COUNTRY NOTES

The following Country Notes on Wave Energy have been compiled by Tom Thorpe and the Editors. Every effort has been made to be comprehensive by making contact with all known wave energy developers. However, it is not an exhaustive list because information is difficult to obtain on some countries and new wave energy devices are being continually conceived. Inclusion of a technology in these notes does not indicate endorsement of that technology. Indeed, there are numerous technologies under development (including some at the prototype stage) that are likely to be uneconomic, if not technically unfeasible.

Wave energy is an immature technology and therefore there are only a few prototype devices installed worldwide, some of which are precursors to the installation of a 'farm' of devices. These Country Notes focus on wave energy activities within each country, with no reference to the levels of deployment. The large number of devices under development would make detailed descriptions of them all extremely lengthy. Therefore, only a brief description is given together with the address of a web site for each device, thus enabling the reader to find out more detailed information.

International Bodies

A number of important international bodies have been involved in ocean energy, including wave energy:

The European Commission

This body has sponsored wave-related activities in a number of areas over a considerable length of time. It has promoted cooperation between leading organisations and institutes, via the formation of a Thematic Network (www.wave-energy.net/index3.htm) and a Coordinated Action (www.ca-oe.net). It has made direct contributions towards developing particular technologies, including: shoreline OWCs at Pico in the Azores, the Wave Dragon (www.wavedragon.com), the Wave SSG (www.waveenergy.no) and the SEEWEC (a multinational project to build a device containing an array of wave energy floats, www.seewec.org/). At the present time, the European Commission is considering supporting several other wave devices as well as the European Ocean Energy Association, which has been formed by all stakeholders in ocean energy (both within and outside Europe). Its aim is: to strengthen the development of the markets and technology for ocean energy in the European Union; act as the central network for information exchange and EU financial resources to its members and the promoting of the ocean energy sector by acting as a single EU voice (www.eu-oea.com/).

The International Energy Agency

In 2001, the International Energy Agency (IEA) formed an Implementing Agreement on Ocean Energy (www.iea-oceans.org), which is the IEA's mechanism for providing a framework for international collaboration in energy technology R&D, demonstration and information exchange. It has grown from the original three Members (Denmark, Portugal and the UK) to nine (Belgium, Canada, the European Commission, Ireland, Japan, USA), with several other countries having been invited to join (Brazil, France, Germany, Italy, Mexico and Norway). This growth reflects how ocean energy is increasingly seen as an viable and important future energy source. The Implementing Agreement has so far completed two important activities: Review, Exchange and Dissemination of Information on Ocean Energy Systems; Development of Recommended Practices for Testing and Evaluating Ocean Energy System.

The European Marine Energy Centre

The European Marine Energy Centre (EMEC) has been established in the Orkney Islands with funding from a number of organisations, Scottish and UK government bodies and the European Commission. It provides four test sites in 50 m water depth for wave energy devices, each with its own subsea cable, as well as a monitoring station and other facilities (www.emec.org.uk). The Centre has hosted a number of wave energy devices (as well as tidal current devices at a nearby site) and is proving pivotal in establishing wave energy as a reliable energy source (e.g. allowing developers to demonstrate their technologies in real sea conditions, coordinating activities around performance measurement and design standards).

Australia

Australia has had little investment in wave energy but developments led by three companies in recent years are stimulating intense interest, especially in using wave energy for desalination of seawater by pumping seawater into reverse osmosis (RO) plant.

Energetech (Australia) Pty Ltd.

Energetech has deployed a prototype tethered 500 kW nearshore OWC device at Port Kembla, New South Wales. It incorporates a parabolic wave collector to focus waves over a wide area onto a central OWC (to compensate for the lower wave power levels near shore) and a novel variable-pitch turbine that has higher efficiencies than turbines normally used in OWCs (www.energetech.com.au). The project has been carried out with support from the Australian Greenhouse Office, under its Renewable Energy Commercialisation Programme. The company has improved on the prototype design by developing a larger floating device rated at up to 2 MW, intended for deeper waters, and a scheme for 10 floating devices, each rated at 1.5 MW, is currently under development for deployment in Portland (Australia) in the near future; some of these will supply an RO unit on the OWC device itself and deliver low-pressure potable water to shore.

Seapower Pacific Pty

Seapower has developed an underwater, sea bed mounted wave energy device (CETO) for delivering pressurised water to an RO plant on-shore (www.seapowerpacific.com). As waves move over the top of the CETO unit, the wave crest depresses a horizontal disk to actuate reciprocating pumps to pressurise water to 7 000 kPa, which is delivered to shore by a small-bore pipe to an RO plant. A prototype device was successfully tested in Western Australia and the company has developed a follow-on design for deployment in 2008/9.

BioPower Systems

BioPower Systems is developing both tidal current and wave energy conversion technologies (www.biopowersystems.com). Their bioWAVE™ wave energy conversion system is based on the swaying motion of sea plants in the presence of ocean waves. Their vertically mounted, waving fronds capture a wide range of incident wave energy without using a large rigid structure and can orientate themselves to the prevailing wave direction. The motion is turned into electricity by their O-DRIVE™ generator, which uses a simple single-stage reciprocating gear mechanism, a direct-drive synchronous permanent magnet generator and high-inertia flywheel to produce smooth AC power. The key innovation is the ability of the system to avoid large loadings in extreme waves by lying flat on the sea bed.

Canada

Canada has not traditionally been thought of as having an interest in wave energy. However, there have been several important developments in recent years, including Canada becoming a member of the IEA's Implementing Agreement on Ocean Energy Systems. A number of organisations have set up the Ocean Renewable Energy Group to promote wave and tidal energy in Canada by addressing common issues (resource assessment, permitting, supply chain); it includes a number of individual device developers (http://oreg.ca). Wave and especially tidal current are seen as a promising energy source, with a number of Provinces actively supporting development projects such as that by BC Hydro for Vancouver Island, where a number of wave and tidal energy developers are seeking to install devices. This activity is starting to be matched at a national level, with the Government undertaking work that will benefit all potential developers, for instance looking into permitting processes.

Canada has several organisations and universities working on wave energy and a few device developers.

Finavera Renewables

This company has taken over the AquaBuOY technology formerly developed by AquaEnergy (www.finavera.com/wave). It consists of a floating, vertical hollow cylinder rigidly mounted under a buoy, with the tube open at both ends so that seawater can pass unimpeded back and forth. Inside the tube are two Hosepumps, one is attached to the top via non-return valves, the other is similarly attached to the bottom and both are attached to a neutrally buoyant disk or piston in the middle. When the buoy is at rest, the piston is held at the midpoint by the balanced tension of the two Hosepumps. When the buoy moves vertically in the waves, the central piston moves with respect to the tube, thereby alternately stretching and compressing the Hosepumps. These are steel-reinforced rubber hoses whose internal volume is reduced when they are stretched, thereby acting as a pump. The pressurised sea water is expelled into a high-pressure accumulator within the buoy which drives a turbine and generator rated at 250 kW. This device has undergone considerable development and is at the pilot plant stage. Finavera has plans for projects in several locations, including a 5 MW scheme in Uculet on the west coast of Canada (later to be upgraded to 100 MW), as well as in the USA, Portugal and South Africa.

SyncWave Energy Inc. (SEI)

SEI is developing a floating device where two floats oscillate out of phase with each other and the relative motion between the floats is harnessed by a mechanical power take-off to generate electricity (www.syncwaveenergy.com). This technology is at the R&D stage.

China

Since the beginning of the 1980s, China's wave energy research has concentrated mainly on fixed and floating oscillating water column devices. In 1995, the Guangzhou Institute of Energy Conversion of the Chinese Academy of Sciences successfully developed a symmetrical turbine wave-power generation device for navigation buoys rated at 60 W. Over 650 units have been deployed along the Chinese coast, with a few exported to Japan.

Other wave energy projects in China include:

- a shoreline OWC at Shanwei in Guangdong province consisting of a two-chambered device with a total width of 20 m, rated at 100 kW began operating in September 1999;
- a 5 kW Backward Bent Duct Buoy (a floating OWC with the opening to the OWC chamber pointing towards the land) in association with Japan;
- a shoreline pivoting flap device (Pendulor) developed by Tianjin Institute of Ocean Technology of the State Oceanic Administration;
- an experimental 3 kW shoreline OWC was installed on Dawanshan Island (in the Pearl River estuary), which is being upgraded with a 20 kW turbine.

Denmark

Between 1998 and 2004 the Danish Energy Agency operated the Danish Wave Energy Programme for supporting development projects initiated by inventors, private companies, universities etc. This covered a wide range of possible converter principles and provided developers with the facilities to have basic research carried out on their devices. At that time, the Danish Wave Energy Association was formed to disseminate information and promote activities for those interested in wave energy.

Several devices have been developed that have been tested at a small scale.

Ecofys

The Ecofys' Wave Rotor comprises a vertical shaft (or monopole) on which a rotor containing both slanted blades (similar to a Darrieus rotor) and horizontal blades. In waves, these experience hydrodynamic lift from the vertical and horizontal components of the motion of particles in the waves. This turns the rotor, which is attached to a 250 kW generator via a gearbox. The key innovations are that, apart from the rotor, there are no other moving parts in the water (the bearings and power take-off are placed 10 m above water level) and the same technology can also extract energy from tidal currents. The concept might also be capable of being mounted on existing structures in the sea. The device has been tested at a small scale in open-sea conditions and is scheduled for tests at 1/5th scale in 2007.

Wave Dragon

The Wave Dragon (a wave concentrating and overtopping device described in the Commentary) is a leading Danish technology. A 20 kW small-scale device is currently operating at Nissum Bredning, the Danish Wave Test Site, which has gained more than 19 500 hours of operating hours experience (www.wavedragon.net). Wave Dragon Wales, a subsidiary of the Danish parent company, is engaged in a project to build a 4-7 MW demonstration device in Wales (www.wavedragon.co.uk). It has formed a project development company, Tecdragon with a group of Portuguese and German investors with the purpose of developing a 50 MW wave energy project in Portuguese waters (www.tecdragon.pt). It has also secured funding from the European Commission for design of a multi-megawatt device.

Wave Plane International A/S

The WavePlane is another floating overtopping device that uses a number of channels for the water to move into, which also act as storage reservoir to smooth out the power. From these, the water is funnelled into a central turbine. Model tests have been carried out in various locations in the world but without any electrical generation. The company additionally proposes to use this device to oxygenate sea water and has representatives in seven countries (www.waveplane.com). This device is at the R&D stage.

Wave Star Energy

The Wave Star device consists of a long structure pointing into the oncoming waves, with a series of floats attached to booms on either side. As a wave travels down the structure, the floats rise and fall, each pressurising its own hydraulic cylinder, which is in turn connected to a common main that powers a central hydraulic motor and generator. The key innovations of the device are the ability to: raise the floats out of the water in large seas; place all the mechanical and electrical plant out of the water on the central structure; perform with only slightly diminished efficiency even when some floats are not functioning. The company, Wave Star Energy, has had a 1/10th scale device with 40 floats of one metre diameter generating up to 5.5 kW connected to the grid since July 2006 and has logged up over 4 000 hours of operation (www.wavestarenergy.com). It has plans for a 500 kW system for use in the North Sea to be installed in 2009.

Finland

Wave energy activities in Finland have been mainly undertaken in universities, with a few exceptions, e.g.:

AW-Energy

This company has developed the WaveRoller. This consists of a vertical buoyant flap hinged along its bottom edge to a structure on the sea bottom. The flap moves back and forth in the waves, operating a piston pump on the sea bed. This can be used directly to operate a hydraulic motor and generator rated at 13 kW or the output of several flaps can be fed into a common hydraulic circuit to power a central generating system, which can be mounted on the shore. The device has been tested at small scale and at 1/3rd scale in the European Marine Energy Centre (EMEC) in Orkney, Scotland (www.aw-energy.com).

France

With its heavy investment and large production from nuclear Pressurised Water Reactor technologies, France has shown little interest in wave energy. However, the École Nationale Supérieure de Méchanique et d'Aérotechnique has carried out an important programme of fundamental research.

Germany

Because of its relatively small resource and low wave-power levels, the only wave energy work undertaken in Germany has been in universities. However, there was an announcement in 2006 of a joint project between Voith Siemens and the German utility EnBW to install a LIMPET OWC plant (see Wavegen in the UK Country Note) on the North Sea coast in 2008/9.

Greece

Greece (like other Mediterranean countries) experiences only low wave-power levels. Nevertheless, it has an R&D programme on wave energy which has been carried out at the

Centre for Renewable Energy Sources and various universities. There were plans for a full scale, semi-commercial demonstration plant for fresh water and electricity production on the island of Amorgos in the South Aegean Sea, based on the technology now being developed by Finavera in Canada.

Daedalus

DAEDALUS Informatics, in coordination with the University of Patras, developed a new device (SEKE), which uses an array of water columns (usually built into a breakwater) to provide compressed air for power generation. Several experimental test scale models of the SEKE device have been developed. Efforts have been focussed on developing a combinatorial system solution, able to harness simultaneously both wave and wind energy using compressed air (http://195.170.12.01/daei/products/ret/general/retww1.html). This device is at the R&D stage.

India

The Indian wave energy programme started in 1983 at the Institute of Technology (IIT) under the sponsorship of the Department of Ocean Development. Initial research identified the OWC as most suitable for Indian conditions: a 150 kW pilot OWC was built onto the breakwater of the Vizhinjam Fisheries Harbour, near Trivandrum (Kerala), with commissioning in October 1991. The scheme operated successfully, producing data that were used for the design of a superior generator and turbine. An improved power module was installed at Vizhinjam in April 1996 that in turn led to the production of new designs for a breakwater comprised of 10 caissons with a total capacity of 1.1 MW. However, this does not appear to have been taken further.

The National Institute of Ocean Technology succeeded IIT and continues to research wave energy including the Backward Bent Duct Buoy (a variant of the OWC design).

Ireland

Ireland has some of the best wave resource in the world and wave energy research has been undertaken there since 1980, with much of the work being conducted at University College Cork (UCC) and Queen’s University Belfast (Northern Ireland), although other universities, such as Limerick, are now playing an increasing role. More recently, the Marine Institute and Sustainable Energy Ireland (SEI) has funded work, for example a wave and tidal energy resource study, as well as helping to develop an ocean strategy (http://www.sei.ie/getFile.asp?FC_ID=1747&docID=913) and supporting several device developers.

Clearpower Technology

Clearpower Technology's Wavebob is a self-reacting point absorber. It comprises two floating bodies mounted vertically that have different responses to waves. This produces relative motion between the bodies, from which energy can be extracted using hydraulics to power a motor and generator. The different frequency responses give the device a greater bandwidth, with scope for tuning over a wider range of sea conditions than is possible with a conventional single buoy point absorber. A 1/4th scale device was deployed in the sea in 2006.

Hydam Technology

Hydam Technology has developed the McCabe Wave Pump. This is a floating device comprising two narrow pontoons that point into the waves and which are attached using hinges to either side of the central generating platform. As waves pass down the length of the device, the pontoons move with respect to the central platform and power is extracted from this movement using hydraulic rams. Although this can be used to generate electricity (~ 400 kW), the device has been designed primarily to produce potable water using reverse osmosis. A prototype scheme was tested in 1996 and a commercial demonstration scheme has more recently been constructed and deployed.

Ocean Energy

Ocean Energy's OE Buoy is a 'backward bent duct buoy', which is a floating OWC with the opening to the OWC pointing away from the incoming waves towards the land. A 1/4th scale device was deployed off the west coast of Ireland in late 2006 and further testing is planned for 2007, before construction of a 1 MW prototype (www.oceanenergy.ie).

Japan

Despite having low wave-power levels, extensive research on wave energy has been undertaken in Japan, which deployed one of the first wave-energy devices (the floating OWC, 'Kaimei'), followed by another floating OWC (the 'Mighty Whale' in 1989). Particular emphasis has been placed on the development of air turbines and on the construction and deployment of prototype devices (primarily OWCs), with numerous schemes having been built:

- a 40 kW OWC was deployed in 1983 on the shoreline structure at Sanze for research purposes. It has since been decommissioned;
- a five-chambered 60 kW OWC was built as part of the harbour wall at Sakata Port in 1989;
- 10 OWCs were installed in front of an existing breakwater at Kujukuri beach, Chiba Prefecture. The air emitted from each OWC was manifolded into a pressurised reservoir and used to drive a 30 kW turbine. This scheme was operational between 1988 and 1997;
- a 130 kW OWC was mounted in a breakwater in Fukushima Prefecture in 1996. This used rectifying valves to

control the flow of air to and from the turbine;

- a floating OWC known as the Backward Bent Duct Buoy was deployed in Japan in 1987. This continues to be developed in co-operation with institutes in China and Ireland;
- the Pendulor wave energy device has been developed by the Muroran Institute of Technology. Wave action causes pendulum oscillations of a plate ('pendulor') at the entrance to a box, this movement being used in conjunction with a hydraulic power take-off to generate electricity.

The only significant wave-energy device currently being studied is an OWC deployed at Niigata in 2005.

Mexico

The only wave-energy activity in Mexico is the development of a wave-driven seawater pump at the Instituto de Ciencias del Mar y Limnología, U.N.A.M., Unidad Académica Mazatlán. This is to be used to recover isolated coastal areas by flushing them out with fresh seawater. A prototype has been successfully tested on the Pacific coast of the state of Oaxaca and a project has been approved to build and install a pump to flush out the port of Ensenada, on the Baja California Peninsula.

Netherlands

The Netherlands experiences low wave-power levels, which has led to Teamwork Technology (www.waveswing.com) seeking to develop their Archimedes Wave Swing (described in the Commentary) in Scotland, where there is a more prospective home market (www.awsocean.com). A 2 MW pilot plant was installed off the coast of Portugal and engineering for a pre-commercial demonstrator is presently being undertaken.

Norway

Research into wave energy has been undertaken at the Norwegian University of Science and Technology (NTNU), Trondheim for the past 30 years and two full-size devices were deployed and operated successfully for a prolonged period during the 1980s. More recently two other devices have been developed.

WAVEenergy AS

The Seawave Slot-Cone Generator (SSG) concept is a shoreline wave-energy converter, based on the wave overtopping principle utilising three reservoirs placed on top of each other. Water captured in each of these reservoirs will then run back to sea through the multi-stage turbine. Multiple reservoirs are used to improve overall efficiency. A 200 kW pilot plant is scheduled to start construction in 2007 (www.waveenergy.no).

SEEWEC

SEEWEC is a consortium involving 11 partners from 5 EU-members (Belgium, Netherlands, Portugal, Sweden and the UK) and 1 associated country (Norway). It aims to build the FO^3, an array of buoys attached to a large floating structure with extensive use being made of composite materials (www.seewec.org). Plans have been made and consent received for 4 x 2.5 MW platforms to be installed in 55 m water depth off the Norwegian coast, in addition to deploying this technology on the Wave Hub (see the UK Country Note).

Portugal

Since 1978 Portugal has played a significant role in wave energy R&D, with considerable work being undertaken at the Instituto Superior Técnico (IST) of the Technical University of Lisbon and the National Institute of Engineering and Industrial Technology (INETI) of the Portuguese Ministry of Economy. Most of the research has been devoted to OWCs and associated turbines, which included the building of a pilot 400 kW OWC plant on the island of Pico in the Azores.

In 2003 the Wave Energy Centre was set up with the objective of providing dissemination, promotion and support to the implementation of wave energy technology and commercialisation of devices. The Centre has a number of ongoing projects, including a 700 kW OWC installed in Foz do Douro breakwater (www.wave-energy-centre.org).

The Portuguese Government is attracting considerable inward investment from wave energy developers by offering enhanced prices paid for electricity derived from wave energy devices (initially, approximately US$ 0.30/kWh). Projects confirmed to date include: a 2.25 MW scheme consisting of 3 Pelamis devices which have already been delivered (www.oceanpd.com) and a 2 MW scheme using the AquaBuOY technology (www.finavera.com/wave), with interest from several others.

Spain

Little indigenous work on wave energy has been undertaken in Spain. However, Spain has also attracted wave energy developers including: Energetech (Australia) for a 1 MW OWC scheme in the port of Bilbao; Ocean Power Technologies (USA) for an initial 40 kW device at Santoña (to be increased to 9 x 150 kW devices, if successful); Wavegen (UK) for a 480 kW shoreline scheme consisting of 16 x 30 kW OWCs built into a shoreline facility in the Basque country.

Sri Lanka

The Ministry of Science and Technology has a two-stage project to survey the wave energy potential of the island. The first stage has established that the potential in the southern coastal belt is around 10-15 kW/linear m. The purpose of the second stage, currently under way, is to design a prototype plant, for which funding is being sought.

Sweden

Sweden has played a significant role in wave energy, despite having a relatively poor wave energy resource. Activity has been mainly in academia, with Chalmers Tekniska Hogskola and Uppsala University making the most contributions. One company, AB Interproject Service AB, has developed the concept of combining the IPS buoy and the Hose-Pump converter, which is the system now being exploited by Finavera (Canada).

Seabased AB

This device is a moored floating buoy affixed via a rope to a 10 kW electrical generator mounted on the sea bed. The key innovation of this technology is its use of a linear generator with a large number of NdFeB magnets, which allows for high magnetic excitation with smaller magnets (www.seabased.com).

Sea Power International

This company has developed a floating overtopping device for mooring in deep water (www.seapower.se/indexeng.html). A considerable time ago it won an opportunity to install a device in Shetland as part of the Scottish Renewables Order but little progress has since been made.

United Kingdom

At one time the UK had one of the largest government-sponsored R&D programmes on wave energy. After a period of reduction, interest has been renewed in recent years, with government-funded research at a number of universities and institutions as well as support for different device developers. There have been a number of initiatives that benefit the ocean energy sector in general:

- development of a market pull price mechanism (similar to Portugal's). The Scottish Executive has confirmed a generous mechanism for the first wave energy scheme (which has already attracted one developer – OPD) and a decision on the price for the rest of the UK is expected shortly;
- establishing a range of wave energy test facilities, ranging from wave tanks, dry-dock testing of large scale devices (e.g. the New and Renewable Energy Centre – NaREC – www.narec.co.uk/facilities-wave-and-tidal-dock.php), test stations for full size devices at sea (www.emec.org.uk) and a facility that will eventually provide a test station for small arrays of full-size devices at sea (the Wave Hub - www.wavehub.co.uk);
- government support for developers of ocean energy devices in the form of direct grants and, more recently, a marine resources development fund of nearly US$ 100 million for pre-commercial devices;

- support for wave energy through official organisations such as the Carbon Trust (www.thecarbontrust.co.uk). This has carried out an assessment of ocean energy devices, established a marine technology accelerator fund and invested in one wave energy device;
- established coordinated academic research on wave energy in several universities (www.supergen-marine.org.uk).

Many different devices at various stages of maturity continue to be developed in the UK under the above initiatives. Among the leading developers are:

Aquamarine Power

This company has developed the Oyster™, a near-shore bottom-mounted wave energy converter for use in water depths of around 12 m. It is an oscillating flap device, similar to the WaveRoller (see the Finland Country Note). It delivers pressurised seawater to the power take-off unit (i.e. conventional hydro-electric generators) on the shore. A full-size prototype device is being tested at EMEC (www.aquamarinepower.com).

C-Wave

C-Wave Ltd has designed a large wave-energy device in which buoyant vertical flaps or 'walls' are mounted via hinges on a long floating platform at a distance of approximately half an ocean wavelength apart. These flaps oscillate back and forth under wave action, activating a hydraulic pump mounted between each flap and the platform. The key innovation of this device is by using such a wide separation, the two flaps experience the peak and trough of a wave, thereby cancelling out any horizontal motion and reducing mooring loads. The device is still at the R&D stage (www.cwavepower.com).

University of Manchester Intellectual Property Ltd

The University of Manchester is developing the Manchester Bobber, which comprises 25-50 floating masses, suspended by wires below a platform in up to 60 m water depth. The masses rise and fall under the action of waves turning a pulley and its shaft in one direction (by using a freewheel clutch). This in turn drives an electric generator via a gearbox. The main advantage is that the pulley and all associated mechanical and electrical equipment are mounted on the platform above the waves. This device is at the R&D stage (www.manchesterbobber.com).

Ocean Power Delivery (OPD)

The technology behind OPD's Pelamis has been briefly described in the Commentary (www.oceanpd.com). It has been tested at full scale at EMEC and has contracts in place to deploy 3 devices in Portugal, 4 devices in Orkney and up to 7 devices at the Wave Hub in the UK. This is clearly the UK's leading device.

ORECon

The ORECon concept is a floating OWC employing a multiple oscillating water column configuration (rather than the single chamber used by other OWC devices) and a self-rectifying impulse turbine. By combining multiple columns within the collector component, the device can be tuned to resonate at multiple rather than single frequencies to capture energy over a much broader waveband. This device is at the R&D stage.

Offshore Wave Energy Ltd (OWEL)

The OWEL is a very large floating platform containing several horizontal channels facing into oncoming waves, which have decreasing cross sectional areas as the waves travel down the channels. These trap the air between successive wave peaks and compress it before discharging into a reservoir, where it is then used to drive a turbine and thus generate power (www.owel.co.uk). This device is at the R&D stage.

Wavegen

Wavegen's pioneering shoreline OWC (the LIMPET) continues to function on the island of Islay. Its output is fed into the local grid but the plant also serves as a test bed for new technology. Wavegen has advanced plans for deploying such devices in Scotland and in Germany, as well as developing its OWC concept for use in arrays of small OWC chambers within breakwaters (www.wavegen.com).

Trident Energy

This device consists of a floating buoy contained within a floating structure. The vertical movement of the buoy with the rise and fall of the waves is directly coupled to a linear generator on the platform (www.tridentenergy.co.uk). This device has been tested at NaREC and is still at the R&D stage.

United States of America

For a prolonged period, there was no official interest in wave energy in the USA. A number of devices were conceived but few made it past the drawing board. However, interest in wave energy has recently been rekindled, thanks in part to an extensive study undertaken by the Electrical Power Research Institute (www.epri.com/oceanenergy/waveenergy.html), which made a 'compelling case for investment in wave energy'. This interest is reflected at both a national and state level and a number of technologies have been developed.

Aerovironment (AV)

AV's device consists of a buoy anchored to the sea floor so that it floats beneath the surface (www.avinc.com/energy_lab_project_detail.php?id=68). As the float moves through the water vertically, responding to changes in pressure resulting from passing waves, it powers a generator on the sea bed (mechanism unspecified). A scale model completed testing in the Pacific Ocean with encouraging results, and plans for broad deployment are being developed. This concept is at the R&D stage.

Ocean Motion International

Ocean Motion International's technology uses a large buoyant vessel to which a number of heavy ballast masses are attached via a sleeve-type pump. The masses rise and fall in the waves, pumping water into a manifold to power a hydroelectric generator or a reverse osmosis (RO) unit. This concept is at the R&D stage (www.oceanmotion.ws).

Ocean Power Technologies (OPT)

OPT has a long history of developing its PowerBuoy™. This system consists of a floating buoy that is moored to the sea bed so that it can freely move up and down in response to the waves. The movement is converted into rotational mechanical energy, which in turn drives the electrical generator, all of which are in a sealed unit. The control system collects data and adjusts the performance of the PowerBuoy™ system in real-time and on a wave-by-wave basis. The current device is about 17 m long, 3 m in diameter and is rated at 40 kW but OPT has plans for a 500 kW PowerBuoy™ system, with a diameter of nearly 14 m and a length of 20 m (www.oceanpowertechnologies.com). OPT has deployed single devices in Atlantic City (New Jersey) and Oahu (Hawaii) and has an agreement for another device at Santoña (Spain). Typically, these agreements allow OPT to demonstrate the performance of its device before going on to install arrays. OPT is the only wave energy developer to have successfully floated on the stock market, but it is expected that others will try to follow in 2007/8.

Independent Natural Resources, Inc. (INRI)

INRI™ has recently developed the SEADOG™ pump (www.inri.us). This comprises a large piston operating over an air-filled buoyancy chamber. The piston moves up and down with the varying pressure under wave peaks and troughs and this movement drives a hydraulic pump to produce pressurised water, which is pumped to shore to produce potable water (via an RO unit) or electricity by filling a reservoir which is allowed to drain back to the sea via hydroelectric turbines. Each pump can produce several tens of kilowatts of power, so in practice an array of devices will be deployed. A single SEADOG™ prototype has been successfully tested in the Gulf of Mexico and the company has plans for deployment of a 16 device array off the Californian coast, which will produce just over 500 kW.

Scientific Applications & Research Associates (SARA)

SARA has developed a wave energy device to extract energy from waves using a magnetohydrodynamics (MHD) generator. It is designing a 100 kW prototype to demonstrate this principle, as well as developing a deep-ocean-moored device to use the MHD generator. This device is at the R&D stage (www.sara.com).

Seavolt

Seavolt's Wave Rider consists of a moored cam-shaped buoy which bobs up and down in the waves. This rolling action powers a hydraulics circuit connected to a motor and generator. The current status of this device is uncertain.