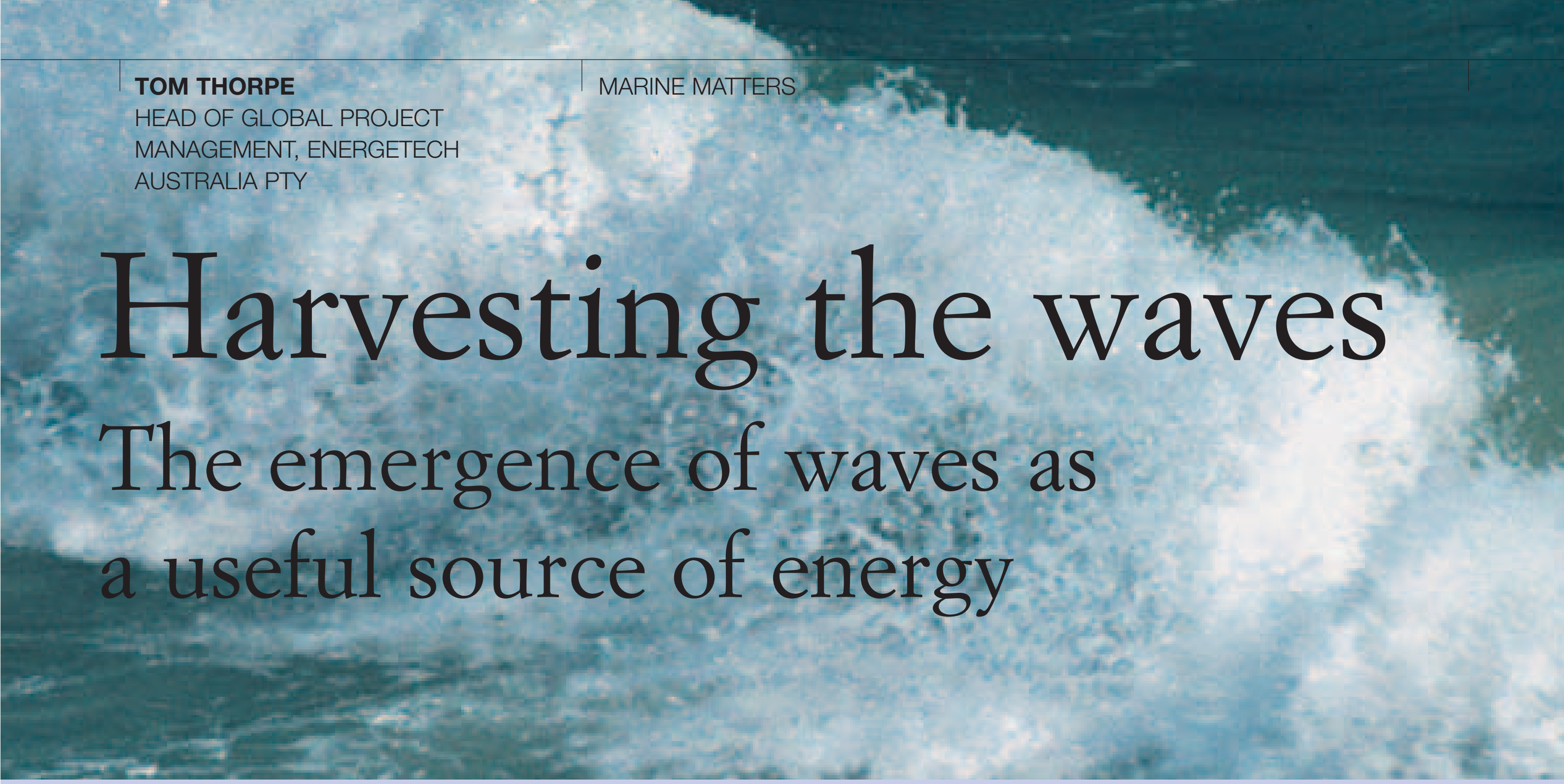


TOM THORPE
HEAD OF GLOBAL PROJECT MANAGEMENT, ENERGETECH AUSTRALIA PTY

Harvesting the waves

The emergence of waves as a useful source of energy

The potential for extracting useful energy from waves has been studied for some considerable time. Following the failure of early Government programmes, support for wave energy declined. In recent years, wave energy has started to make a comeback due to the efforts of a range of small companies with innovative ideas for overcoming the technical and economic challenges facing this new technology. This paper outlines the recent developments in wave energy, highlighting some of the devices and reviewing costs and potential markets.

Wave energy represents a potentially powerful source of renewable energy, with global wave power levels being in excess of 1 TW (1,000,000 MW) (see Box 1). Work on exploiting this large resource began in earnest during the early 1970s as a response to the oil crises. There were several government sponsored programmes throughout the world, particularly in Japan, Norway and the UK. These programmes advanced the technology considerably and their achievements were impressive, including the building of several devices. Nevertheless, the failure of these programmes to deliver economic supplies of electricity from wave energy

Box 1 The source of wave energy

Wave energy is basically a concentrated form of solar energy. Differential heating of the Earth's surface causes winds to blow. As these winds pass over seas, they transfer some of their energy to the water in the form of waves. The amount of energy transferred depends on:

- the speed of the wind
- the length of time for which it blows
- the distance over which it blows (the 'fetch').

The power stored in waves can be defined in terms of their physical characteristics, as shown below. The power present in waves is described by:

$$P = \alpha H^2 T$$

where P is the power per unit of crest length, H is the wave height, T is the wave period and α is a constant.

The figure below shows the global distribution of wave energy in deep water. It can be seen that Europe is particularly well suited to developing wave energy, being at the end of a long, stormy fetch otherwise known as the Atlantic Ocean.

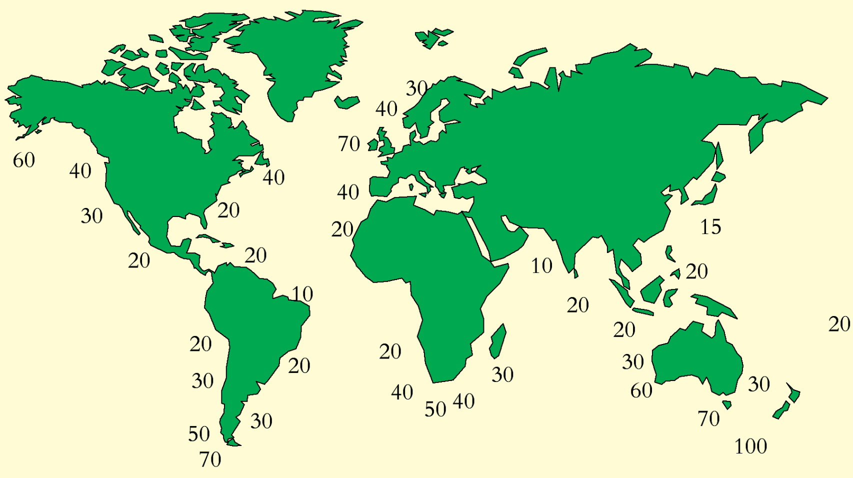


Figure 1: Global distribution of wave power levels in kW/m

left the technology with a credibility problem that has been hard to overcome.

The technical challenge

The basic reason for these failures was the challenge of putting something in the sea that would survive and also produce electricity at a competitive price. This is a particularly difficult task because of the variation in wave direction and power levels (see Box 2). The cost of building a structure that can withstand the forces imparted by extreme waves (wave heights in excess of 30 m have been recorded in the North Atlantic) would be prohibitively expensive. Therefore, modern wave energy devices employ two main methods of avoiding such large loads:

- The simplest method is to move the device close to the shore, where the water depth limits the maximum size of wave to which the device can be subjected. This has the disadvantage that the average wave power levels are also reduced, but this can be overcome to some extent by seeking out areas where wave energy is concentrated – 'hot spots' (see Box 2).
- Devices stationed in deep water are either submerged (so they can be lowered out of the region of wave action during very stormy seas) or else are elongated, presenting a small cross section to the waves.

There are other designs that do not use these simple tactics but they have yet to prove that they are capable of surviving. Examples of both approaches to meeting the technical challenge are given in the following sections. These will be presented in terms of the achievements of the various small companies developing wave energy devices. However, emphasis should also be given to the important role that academia has played in the development of wave energy, in particular in Scotland, Norway and Portugal.

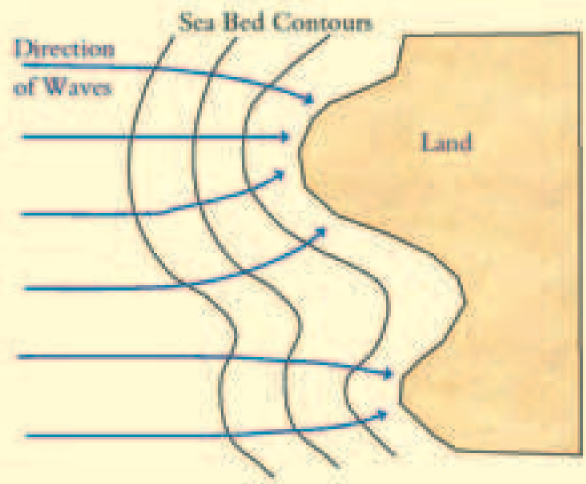
Box 2 Variability in wave energy

The energy present in waves can vary for a number of reasons.

- In deep water, the waves vary in direction according to the direction of the original wind field that generated the waves.
- As waves travel towards the shore, the waves start to loose energy through friction between the water particle movements and the sea bed.
- Waves approaching the shore are subject to diffraction, so that the waves travel at right angles to the sea bed contours. This can lead to energy being focussed on promontories known as 'hot spots' (Figure 2).
- Wave energy levels can vary on timescales of minutes (well known to surfers who wait for the largest wave in a wave train) and days (between storm and calm).

The last is the most difficult technical challenge. In the interests of good economics and efficiency, the mechanical and electrical plant are rated for waves which occur often, but the structure of the scheme has to be designed against extreme waves (Figure 3). Hence the revenue is obtained from waves of modest power levels but the capital cost is driven by waves of very high power levels.

Figure 2: Diffraction of waves as they approach the shore



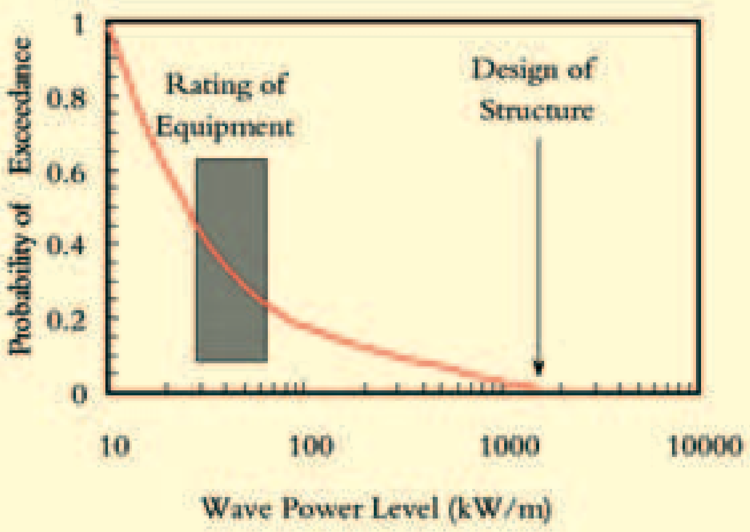


Figure 3: Variation in wave power levels In one year

Shoreline devices

The most common design of shoreline device is the oscillating water column (OWC). These take the form of a partially submerged chamber that has a small exit at the top and a large opening below sea level (Figure 4). As the sea water flows in and out of the device, the level of water in the chamber rises or falls in sympathy. The column of air above the water level in the chamber is alternately compressed and decompressed by this movement to generate an alternating stream of high velocity air in an exit blowhole. If this air stream is allowed to flow to and from the atmosphere via a pneumatic turbine, energy can be extracted from the system and used to generate electricity. In this way, the OWC acts as a pneumatic gearbox, turning the slow movement of the waves into a fast airflow suitable for powering turbines.

There are two main types of OWC currently being deployed world-wide as represented by the designs developed by Wavegen and Energetech.

Wavegen's Limpet

The Limpet comprises a sloped OWC optimised for annual average wave power levels of between 15 and 25 kW/m. A water column with a water plane area of 170 m^2 feeds a pair of Wells turbines each of which drives a 250 kW generator, giving a nameplate rating of 500 kW. The 2.6 m diameter turbines utilise symmetric aerofoil blades mounted at right angles to the airflow, so that the turbine rotates in the same direction regardless of the direction of air flow (Figure 5). The turbines are fixed back-to-back to give the combined effect of a contra-rotating bi-plane unit. The first commercial size device (rated at 500 kW) has been deployed on the island of Islay in Scotland (Figure 6). In this application, a hollow was carved out behind the cliff edge and the OWC deployed behind the resulting rock bund, which was finally destroyed to allow the sea to access the OWC. The company is currently seeking new sites for deployment and continuing its research and development activities. Wavegen also developed and deployed a non-shoreline OWC device in Scotland (the OSPREY), which also had the capability to support a wind turbine. However, this device was destroyed by wave action soon after arriving on site and the company is now concentrating on developing a new floating offshore wave energy device.

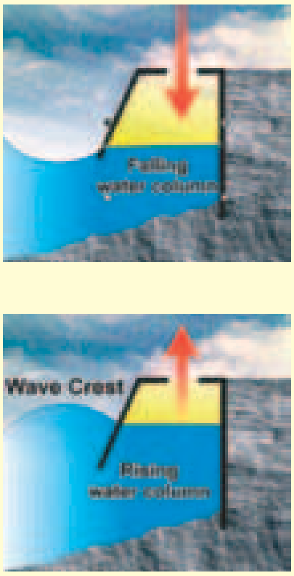


Figure 4: The principles of operation of an OWC
Sketch courtesy of Wavegen

Figure 5: The Wells Turbine
Photograph courtesy of Wavegen

The Energetech OWC

The Energetech device represents an evolution in OWC design in two main areas:

- The loss of wave power level as waves approach the shore is compensated by utilising a 40 m wide parabolic reflector to reflect waves onto the 10 m wide OWC chamber situated at the focus of the parabola (Figure 7). Hence, for an increase in capital cost of approximately 30%, the parabolic walls increase output up to 300%.
- Energetech has developed a novel turbine, which uses a variable-pitch mechanism to cope with the change in direction of air flow (Figure 8). Initial tests indicate that it has a higher peak and average efficiency than the Wells turbine.

The first full size device is currently under construction at Port Kembla, south of Sydney, Australia. If the innovations achieve their potential, this 500 kW scheme will achieve significant improvements in the economics of OWCs. Further devices of up to 2 MW are being planned for British Columbia and Spain.

Figure 6: The Wavegen Limpet at Islay
Photographs courtesy of Wavegen

Figure 7: Artist's impression of the Energetech OWC
Sketch courtesy of Energetech

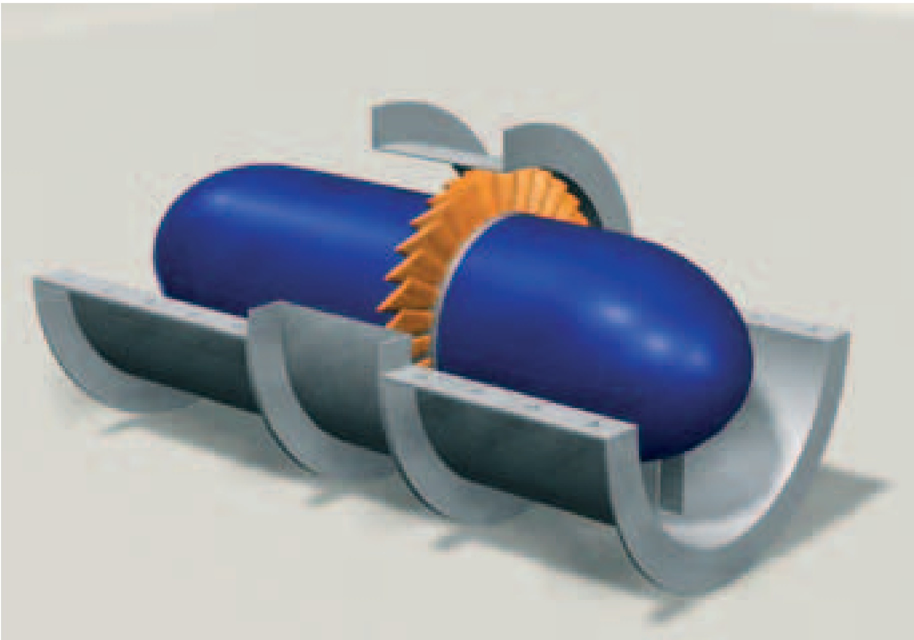


Figure 8: Outline of the Energetech variable pitch turbine
Sketch courtesy of Energetech

Offshore devices

The technical challenge faced by offshore devices is greater than that facing shoreline devices, but the potential market is greater. A plethora of designs has been developed to overcome the difficulties but, as yet, very few have actually been tested in service. This article has selected those that are expected to be tested at full scale within the year.

The McCabe Wave Pump

This device consists of three narrow steel pontoons that are hinged together across their beam and point into the incoming waves. The front and back pontoons move in relation to the central pontoon by rotating about the hinges. Energy is extracted from the rotation by hydraulic rams. While this energy can be used to provide electricity (approximately 400 kW), the inventor (Peter McCabe) intends to use this device to be the source of potable water by supplying pressurised sea water to a reverse osmosis plant. It is designed to produce approximately 270 million litres per annum in wave climates typical of arid countries with shorelines. A 40 m long prototype of this device was deployed off the coast of Kilbaha, County Clare, Ireland (Figure 9) and a new commercial demonstration scheme has been built and is about to be tested.

The Pelamis

Ocean Power Delivery's Pelamis (Latin for sea snake) is a semi-submerged device composed of cylindrical sections linked by hinged joints. The device points into the incoming waves and the sections move with respect to each other as each wave passes down the length of the device. This motion is resisted by hydraulic rams at the joints, which pump high pressure oil to drive electrical generators. This restraint can be varied to tune the device for maximum efficiency in each sea state or to limit loads in stormy seas. Power from all the joints is fed down a single umbilical cable to a junction on the sea bed. A device is being developed for

Figure 9: The McCabe Wave Pump
Photograph courtesy of Peter McCabe

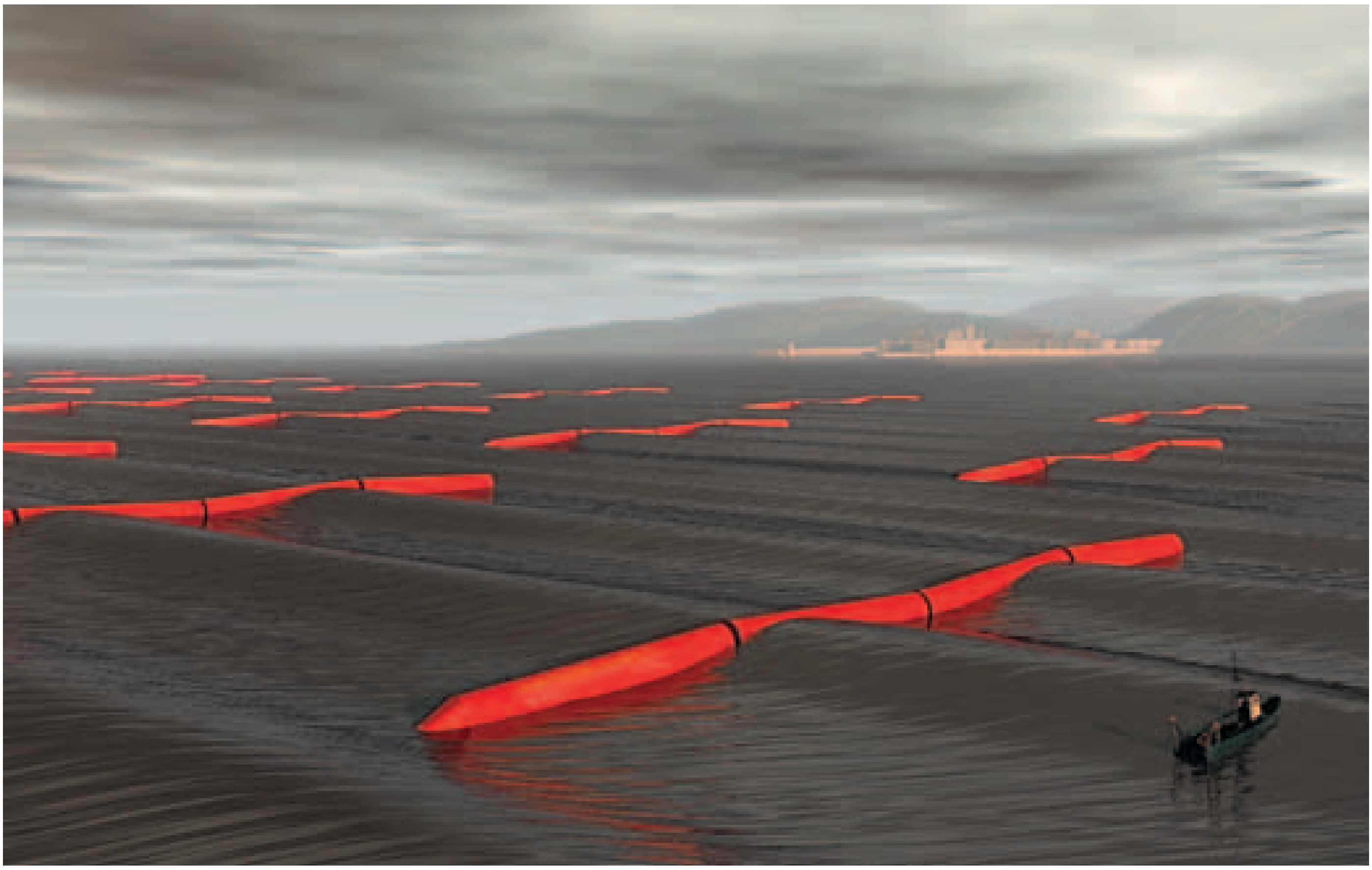


Figure 10: The Pelamis

Artist's impression of a wave farm courtesy of OPD

Scotland, which is rated at 750 kW and is 150 m long and 3.5 m in diameter; it has already been tested successfully at ⅐th scale.

The Archimedes Wave Swing (AWS)

Teamwork Technology's AWS consists of a cylindrical, air-filled chamber (the 'floater'), which can move vertically with respect to the cylindrical 'basement', which is fixed to the sea bed in sufficient water depth to ensure that the floater is below the waves. The air within the 10–20 m diameter floater ensures buoyancy but a wave passing over the top of the device, alternatively pressurises and depressurises the air within the floater, changing this buoyancy. This causes the floater to move up and down with respect to the basement and it is this relative motion that is used to produce energy using a novel, linear electrical generator. This is the most powerful device currently under construction: a 2 MW pilot scheme has been built for deployment off the Portuguese coast (Figure 11).

The economics of wave energy

The economics of generating electricity from waves has been an area of considerable contention, with some wave energy developers having made widely enthusiastic claims. In recent years this has been solved by the development of a widely peer-reviewed methodology, which was used in the last UK review of wave energy for the UK Department of Trade & Industry (see suggested reading). The generating costs for a number of devices (at 10%

Figure 11: The Archimedes Wave Swing
Picture courtesy of AWS

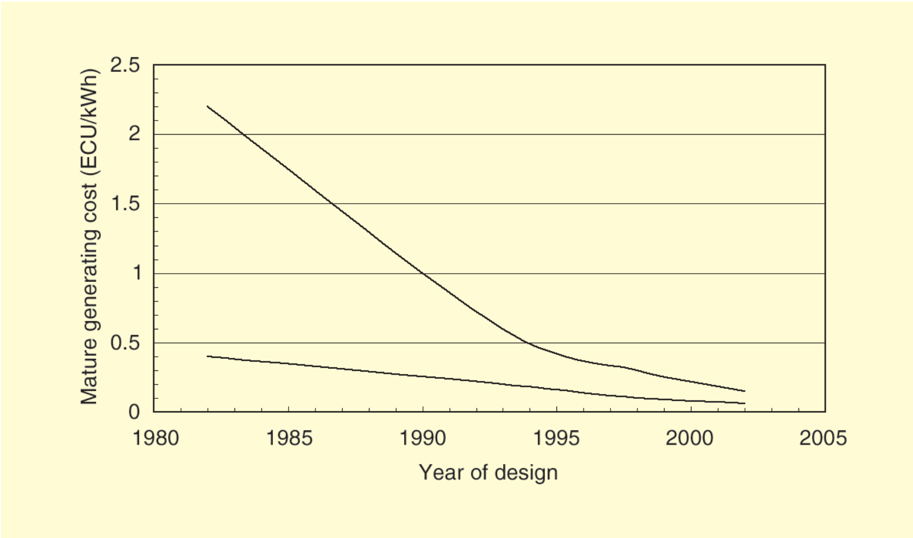


Figure 12: Evolution of range of generating costs for wave energy Costs are in 2002 monetary units for mature technologies

discount rate) predicted by this methodology have been plotted in Figure 12 against the year in which the design of device was completed. This graph shows that there have been significant reductions in the predicted generating costs of devices. These results indicate that, if these devices can be successfully built and if they perform as predicted, wave energy is already economically competitive in niche markets such as supplying electricity to isolated communities that are not connected to the grid. In addition, wave energy devices could attract further economic advantage from their low life cycle emissions of greenhouse gases and other pollutants. However, it should be emphasised that the economics predicted in Figure 12 are for mature devices. The generating costs of the first devices will be much higher because of:

- technical immaturity (learning curve benefits will follow)
- perceived risk (which will inflate the costs of the initial schemes)
- lack of economies of scale initially.

In this, wave energy is expected to follow the same pattern as other new, renewable energy technologies, such as wind where (according the the US National Renewable Energy Laboratory), the levelised cost of wind energy has fallen by a factor of six over the past 20 years.

The potential market

There are well advanced plans to increase the wave energy capacity throughout the world to nearly 10 MW in the next few years. Further predictions for future world-wide capacity are, at present, speculative, but several companies have plans for the deployment of several tens of megawatts per year in the period starting 2005. Deployment at this rate is necessary for some years if devices are to start to achieve the mature generating costs outlined in Figure 12.

An independent assessment of the likely markets has been made for the UK Department of Trade & Industry, taking into account competing sources of electricity. This indicated that, if the performance and costs of wave energy devices agreed with independent predictions, then their economic contribution could be approximately 2000 TWh/year. This is comparable to the amount of electricity currently produced world-wide by large-scale hydroelectric schemes and would correspond to an investment of over €750 billion. This market would increase if the environmental benefits associated with the reduction in emissions associated with electricity generation from wave energy devices could be internalised in the cost of generation. However, before such markets can be realised, the wave energy devices currently being constructed have to prove their technical and commercial viability – the next year promises to be a very exciting one! ■

Further Reading and Websites

There are few existing books or reports on wave energy.

'A Brief Review of Wave Energy', ETSU Report R-122 for the DTI and other publications are available from the Department of Trade and Industry's web site at

http://www.dti.gov.uk/renewable/

The World Energy Council has an overview of current wave energy activities at

http://www.worldenergy.org/wec-geis/publications/reports/ser/wave/wave.asp

Most wave energy developers have their own web sites

Wavegen web page – www.wavegen.co.uk
Energetech web page – www.energetech.com.au
Ocean Power Delivery web page – http://www.oceanpd.com
Archimedes Wave Swing web page – www.waveswing.com

Tom Thorpe is the former Principal Consultant on renewable energy and the environment at AEA Technology. In that position, he specialised in wave and tidal energy, providing advice to a range of international bodies, several governments, industry and investors. He has recently taken up a post as Head of Global Project Management at Energetech Australia Pty, a company developing its own wave energy device.