

## Quick Facts

- Hydrokinetic technologies use the power of moving water – ocean waves or currents in canals, rivers, and tidal channels - to produce electricity.
- New hydrokinetic generation technologies are primarily in the development, demonstration, and pilot phases of deployment and have not yet been commercialized.
- In 2011, the United States had less than 1 megawatt (MW) of installed hydrokinetic, as compared to more than 77,000 MW of conventional hydroelectric generation capacity.<sup>1,2</sup>
- Many hydrokinetic development projects are underway in the United States - as of 2011, the Federal Energy Regulatory Commission (FERC) has issued 70 preliminary permits for hydrokinetic projects.<sup>3</sup>
- Some experts predict that hydrokinetic energy could provide 13,000 MW of new generation capacity to the United States by 2025.<sup>4</sup>
- Like some other renewable energy sources, ocean wave power is variable, with actual generation changing with fluctuations in wave height and/or period. Unlike wind and solar power, however, this variability is highly predictable (for days ahead) facilitating the integration of ocean wave power into electrical grid operations. Tidal current flows can be nearly constant throughout the year, so these hydrokinetic power sources can supply baseload generating capacity. River currents typically fluctuate seasonally and with precipitation events.

## Background

The power of tidal, river, and ocean currents and ocean waves is tremendous, and the basic concept behind hydrokinetic power is not new. For centuries people have harnessed the power of river currents by installing water wheels of various sorts to turn shafts or belts.<sup>5</sup>

Modern ocean wave energy conversion machines use new technology that is designed to operate in high amplitude waves, and modern tidal/river/ocean current hydrokinetic machines use new technology that is designed to operate in fast currents. Both of these emerging technologies have the potential to provide significant amounts of affordable electricity with low environmental impact given proper care in siting, deployment, and operation.

## Description

Tidal/river/ocean current energy and wave energy converters are sometimes categorized separately,<sup>6</sup> but this factsheet covers both types of technology under the general term “hydrokinetic power.” Another marine energy technology, ocean thermal energy conversion, is not covered in this factsheet because it is not applicable to the continental United States but rather to tropical areas.<sup>7</sup>

Wave energy converters take many forms. The simplest are tethered floating buoys that convert the energy in the rise and fall of the passing waves into electricity (often via hydraulics). Other machines have chambers

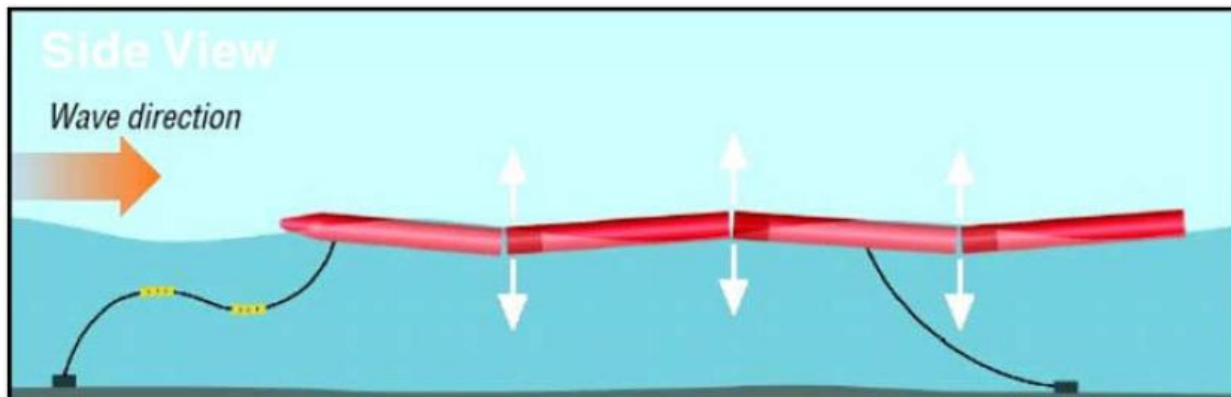
that, when filled and emptied by rising and falling wave water, compress and decompress air to drive an electric generator. Yet another type of machine looks like a giant sea snake with floating pontoons that heave and sway on the ocean surface, driving hydraulic pumps to power an electric generator (see Figure 1 and Figure 2). All of these machines are anchored to the seabed and must withstand marine environments. Waves powerful enough to drive these generators are often found off coasts with large oceans to their west (providing long wind fetch) and strong prevailing winds such as the west coasts of the United States, Chile, and Australia and in the North Sea, amongst many other places.<sup>8</sup>

**Figure 1: The 750 kilowatt (kW) Pelamis sea “snake” converting wave energy to electricity during sea trials in Aguçadoura, Portugal.**



Source: [Pelamis Wave Power](http://www.pelamiswave.com), August 2009.

Figure 2: Illustration of the sea snake's operation.



Source: [Pelamis Wave Power](#), August 2009

Rotating devices take a variety of forms but in general capture energy from water flowing through or across a rotor. Some of these devices are shaped like propellers and can swing, or yaw, to face changing tidal currents. Other rotating devices are shaped like a jet engine, having many vanes turning within a fixed outer ring (see Figure 3). Fast currents, like those in the Missouri and Mississippi Rivers, in tidal channels such as the Puget Sound, or in ocean currents such as the Gulf Stream off Florida, have enough power to turn large rotating devices. The power from a hydrokinetic machine is proportional to the cube of the current velocity. Faster currents are better, and sites with current velocities reaching 3 meters per second (m/s) are desirable. Tidal barrage technology takes advantage of predictable ocean tides. A barrage, or dam across an estuary or tidal channel, traps tidal flows and then releases them through turbines as tides fall.

Figure 3: An ocean view of OpenHydro's tidal current turbine installed near the Orkney Islands at the European Marine Energy Consortium (EMEC) test site.



## **Environmental Benefit/Emission Reduction Potential**

Deploying hydrokinetic power generation instead of relying on fossil fuels for electricity generation avoids greenhouse gas (GHG) emissions and other air pollution associated with fossil fuel use. It has been estimated that 13,000 megawatts of hydrokinetic capacity could be developed by 2025.<sup>9</sup> At full potential, hydrokinetic sources could generate 400 terawatt-hours (TWh) per year, or around 10 percent of U.S. demand in 2007.<sup>10</sup> Assuming hydrokinetic generation displaces generation from the current mix of U.S.

fossil fuel power plants, this level of hydrokinetic power generation would avoid over 250 million metric tons of carbon dioxide (CO<sub>2</sub>) emissions per year, equal to 4 percent of total U.S. CO<sub>2</sub> emissions in 2007.<sup>11,12</sup>

Unlike conventional hydroelectric generation, hydrokinetic power does not require a dam or diversion, thus avoiding the negative environmental impacts associated with dams.

## Cost

Because no commercial hydrokinetic power projects are currently licensed and operating in the United States, it is difficult to estimate the cost of hydrokinetic power production. A 2005 report by the Electric Power Research Institute (EPRI) estimated that some U.S. utility-scale wave power projects could produce electricity for about 10 cents per kilowatt-hour (kWh) once the technology has matured.<sup>13</sup> The present state of technology makes hydrokinetics a long-term investment opportunity with potentially significant but highly uncertain returns. In the meantime, the early stage of the technology and high regulatory costs associated with lengthy permitting requirements and licensing uncertainties are likely to continue presenting major economic hurdles to commercialization of the technology.

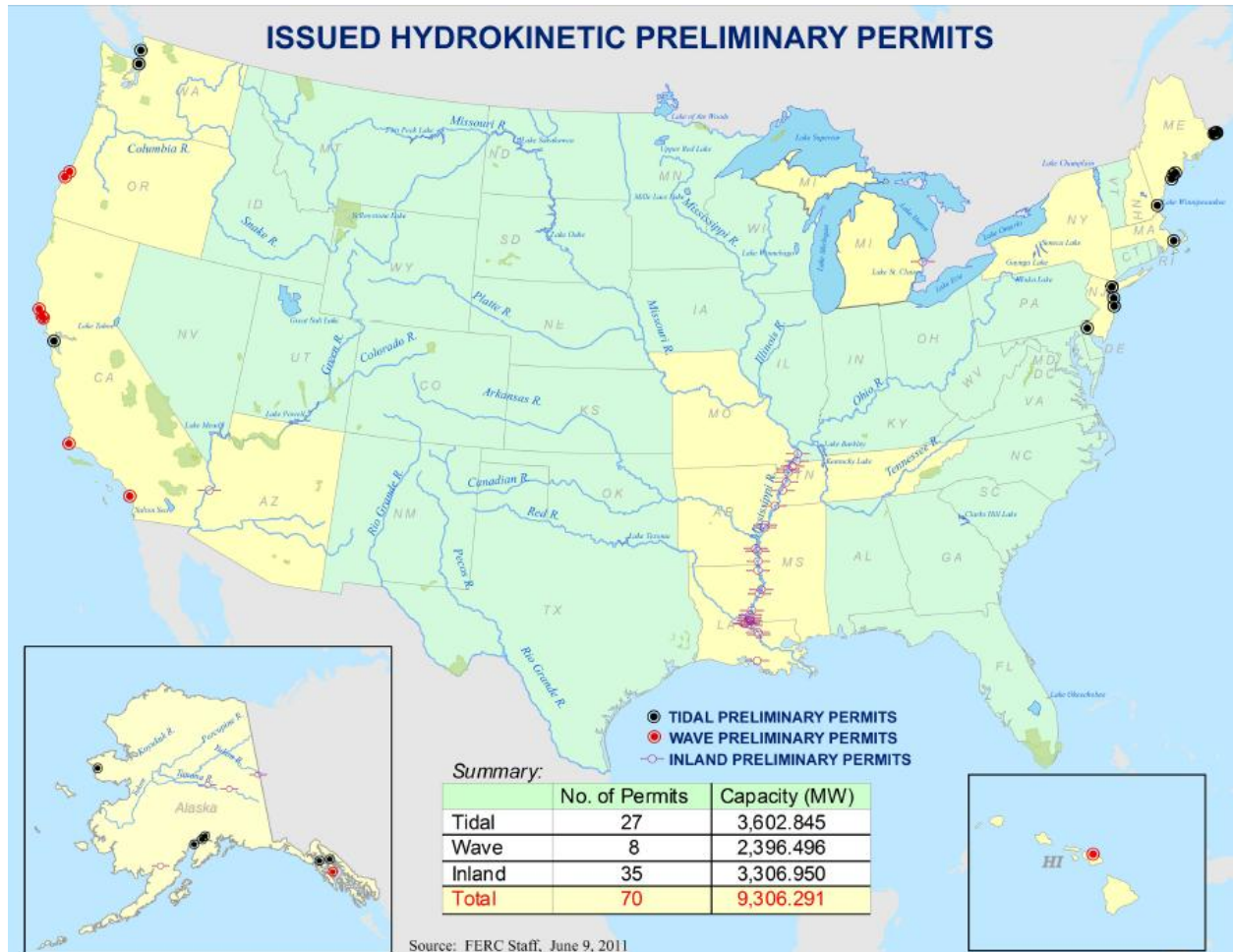
## Current Status of Hydrokinetic Electric Power

A number of hydrokinetic generation technologies are moving beyond pilot or demonstration stages in the United States and globally, and several U.S. commercial wave and tidal energy projects are likely to apply for federal operating licenses in the near future. Areas in the United States with good wave energy potential include most of the continental U.S. west coast, Hawaii, and Alaska. For tidal energy, good sites exist in the Puget Sound, San Francisco, a variety of east coast tidal channels, and in Alaska. For river hydrokinetic energy, large inland rivers such as the Mississippi, Missouri, and Yukon have promising potential power.

As of June 2011, the Federal Energy Regulatory Commission (FERC) had issued 70 preliminary permits for hydrokinetic projects (27 tidal, 8 wave, and 35 inland) with 9,306 megawatts (MW) of generation capacity (see Figure 4). Preliminary permits are pending for an additional 147 projects with 17,353 MW of capacity.<sup>14</sup> These preliminary permits allow feasibility studies but no permanent or large-scale installations. In 2010, a utility-scale wave power project in Reedsport, Oregon, capable of supplying electricity to 1,000 homes, received the first-ever Settlement Agreement with FERC and is expected to apply for a commercial license in the next couple of years.<sup>15</sup> In addition, the Department of Energy awarded \$34 million to hydrokinetic research and development (R&D) projects in the FY2010 budget.<sup>16</sup>

On a global scale, at least 25 countries have initiated hydrokinetic R&D activities.<sup>17</sup> Only tidal barrage technology has achieved commercial scale, and it accounts for 262 MW of the nearly 270 MW of hydrokinetic installed capacity.<sup>18</sup> Approximately 2 MW of wave power and 4 MW of tidal power have been installed, but mostly as short-run tests or prototypes.<sup>19</sup> As in the United States, the development of hydrokinetic projects is also reaching the early commercial stage in other countries, including the under-development 254 MW Sihwa tidal barrage power<sup>20</sup> project in South Korea and the proposed 50 MW tidal current power project off the coast of Gujarat, India.<sup>21</sup>

Figure 4: Map of FERC preliminary permits issued for hydrokinetic projects, June 2011.



Source: Federal Energy Regulatory Commission, June 2011.<sup>22</sup>

Facilities for testing and demonstrating new hydrokinetic technologies are also being established. Prominent R&D centers for each technology include:<sup>23</sup>

- Wave Energy - the European Marine Energy Consortium (EMEC) in Scotland, Wave Hub in Cornwall England, The Danish Wave Energy Center in Hanstholm, the New England Marine Renewable Energy Center (MREC) at the University of Massachusetts Dartmouth, the Northwest National Marine Renewable Energy Center (NNMREC) at Oregon State University, Hawaii’s National Marine Renewable Energy Center (HNMREC), and the Southeast National Marine Renewable Energy Center at Florida Atlantic University. Other notable facilities are found in Galway Bay in Ireland and the Azores in Portugal.
- Tidal Energy - the European Marine Energy Consortium (EMEC) in Scotland, the New England Marine Renewable Energy Center (MREC) at the University of Massachusetts Dartmouth, the Northwest National Marine Renewable Energy Center (NNMREC) at the University of Washington, and the

Southeast National Marine Renewable Energy Center at Florida Atlantic University. Another notable facilities are found in the Minas Passage in the Bay of Fundy in Canada.

There are a number of hydrokinetic devices that have had successful trials and remained in operation after many years of service. For tidal current power, notable examples include: the Irish Open Hydro 1-MW turbine, the first commercial-scale turbine deployed in North America; the 250 kW TREK turbine; Verdant Power's horizontal axis turbines in the St. Lawrence River, developed following Verdant's 2006-2008 RITE project in New York City's East River; the 1.2 MW SeaGen turbine operating in Northern Ireland since 2008; and the 1.5 MW Morild II floating horizontal-axis prototype in Norway.<sup>24</sup> For wave power, notable examples include next generation .75 GW Pelamis Wave Power devices; Aquamarine's Oyster 1 device operating at EMEC since 2009; and Ocean Power Technologies' 150 kilowatt PB150 PowerBuoy in Oregon.<sup>25</sup>

## Obstacles to Further Development or Deployment

- **Cost**

Although equipment costs are likely to fall as technology matures, installation costs could remain high due to extreme marine environments and the specialized engineering required for large marine infrastructure projects. Operation and maintenance (O&M) costs could remain high due to difficult access and working conditions unless machines are developed that can be unattended for long periods of time.

- **Technology**

The technology required for hydrokinetic generation - turbines, generators, structural components, and transmission lines - must withstand extreme marine and river environments. Although the technical issues are challenging, they are not insurmountable. A wide variety of propeller designs and wave energy devices are being tested, and much remains to be learned. Wave energy converters must be designed to withstand very harsh marine conditions for long periods of time. Some of the pilot projects have suffered very rapid failures for this reason.

- **Permitting Requirements**

Developers of hydrokinetic generation projects in the United States face considerable hurdles as regulatory agencies, such as FERC and the Minerals Management Service (MMS), adapt permitting policies to new technologies. Resource agencies, such as the Fish and Wildlife Service, will also require time to learn about the environmental effects of the new technologies. The permitting process for conventional hydroelectric projects is lengthy, taking as much as seven years to obtain an initial FERC operating license, due to a comprehensive review process and environmental study requirements. Hydrokinetic projects must go through a similar review process, and the environmental study requirements are, at this point, even lengthier because so much is unknown about environmental impacts of the new technologies. In 2007, the FERC adopted the Hydrokinetic Pilot Project Licensing Process, which streamlines the issuance of construction and operation licenses for pilot demonstration projects with rated capacities of less than 5 MW, with periods of operation of less than 5 years, and whose purpose is experimental in nature.<sup>26</sup>

- **Environmental Impacts**

Because hydrokinetic power does not require the construction of a dam, it should have less impact on the environment than a conventional hydroelectric project. However, there is still considerable uncertainty about environmental impacts and recognition that impacts will vary with technology and site characteristics. The pilot demonstration projects currently in operation are providing valuable data that regulators and resource agencies need to understand environmental impacts. Attention is focused on the questions of harm to fish and other marine life, detrimental changes to currents and sediment transfer, site impacts from installation and decommissioning, conflicts with other uses of the water body, and intrusive visual appearance. In 2009, the U.S. Department of Energy (DOE) delivered a comprehensive report on environmental impacts of hydrokinetic power generation to Congress. The report stated there is no conclusive evidence that hydrokinetic technologies will cause significant environmental impacts on aquatic environments, fish and fish habitats, ecological relationships, and other marine and freshwater resources.<sup>27</sup>

## Policy Options to Help Promote Hydrokinetic Power Generation

- **Price on Carbon**

A price on carbon, such as that which would exist under a GHG cap-and-trade program, would raise the cost of electricity produced from fossil fuels relative to the cost of electricity from renewable sources, such as hydrokinetic power, and other lower-carbon technologies. A price on carbon would increase both deployment of mature low-carbon technologies and R&D investments in less mature technologies.

- **Research, Development, and Demonstration (RD&D)**

Increased government funding for technology development and testing can help accelerate the commercialization of hydrokinetic technologies. Establishing test sites with existing permits and licenses for testing of wave energy conversion devices and hydrokinetic turbines and generators under standardized conditions could also speed technology development.

- **Addressing Environmental Impacts**

Government-funded test programs with resource agency participation could determine environmental impacts of hydrokinetic power generation with more certainty and inform guidelines and regulations for mitigating such impacts.

- **Streamlining Licensing and Permitting**

Continued efforts to simplify and accelerate project licensing and permitting would enable pilot and commercial-scale projects to be deployed more rapidly and inexpensively.

- **Renewable Portfolio Standards**

A renewable portfolio standard (RPS, sometimes also called a renewable or alternative energy standard, RES/AES) requires that a certain amount or percentage of a utility's power plant capacity or electricity sales come from renewable sources by a given date. Power generators or utilities receive credits for qualified renewable generation and must have sufficient credits to meet the states' targets. At present, 31 U.S. states and the District of Columbia have adopted RPSs (8 U.S. states have renewable energy

goals).<sup>28</sup> In addition, Congress has several times considered a federal RPS. State RPSs or a federal RPS could promote hydrokinetic power technologies by making them qualifying renewable technologies whose generation counts towards compliance with the RPS. In addition, RPS policies or proposals often have carve-outs for specific renewable technologies or provide extra credits for generation from certain technologies, generally in order to promote less commercially mature technologies.

### **Related Business Environmental Leadership Council (BELC) Company Activities**

- [Alstom](#)
- [Lockheed Martin](#)
- [PG&E](#)

### **Related Pew Center Resources**

[Climate Change 101: Technology](#), 2011

[Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards](#), 2006

### **Further Reading/Additional Resources**

Cada, Glenn et al., "[Potential Impacts of Hydrokinetic and Wave Energy Conversion Technologies on Aquatic Environments](#)," *Fisheries*, April 2007.

The Carbon Trust, [Future Marine Energy: Results of the Marine Energy Challenge - Cost Competitiveness and Growth of Wave and Tidal Stream Energy](#), 2006.

U.S. Department of Energy (DOE)

- [Marine and Hydrokinetic Technology Database](#)
- [Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies](#)
- [National Renewable Energy Laboratory, Ocean Energy Technology Overview](#)

Electric Power Research Institute (EPRI)

- *Assessment of Waterpower Potential and Development Needs*, EPRI Report 1014762, Palo Alto, CA March, 2007.
- [Ocean Energy Program](#)
- *Ocean Tidal and Wave Energy: Renewable Energy Technical Assessment Guide—TAG-RE: 2005*, EPRI Report # 1010489, Palo Alto, CA, December 2005.

- *Primer: Power from Ocean Waves and Tides*, Palo Alto, CA, June 2007.

Federal Energy Regulatory Commission (FERC)

- [Hydrokinetic Pilot Project Licensing Project](#)
- [Joint guidance issued with Minerals Management Service \(MMS\) for licensing offshore hydrokinetic projects](#)
- [Hydrokinetic project licensing website, including maps of existing projects](#)

Hagerman, George, [Energy from Tidal, River, and Ocean Currents and from Ocean Waves](#), Presentation, 8 June 2007, Washington, DC.

[Idaho National Laboratory, Hydrokinetic & Wave Technologies](#)

International Energy Agency Implementing Agreement on Ocean Energy Systems (IEA-OES)

- [Annual Report 2010](#)
- [Ocean Energy: Global Technology Development Status, 2009](#)

[Union of Concerned Scientists, Hydrokinetic Overview](#)

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<sup>1</sup> U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), “Marine and Hydrokinetic Technology Database.” Accessed 17 August 2011. <http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx>

<sup>2</sup> U.S. Energy Information Administration (EIA), [Electric Power Annual Report with data for 2009](#), Table 1.2, April 2011.

<sup>3</sup> Federal Energy Regulatory Commission (FERC), “Hydrokinetic Projects.” 9 June 2011. <http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/hydrokinetics-projects.pdf>

<sup>4</sup> Electric Power Research Institute (EPRI), *Assessment of Waterpower Potential and Development Needs*, EPRI Report 1014762, Palo Alto, CA, March 2007.

<sup>5</sup> For example, in the American colonies, undershot waterwheels, built so that only the bottom of the wheel was in the river, drove flour and lumber mills. Dams and diversions, which are required for conventional hydroelectric (which uses the hydro potential energy) but not for hydrokinetic power, were built across rivers in the United States to power mills and factories throughout the 19th and 20th centuries. And over a century ago, ocean waves were used to pump seawater up to a tank on the cliffs in Santa Cruz, California, for spraying on dirt roads and dust control.

<sup>6</sup> Schwartz, SS, editor, *Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop*, Washington, DC, October 2005, prepared by RESOLVE, Inc., March 2006.

<sup>7</sup> For more information on ocean thermal energy conversion, see the U.S. DOE’s [website](#).

<sup>8</sup> Wind fetch refers to the unobstructed distance over which wind can travel across a body of water in a constant direction. Wind fetch is important because longer fetch can result in larger wind-generated waves.

<sup>9</sup> EPRI. “The Future of Waterpower: 23,000 MW+ by 2025” EESI Briefing, June 8, 2007. Accessed 4 August 2011. <http://files.eesi.org/Dixon-Epri.pdf>

<sup>10</sup> Bedard, et al. *North American Ocean Energy Status – March 2007*. Accessed 4 August 2011. [http://oceanenergy.epri.com/attachments/ocean/reports/7th\\_EWTEC\\_Paper\\_FINAL\\_071707.pdf](http://oceanenergy.epri.com/attachments/ocean/reports/7th_EWTEC_Paper_FINAL_071707.pdf)

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- <sup>11</sup> U.S. Environmental Protection Agency (EPA), [Greenhouse Gas Equivalencies Calculator based on eGRID2007 Version 1.1](#).
- <sup>12</sup> EPA, [Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007](#), 2009.
- <sup>13</sup> EPRI, *Ocean Tidal and Wave Energy: Renewable Energy Technical Assessment Guide—TAG-RE: 2005*, EPRI Report # 1010489, Palo Alto, CA, December 2005.
- <sup>14</sup> Federal Energy Regulatory Commission (FERC), “Hydrokinetic Projects.” 9 June 2011. <http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/hydrokinetics-projects.pdf>
- <sup>15</sup> IEA Energy Technology Network. *Annual Report Implementing Agreement on Ocean Energy Systems*. 2010. [http://www.iea-oceans.org/fich/6/2010\\_Annual\\_Report.pdf](http://www.iea-oceans.org/fich/6/2010_Annual_Report.pdf)
- <sup>16</sup> Ocean Renewable Energy Coalition. “MHK Talking Points.” 2011. Accessed 5 August 2011. <http://www.oceanrenewable.com/wp-content/uploads/2011/03/mhk-talking-points.pdf>
- <sup>17</sup> REN21. *Global Status Report (GSR) 2011*. 2011. [http://www.ren21.net/Portals/97/documents/GSR/REN21\\_GSR2011.pdf](http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR2011.pdf)
- <sup>18</sup> IEA 2010.
- <sup>19</sup> Ibid.
- <sup>20</sup> Ibid.
- <sup>21</sup> REN21 GSR 2011.
- <sup>22</sup> Federal Energy Regulatory Commission (FERC). “Issued Hydrokinetic Preliminary Permits.” August 2011. <http://www.ferc.gov/industries/hydropower/gen-info/licensing/hydrokinetics/issued-hydrokinetic-permits-map.pdf>
- <sup>23</sup> IEA 2010.
- <sup>24</sup> Ibid.
- <sup>25</sup> Ibid.
- <sup>26</sup> Federal Energy Regulatory Commission (FERC). “Licensing Hydrokinetic Pilot Projects.” April 14, 2008. [http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/pdf/white\\_paper.pdf](http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/pdf/white_paper.pdf)
- <sup>27</sup> U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), *Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies*. December 2009. [http://www1.eere.energy.gov/windandhydro/pdfs/doe\\_eisa\\_633b.pdf](http://www1.eere.energy.gov/windandhydro/pdfs/doe_eisa_633b.pdf)
- <sup>28</sup> For more information on state RPSs, see the [Pew Center's state RPS page](#).