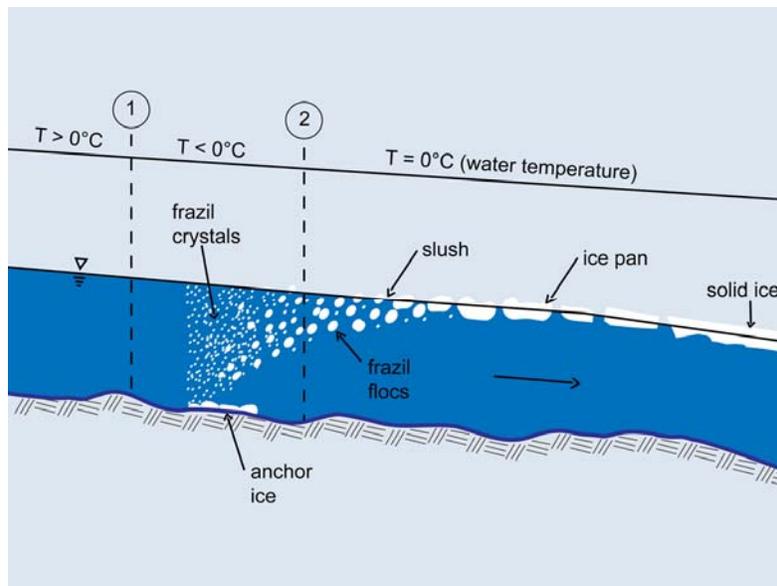


Figure 18. River ice freeze-up process

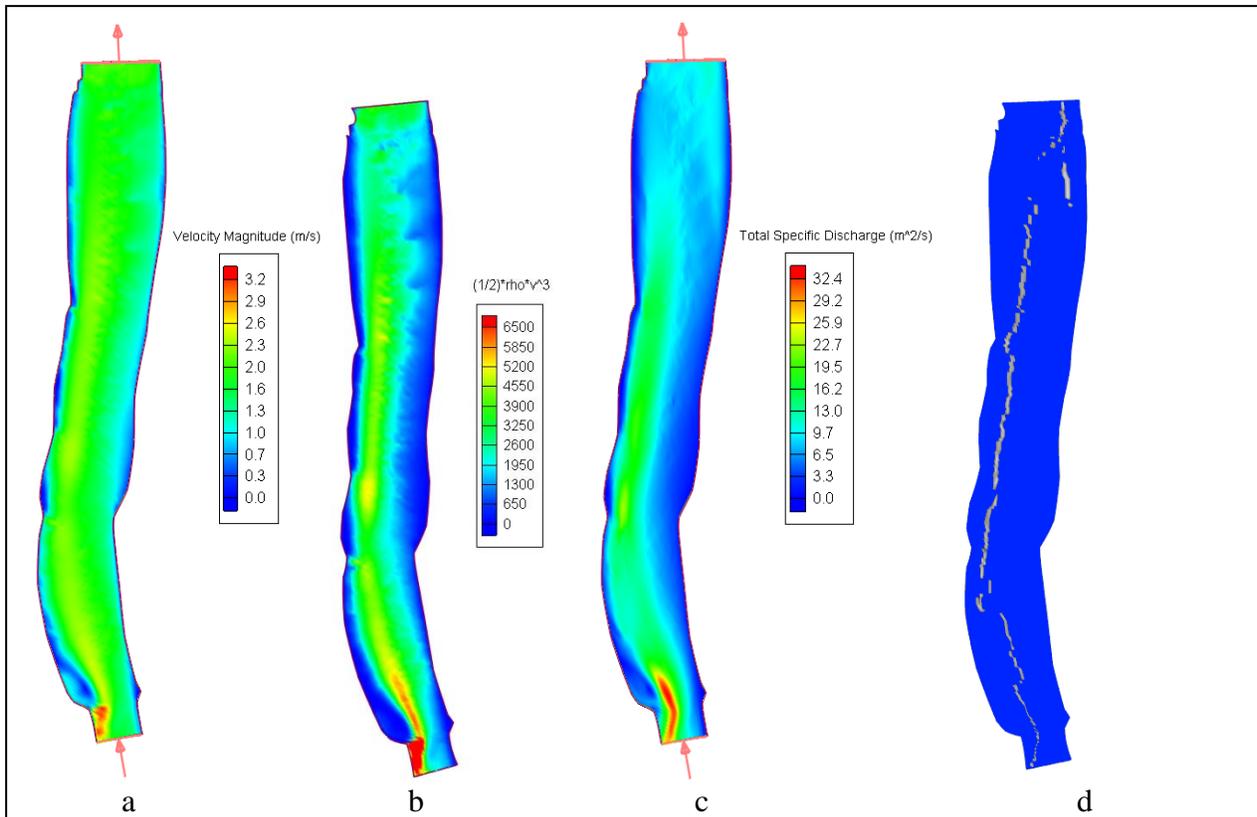


Figure 19. Calculated current velocity (a), specific power density (b), total specific discharge (c), and maximum total specific discharge (d) for the Tanana River based on measurements made in August 2009. The main channel is stable from the upstream location (bottom of images), but becomes unstable at the downstream location (top of images) as indicated by lower and less concentrated velocities, specific power density, and total specific discharge. The migration of the main channel to the right bank is indicated by the shift of the line of maximum total specific discharge from the left bank to the right bank at the downstream location (d) (Toniolo et al., 2010).

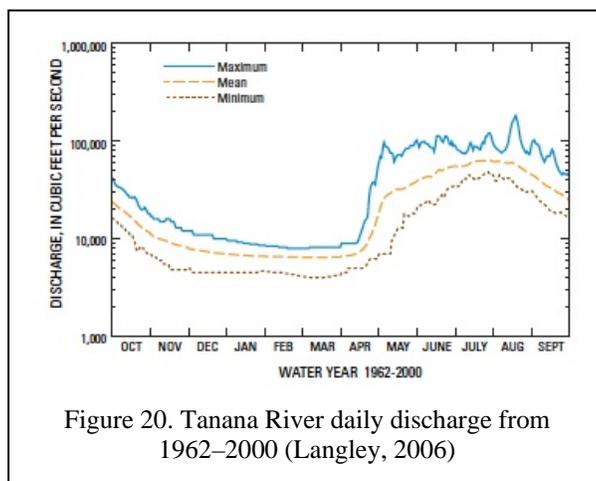


Figure 20. Tanana River daily discharge from 1962–2000 (Langley, 2006)



Figure 21. Overnight accumulation of frazil ice on four different material types during Tanana River freeze-up. From right to left, the samples consist of an ABS sample mount for (1) teflon, (2) stainless steel, and (3) steel. Frazil ice also adhered on the ABS (seen as the darker material in the lower half of each sample). The accumulation of frazil ice on teflon was about the same as on the other samples (5–9 cm on the upstream side of the samples), but slid off the teflon sample as it was removed from the water due to low adhesion.

The challenges described in this section are primarily related to river deployment of hydrokinetic turbines, since bottom-founded turbines in many tidal locations will be well below the water surface, thus avoiding surface debris and many problems related to ice in winter. However, concern about interaction with fish and marine mammals and the influence of current flow dynamics including turbulence are common concerns to both tidal and river deployments. In addition, in a location such as Cook Inlet, sediment, turbulence-induced scour and shear, subsurface debris, and neutrally buoyant ice can influence turbine operations. In addition, there is the ever-present need to address the concerns of permitting agencies and other stakeholders over the relative benefits and impacts of hydrokinetic technology in both river and marine environments.

Stakeholders with an interest in protecting aquatic environments will want to know the potential impacts of hydrokinetic conversion technologies on fish and marine mammals and the aquatic habitat, and will

want to have input to the permitting process to protect stakeholder interests. Support or opposition from stakeholders can affect the pace of acceptance for hydrokinetic energy in local communities (Hartzell, 2010). Conversely, many turbine developers and hydrokinetic power generation advocates express frustration with the extent of study and the expense of meeting imposed permit requirements (Greenemeier, 2010). The ability of turbine developers to raise investment capital is restricted when it takes an excessively long time to obtain permits or when the permitting requirements are not well known, a problem that permitting agencies recognize (Wellinghoff et al., 2008).

Conclusions and Approaches to Facilitating Hydrokinetic Power in Alaska

Turbines placed directly in river, ocean, or tidal current generate hydrokinetic power from the kinetic energy of moving water, typically require a minimum current of 2–4 knots (1–2 m/s), and provide optimal performance at currents of between 5–7 knots (1.5–3.5 m/s). With over 90% of the total U.S. tidal hydrokinetic resource and 40% of the U.S. river hydrokinetic resource, Alaska is well positioned to use hydrokinetic turbines to help replace the use of fossil fuels. This is an especially attractive option for reducing dependence on high-cost diesel in the many remote communities in Alaska that are situated along navigable waterways.

Studies to characterize the hydrokinetic potential of Alaska river and tidal currents have concluded that hydrokinetic turbines are a viable method of generating power in Alaska, with the cost of electricity varying significantly depending on the location of the installation. In 2010 dollars, a 17 MW tidal power generating facility at Knik Arm is estimated to cost around \$2,500/kW, with electrical cost of about \$0.11/kWh. River hydrokinetic turbines located in remote locations range from \$3,300–\$8,000/kW, with electrical costs of \$0.19–\$0.68/kWh (using 2010 dollars). Further studies are in progress not only to characterize Alaskan river and tidal hydrokinetic power potential, but also to provide information needed to plan future projects in Cook Inlet and the Tanana River and information of general interest for future planning at a number of other Alaska rivers.

At present, only two hydrokinetic turbines have been tested in Alaska: a 5 kW turbine at Ruby for short periods during 2008, 2009, and 2010, and a 25 kW turbine at Eagle during 2010. The deployment at Eagle, which was grid-connected, can be readily converted to full commercial operation if tests are successful. Additional demonstration projects are planned for Cook Inlet, the Tanana River, and the Kvichak River, with other interested communities developing turbine deployment concepts. Additional hydrokinetic projects outside of Alaska include Hydro Green Energy's 100 kW installation in Hastings, Minnesota; Clean Current's 65 kW installation at Race Rocks Ecological Reserve in Canada; and Verdant Power's tidal installations at Roosevelt Island in New York and a 5 MW installation on the St. Lawrence River near Cornwall, Ontario.

Challenges to developing a commercial hydrokinetic industry in Alaska include determining the technological, operational, and economic viability of hydrokinetic turbines, meeting permitting requirements, and gaining stakeholder acceptance. Hydrokinetic technology can be affected by debris, sediment, frazil and surface ice, river dynamics (turbulence, current velocity, channel stability), and the effect of turbine operations on fish and marine mammals and their habitat. The question of turbine-operation impacts on the aquatic environment is one of the major issues that will determine stakeholder and permitting agency views toward this new technology.

River and marine hydrokinetic technology (RMHT) is still at the emerging stage of development and is approximately at the same stage that wind power generation technology was 15 to 20 years ago (Marine Hydrokinetic Technologies, 2009). Moving RMHT from the emerging stage into the practical commercial stage will require support similar to that provided to wind technology development during its nascent years. This support includes funding for research to develop emerging RMHT and developing an

understanding of the river and marine environments that will host RMHT. Funding support will also be needed to develop data and modeling tools required to describe the interactions between RMHT and aquatic environments. There is a need to engage all relevant stakeholders through dialogue at the earliest stages of project development in order to develop reasonable approaches to permitting and to develop Alaska-based expertise that is well integrated with the national scene.

In Alaska, the beginnings of many of the structures described in the previous paragraph are already in place and can be used to help push RMHT toward commercial realization. The state legislature has recently created an Emerging Technology Grant Fund to complement the existing Renewable Energy Grant Fund, and the Denali Commission is actively supporting a hydrokinetic demonstration project at Eagle. These are important steps, as they provide funds that directly develop in-state capabilities; they demonstrate to federal agencies such as DOE and BOEMRE that the state has a serious interest in this technology; and they provide a funding source that can be used to match federal grant funds at the national level.

The beginnings of in-state capability and expertise for RMHT is also in place, with active efforts to develop and deploy systems and conduct studies of river and marine environments, as described in earlier sections. These projects and contacts involve partnerships in nationally funded and state-funded projects (e.g., DOE, BOEMRE, AEA, and Denali Commission) and participation in workshops to examine the ecological effects of tidal hydrokinetic technology. The AEA has created an Ocean/River and Geothermal division that has established a RMHT interest group, is engaging manufacturers, users, and agencies in dialogue, and is providing information through its online portal. The Alaska Hydrokinetic Energy Research Center is working with industry, agency, and community stakeholders to provide applied research, outreach, and training needed to facilitate development of an Alaska hydrokinetic industry.

Alaska is well positioned to facilitate the transition of RMHT from emerging technology through the next five- to ten-year period that it is estimated to take before long-term prototype testing and commercialization is realized (Marine Hydrokinetic Technologies, 2009). By building on existing structures to ensure access to adequate development research funds (state and federal), developing in-state expertise and capabilities, and engaging stakeholders, balanced and coordinated progress is possible.

The one area where existing efforts and funding is lagging is the development of a science-based understanding of how fish and marine mammals will interact with RMHT. Issues of fish and marine mammals have a large stakeholder base related to ecological stewardship, economics, culture, and lifestyle that significantly affects agency views toward what requirements may be needed to permit RMHT. Agencies have indicated repeatedly that what they wish to know is how hydrokinetic technology will affect aquatic habitats and biology, to ensure that aquatic resources will be available to future generations. The design and conduct of targeted studies, in cooperation with agencies, turbine manufacturers, and communities, to assess the impacts of hydrokinetic turbine technology on the aquatic environment would provide agencies with information needed to rationally define specific permit requirements.

Expected Five-Year Trajectory for Hydrokinetic Technology in Alaska

Five years ago, hydrokinetic technology consisted primarily of ideas in papers and studies. During the ensuing five years, these concepts have been developed into actual devices and demonstration projects. If the current state of activity and high interest in developing RMHT continues, and with supportive involvement of agencies and stakeholders, procedures for conducting demonstration projects should be well defined in the near future. In addition, knowledge developed from the initial deployment of devices will point to problems, solutions, and improved technology that aid second-generation efforts and longer-term deployment systems. Over the next five years, it is likely that several long-term demonstration projects will have been completed and that initial small-scale commercial systems will be installed and

operational. It is also likely that studies needed to better define the interaction between hydrokinetic technology and the aquatic environment will be completed and that permit requirements for projects will be well defined. A better understanding of the limits of application of RMHT during winter months should also be known. The focus of development will be to optimize existing hydrokinetic technology, improve technology based on identified operational problems, and develop better economic understanding of how hydrokinetic power generation technology can be integrated into the family of other renewable and fossil fuel energy sources and transmission systems.

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