Wave Power

Joao Cruz

When thinking about renewable energy, wind and solar energy immediately come to mind. To tackle climate change and all the challenges imposed by the need to find alternative and reliable energy sources, there is one major resource that has remained untapped until now: wave power. In this article, Joao Cruz describes the size of this resource and presents the leading technological solution to the problem of harnessing it.

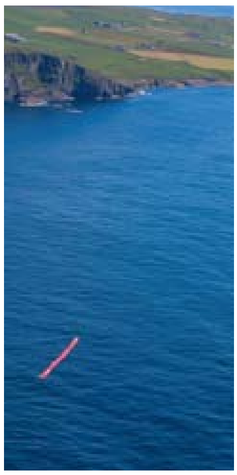
Key words
Wave energy
Kinetic energy
Gravitational potential energy
Energy resource

Ocean waves

Wave energy is a concentrated form of solar energy: the Sun produces temperature differences across the globe, causing winds that blow over the ocean surface. These cause ripples, which grow into swells. Such waves can then travel thousands of miles with virtually no loss of energy. Don't confuse these deep-water waves with the waves you see breaking on the beach. When a wave reaches shallow water (roughly when the depth of the water is less than half a wavelength), it slows down, its wavelength decreases and it grows in height, which leads to breaking. The major losses of energy are through breaking and through friction with the seabed, so only a fraction of the resource reaches the shore.

A wave carries both kinetic and gravitational potential energy. The total energy of a wave depends on two factors: its height H and its period T. The power carried by the wave is proportional to H^2 and to T, and is usually given in watt per metre of incident wave front. Figure 1 shows the worldwide distribution of wave power, in kW/m. From the map, you can see that the coastline of western Europe has an average 'wave climate' of about 50 kW of power for each metre width of wave front.

The overall resource is of the same order of magnitude as world electricity consumption (around 2 TW). A conservative estimate is that we might extract 10-30% of this, suggesting that wave power could make a significant contribution to the energy mix. On a typical day, about 1 TWh of wave energy enters the coastal waters of the British Isles. This corresponds to approximately 1/3 of the average daily energy needs in the UK, and is about the same amount of energy as that of the Indian Ocean tsunami of the 26th December 2004. These figures put into perspective the sort of demand that human beings put on available natural resources, and the urgent need to find sustainable solutions.



Pelamis installed at the European Marine Energy Centre, Orkney

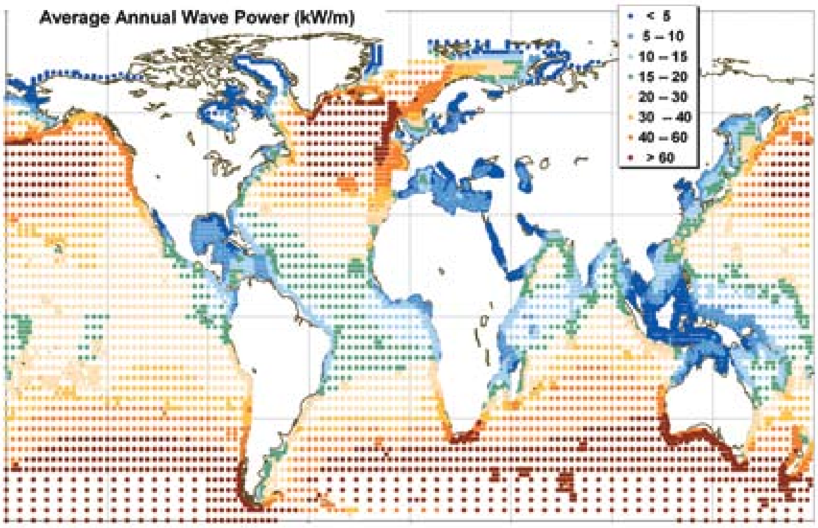


Figure 1 *World's distribution of wave power in kW/m (Courtesy of Oceanor)*

Why is the resource still untapped?

It was only in the 1960s that electricity from waves was first put into practice: the Japanese navy built a marker buoy which used waves to power its lamp. The turning point that spurred research in several countries was the publication in 1974 of an article in the widely-read scientific journal *Nature* by Prof Stephen Salter, of the University of Edinburgh. This came as a direct reply to the oil crisis of the 1970s, and its attraction was immediate. The concept, a cam-shaped floating body known as the Salter duck, is still renowned as one of the most efficient at absorbing waves.

Why didn't wave power take off after this? Around the early 1980s, the UK government made the bold decision to focus all funding on large generating systems rated at 2 GW, the capacity of a large coal-fired or nuclear station. Many scientists and researchers believed that this was not the way forward, and that it would be better to think in terms of arrays of smaller units, each producing a few MW. Experience suggests they were right - see 'How does it work?' below. Some supporters of alternative energy claim that the government's policy was designed to stop wave energy research and to justify the route to nuclear power. The lack of funding virtually halted the significant progress that was taking place.

Starting in the mid-1990s, there have been significant achievements in the development of offshore wave power systems, with several full-scale prototypes being tested and connected to national grids. As with wind energy fifteen years ago, there are still several competing approaches, and it is unclear which one (if any) will make the final leap towards commercial applications. An Edinburgh-based company, Pelamis Wave Power Ltd, has been developing a wave energy converter since 1998, and is in the front row of the technology

How does it work?

Ocean Power Delivery's solution is named Pelamis, after *Pelamis platurus*, a metre-long sea snake which lives in the Indian and Pacific Oceans. The Pelamis wave energy converter is 150 m long and has a diameter of 3.5 m. 74 members of staff work on current projects and are also developing future generations of machines.

The Pelamis is a semi-submerged, articulated floating structure composed of four long cylindrical sections linked by hinged joints. At each joint there is a power conversion module. Its mooring system ensures that the Pelamis machine aligns itself head-on with incoming waves. How does Pelamis make electricity?

- As waves travel down the length of the machine the structure bends around the joints.
- This motion pushes hydraulic rams that pump high-pressure oil through hydraulic motors.
- The hydraulic motors drive generators to produce electricity.
- Power from all the joints is fed down a single umbilical cable to a junction on the seabed.

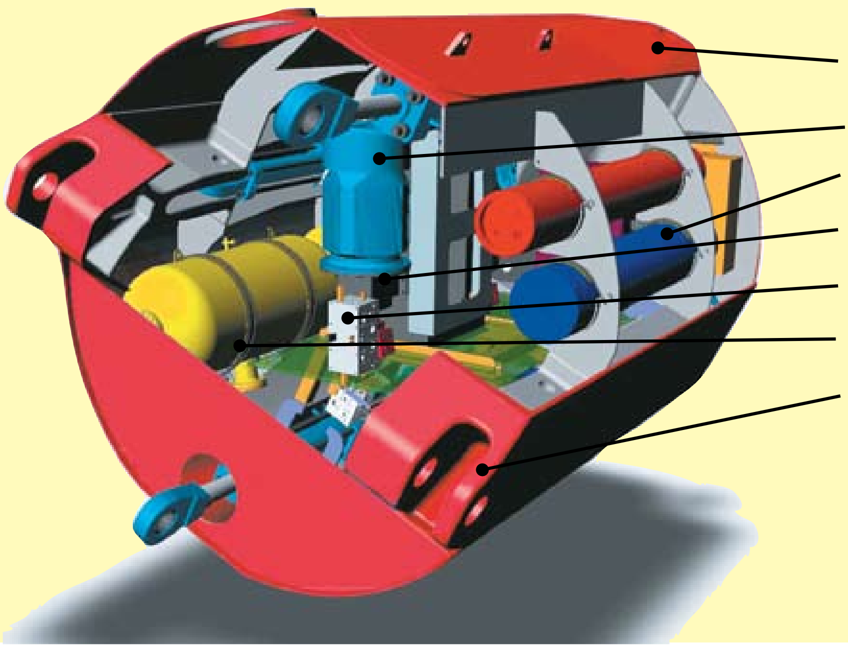


Figure 2 *Detail of the Pelamis power conversion module*

race. The world's first wave energy farm is about to be installed offshore near Póvoa de Varzim in the north of Portugal, in a project led by utility company Enersis, and the Scottish Executive recently announced support to build another wave energy farm in Orkney, in a project led by Scottish Power, and with Pelamis again supplying the technology. Portugal and Scotland have shown the political will and are leading the way to an environmentally-friendly solution to the energy problem.

An artist's impression of a wave farm.

A number of devices can be connected together in an array, resulting in a wave farm. A 30 MW installation (40 Pelamis machines) would occupy a square kilometre of ocean and provide electricity to 20 000 homes. Working at sea is difficult and expensive, so the Pelamis is constructed, assembled and commissioned before it is moved out to sea. For maintenance operations, electrical and moorings connections can be rapidly detached, allowing the quick recovery of the machines, again minimising the cost of offshore operations. Pelamis can be installed in a variety of water depths and sea bed conditions, which increases flexibility.

Developing Pelamis

Two main requirements governed the design of the Pelamis machine: survivability and availability. A wave energy converter should be designed to resist any sea state, even the most extreme one, and then designed to maximise the power capture. In addition, Pelamis is designed to use readily-available components; it is innovative in its over-all design and assembly.

Pelamis Wave Power were very thorough in their development of Pelamis. They used several numerical (computer) models of different levels of complexity, and many scale models were built and tested in wave tanks to validate the numerical predictions.

In 2004 a full-scale prototype was tested in the North Sea and later installed in the European Marine Energy Centre. The success of the test programme led to the sale of three machines to a Portuguese consortium lead by Enersis. These machines have been assembled in a shipyard in Portugal and they are being installed about now (autumn 2007). A second stage with 27 more machines is already planned.

The next few years will determine if the new wave energy industry can emulate what has been created for wind energy in the recent past. The technology exists, conditions have never been better and the sea has been waiting for far too long.

Follow the progress of Pelamis at www.pelamiswave.com

Martin Bond/SPL

Another approach to wave power: this land-based wave power station generates enough electricity for 300 homes on the Scottish island of Islay.

Alternative Applications

Is electricity the only product than we can extract from wave power? The answer is no, and the main alternative is easy to guess: fresh water. At the University of Edinburgh researchers are developing a version of the original Edinburgh duck, which aims to produce freshwater rather than electricity. Even in moderate wave conditions (say 12 kW/m) the output can be very significant, up to 1000 m^3 per day for each unit. This stand-alone concept has no moving parts, minimising maintenance. Because the water is heated to produce steam which is then condensed, the output is pure water even if the feed water is polluted. Several numerical models have been created and a 1:40 scale model has been tested in a wave tank, helping to validate the approach.
More details at www.easywaves.eu

***Joao Cruz** is a mechanical engineer at Pelamis Wave Power in Edinburgh, where he develops software and methods to better characterise and predict the state of the sea. He and his colleagues will be monitoring the world's first wave energy farm which will be installed later this year (2007) in Portugal. He has worked on the monitoring of other prototype wave power plants and on research institutes spread throughout Europe.*