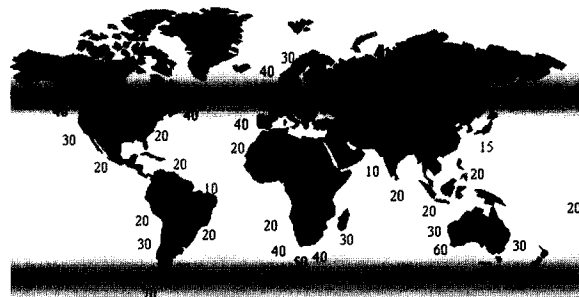


Special Focus

Wave Power

"The overall market for electricity is massive, established, and steadily growing. In the U. S. alone, energy represents an annual \$350 billion market. Clean energy technology...represents a market expected to grow from less than \$7 billion in 2000 to greater than \$82 billion by 2010...wave energy has the potential to eclipse wind power as wave energy is demonstrably more abundant, concentrated, predictable and reliable than wind."—SeaVolt Technologies



Global wave power distribution in kW/m of crest length

Wave Power is as obvious a solution to sustainable and clean energy as wind. Wind waves are derived from the winds as they blow across the oceans. The energy transfer provides a natural storage of wind energy in the water near the free surface proportional to the square of the amplitude and to the period of the motion. As early as 1799 inventors (Girard & Son, France) have been filing patents for systems that capture power from the waves. Extensive R&D of wave energy conversion saw a dramatic increase after the increase in oil prices in 1973. In this issue we address the politics and technology developments currently being considered or underway in this most exciting element of Ocean Energy. Some believe that wave energy in the U.S. is limited. However some areas such as the Pacific Northwest have great potential.

The Solar Plan for the State of Washington—Ocean Wave Energy, a Report to the Solar Planning Office, July 2003 (David Sjoding, Washington State University Cooperative Extension Energy) stated that "In 1980 the U.S. Department of Energy stopped development of ocean wave energy technologies. Efforts shifted elsewhere in the world: Sweden, Scotland, Japan, and Australia to name a few. The development of ocean wave technology continued to progress but not until recently did further development occur in the U.S. Ocean wave renewable energy is important for a number of reasons:

- The further north of the equator one goes, the better the ocean wave energy potential becomes;
- Ocean wave energy peaks in winter and many of our Pacific Northwest utilities are winter peaking;
- Ocean wave energy is environmentally benign;

One problem encountered in the extraction of wave energy is the tremendous seasonal and daily variations in usable power. The amount of available wave power seems to depend on the fifth power of the wind speed. If the winds in a given region of the ocean vary by a factor of 5 from day to day, the wave power may vary by a factor of 3000. A second constraint is that the wave extraction device must be able to withstand severe storm waves. The available wave power off Coos, Oregon, during a particularly severe winter storm exceeded the average winter wave energy density by a factor of 14. However, equipment that can withstand such strain and capture the energy is not yet available.

Most wave energy extraction systems are being developed in England, where funds have been appropriated for research and development in wave energy extraction. Devices for harnessing wave energy can be divided into four groups: propulsion schemes, buoy power supply, offshore power generation, and shore-based power supply.

Wave-powered equipment must have the ability to amplify the relatively low water head associated with wave height, have a broad range of responses over wave amplitude and frequency and the capacity to respond to smaller waves and to withstand destructive accelerations from storm waves."

Wave Power Generation Systems

There are several types of wave generating systems considered to be either shoreline, near shore or offshore. The following, taken from the Washington State ocean wave energy plan describes the various types of systems. Wave power systems do not all extract energy from waves in the same manner. Some harness the rotational part of the wave while other capture the horizontal movement to produce energy.

Rocking duck theory

This system employs devices called "rocking ducks" that make use of the rotational pattern that water molecules follow as waves pass through them. The "rocking ducks" are cylindrical with an almond-shaped cross section; this shape was selected to make the best use of the oscillatory action of waves. The system includes a full-scale power installation that uses a large number of ducks, each measuring approximately 10 m in diameter and 16 m in length, and attached to a cable 1 km long. The ducks float freely several kilometers off shore, eliminating the need to anchor them. Hydraulic pumps, which take oscillatory power from the outer envelope of the duck and convert it to high-pressure hydraulic power to turn sealed electrical generators. The ducks are capable of extracting 85% of the wave energy. The designer believes that in two years full-scale ducks can be constructed for use in a prototype offshore installation. However, the problem of sending the power to shore remains unsolved. One solution might be production of hydrogen from sea water by electrolysis for later use in onshore power stations. The calculated costs for the rocking duck system are comparable to those for nuclear power plants, and should improve in the future.

Airbag theory

In this system, wave power is used to drive generators by means of air squeezed out of large airbags. The device consists of a hollow concrete beam, buoyed by an air-filled tube. The tube is composed of a continuous row of airbags, or cells, made of rubberized fabric and separated by flexible membranes. As the sausage-like balloon bends with the wave action, air is squeezed into a high-pressure channel in the beam and directed toward a turbogenerator attached to the beam. Additional modules could be added to an airbag system as needed. In comparison with

American Superconductor to Supply Reactive Power Support to Wind Farm

American Superconductor Corporation announced that it is providing its D-VAR(R) (Dynamic Volt-Ampere-Reactive) reactive power compensation system to Canada's largest wind farm developer, Vision Quest Windelectric (www.greenenergy.com), a subsidiary of TransAlta Corporation. The D-VAR system will provide reactive power support and regulate voltage at the Summerview wind farm, which is located approximately 100 miles south of Calgary, Alberta. AMSC's D-VAR system will enable the wind farm to meet the voltage control standards required for interconnection to the regional power grid — the Alberta Interconnected Electricity System. AMSC's system will be located in the 138 kilovolt (kV) substation at the Summerview wind farm near Pincher Creek, Alberta. **Circle No. 89**

Technology

Profiler Powered by Ocean Waves

Late last year, a multidisciplinary experiment AOSN (Autonomous Ocean Sampling Network), took place in Monterey Bay. A Brooke Ocean Technology Ltd. SeaHorse was deployed for 12 days during AOSN 2003. SeaHorse is a self-contained profiling system that moves up and down a mooring wire, powered by the energy of the surface waves. The use of wave energy allow for long term deployments without the need for large amounts of battery power. Because the SeaHorse can profile vertically through the water column on a regular basis, it eliminates the requirement for multiple sensors on a mooring. **Circle No. 90**

INRI Validates Wave Pump Technology

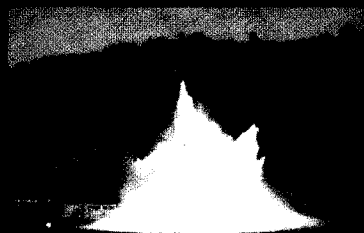
Minnesota-based energy technology company Independent Natural Resources Inc. (INRI) today announced it has successfully tested its new system for transferring ocean-wave power into renewable energy. Conducted in a wave tank at Texas A&M University's Offshore Technology Research Center, INRI's tests validate the results of several years of concepts and planning, showing the company's "SEADOG" wave-pump technology has the potential to serve as a viable source of renewable power — harvesting renewable power from ocean waves. To further prove the wave pump's viability, INRI is now looking to create a "wave farm" test field in a coastal area capable of providing consistent ocean swells — a concept similar to electricity-generating "wind farms." "Our tests at Texas A&M last month exceeded our expectations and we're confident that our engineers have developed a new proprietary technology that can serve as a safe, efficient system for gathering renewable energy from ocean waves," said Mark A. Thomas, chief executive officer, INRI.

"Going forward, we're seeking actual ocean environments where we can place a wave-farm test field involving either 14 or 200 SEADOG wave pumps. If the wave pump continues to perform as well as our tests have shown, we believe it has the potential to be a breakthrough for global energy production. "INRI's SEADOG ocean-wave pump captures energy from ocean swells or waves to pump seawater to a land-based reservoir or water tower, where the water can be

returned to the ocean through hydroelectric turbines, thereby producing inexpensive, renewable electricity. Tests on a scale SEADOG prototype proved that a full-size version of the pump can consistently pump water 275 feet uphill at a pre-determined flow rate. "Our technology avoids many of the problems other ocean-based power-generating technologies are struggling with today, because the SEADOG doesn't involve any electrical components that can be damaged by sea water," said Doug Sandberg, vice president, INRI. "And, because our device pumps water to a reservoir, it can store potential energy and generate power on demand, even when waves are too low to generate power. These two factors represent key advantages for our product." According to INRI calculations, the company's wave-pump technology is potentially capable of generating 755 megawatts of hydroelectric energy for every one-square-mile pump field, assuming ocean swells averaging at least nine-feet. With swells of at least five-feet, a one-square mile pump field could generate approximately 242 megawatts. "Coastal locations offering consistent wave heights of five-feet or greater aren't that uncommon," Thomas said. "For example, Point Reyes, off the coast of northern California, features more than 50-miles of coastline with wave heights regularly reaching five to 21 feet." To access online photos of INRI wave-pump technology tests at Texas A&M's Offshore Technology Research Center.

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other wave-action schemes, construction and installation of the airbag system would be relatively inexpensive.

Float-piston theory

This system employs a chain of floats hinged together, each float having a piston and cylinder. As the waves cause the floats to undulate, the piston in one float moves back and forth in the cylinder of the adjoining float. This action is used to pump water to an elevated reservoir located onshore. All the components of this device are within the capabilities of current technology and could easily be mass-produced. This system would be more attractive from a financial standpoint if it were also used as a breakwater.

Crane-float theory

This is a simple system that employs a crane, float, chain, counterweight, and reciprocal pump. The float is positioned in the water by means of a chain. One end of the chain is suspended from a crane and attached to the float, while the other is attached to a counterweight on shore. The pump is placed between the counterweight and the float. Wave action causes the float to move up and down, with the motion being translated to the pump via the chain. The pump then moves water up to an elevated reservoir for use by a hydroelectric plant.

Scripps-FOR wave pump

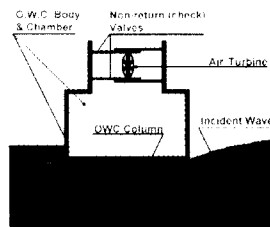
The Scripps-FOR wave pump consists of a vertical riser pipe containing a flapper valve and a buoyant float at the surface. The wave pump amplifies the pressures in the wave displacement, raising water to successively higher levels until a pressure level suitable for power generation is reached. Estimated cost of a 20-kW production model is about \$2000/kW, with a 350-kW unit having a capital cost of \$300/kW.

Wave Power Technology Developments

ON&T researched wave power companies briefly and the following is representative of projects that are underway around the world.

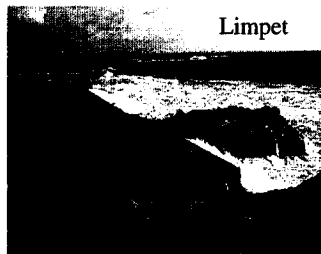
Shoreline

The most common type of system proposed for shoreline systems is the oscillating water column (OWC) system first proposed by Professor Yoshio Masuda. The Masuda device turned water power into a stream of air.



Limpet

In November of 2000, the world's first commercial wave power station began delivering power to the national grid in Scotland. The Limpet (Land Installed Marine Powered Energy Transformer) is a shoreline energy converter developed by Inverness-based Wavegen and Queen's University, Belfast. The Limpet unit on Islay has an inclined oscillating water column (OWC) that couples with the surge-dominated wave field adjacent to the shore. The water depth at the entrance to the OWC is typically seven meters. The design of the air chamber is important to maximize the capture of wave energy and conversion to pneumatic power. The turbines are carefully matched to the air cham-



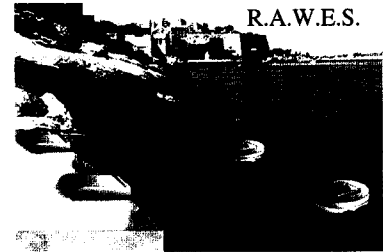
ber to maximize power output. The performance has been optimized for annual average wave intensities of between 15 and 25kW/m. The water column feeds a pair of counter-rotating turbines, each of which drives a 250kW generator, giving a nameplate rating of 500kW. The Limpet's design makes it easy to build and install. Its low profile gives low visibility, so it doesn't intrude on coastal landscapes or views.

European Pilot Plant

The European Pilot Plant was installed on the Pico Island in the Azores. It is a 400 kW OWC plant developed by a coordinated by Instituto Superior Tecnico (Portugal) and consisting of a team of six Portuguese partners and two from the UK and Ireland. The plant was designed as a full-scale testing facility and is fully automated supplying a sizable part of the island's energy demand.

R.A.W.E.S.

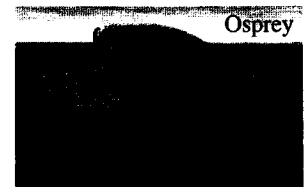
Rawes Wave Energy is developing cliff or shore installations. A shore-based system using 64 R.A.W.E.S. units and a two-meter high wave will produce 1.2 MW of electrical power. The same system can be used for pumping fluids as well.



Near-Shore

Osprey

Wavegen in the UK developed a prototype device called Osprey, for depths to 20 meters that was designed to be installed on the seabed.



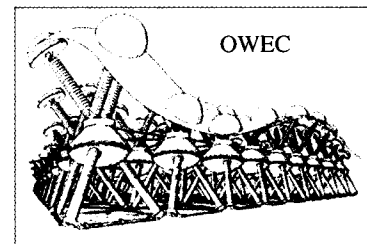
ORECon

ORECon in the UK has developed a system to be used in a wave farm. The massive device, measuring 40 meters long, has a diameter of 25 meters and weighs nearly 1,000 tons. It produces Power through a series of water filled tubes which resonate as waves pass by, pushing air through a turbine. An earlier prototype developed 10 kW of electricity with an efficiency of 35 percent. The company's work is supported by a grant from the UK Department for Trade and Industry.



OWEC

The Ocean Wave Energy Company (OWECO), located in Rhode Island is pioneering yet another novel device called the Ocean Wave Energy Converter (OWEC). Submerged arrays of an interconnected OWEC array. Wave action on buoys induce a relative motion between drive shafts and remaining module portions to drive transmissions and electrical generators.

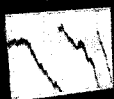


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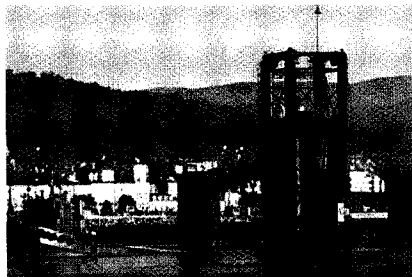
Circle No. 29

Wave Power

Offshore

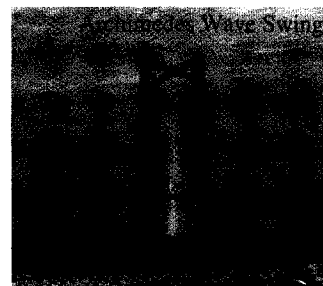
Archimedes Wave Swing

The Archimedes Wave Swing was developed by TeamWork Technology BV, in the Netherlands. It consists of a hollow, pressurized structure, the upper part of which is initiated to heave motions by the periodic changing of hydrostatic pressure beneath the wave.



The AWS

consists of an upper part (the floater), an underwater buoy and a lower part (basement or pontoon) which stays in position on the sea floor. A 2 MW pilot plant was constructed for installation off the coast of Portugal. Today the company, AWS BV is exploiting the technology and is directed by Teamwork Technology BV and consists of many participants.



Makah Bay Pilot Plant

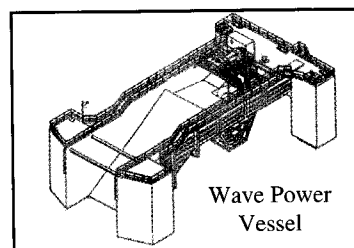
AquaEnergy Group Ltd. is developing a 1 MW pilot offshore power plant to demonstrate wave energy power generation. The pilot plant site is Makah Bay, Washington. Their wave power conversion technology is based on third generation heaving buoy technology consisting of modular buoys, AquaBuOY™, capable of delivering 80-250 kW of power each. It uses a closed-loop water hydraulic system to convert wave energy into high pressure water flow that, in turn, drives a turbine generator.

McCabe Wave Pump

The McCabe Wave Pump consists of three rectangular steel pontoons, which are hinged together across their beam. The bow of the pontoon is slack-moored and two more slack moorings are attached part way down the aft pontoon. This allows the system to vary its alignment in order to head into the oncoming seas. A 40 meter long prototype was deployed in 1996 off the coast of Kilbaha, County Clare, Ireland.

Floating Wave Power Vessel

The Floating Wave Power Vessel is an overtopping device for offshore operation developed by Sea Power International in Sweden. It consists of a floating basin supported by ballast tanks in four sections. A patented anchor systems allows the orientation of the vessel to the most energetic wave direction. A pilot plant was developed and deployed in the 1980s near Stockholm.



Wave Power
Vessel

Pelamis

The Ocean Power Technologies Pelamis system is a semi-submerged articulated structure composed of cylindrical sections linked by hinged joints. The wave induced motion of these joints is resisted by hydraulic means which pump high pressure oil through hydraulic motors via smoothing accumulators. A 130 meter long and 3.5 meter diameter device, rated at 375 kW is being developed by Ocean Power delivery Ltd. in Scotland.

Top View



Pelamis System



ON&T January/February, 2004

Point Absorber Wave Energy Converter

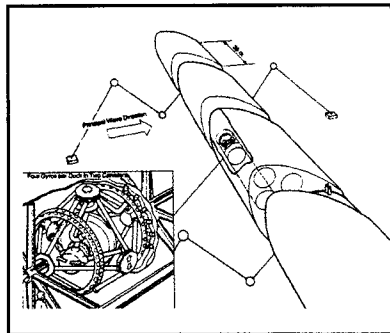
The Point Absorber Wave Energy Converter was developed by Ramboll in Denmark. It consists of a float connected to a suction cup anchor by a polyester rope. The relative motion between the float on the sea surface and the seabed structure activates a piston pump inserted between the rope and the float. A 1/10th scale model was tested at sea at a Danish test site.



Wave Point Absorber

Salter Duck

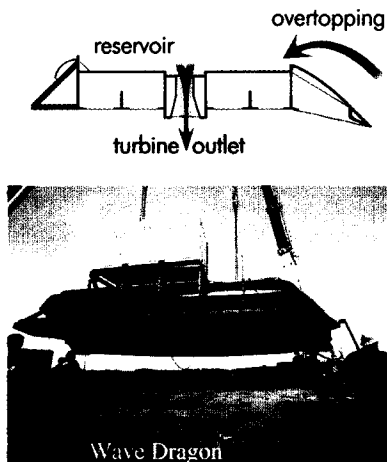
The concept of the Salter Duck was introduced by S. Salter in 1974. The important feature of this device is that it has the capability of converting both the kinetic and potential energies of the wave, achieving a very high absorption efficiencies (over 90% theoretical). The system has undergone considerable development since 1983 and was redesigned in 1993.



Salter Duck

Wave Dragon

The Wave Dragon is an offshore wave energy converter of the overtopping type developed by a group of companies lead by Wave Dragon ApS, in Denmark. It utilizes a patented wave reflector design to focus the wave towards a ramp and fill a higher-level reservoir. Electricity is produced by a set of low-head Kaplan turbines. A 57-meter wide, 261-ton prototype has been deployed off Denmark.



Wave Dragon

Many other companies are performing research, if not developing, wave power generation devices. The Engineering Business has proposed a wave generator device called the Frond. Ocean Power Technologies, Inc. has been selected by ONR to develop a \$4.3 million wave power project in Hawaii. An investment group has committed \$3.75 million to Energetech Australia Pty. Limited to commercialize their proprietary wave technology. Earlier, the company was funded by the Vancouver Island Project, the first wave energy project to be funded by a major utility. The U.S. Navy has an R&D program underway to study floating mats that use piezoelectric devices embedded in the mat to generate electricity. The mat is to be used for forward deployments in foreign waters where power generation is not available. Although this article only touches on this technology, it shows how wave energy technology has now become commercially viable. ■

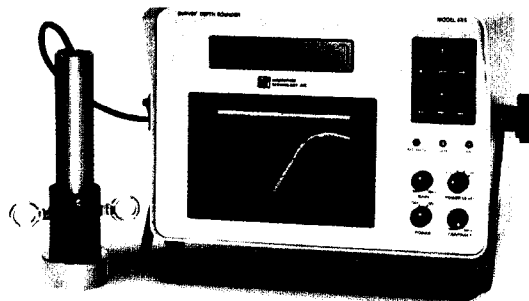


Frond

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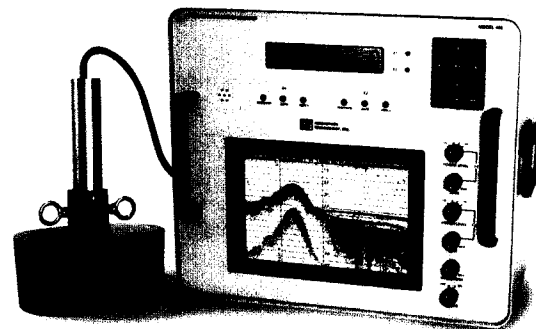
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RENEWABLE Energy from the Ocean SUSTAINABLE

The World has seen an increase in interest in "renewable or alternate energy from the ocean" over the past year and is watching this market grow with great interest. The ocean holds so much energy it is hard to quantify its potential. Energy is available in many different forms including wind, wave, current, thermal, geothermal, solar, salinity gradients, biomass, methane hydrates and probably some we haven't thought of yet. ON&T is pleased to announce that it will be sponsoring the first renewable ocean energy conference and exhibition in the United States in 2004. Technology from around the world will be showcased at this most exciting and visionary conference.

EnergyOcean News Update

Technical Program Takes Shape Company Plans Offshore Demonstration Renewable Power Association Sponsors Event

The First Focused Event on Renewable Ocean Energy in the USA

On June 28-29, 2004 in Palm Beach, Florida, the first international conference & exposition on renewable ocean energy to be held in the USA takes place. Sponsored in part by Ocean News & Technology magazine, the conference will begin an annual event that will focus on the activities offshore to develop sustainable energy sources for the future of our civilization. It is well-known that the US is only now beginning to place importance on sustainable and renewable energy sources on and provide a new push for wind energy that is complimentary to existing onshore development.

Sponsors

Two major sponsors have joined the conference. The United Kingdoms Renewable Power Association (RPA) is representing companies in Europe developing ocean power technologies in the UK and Europe.

The Natural Energy Laboratory Hawaii authority, the birth place of OTEC, is a major sponsor of the event.

What You Will Hear and See

EnergyOcean 2004 features many exciting speakers who will talk about such exciting subjects as Offshore Wind Power Programs, OTEC, Wave and Current Energy Generation and other forms of Renewable Ocean Energy. Early abstracts include:

—Hear an Economic Forecast for Renewable Ocean Energy Technologies by two of the foremost experts in the field in the U.S. and the U.K. Forecasts for offshore wind, wave energy and underwater currents will be covered.

— The Natural Energy Laboratory of Hawaii Authority (NELHA) located on the Big Island of Hawaii will talk about the Lab's programs, OTEC projects and its newest NELHA Gateway program as well as other exciting programs centered around its deep (cold) water facility.

— Hear about the imminent installation of a series of 3 MW underwater turbines that will be installed in the Gulf Stream off South Florida at a depth of 200 feet in 5 knots of current and capable of producing constant electrical power to the grid. The turbines are also capable of producing Hydrogen for power generation. The US Navy is designing the turbines and will assist in the monitoring of the turbines offshore.

— Hear the latest on the Regulation of Ocean Energy Systems and Regulatory Barriers from respected Washington DC attorney Carolyn Elefant who has been assisting Ocean Energy developers in the USA for the past 10 years

— Learn about the National Renewable Energy Laboratory's (NREL) new offshore wind program. Until recently, the offshore wind energy potential in the United States was ignored because the vast onshore wind resource of the United States has the potential to fulfill the electrical energy needs for the entire country. However, the challenge of transmitting the energy to the large load centers has limited short-term grid penetration. Offshore wind turbines can generate power much closer to higher value coastal load centers. Reduced transmission constraints, more energetic and steady winds, coupled with recent European success, have made offshore wind energy look more attractive for the U.S. However, U.S. waters are generally deeper than the European coast, which will require new technology. The speaker presents an overview of US coastal resources, explores promising deepwater wind technology, and predicts long-term cost-of-energy (COE) trends. Offshore wind systems can diversify the future U.S. electric energy supply, and provide a new push for wind energy that is complimentary to existing onshore development.

Demonstrations

Florida Hydro Power plans on having a working 100 kW underwater turbine offshore of the hotel producing power from the Gulf Stream that will be used in their exhibit booth.

Conference Location—The Breakers Hotel

The event will be held in Florida, close to one of the greatest ocean energy sites on earth—the Atlantic Gulf Stream—at the newly renovated and world renowned Breakers Resort. It is fitting that the name "Breakers" means waves and stands as an icon for wave power. Formerly the Flagler Hotel a century ago, this incredible venue is over 100 years old and renowned as one of the most modern yet historic facilities in the world. Accessible through four international airports (Miami, Ft. Lauderdale, West Palm Beach and Orlando), the event can be conveniently reached by European and Asian delegates alike. The Breakers Hotel is located just a few miles east of the West Palm Beach International airport and directly on the beach. The Breakers is also located near the US Navy's facilities and South Florida's Universities.

For technical papers contact Dan White at (772) 221 7720 or dwhitetse@mac.com or for exhibiting, sponsoring or registering contact Mj McDuffee at mjmcduffee@ocean-news.com