renewable **sea** power

Waves, tides, and thermals—new research funding seeks to put them to work for us. By Michael E. McCormick and R. Cengiz Ertekin

For the first time in more than a decade and a half, on September 18, 2008, the U.S. Department of Energy announced the funding of projects dealing with renewable marine energy technologies. The program will address one of the great sustaining resources of our planet to see if it can yield benefit to mankind in new ways.

The ocean has always been a provider. Its fish and plants nourish a large portion of the Earth's population. It is a vast recycling engine that replenishes oxygen in our atmosphere. It is also an immense store of energy, much of it derived from the sun and most of it untapped.

The DOE's program will explore technology that aims to harness some of the ocean's energy and put it to work for us. While several awards specifically were made to private companies for technology development and market acceleration, DOE also created two National Marine Energy Centers, one in Hawaii operated by the School of Ocean and Earth Science and Technology at the University of Hawaii and the other in the Pacific Northwest under a partnership of Oregon State University and the University of Washington. They will study various technologies designed to generate power from forms of energy in the ocean.

The portion of the solar energy absorbed by the ocean is initially thermal in nature. We find that the surface waters heat during the day and cool during the night. The air adjacent to the water surface is also heated and cooled, and thermal currents occur in both the air and water. Hence, the absorbed radiant solar energy is partially transformed to thermal energy and, then, to hydraulic and pneumatic energies, giving rise to winds. Winds and the Earth's rotation create waves on the water surface. These energy transformations give rise to the fields of ocean thermal energy conversion, ocean wave energy conversion, ocean current energy conversion, and offshore wind energy conversion.

The tide is also partly solar. Tides are predictable energy forms at any site in the world, since they are due to the gravitational attractions of the moon and the sun.

Offshore wind energy is an established technology. Tides are site-specific, and there are plants producing electricity at places like the Bay of Fundy in Canada and the Rance Estuary in France. The other forms of energy conversion are in development.

The new Marine Energy Centers will both be active in the promotion of wave power conversion; Hawaii also will lead efforts to advance ocean thermal energy conversion, while the Northwest will be involved in tidal energy development.

Jefferson W. Tester, Croll Professor of Sustainable Energy Systems at Cornell University, and four researchers from Massachusetts Institute of Technology, Elisabeth M. Drake, Michael J. Driscoll, Michael W. Golay, and William A. Peters, jointly wrote a book, *Sustainable Energy: Choosing Among Options*, published in 2005 by MIT Press. In it they estimate the relative potentials of ocean energy resources. According to the authors, the wave action of oceans deliver 2,700 gigawatts of power, and the power available for use totals about 500 GW. Currents are estimated at a total of 5,000 GW, of which perhaps 50 GW is of practical use for energy conversion. Ocean thermal resources may be as high as 200,000 GW, although practical exploitation would be about 40 GW. Tides represent 2,500 GW and maybe 20 GW can be used for energy conversion.

Ocean thermal energy conversion (often abbreviated as OTEC) uses the temperature differences between warm surface waters of the ocean and the cold deep water. The temperature of ocean water at a depth of 1,000 meters is only slightly above freezing. If surface waters are at least 18 °C warmer, the heat of the warm surface water can evaporate a fluid such as ammonia, which can drive a turbine. The fluid is then condensed by up-welled cold deep-ocean waters to begin the cycle again.

The ideal regions of the world for ocean thermal energy conversion are between 20° north latitude and 20° south, where the average surface temperature in tropical oceans can rise above 30 °C. Although the ideal latitude band is well away from much of the industrialized world, we can take advantage of OTEC by creating a product other than electricity. For example, if we build a floating aluminum plant at the OTEC site, and make the aluminum from imported bauxite, then we have produced an energy-intensive product, relieving a nation's power grid from that task.

The state of Hawaii is in the ideal band for OTEC. In the late 1970s, a modest effort was started to build a land-based OTEC power plant. The electrical power output from the original power plant was of the order of tens of kilowatts. Over the years, this effort has expanded. The state of Hawaii recently agreed to have a 10 megawatt OTEC plant constructed.

riding the waves

Wave energy conversion devices exploit the rise and fall of waves, often to produce electricity. There are prototype systems deployed around the world, but no commercial-scale installations.

Michael Pleas and Douglas Hicks of the University of Delaware recognized in the 1970s that the production of potable water, rather than electricity, might be a more efficient use of converted wave energy. Efforts in this direction are now under way in the United States, Ireland, and elsewhere.

The average U.S. citizen, who requires electrical power of 1 kW, also requires approximately 60 gallons (about 227 liters) of water per day. For electricity production,

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consider a sinusoidal wave approaching a mid-Atlantic U.S. state. The wave might have a wave height of 1.5 meters and a period of 7.5 seconds. For this wave, the power per crest width is about 16.6 kW/m. Let us assume that this power is to be converted into electricity with a bus-bar efficiency of 25 percent. The electricity supplied to the grid, then, is 4.15kW per meter of converted wave crest. For a coastal town of 1,000 citizens, approximately 241m of the wave crest must be addressed.

The population of the same coastal town would require 227 kiloliters of potable water per day. In the same sea, a wave-powered desalination system operating at an average pressure of 60 atmospheres and pumping 379 kL of

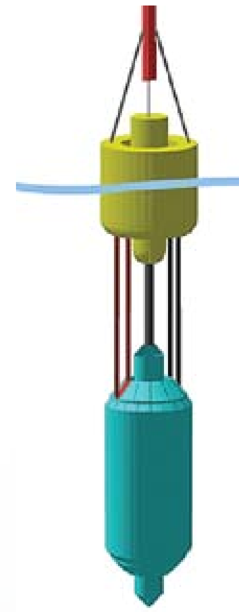
▼ A conception of a field of water mills designed by Marine Current Turbines that turn the currents of tides into electricity.

MARINE CURRENT TURBINES LTD.

salt water per day to obtain the 227 kL of fresh water would require about 26.3 kW of power. For a 25 percent efficient system, only 6.34 meters of crest width would be required.

A promising wave-powered electrical generating system is the Pelamis of Pelamis Wave Power in Scotland. It is an articulated-body system with an internal closed hydraulic system that is part of the power takeoff sub-system. It has four components, each 45 meters long. Three Pelamis units have been constructed for deployment 5 km from the coast of Portugal. Each unit is rated at 750 kW.

Other systems for capturing wave energy are buoy-like designs. One, PowerBuoy from Ocean Power Technology, has been deployed in Hawaiian waters. Another, WaveBob from WaveBob Ltd., has been deployed in Galway Bay off the coast of Ireland.



▲ The WaveBob generates power by using the out-of-phase heaving motions of the float and a submerged inertial body.

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The use of the tides to produce electricity has been done on a commercial scale, but the energy resource is site-specific. Although there are numerous low-capacity tidal power plants along the coastal waters of the Chinese mainland, there are few high-capacity plants in existence in the rest of the world. The best locations for tidal power plants are the Bay of Fundy in Canada, the Severn Estuary in the United Kingdom, Port of Ganville and the Rance River at San Malo in France, Puerto Rio Gallegos in Argentina and, in Russia, the Bay of Mezen on the White Sea and Penzhinskaya Guba on the Sea of Okhotsk.

Tidal energy plants are costly. The turbines must be bi-directional, to take advantage of incoming and outgoing tides. They must also be of high capacity. Most tidal plants require construction of a barrage as well. But the amortized cost of electricity is relatively small because the static tidal power systems are robust and have a long operational life.

The French built a tidal power plant at St. Malo in the Rance estuary, where the mean tidal range is 8.55 meters. That power plant delivers an average of 240 MW of power (240,000 kW) at a cost of about 1.8 cents per kilowatt-hour, which is quite inexpensive.

More recently, attention has been focused on the dynamics of the tides in the form of tidal currents. To convert the hydrostatic tidal energy into electricity, tidal water mills are deployed. For example, in the East River at New York City, the Verdant Power Co. has installed submerged water mills. According to Verdant Power, six turbines in the East River will generate approximately 10 megawatts. A British company, Marine Current Turbines Ltd., has installed a 300 kW plant in the English Channel off the coast of Cornwall.

The tidal energy resource is both reliable and predictable. With the escalating costs of oil and natural gas, it will become a viable resource in the near future.

research partnerships

The Department of Energy's new program in marine renewable energies is an attempt to tap into a vast resource.

The proposed level of funding for the National Marine Energy Centers in Hawaii and the Pacific Northwest currently stands at $1.25 million annually for five years, but overall cost-matching from non-federal money must be achieved. This requirement is meant, in particular, to foster active cooperation between academia and the private sector.

Electrical utilities (e.g., HECO and MECO in Hawaii) and private companies (e.g., Ocean Power Technologies and Lockheed Martin) have made early commitments to participate in the centers, The scope of planned activities is, however, quite broad.

While conducting their own research, the universities will assist in the establishment of ocean field testing sites and help the DOE keep a recently created marine renewable energy data base up to date. Research areas themselves are expected to cover different aspects of marine renewable energy conversion. In Hawaii, for example, such issues as wave resource forecasting, novel wave power device testing, wave power focusing, OTEC environmental impact, OTEC heat exchanger testing, corrosion mitigation, and electrical grid stability have initially been considered.

The world's appetite for energy can only continue to grow. As Tester and his co-authors point out, there are tremendous energy resources in the world's oceans if we can develop the technology to harness them. We are hopeful that with research we will see one or more of the ocean energy options achieve its great promise. ■

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▲ The Pelamis wave-power electricity generator has a closed hydraulic system inside its articulated components.

to learn more

In a companion article, "To Harness the Seas," published by Mechanical Engineering Online, the authors present a closer look at some of the technologies in use or proposed for ocean energy conversion. The article is available online at www.memagazine.org.

Ocean energy conversion is a subject addressed by ASME's annual International Conference on Ocean, Offshore, and Arctic Engineering. The conference this year, known as OMAE 2009, will meet May 31 through June 5 in Honolulu. Details are available online at http://www.asmeconferences.org/OMAE09. The proceedings will be available after May 2009.

The text of the Department of Energy's announcement of its ocean renewables funding program is archived at http://www.energy.gov/news/6554.htm.

An excellent summary of the dynamic tidal energy locations is found in the Electric Power Research Institute (EPRI) Report TP-008-NA, published in June 2006.

The DOE's new marine renewable energy data base is online at http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx.

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