The Renewable Future of the UK: Wave Power.

Wave Power – The Resource

Waves are created by the interaction of the wind on the surface of the sea. The wind blows across the ocean from America. This large fetch means that the UK has one of the highest wave power levels in Europe (Figure 1) and the world (Figure 2). Wave power is a highly concentrated energy source (most of the power in the top 50m of the sea) with a smaller hourly and day-to-day variation than other renewable resources. Conveniently, the seasonal variation of wave power closely follows the trend for electricity consumption in Western Europe (Ocean Power Delivery Limited, 2005). The amount of the resource that is readily exploited is determined by the geographical location and also the position of the devices, whether it be shoreline, near shore or offshore. The waves are strongest in the open ocean, as the waves get closer to land their energy is dissipated due to the rising seabed and the action of the wind. It is estimated that only one tenth of the wave's energy remains after a wave hits the shore (Thompson et al., 2001). According to Ross (1995) the waves in the ocean contain as much energy as the world is using today and the World Energy Council estimates there is enough energy to generate twice the amount of electricity as the world now produces (Wavegen, 2005). This huge potential, however, has not yet been harnessed.

Figure 1. European Wave Resource Chart The chart shows annual average wave power in kilowatts per metre of crest width for various European sites. (Ocean Power Delivery Limited, 2005)

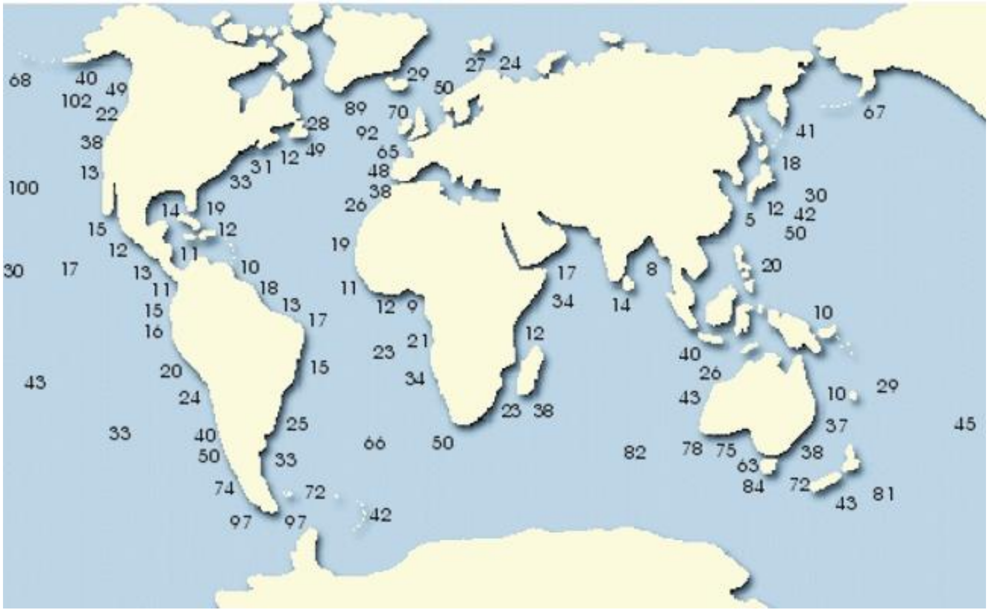

Figure 2. World Wave Resource Map The map above shows annual average wave power in kilowatts per metre of crest width for various sites around the world. (Ocean Power Delivery Limited, 2005)

Although, any site with an average wave power level of 15kW per meter has the potential to generate wave energy at competitive prices (Ocean Power Delivery Limited, 2005). Figure 1 shows that the West coast of the UK, especially Scotland has average values that greatly exceed 15kW per meter. However, some regions of the world have very lower averages, making them economically inappropriate. Figure 3 shows the most promising sites in the UK for wave technologies.

Figure 3: Promising UK and Irish Sites for Wave technology (Thorpe, 2003)

Several influential events have occurred in the last 10 years, resulting in benefits for wave power. The Kyoto Protocol in 1997, provided the driver for various governments to set targets for increased proportions of renewable energy over the first decade of the new millennium. Also the UK review of Renewables in 1999 as part of this, wave power RD&D funding was re-introduced for the UK (Griffiths, 2002) after wave power funding being cancelled in 1982 in favour of Hot Dry Rock Geothermal (Ross, 1995). Finally, the large increase in the price of oil in 2000 from the very low levels of 1998 has caused re-evaluation of economic thresholds of conventional energy projects and improved the attractiveness of emerging renewable technologies (Griffiths, 2002). The UK hopes to reach the targets set by the Kyoto Protocol with the use of a diversity of renewable technologies. By 2020 the UK hopes to be generating 20% of its electricity using renewable sources, Scotland, however, has set itself higher aims of 40% by 2020, with the aims of using lager amounts of wave power due to the steadily rising opposition towards wind power.

Technologies

At present, nearly 300 concepts for wave-energy devices have been proposed, but because of the difficulty of developing an efficient, reliable, and cost-effective wave-energy converter, fewer than 10 are likely to meet commercial demands by the end of the decade (Jones and Westwood, 2005) and only a few key devices have so far been installed at prototype level (Westwood, 2004). The full scale commercialisation of wave power is not expected until 2010 at the earliest (Department of Trade and Industry, 2003).

The technologies can be split into shoreline, near-shore and offshore devices.

These devices are some of the most technologically advanced due to the timescale over which they have been being developed. The Wavegen Limpet shoreline device has been installed on the Island of Islay, Scotland, since 2000. This device has a generating capacity of 500kW (Boyle *et al*., 2003) this is enough to supply 300 houses on the island (TVE, 2000). The Limpet wave energy plant uses the 'Oscillating Wave Column' technology, this is one of the most widely used technologies in shore-based generating. In the OWC, the motion of the waves inside a chamber blows and sucks air through an air turbine which when linked with a generator produces electricity (Boyle *et al*., 2003). Wavegen and SEV, the Faroese electricity company, are jointly developing a wave plant based on the oscillating water column technology successfully developed at the Islay plant. The energy will be harnessed by cutting tunnels into the cliff, the benefit of this being that it is unobtrusive (Wavegen[2], 2005). Other devices such as the Tapchan work on a technology based on a Tapered Channel and an adaptation of hydroelectricity (Murdoch University, 2005).

The advantages of shoreline devices is that due to their location they are easier to install and maintain. These devices are also particularly useful for supply electricity to remote communities. The major disadvantages for shoreline devices is that as waves move into shallower water much of their energy is lost (Figure 4 shows how wave heights decrease with proximity to land, this is the same pattern as energy). This problems means the devices have a lower capacity. These devices also have to be built into hard rock coastlines, because of this the East coast and the South coast with the exception of Cornwall are unsuitable. Tidal range can also mean that devices can not be sited in specific areas, is especially relevant with the Tapchan. Economies of scale also mean that these individual shore line devices can be more expensive.

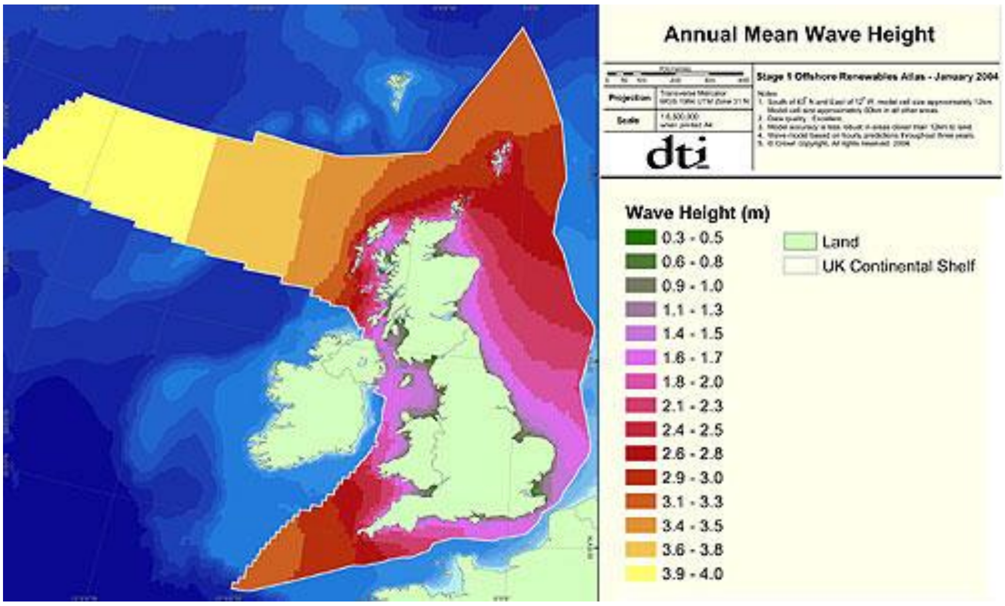

Figure 4: Annual Mean Wave Height (BWEA[2], 2005)

Near-shore technologies have been research with the OSPREY being the most famous to date. However, this fame is mainly due to its demise in 1995 due to the strength of the waves. This device was also designed to serve as a foundation for a 1.5 MW wind turbine, representing an important synergy of renewable energy sources. Further research and re-design led to OSPREY 2000 and the announcement, in 1998, that Wavegen had gained the Irish Government Alternative Energy Requirement III. This would have resulted in a 15-year contract but funding has not been forthcoming and the project is now on hold (Griffiths, 2002). The PowerBuoy has recently been developed by Ocean Power Technologies Inc. This device is submerged 1m below the waters surface. Inside, a piston-like structure moves as the PowerBuoy bobs with the rise and fall of the waves. This movement drives a generator on the ocean floor, producing electricity, which is sent to the shore by an underwater cable (Ocean Power Technologies Inc., 2005). These buoys are tied in arrays so as to generate the desired amount of electricity.

The majority of the power we could gather from waves is found offshore. For example, experts estimate that 0.2 percent of the ocean's untapped energy could power the entire world. (Piquepaille, 2005). Therefore to generate electricity to meet our growing demands we need to move offshore. The most advanced of the offshore technologies is the Pelamis Wave Energy Converter (WEC). The Pelamis WEC is a semi-submerged structure. Wave-induced motion of hinged joints is resisted by hydraulic rams. This pumps oil through hydraulic motors which drive electrical generators giving electricity (Ocean Power Delivery Limited[2], 2005). Each device is 3.5 m wide and 120 m long and can generate 750 kW of electricity. A typical 30MW installation would occupy a square kilometre of ocean and provide sufficient electricity for 20,000 homes. Twenty of these farms could power a city such as Edinburgh (Ocean Power Delivery Limited[3], 2005). It is thought single devices of the Pelamis if modified could generate 1 MW. However, cost is a worry as the estimated full cost for the 500 kW prototype machine costing £1 million (Department of Trade and Industry[3], 2003). There are other devices such as the Archimedes Wave Swing and the McCabe Wave Pump. These devices are less well developed than the on shore devices and there are still some problems with transmission cables and mooring of the devices although major advances in offshore oil and gas technology and in the subsea sector have removed many of the technical barriers. Subsea flexible power cables and connectors, floating mooring systems have all been developed to have a long life and low operating costs (Thompson et al., 2001). Work to lower the costs of these technologies also needs to be considered of the costs could be exorbitant.

Wave energy produces no green house gases and has fewer environmental impacts than other green technologies, such as Hydroelectricity. Some of the plants are visually intrusive but as with Faroes, ideas are being thought up to produce less obvious devices, this also applies with near shore devices which are submerged. Interference with navigation is a worry, especially with offshore devices which could possibly break loose of their moorings in very sever conditions. The Pelamis farms are also very large and sighting will have to be careful to consider shipping. On Islay a few issues of noise have been raised, as with wind, if opposition to devices being build rises this could be a big deterrent for communities.

The cost of wave power is a major concern. Laying of cables may have environmental implications as well as high costs. The environmental impact may be hard to avoid although the transmission may be more successful using hydrogen technologies. There has been a significant improvement in the predicted economics of wave energy (see Figure 4), so that there are now several devices with costs of ~5 p/kWh or less at 8% discount rate (Thorpe., 1999). Although the cost is reducing the prices still do not compete with fossil fuels (~3p/kWh). These technologies are also thought to be unreliable due to the intermittency of the recourse. If this perception was overcome wave power may gain more funding and support.

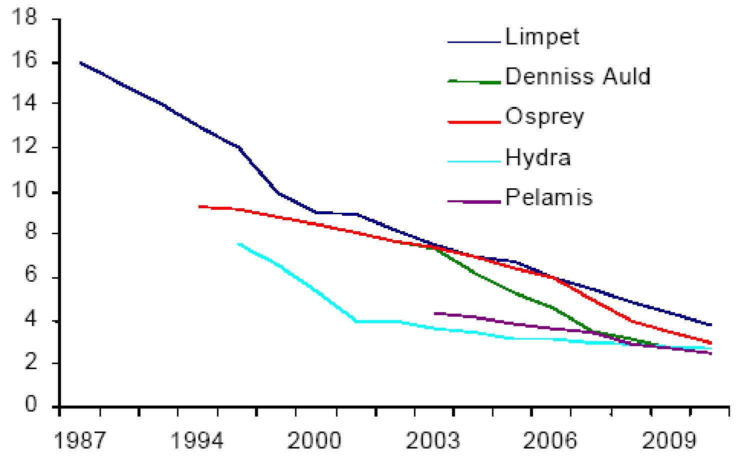

Figure 4: Shows the reducing costs of Wave Power (cents/kWh) (Thompson *et al.*, 2001)

Predictions

Offshore Wave Technology

The wave industry is not believed to be ready to go commercial until at least 2010, as state above. This is believable as the Pelamis WEC has so far taken 7 years to build and test. Due to this my predictions for 2010 are 0PJ.

Due to scale of Pelamis I predict there will be a yearly build rate of 200 devices. Each device will take roughly 3 months to build and due to their large size I believe they will be limited to building only 50 devices at a time.

The load factor for wave generation is less than that for wind, which is 0.3. This is because when the sea is calm the devices can not generate electricity and also when the sea is too rough the devices go into 'Survival Mode' this reduces the possibility of damage and therefore need for maintenance and also lowered costs seas. Controls have also been placed on the joints to limit loads and motions in survival conditions (Department of Trade and Industry[2], 2003). Due to the limitations of capture a load factor of 0.2 will be used.

<u>Calculations for 2015</u>

Number of devices built per year x generating capacity

200 x 750 = 150 000 kW

Number of kW x Load factor x hours in a year

150000 x 0.2 x 8736 = 262 080 000 kWh

Number of kWh generated per year x number of years

262 080 000 x 5 = 1 310 400 000 kWh

Conversion to MWh/y-1

1 310 400 000 / 1000 = <u>1 310 400 MWh/y-1</u>

Conversion to PJ

(1 310 400 x 3.6) / $1\text{x}10^6$ = <u>4.72 PJ</u>

Box 1: Shows the method used to calculate the number of PJ generated by offshore wave energy in 2015.

In 2015 offshore wave power will be generating 4.72 PJ. Due to the scale of building, the number of devices will double every five years. Due to this the number of Peta Joules that are generated will also double.

YEAR	PJ Generation
2010	0 PJ
2015	4.72 PJ
2020	9.43 PJ
2025	14.15 PJ
2030	20.75 PJ

Table 1: Shows the Predicted PJ generation of offshore wave devices from 2010 to 2030. The Calculation in Box 1 was used to work out the figures.

What percentage of the UK's energy demand will wave contribute?

The energy consumption for the UK is **10500 PJ** per year.

With Offshore Wave power producing **20.75 PJ**

(20.75 / 10500) x 100 = 0.2 %

Wave power will therefore be able to contribute
0.2%
of the UK's energy demand

Box 2: Calculation showing the percentage of the UK's energy demand that wave contributes.

This result shows that offshore wave energy is not developing fast enough to provide significant amounts of electricity to the UK in the short term.

Onshore Wave Technology

Again these devices such as the limpet are not likely to be fully commercial until after 2010. Due to this the prediction would be 0PJ.

As mentioned above a constraint for shoreline technologies is location, the main location will therefore be along the Scottish coast. Devices can not be built along the entire length of the coast line as this is inappropriate. Some areas may be unsuitable due to the average wave power values being to low. Issues such as tourism and habitat protection must also be considered when sighting a device. Due to this I have just calculated the maximum number of devices that can be built in this location up until 2030.

Calculation of the Maximum number of devices that can be built.

Scottish coastline length: 16,491 km
Spacing of devices 1 device per 1 km
To fill every km - maximum number of devices is 16, 491.
~10% of coastline is probably optimal.

This is equal to **1649 devices**

Box 3: Show the calculation of the maximum number of devices that could be built along the Scottish Coastline.

This, however, does not show the number that can be built by 2030. As shore based devices had to be built and installed individually unlike offshore devices, which can be built in larger numbers and then towed out to sea to be installed, the build rate will be lower.

<u>Generation of Shoreline Wave in 2030</u>

Build scale of around 30 per year
This would take up 30 km/y-1
(as 1 device per km as shown in Box 3)

30 devices built every year for 20 years
600 devices

600 x 500
=300000 kW / 1000
=300 MW

300 x 0.2 x 8736
= 524 160 MW
1.89 PJ

This works out at
0.02%
of the UK's demand

Box 4: Shows the amount of energy generated by shoreline wave devices in PJ in 2030. It also shows the contribution this will have to the UK's energy demand.

Together:

Together the Shoreline and the offshore technologies will prove the UK with 22.64 PJ of electricity. This works out to be 0.22% of the UK's current energy demand. Wave technology unlike wind is still very much under development. Wave seems to have potential in the long term if not now. If the development of 1 MW devices were achieved and costs were to become lower and able to compete with fossil fuels it may have great potential in the long term.

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