mechanical engineering

feature article

POWER & energy

harvesting the waves

Researchers are closing in on how best to harness the power of the ocean.

by Annette von Jouanne

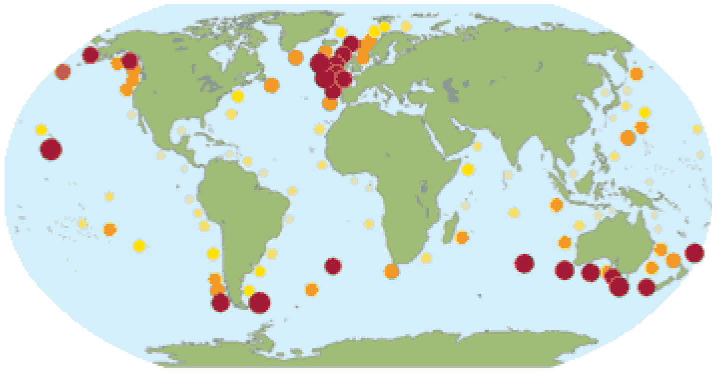
in theory, at least, sources of energy that don't emit pollution or greenhouse gases should be greeted enthusiastically by people concerned with the health of the environment. And those sources that are in some sense renewable—recurring natural forces—ought to be the most highly prized of all. Yet there is scarcely a form of renewable energy that has not been attacked for doing more harm than good.

Hydroelectric dams, which are common in the Pacific Northwest, have been criticized for drowning riverside habitats and decimating salmon runs. Large wind turbines are opposed by some due to their visual impact and the threat they pose to bird and bat populations. Some experts contend that crop-derived fuels such as ethanol are inefficient and occupy land better used to feed people. And solar energy, while too expensive to use on a wide scale, could one day be denounced for glazing over square miles of natural landscape.

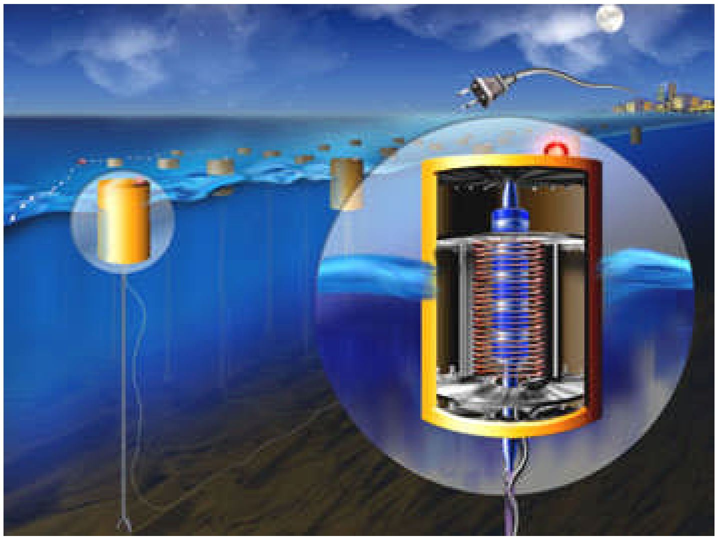
To produce sufficient power in the future without blanketing the Earth in carbon dioxide, these renewable sources will be exploited, environmental concerns notwithstanding. But another, significantly untapped renewable energy source also exists: the world's oceans. The ocean is a vast repository of energy that can be derived from its motion, temperature, and chemistry. In fact, it is estimated that harnessing just 2 one-thousandths of the oceans' untapped energy could provide power equal to current worldwide demand.

Engineers have attempted, with varying success, to tap ocean energy as it occurs in waves, tides, marine currents, thermal gradients, and differences in salinity. Among these forms, significant opportunities and benefits have been identified in the area of wave-energy extraction.

As a form of harvestable energy, waves have advantages not simply over other forms of ocean power, but also over more conventional renewable energy sources, such as the wind and the sun. Waves may be seasonal, but are more constant—and more predictable—than wind or sunlight. Constancy and predictability enable a more straightforward and reliable integration into the electric utility grid. Wave energy also offers much higher energy densities, enabling devices to extract more power from a smaller volume at consequent lower costs.



The dark red circles on the map above show areas of the world's oceans with the greatest wave power. Several groups are developing buoyant devices to harvest this energy. In one scenario, tethered buoys bobbing in the waves would move large wire coils past permanent magnets. The induced current from each buoy would be sent via submarine cable to users on the shore.



Around the world, research teams are making progress in devising effective and efficient means for tapping wave energy. In many important ways, the state of development is similar to that of wind power two decades ago: an obvious potential, but little in the way of mature technology. But as we go forward, I believe wave power will play an important role in the country's energy portfolio.

The experience of the beach, with gentle waves of ocean water lapping at one's feet, may give people a false impression of the potential of wave power. Likewise, the curling waves prized by surfers may give pause when one considers how to tap this power. In fact, waves located some distance from the shoreline are remarkably steady and powerful.

Take the Oregon coast as an example: Wave heights measured offshore average 3.5 meters during the winter, which translates to about 50 kilowatts per meter of crest length. During the summer, average wave heights are lower, about 1.5 meters, which convert to 10 kW per meter of crest length. Considering an overall average of 30 kW per meter, the total energy potential intercepted along the entire Oregon coast (which is 460 kilometers—or 280 miles—in length) is in the range of 13,800 megawatts. The average electrical energy consumption in the state is about 5,000 to 6,000 MW.

Conditions off the Oregon coast are exceptionally favorable to wave power, to be sure, but other areas also experience strong waves. Chile, Australia, New Zealand, Ireland, Scotland, Portugal, and Norway have substantial wave power potential. That is due to features they all share: a location in a relatively high latitude and a long stretch of ocean immediately to the west.

It's not difficult to envision just how to tap this energy using a water-borne analogue to the terrestrial wind farm; call it a wave park. In the place of wind turbines, there would be wave energy-capturing buoys. Each buoy would have a power cable dropping down along the tether to the anchor, which would then be routed to a central junction box located on the seafloor at the front of the wave park. At the central junction box, the unregulated voltages from all of the buoys could be "combined" and conditioned as regulated dc for delivery to the shore through a single submarine cable. At the shore substation, the dc power provided by the wave park could be inverted to ac, and connected to the grid.

The buoys would be placed in water depths of 100 to 200 feet—before the waves start to break and dissipate their energy—at about one to three miles offshore. That far out, the parks would be virtually imperceptible from the beach, thus preserving views. It would be an almost invisible, inexhaustible source of carbon-free power.

Interest in extracting power from waves (as distinctly different from flowing water, such as rivers or tides) began in earnest in the 1970s. Unfortunately, none of the schemes was able to get a full-scale trial. The field remained largely quiet until the past decade, when the success of the wind power industry spurred renewed interest in discovering what might work in the ocean.

Indeed, today there are several wave power systems that are in service or development. The Pelamis, developed by Ocean Power Delivery Ltd. of Edinburgh, Scotland, consists of semi-submerged, articulated pontoons. Ocean waves articulate the pontoons at their joints, which then pump fluid through a hydraulic motor to drive a generator. The first deployment of the Pelamis is a 2 MW array off the coast of northern Portugal slated to be operational in 2007.

The Pelamis system, set for deployment next year, generates electricity when waves bend its pontoons, pushing hydraulic fluid through a motor.

Meanwhile, Ocean Power Technologies of Pennington, N.J., has tested a buoy-based system for the U.S. Navy, and plans to have a wave park up and running off the Atlantic coast of Spain next year. It is also planning a wave park off Reedsport, Ore. In this scheme, a hydraulic generator operates using a tethered point absorber buoy concept.

Due in part to our proximity to one of the best wave resources, Oregon State University has taken a leading role in studying wave energy in the United States. The Oregon State wave energy team's research and development goals have focused on such important issues as survivability, reliability, and maintainability, in addition to efficient and high-quality power conversion. To that end, the team has pursued wave-energy developments by researching novel direct-drive generators. The team has also created an action plan for a National Wave Energy Research and Demonstration Center in

Oregon and has worked closely with the Oregon Department of Energy and a variety of stakeholders to promote Oregon as the optimal location for the nation's first commercial wave parks.

The term "direct drive" describes the direct coupling of the buoy's velocity and force to the generator without the use of hydraulic fluid or air. The advantage of direct drive over other wave power systems is simplicity. A direct drive replaces intermediate hydraulics or pneumatics with a system that enables generators to respond directly to the movement of the ocean by employing magnetic fields for contactless mechanical energy transmission, and uses power electronics for efficient electrical energy extraction.

Designing Direct Drives

The Oregon State University wave energy team is developing several novel direct-drive prototypes, including buoys that incorporate permanent magnet linear generators, permanent magnet rack-and-pinion generators, and contactless force transmission generators. These buoys are designed to be anchored one to three miles offshore, at typical water depths greater than 100 feet, where the buoys will experience gradual, repetitive ocean swells.

Each of these three approaches to direct drive is subtly different. Inside the permanent magnet linear generator buoy, for instance, the wave motion causes specially designed electrical coils to move through a magnetic field, inducing voltages and generating electricity. In the permanent magnet rack-and-pinion generator buoy, linear-to-rotary conversion is being developed as an extension of the concept of permanent magnet gears. The contactless force transmission generator buoy exhibits linear force transmission, using large, high-strength permanent magnets configured in a piston. The motion of the piston is then transformed to rotation, using a ball screw to drive a permanent magnet rotary generator.

Advanced designs of these prototypes are being developed to achieve higher efficiencies and power output performance.

Ocean wave-energy extraction is, in a real sense, where wind power was 15 or 20 years ago, with no

The OSU researchers are also interested in small-scale wave-energy generators, which could be integrated into boat anchor systems to power a variety of small craft electronic devices. These similar small-scale systems could enable ocean data collection and monitoring buoys to become self-powered.

As can be inferred from the different approaches outlined here, ocean wave-energy extraction technology is currently in the preliminary stages of development. In a real sense, the situation is similar to where wind turbines were approximately 15 or 20 years ago, with several topologies developing, and no clearly superior clearly superior engineering solutions.

engineering solutions yet established. In time, however, research into wind led to the development of an optimal configuration: the now-predominant horizontal-axis, three-blade turbine design.

To speed wave energy along that sort of development path, one needs some state-of-the-art testing facilities. Oregon State is already home to the Motor Systems Resource Facility (with a 750 kVA dedicated power supply and full capabilities to regenerate back onto the grid) and the O.H. Hinsdale Wave Research Lab with world-class wave tank facilities, including a 342-foot wave flume. But OSU is also planning to upgrade the lab with wave energy linear test bed equipment.

The LTB is designed to generate the relative linear motion created by ocean waves that will be experienced by wave-energy device technologies. For example, the test bed will create the linear motion between a vertically oriented center spar and the active components of a surrounding float. Thus, the LTB will enable the dynamic and controlled testing of wave-energy devices, using wave profiles measured by ocean monitoring buoys, while simulating the actual response of ocean waves.

In detail, the mechanical machine oscillations in the vertical axis will simulate sinusoidal vertical velocity, predetermined velocity profiles, or dynamically controlled force interactions to simulate the real response of the buoy in ocean waves. Simulating ocean waves requires very high forces. For this LTB system, driving forces of up to 20,000 newtons (4,500 pounds) at speeds of 1 meter per second are required.

The LTB will significantly increase OSU's wave-energy research capabilities as part of the planned National Wave Energy Research and Demonstration Center to be located off the Oregon coast, possible near Newport. Establishing such a research center there would encourage research into other important wave-energy issues, including environmental impacts, optimum device placement, buoy mooring, and navigational identification.

My colleagues and I, along with Oregon Sea Grant, realized the significant need for partnership and collaboration with stakeholders in the offshore ecosystem, such as fishermen and crabbers. Together, we formed a port liaison project team of commercial fishing industry experts to aid in wave park siting and ocean technical expertise. To make the leap from lab to a "real-world scenario" in the ocean, it's important to incorporate input from fishermen and experiences from other offshore projects.

To be sure, some people may object to the very idea of harvesting energy from the ocean—better to do without the electricity than to despoil yet another natural environment. But the demand for electrical power is all but insatiable, and the choice isn't between wave energy and a low-tech society but between wave energy and other sources of power— renewable or fossil. By that measure, wave energy has tremendous potential. It can be clean, efficient, and reliable—something both utility managers and environmentalists can embrace.

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