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U.S. DEPARTMENT OF ENERGY

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

U.S. HOUSE OF REPRESENTATIVES

HEARING EXAMINING

MARINE AND HYDROKINETIC ENERGY TECHNOLOGY: FINDING THE PATH TO COMMERCIALIZATION

DECEMBER 3, 2009

Chairman Baird, Ranking Member Inglis, Members of the Committee, thank you for the opportunity to appear before you today to discuss the U.S. Department of Energy's Water Power Program and its activities related to marine and hydrokinetic energy generation technologies.

The global marine and hydrokinetic industry consists of energy extraction technologies that utilize the motion of waves, the currents of tides, oceans, and rivers, and the thermal gradients present in equatorial oceans. The Department of Energy (DOE) believes that marine and hydrokinetic energy technologies have significant potential to contribute to the nation's future supply of clean, cost-effective, renewable energy. In its March 2007 *Assessment of Waterpower Potential and Development Needs,* the Electric Power Research Institute (EPRI) conservatively indicated that marine and hydrokinetic power (exclusive of ocean thermal energy resources) could provide an additional 23,000 megawatts (MW) of capacity by 2025 and nearly 100,000 MW by 2050. In a more recent 2009 study appearing in *HydroReview*, collaborating authors from the University of Washington, the Virginia Tech Advanced Research Institute, and EPRI refined earlier estimates to conclude that resources could conservatively yield a total of 51,000 MW of extractable energy.[1] This estimate is the equivalent of 34 conventional coal-fired power plants.[2] The Department is currently developing predictive cost and performance models to assess the near- and mid-term economic potential for developing these resources.

According to recent industry studies, [3] potential ocean thermal energy conversion (OTEC) resources may be even larger.[4] However, it is necessary to note that preliminary estimates of extractable U.S. resources are just estimates of technical potential that do not equate to economically recoverable energy. There still remains an industry need for detailed, comprehensive resource assessments and validation of the costs for recovering this energy, which the Department is currently supporting through its programs.

The marine and hydrokinetic energy industry is still at a relatively early stage of development with less than a half dozen small commercial projects installed worldwide and only one operating in the U.S, a river hydrokinetic project in Hastings, Minnesota. Much of the work being funded through the Department is, therefore, focused on evaluating the size, location and specific characteristics of the Nation's off-shore ocean and river energy resources, establishing baseline cost, performance and reliability data for a variety of devices, and assessing the environmental impacts associated with various technologies.

As part of our comprehensive effort to evaluate marine and hydrokinetic energy, the Department also funds targeted, innovative research and development projects with

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[1] Bedard, Roger. George Hagerman. Brian Polagye. Mirko Previsic. "Ocean Wave and In-Stream "Hydrokinetic" Energy Resources of the United States." Forthcoming publication in *HydroReview*. 2009.
[2] Figures are based on the assumptions of an average coal plant with 500 MW of capacity, operating with a 90% capacity factor, and the average marine and hydrokinetic plant operating with a 30% capacity factor.
[3] Nihous, Gérard. "An Order-of-Magnitude Estimate of Ocean Thermal Energy Conversion Resources." *Journal of Energy Resources Technology*. December 2005. Vol. 127. p 328; Nihous, Gérard. "A Preliminary Assessment of Ocean Thermal Energy Conversion Resources." *Journal of Energy Resources Technology*. March 2007. Vol. 129. p 17.
[4] Estimates are between 3,000,000-5,000,000 MW for global installed capacity.

industry partners and the National Laboratories to address the near-term technical challenges to device development and deployment, helping to generate reliable, validated performance data and indentify key cost drivers and reduction opportunities. The Department leverages its extensive expertise in technology development to identify and fund research in areas where industry currently lacks either the capabilities or financial resources.

Technology Overview

In order to monitor this developing industry, the Department has recently created an online database for marine and hydrokinetic devices that provides detailed information about the different technologies and deployment activities occurring around the world. There are currently dozens of unique device designs, and no firm industry consensus as to which technologies will perform the most efficiently and effectively. The database can present a snapshot of projects in a given region, assess the progress of a certain technology type, or provide a comprehensive view of the entire marine and hydrokinetic energy industry.[5] Based on information collected for this database, the following is an overview of the different types of marine and hydrokinetic technologies being developed around the world.

Wave Energy Technologies

Wave energy can be harvested from offshore, near shore, and shore-based environments through a number of engineering approaches. While there is currently no international consensus on nomenclature for wave energy devices, the Department is working with the Intergovernmental Panel on Climate Change and the International Electrotechnical Commission on standards to better define terminology. Major technology types are listed below.

- *Attenuators*: linear, jointed structures aligned parallel to the direction of the oncoming wave. Attenuators capture wave energy from the relative motion of their jointed parts as the wave passes along them.

- *Point absorbers*: floating structures that captures energy through mechanical motion as they rise and fall with the waves at or near the water surface.

- *Oscillating wave surge converters*: near shore designs that derive power from the back and forth movement of wave surge. These devices often function as pumps, using pistons to drive water through submerged or land based turbines.

- *Oscillating water columns*: channel waves into a partially submerged hollow chamber. The rise and fall of water within the structure pressurizes the chamber's air column and forces air through a turbine at high velocities.

[5] The database can be accessed at http://windandhydro.energy.gov/

- *Overtopping devices*: a category of floating or shore-based structures that are partially submerged, and funnel waves over the top of the structure into an elevated reservoir. Water then runs out of the reservoir through a turbine.

- A variety of fully submerged devices are under development that capture energy from the pressure differential induced within a device from passing waves. Such pressure difference can be used to drive a fluid pump to create mechanical energy.

Wave energy currently represents the largest sector of the marine and hydrokinetic industry both nationally and globally. The U.S. has experienced significant growth in the number of wave technology developers in the last decade, and there are now more than a dozen operating throughout the country, with the majority developing point absorber technologies.[6] However, the United Kingdom still leads countries in the total number of wave technology developers, as well as the number of technologies in the latter stages of development. To date, the U.K. is the only country in which a company's commercialized wave technology has been sold to a publicly traded utility.

Current-Based Energy Technologies

Technologies designed to capture the energy from moving ocean, tidal, or river currents represent a smaller sector of the marine and hydrokinetic industry, but can be considered more mature relative to wave technologies due to the mechanical similarities hydrokinetic turbines share with wind turbines. One of the main technological differences between tidal current devices and those designed to capture energy from ocean or river currents is the need for tidal devices to be either bi-directional or change their orientation with the ebb and flow of the tides. Generally, current-based technologies can be divided into three categories: axial flow turbines, cross flow turbines, and reciprocating devices.

- *Axial or horizontal axis turbines*: typically consist of three or more blades mounted on a horizontal shaft to form a rotor that is oriented toward the direction of the flow. The kinetic motion of the water current creates lift on the blades causing the rotor to turn driving a mechanical generator. Axial flow turbines can also utilize a shroud to protect and accelerate water past the blades.

- *Cross flow turbines*: typically have two or three blades mounted along a vertical shaft to form a rotor. These devices can extract multi-directional flows without the need to orient to the direction of the flow. The kinetic motion of the water current creates lift on the blades causing the rotor to turn driving a mechanical generator.

- *Reciprocating devices*: generate electricity through an oscillating motion caused by the lift and drag forces of the water stream (similar to the tail motion of a fish or marine mammal like a whale or dolphin). Mechanical energy from this oscillation feeds into a power conversion system.

[6] "Marine and Hydrokinetic Technology Database." Wind & Hydropower Technologies Program. (Online, 6/19/2009, http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx).

Although the roots of the modern current technology sector can be found in the U.S., developers of current-based technologies in the U.K. were quick to develop and deploy axial flow turbines during the late 1990s and early 2000s to take advantage of the strong tidal flows located in U.K. waters. The first grid-connected axial flow turbine, known as "Seaflow," was installed in May of 2003 on the North Devon Coast in the U.K. Most of the technology development in this sector is focused on axial flow turbines and is occurring in the U.K., U.S., Ireland, Canada, Norway, Australia and New Zealand. With the exception of two companies that are currently developing cross flow turbines, all development of current-based technology in the U.S. has focused on axial flow turbines.

Ocean Thermal Energy Technologies

Ocean thermal energy conversion (OTEC) systems use the ocean's natural thermal gradient to drive a power-producing cycle. Temperature differences between warm surface waters and colder deep waters need to differ by about 20° C (36° F) for OTEC devices to produce significant amounts of power.

The technology's lack of widespread development is due in part to high upfront capital costs, which has delayed the financing of a permanent, continuously operating OTEC plant. However, OTEC technologies could potentially produce significant amounts of alternative energy for tropical island communities that rely heavily on imported fuels. Most research and development to date has taken place in the U.S., Japan, Taiwan, and India.

Tidal Energy Case Study: Puget Sound

As one of the most promising areas in the country for the development of tidal energy, the Puget Sound in Washington State is currently home to a number of projects being funded by the Department. For the past year, the Department and the Snohomish County Public Utility District (SnoPUD) have jointly funded the initial survey, siting and permitting work necessary for the construction and installation of up to three turbines at a tidal energy pilot plant in the Admiralty Inlet, west of Whidbey Island. It was recently announced that the turbines will be designed and constructed by OpenHydro, a company specializing in shrouded, horizontal-axis turbines. SnoPUD will also be working with the Department and the Pacific Northwest National Laboratory over the coming year to determine the types of aquatic species present in the Admiralty Inlet, and will further determine both baseline levels of background noise as well as the acoustic impacts that hydrokinetic turbines could have on these species. Finally, as part of an ongoing project between the Department and the Northwest National Marine Renewable Energy Center to develop integrated instrumentation packages to collect environmental data, researchers at the University of Washington have deployed state-of-the-art equipment at the potential SnoPUD site to evaluate water quality, flow characteristics, substrate composition and sedimentation rates.

Overview of the Water Power Program

The primary objective of the Department's marine and hydrokinetic energy activities is to evaluate the potential contribution that each of the aforementioned technologies can make to the nation's energy supply, through the development of accurate resource assessments, performance profiles, and lifecycle costs. Once the potential of the various technologies is better understood, the Department can make more targeted strategic decisions about which portfolio of research and development projects to support, based on the most promising marine and hydrokinetic technologies.

Resource Assessments

The Department is currently funding five separate resource assessments to quantify potential technically extractable marine and hydrokinetic energy by resource type and location. These include assessments for wave, tidal, ocean current, river current, and ocean thermal energy potential. The data generated by these projects will help stakeholders assess the potential contribution to the U.S. renewable energy portfolio and prioritize the level of investment for each resource type. Two assessments (wave and tidal) are scheduled to be completed by the end of fiscal year 2010. The other three assessments were only recently awarded in September through the Department's competitive solicitation process and are thus still in the process of negotiating contracts for the data collection. The Department aims to have each of those three assessments completed within one calendar year of project initiation.

Siting Issues and Environmental Impacts

The Department is also working to understand the environmental and navigational impacts of marine and hydrokinetic energy technologies and to find ways to mitigate any adverse impacts. DOE is using this information to identify best siting practices for marine and hydrokinetic technologies and to create mitigation strategies to address these impacts. DOE is also working with other government organizations to develop best practices for ensuring the process of siting and permitting is effective and efficient.

Under a cost-share contract with the Department's Bonneville Power Administration (BPA) and funds from certain BPA customer utilities and Washington State organizations, Golder Associates has been developing the "Integrated Decision Support System (IDSS)" for location, assessment, and optimization of in-stream tidal power development in Washington State. The IDSS is a computing platform to identify and analyze potential environmental, navigation, and fisheries issues and conflicts related to siting. The platform will be a multi-user, web-based geographic information system and tidal simulation model database, including power estimation tools. The IDSS is intended to provide siting decision-makers the information they need to make sound siting decisions.

In addition, the Department conducts targeted research into the impacts of marine and hydrokinetic technologies on ocean habitats and individual wildlife populations, including fish and marine mammals. This research includes studies how different types of hydrokinetic turbines can harm or change the behavior of fish, investigates the impacts of

extracting energy from an ocean system on sedimentation rates, and tests a limited range marine mammal acoustic-deterrent system at an open water location.

Technology Performance and Cost Modeling
To determine the economic feasibility of harnessing the Nation's marine and hydrokinetic energy resources, the Department is supporting the development of numerical predictive cost and performance models as well as technology development projects in each area to generate real-life data to support and validate the models.

Although certain marine and hydrokinetic energy devices have been developed and deployed as pilot-scale demonstration projects, very few have operated continually for significant periods of time. As a result, the efficiency, reliability, survivability, and cost of the various devices types are not well quantified.

To validate, refine, and improve these models, the Department is also partnering with industry to develop and deploy individual marine and hydrokinetic devices that will generate the real-world data necessary to inform accurate analyses of device cost, performance, and environmental impacts. Partnering with industry will directly reduce the time required to develop projects, and will provide critical data on device performance and reliability. The Department's efforts include support for in-water testing and development projects, as well as work to design devices, sub-systems, and components

Specific industry-led technology design and development projects include:

- Siting studies and the design of a grid-connected test berth being developed by Pacific Gas & Electric Company for multiple wave energy devices;

- Construction and demonstration of an oscillating water column device (called the Ocean Wave Energy Converter) by Concepts ETI, Inc.;

- Development and installation of a tidal energy device in the Puget Sound by Snohomish County Public Utility District;

- Demonstration of advanced composite cold water pipes for ocean thermal energy conversion devices by Lockheed Martin;

- Design and testing of a 2.5 MW Aquantis Current Plane ocean current turbine, intended for eventual deployment off the coast of southeastern Florida, by Dehlsen Associates, LLC;

- Optimization, demonstration, and validation of an intermediate-scale wave buoy from Columbia Power Technologies, Inc. in preparation for a full-scale ocean deployment;

- Scale-up of a previously tested power-buoy from Ocean Power Technologies, which will increase the power extraction rate, increase survivability, and reduce operation and maintenance costs;

- A Cooperative Research and Development Agreement with Verdant Power to improve and refine the company's tidal turbine rotor;

- Design and validation of an innovative floating support structure from Principal Power Inc. that combines wave and wind energy power take-off mechanisms to defray the mooring and installation costs associated with higher power output;

- Design and testing of an easily replicable, modifiable mooring system for fast-water tidal energy devices by Ocean Renewable Power Company, LLC; and

- Design, testing, and deployment in the Mississippi River of a pylon-based mooring structure for in-river turbine current technology from Free Flow Power Corporation.

In addition to the above projects that are focused on developing specific devices and technologies, the Department also funds the development of models, tools, and materials that can be widely used by the entire industry to optimize performance, predict loads, minimize failures, and reduce costs. The Department also maintains a database of all U.S. facilities capable of conducting hydrodynamic testing of marine and hydrokinetic devices, and is developing a program to aid developers in testing and validating initial sub-scale device designs.

Budget and Funding for Specific Technologies

The Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) has allocated a substantial portion of its Congressional appropriation for Water Power toward the support of marine and hydrokinetic projects. In fiscal year 2008, $9.05 million supported marine and hydrokinetic projects, while $31.3 million in fiscal year 2009 funding supported these projects. Some projects utilizing these funds are technology-specific while others are cross-cutting in nature. The Department plans to continue to provide financial support for marine and hydrokinetic projects as appropriate and according to Congressional appropriations and guidance.

In fiscal years 2008 and 2009, the Department awarded approximately $5.8 million to five separate projects focused specifically on wave energy development. These projects included a resource assessment, the design and siting of a grid-connected open-water device testing berth, engineering and testing an intermediate scale oscillating water column device, and two projects to build and test next generation point absorbing buoys.

During the past two years, the Water Power Program awarded approximately $4.5 million to six tidal energy-specific projects. These include a U.S. tidal energy resources assessment, the testing of new environmental monitoring equipment for tidal projects, surveys of aquatic species in the Admiralty Inlet, engineering design and construction

approvals for a pilot tidal plant, and projects to design more efficient tidal turbine rotors and more reliable mooring systems.

In the area of ocean-current energy, the Program awarded $1.9 million across three ocean-current-specific projects, including the development of the first drive-train uniquely designed for large ocean current devices, a U.S. resource assessment, and the development of environmental survey methodologies for potential projects located off the southeast coast of Florida.

For river-current technologies, the Program awarded approximately $1.3 million to two river-current-specific projects, including the development of a pylon-based mooring system designed to reduce device installation and maintenance times and increase efficiency, and a nationwide assessment of in-stream hydrokinetic resources.

The Department awarded approximately $2.6 million in fiscal year 2008 and fiscal year 2009 to four projects focused on OTEC. These projects include a specific evaluation of the environmental impacts associated with the water intake systems, the validation and testing of a new manufacturing method for OTEC cold-water pipes, a resource assessment, and an assessment of the lifecycle costs of OTEC devices. In August 2009, the Navy also announced that it would award over $8 million to Lockheed Martin for OTEC component and subsystem design and testing. That project will be able to build upon the research currently being conducted by DOE, and collaboration between our two agencies will continue to ensure that there are no duplicated efforts.

The Department is developing lifecycle cost and performance profiles for different marine and hydrokinetic energy device classes, including wave, tidal, ocean current, in-stream hydrokinetic, and ocean thermal energy conversion. These profiles are informed by baseline representative commercial project development data from specific sites. The baseline cost of energy data will allow the Department to characterize and evaluate competing device classes and to identify the key drivers affecting the cost of marine and hydrokinetic energy. Verification of these data will also help the Department prioritize research and development efforts in a manner that assists and complements the industry's efforts.

National Marine Renewable Energy Centers

One of the mechanisms for achieving Departmental objectives has been to create and utilize National Marine Renewable Energy Centers (NMRECs), where a wide variety of work can be conducted. In 2009, two NMRECs were formally established—one at the University of Hawaii, and another as a partnership between the University of Washington and Oregon State University (known as the Northwest NMREC). The Centers are public-private partnerships between the universities, private companies, non-profits and governmental organizations, all with the goals of promoting research, development and deployment of marine energy technologies.

The work at the Northwest NMREC is primarily focused on wave and tidal research, with Oregon State focusing on wave technology applications and the University of Washington concentrating on tidal technology. Projects currently underway include:

- development of advanced wave forecasting technologies;
- creation of models used to optimize the placement and spacing of wave devices;
- site selection and design for an open water test berth for wave energy devices; and
- development of integrated instrumentation packages to collect environmental data.

Projects at the NMREC in Hawaii are focused on both wave and ocean thermal energy conversion technologies, and include:

- validation of wave forecasting models using real-time data;
- upgrades to wave tank facilities to accommodate device testing by developers;
- identification and testing of environmentally friendly material coatings; and
- modification of a submersible transport and recovery vessel able to deploy large instrumentation packages.

The Department is pleased with the progress that has taken place at the Centers over the short one year period since inception. During the past month, the programs at both Centers were critiqued by a panel of independent experts as part of an EERE-mandated peer review for all marine and hydrokinetic projects. Peer Reviews are rigorous, formal, and documented evaluation processes that use objective criteria and qualified, independent reviewers to evaluate the technical, scientific or business merit, and the productivity and management effectiveness of programs and projects. The results of the peer review for the Department's marine and hydrokinetic technology program will be made publically available within the next three months.

Because of the significant research and development work occurring outside the U.S., establishing and maintaining collaborative efforts with the international community has also been extremely important. Currently, representatives for the Department are leading work on Annex IV of the International Energy Agency's Implementing Agreement on Ocean Energy Systems. The goal of this international collaboration is to assess worldwide research on the environmental effects and monitoring efforts for ocean wave, tidal, and current energy systems and will result in a global, publicly-available database of information, studies and best monitoring practices.

The need for international metrics to determine technology readiness levels and performance is also paramount, and so the Department is engaged with the International Electrotechnical Commission (IEC) to facilitate the development of relevant industry standards, provide consistency and predictability to their development, and to better represent U.S. interests. The IEC is based out of Geneva, Switzerland and is actively supported by 76 member countries in its efforts to prepare and publish international standards for all electrical, electronic and related technologies. Because of their technical expertise, the National Renewable Energy Laboratory (NREL) and Science Applications

International Corporation (SAIC) were jointly selected to represent the Department on the U.S. Technical Advisory Group to the committee and to support the participation of key U.S. industry technical experts in the four relevant standards development working groups of the IEC.

Strategic Program Planning

Looking to the future, the Department is supporting the marine and hydrokinetic energy sector in developing a unified industry vision and roadmap. This effort will detail the various technical, non-technical and market barriers that limit progress and highlight the technology developments, policies, and other activities necessary to overcome such barriers. Based on industry consensus, NREL was selected to lead the project to develop this roadmap on behalf of the Department, with work scheduled for completion by the end of fiscal year 2010.

The Department has also convened several workshops with members of the marine and hydrokinetic industry in order to better align the Department's efforts with the needs of industry stakeholders before a formal roadmap is completed. The first of these meetings, hosted by the Department and EPRI, was held in October 2008, and the resulting report is publically available at http://oceanenergy.epri.com/oceanenergy.html#briefings.[7]

The development of a marine and hydrokinetic industry roadmap directly supports DOE's ongoing internal efforts to develop a detailed Multi-Year Program Plan for the Water Power Program. All of the resource and technology characterization work currently underway is a crucial part in developing such a plan. As an industry roadmap is developed and ocean energy resources are accurately characterized, the program will be able to more efficiently prioritize future efforts, and tackle the barriers to technology development and deployment that it is best suited to address. The Multi-Year Program Plan for the Water Power Program is scheduled to be completed and made publically available by May 2010.

The Department currently coordinates and leads an ad hoc advisory committee to the Interagency Working Group on Ocean Partnerships (the Joint Subcommittee on Ocean Science and Technology) focused on marine and hydrokinetic issues, which includes the Federal Energy Regulatory Commission, Minerals Management Service (MMS), National Oceanic and Atmospheric Administration (NOAA), U.S. Navy, U.S. Coast Guard, Fish and Wildlife Service, National Park Service, Environmental Protection Agency, and the U.S. Army Corps of Engineers.

DOE is providing support to the National Park Service in their development of a report titled, "Marine and Hydrokinetic Energy Technologies and Recreation: A Guide to Concepts and Methods," which will focus on potential impacts to recreation from marine

[7] Prioritized Research, Development, Deployment and Demonstration (RDD&D) Needs: Marine and Other Hydrokinetic Renewable Energy. EPRI, Palo Alto, CA 2008. www.epri.com/oceamemergy/

and hydrokinetic technologies, and suggest ways in which those impacts can be studied and mitigated.

The Department is collaborating closely with NOAA to develop an integrated permitting process for OTEC demonstration projects, which DOE has authority over, and OTEC pilot projects, which are to be regulated by NOAA. The Navy is also very involved in this process, based on their high levels of technical knowledge and experience with OTEC research.

The Department also participates in the West Coast Governors Association's Ocean Energy Action team and worked with MMS to organize its 2008 Alternative Energy Workshop. Finally, the Program helps to shape the Department's position on national marine spatial planning efforts currently underway at the Federal level, and continually works to ensure that there is due consideration of marine and hydrokinetic energy technologies in all discussions and decisions.

As stated previously, the marine and hydrokinetic industry is at a relatively early stage of development and maturity when compared to other renewable energy technologies, but the Department believes this industry can play a substantial role in the portfolio of clean, cost-effective, domestic energy that our Nation is dedicated to developing. To this end, DOE is committed to evaluating the realistic potential of the various resources and energy generation technologies and focusing Departmental efforts in the most efficient and effective areas. DOE has made key investments in this nascent industry and will continue to do so. Furthermore, DOE is uniquely positioned to aid in the development of marine and hydrokinetic technologies through continued support and collaboration with industry stakeholders, international partners and other non-governmental organizations. Most importantly, DOE's continued involvement will help speed the deployment of these technologies, just as the Department's commitment to wind energy has helped that industry to rapidly develop in recent years.

Thank you again for the opportunity to appear before you today to discuss these important issues. I am happy to answer any questions.