4. Wave

Wave energy technologies are designed to extract energy from the energy contained in the movement of waves.

4.1. History and Development

Intensive research into wave energy began in the 1970s when the oil crisis promoted an increased interest in renewable energy. A wide variety of wave energy devices were proposed and developed at this time, but the success was in general far below the expectations. In many cases, the destructive forces of the ocean waves were largely underestimated, and premature power conversion devices have not always shown satisfactory results. As a consequence, when the energy-crisis came to an end, interest in wave power diminished and the early 1980s saw many of the trials discontinued.

The research which did continue led to the installation of shoreline prototype devices from the mid 1980s. The evolution of the technologies remained slow until early in the new century, following the new drive for renewable energy. Wave energy Research and Technology Development (RTD) has experienced a significant revival since 2000, as a consequence of the European-wide quest for a substantial increase in renewable energy production. The success of the wind energy sector has certainly contributed to allow for new bid into ocean wave energy conversion.

Distinct technologies have been developed for shoreline, near-shore and offshore applications, the latter being the focus of many new devices being tested, due to the higher energy levels in deeper waters offshore.

According to the characteristics of their deployment sites, wave energy technologies are frequently divided into shoreline (or coastal), near-shore and offshore devices. The physical conditions (e.g. water depth, power level, directionality, and hydrodynamics) relevant for wave energy conversion are different according to the water depth and distance from shore. The waves travel in deep water almost without energy loss across the ocean, which is why floating technologies moored in deep water are expected to have the largest potential for large-scale implementation. Typical water depths for offshore technologies are in the range of 50m. In shallower water, the waves suffer increasingly from bottom friction, making such sites less interesting from an energetic viewpoint. However as these are closer to shore ('near-shore'), mooring and grid connection costs decrease, and in some cases bottom-standing devices can be viable. Finally shoreline devices, which are typically integrated in the shoreline or into an artificial coastal defence structure, have lower incident power levels available but facilitated access and different structural solutions.

4.1.1. Level 2

The most investigated and frequently installed technology to date is the oscillating water column (OWC). Full sized OWC prototypes with installed capacity in the range of several tens to hundreds of kilowatts (kW) were built and tested under real sea conditions in Norway (Toftestallen, 1985), Japan (Sanze, Niigata, Kujukuri, Sakata, ~1985-90), India (Vizhinjam, ~1990), Portugal (Pico/Azores, 1999), and the UK (Islay, 1986; LIMPET, 2000, Islay island, Scotland).

It would seem that the Pelamis device is the offshore wave energy technology that is closest to park-scale deployment. It has been developed and commercialised by Pelamis Wave Power Ltd (based in Scotland, and p0reviously known as Ocean Power Delivery Ltd), and was designed with the priority of survivability and of using off-the-shelf technology. A prototype was tested in 2004/2005 (Orkney, UK) and since 2006, a small park deployment (i.e. 3 devices) in northern Portugal has been in progress, under a commercial agreement with the renewable energy project developer Enersis.

The AWS is another example for the “new” generation of wave energy technologies. The device was invented and developed by the Dutch company Teamwork Technology since the mid nineties and is now promoted by the Scottish enterprise AWS Ocean Ltd.

Among other technologies at advanced development stage are the Wave Dragon, WaveBob, AquaBuoy, OE Buoy, Powerbuoy, FO3 and Wavestar.The Wave Dragon differs from other wave energy devices with respect to hydrodynamic conversion philosophy and dimensions. The device - developed and managed by Wave Dragon ApS/Denmark - basically consists of a large floating basin that accumulates water level above the mean sea level by wave overtopping into the device. Also in this undertaking, a priority has been the use of off-the-shelf technology and a professional approach to gradually upgrading the experience from reduced-scale operational experience (Nissum Bredning/Denmark) to the presently ongoing pre-commercial demonstrator project in Wales with a rated capacity of 5-7MW.

Other developments that have recently reached the stage of real sea testing are typically of the floating point absorber type, for example the OPT Power Buoy (Ocean Power Technologies, USA/UK), the WaveBob (Wave Bob Ltd, Ireland), the Aquabuoy (Finavera Ltd, Ireland), and the OE Buoy (Ocean Energy Ltd, Ireland) (which is a floating OWC of the Backward Bent Duct type).

Further, platform-based arrangements of small point absorber floats have been tested on larger scale, as e.g. the FO3 (Fred Olsen, Norway) and the Wavestar (Denmark).

More than other renewable energy technologies, wave energy technology is perceived as being unreliable, cost-intensive and unrealistic for large-scale contribution. The main factor for this image is certainly the lack of preparedness of the developing teams for the demanding offshore environment. The diversity of concepts and the need of extremely cost-efficient power-take-off (PTO) mechanisms that are subject to occasionally very high extreme loads (i.e. high loads that occur only in extremely rare events) and many operational cycles (a wave energy device is typically driven by cyclic linear movements every few seconds, according to the wave period), does not allow for matches with other technologies. While many material and survivability issues for wave energy technologies are similar to the offshore oil and gas industry, the application of existing solutions results in prohibitive expenses. Renewable energy technologies are much less revenue intensive than fossil fuels, which is why mostly new methodologies and alternative materials seem to be the only option.

This aspect has substantially delayed development, and contributed to the caution with which strong industrial players handle their potential involvement.

Offshore devices – oscillating bodies, floating or fully submerged, can exploit the more powerful seas in deep water and several are at the stage of testing at sea, or have already concluded relevant tests. It can be expected that at least two or three of the several technologies that have achieved some proof of concept at prototype stage and are at a sufficiently commercial setting at present, will be relevant for large-scale deployment in near future. An exclusive “winner” as was the case in wind energy, is not necessarily expected, due to site and demand variability, as well as diverse simultaneous regional efforts to bring forward certain concepts.

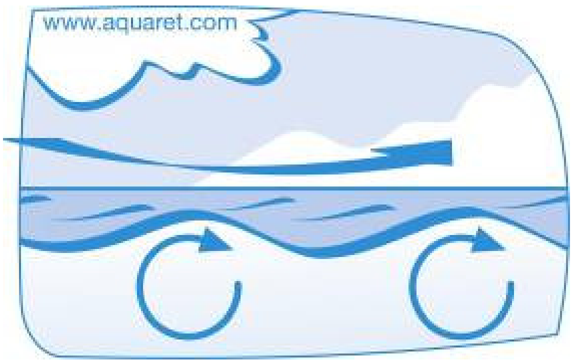
While the first wave farm consisting of three Pelamis devices is already in the installation phase (as of 2006) and has prospects of growing to 30 devices in the near term, other buoy systems also appear to be on the way towards commercial-scale deployment. Among them are:

- The AquaBuOY which originated from a combination of the Swedish hose pump and the classical point absorber, and is being developed by a subsidiary of Finavera Renewables Ltd
- The OPT Powerbuoy – promoted by the US/UK Company Ocean Power Technology
- The Wavebob, developed by the company of the same name, Wavebob (Ireland)

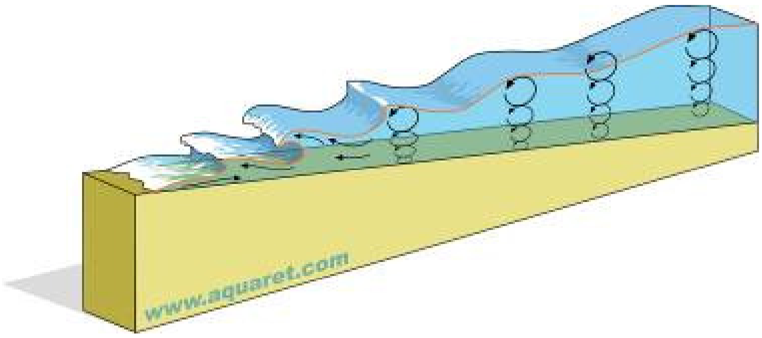
Due to its characteristics, testing period and size (allowing for economies of scale in the early phase of development), the Wave Dragon may be another candidate for being among the first large-scale contributors of wave energy conversion.

4.2. Energy Source and Location

Waves are formed by winds blowing over water, and will occur only in water near the surface of the sea. The size of the waves generated will depend upon the wind speed, its duration, and the distance of water over which it blows (i.e. the fetch). The resultant movement of water carries kinetic energy which can be harnessed by wave energy devices. The physical parameters describing waves are height and period (and/or length). The wave period/length is directly proportional to its propagation speed. In a large basin like the Atlantic Ocean, waves from different origins superimpose and form wave groups in which they cross the ocean with almost no energy losses.



The best wave resources occur in areas where strong winds have travelled over long distances. For this reason, the best wave resources in Europe occur along the western coasts which lie at the end of a long fetch (e.g. the Atlantic Ocean). Nearer the coastline, wave energy decreases due to friction with the seabed; therefore waves in deeper well exposed waters offshore will have the greatest energy.



As wave energy devices typically work with resonance that responds to the wave period, more regular wave patterns (i.e. almost equal and repeating periods over a long time span) mean a better wave energy conversion than with irregular sea states.

The power density (i.e. available resource per unit area, e.g. 40 kW/m^2) of waves is 10 times higher than wind energy, and 100 times higher than solar radiation, which shows the undeniable energetic potential of ocean waves.

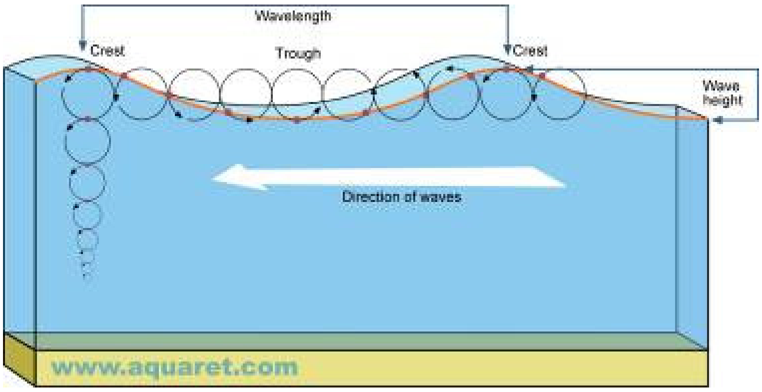
4.2.1. Level 2

The first and most obvious factor for wave energy implementation is naturally the resource, which is closely linked to the orientation of the coastline towards the open sea, and its latitude. The energy can be exploited on an economically viable basis when levels are greater than 15~20 kW/m (i.e. the common measure for wave power levels is the average annual power per metre of wave crest width parallel to the shoreline). The energy of a real sea state is measured by statistical properties of the waves; namely, their height and period. The common parameter to express representative wave height of a real, irregular sea state is the significant wave height, Hs. This value is the average height of the highest third of waves during a certain period, typically 30 minutes, and corresponds roughly to what experienced sailors would estimate. Together with the peak-period (T) or energy period (Te), the average energy of a certain sea state characterised by Hs and Tp or Te, is usually estimated by the formula:

E = 1/8 ρg Hs

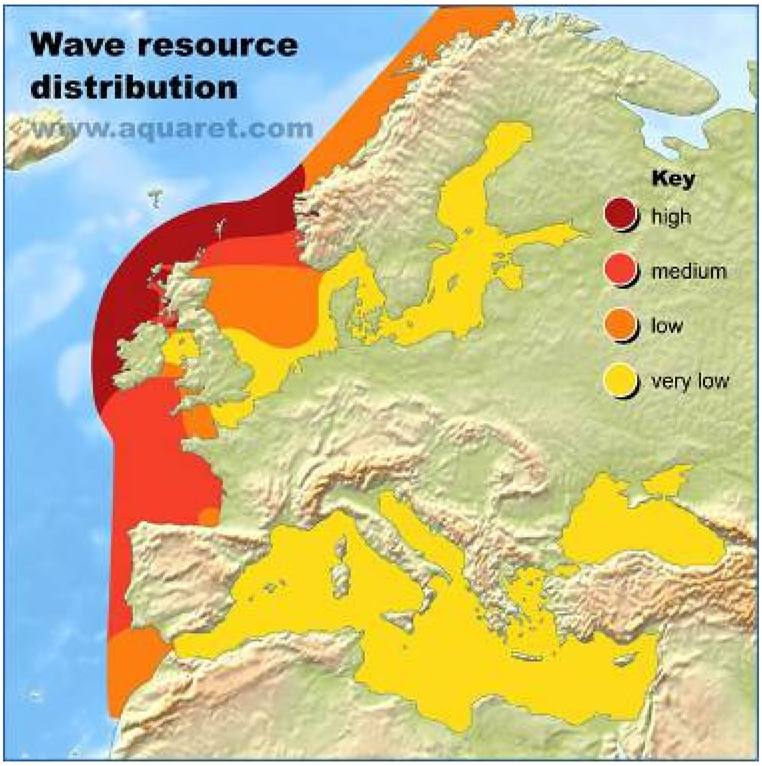
(E = energy averaged over specific time interval; ρ = sea water density; g = gravitational constant; Hs = significant wave height)

In order to estimate the wave power level of a certain area, the annual mean value of all sea states (P---) is taken. This is an important factor, as the seasonal variability can be very high.



4.2.2. European Resource Map

The map below indicates the level of resource across Europe.



There are two latitudes where original wave energy resource is the highest. Depending on the coastline's orientation towards the open ocean and the latitude, certain countries are well suited for ocean wave energy conversion, while others almost have no potential in the initial phase.

Countries best suited for ocean wave energy conversion are Great Britain, Ireland and Norway, New Zealand and Southern Australia and Chile, followed by Northern Spain, France and Portugal, and the North American and South American coasts and South Africa.

Depending on orientation of coastline, and in particular for islands), and main sea states (i.e. weather phenomena at origin of waves), the waves may reach the target area under different conditions. On western European coastlines, in particular in Portugal, Spain, and France, the summer months (i.e. June-September, but in particular July-August) may be extremely poor in wave resource. Apart from being important for the comparability of general wave power levels between different regions, the annual average power can be misleading, if not interpreted together with its seasonal variability. Annual averages can be based on high power levels, which cannot be used but may have destructive forces, during short time intervals, and long intervals with almost no exploitable resource. It is essential that this periodicity does not mismatch the regional electricity demand, if wave power is to be a major contributor to the electricity feed-in of that region.

A decisive factor for the suitability of a coastline is also its bathymetric properties (i.e. the inclination and shape of its bottom). As opposed to offshore wind, wave energy technologies do in general not represent a visual impact for the coastline, which makes it preferable to install the farms as close as possible to the coastline. This will mean that cable and installation costs can be reduced significantly, while supervision and maintenance can be done more efficiently. The most appropriate depth range for wave energy devices is 50m, taking into consideration a trade-off of available energy and mooring expenses, as well as distance to land.

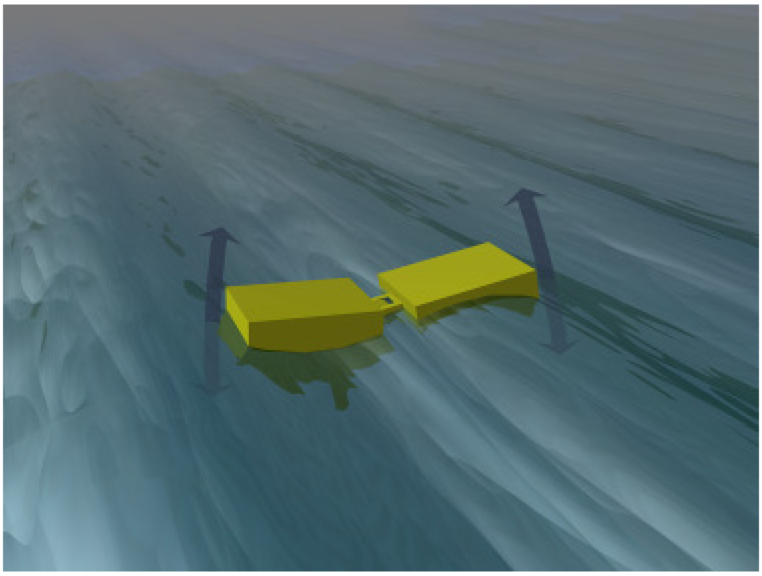
Regions with a sharp bathymetry (i.e. steep continental shelf, with deep water close to coast), for example Portugal, are advantageous for wave energy deployment. The seabed conditions are not the most critical aspect, as most technologies are floating. For cable passage towards land, generally sandy bottoms are preferable. With respect to conditions on land, it is important that the land station and/or the substation providing the interface to the on-land grid, are as close to the generation units, and that, if further inland, soil and topography allow cable laying at reasonable costs. It is realistic to expect that other infrastructural needs will be an important geographic factor for the implementation of this technology branch. In some areas, the need for building a domestic industry will drive the development, while in other regions, the existence of complementary industries (e.g. shipbuilding, steel construction, offshore business, maritime civil contractors, etc.) will substantially support the development of a wave energy industry.

In large-scale projects, the major obstacle will be the capacity and availability of transmission grid. This is because favourable wave energy resources can be in areas with relatively weak grid, even within Europe. The future for large-scale implementation of wave energy will be in part determined by the extent to which maritime renewable energy sources are a priority on a trans-national level. It will not be sufficient to succeed in technology development and in single national initiatives to integrate large-scale marine renewable energy into the grid, but major investments on international level will have to be made into the grid structure, both on- and offshore, and between different countries (e.g. European Transnational Grid). The SUPERGRID proposal has been made by Airtricity, a utility company, suggesting establishing strong international grid backbones offshore, in order to plug in the several marine renewable energy farms to be deployed in the region. Although this proposal focused on offshore wind, massive wave energy exploitation might benefit similarly from such infrastructures. Obviously, due to the high technology development costs of offshore renewable energy, it will be impossible to incorporate such grid-related issues into the budgets of the technology developing sector, which is why this will require additional efforts.

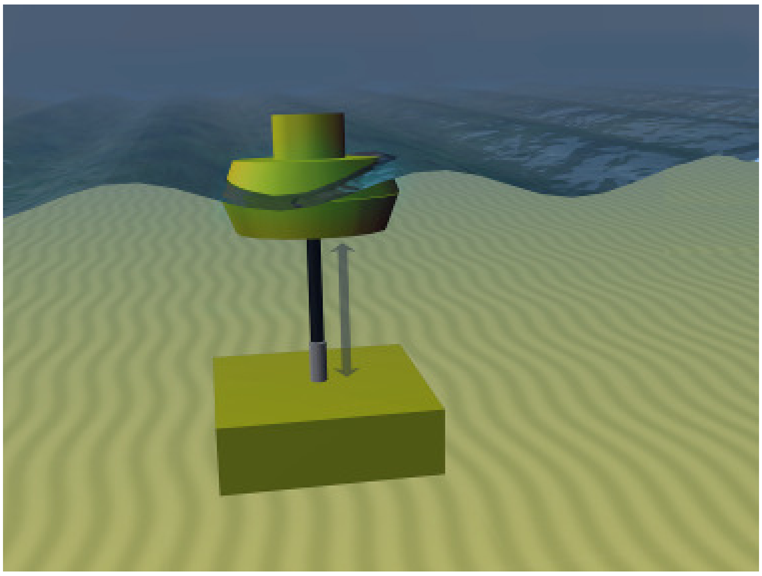
4.3. Technology Types

There are many designs being pursued by developers to harness the power of waves. Wave devices can be categorised according to the location and depth in which they are designed to operate, i.e. shoreline, near shore or offshore; or by the method used to capture the wave power. Here, the latter method has been used to categorise the devices as follows:

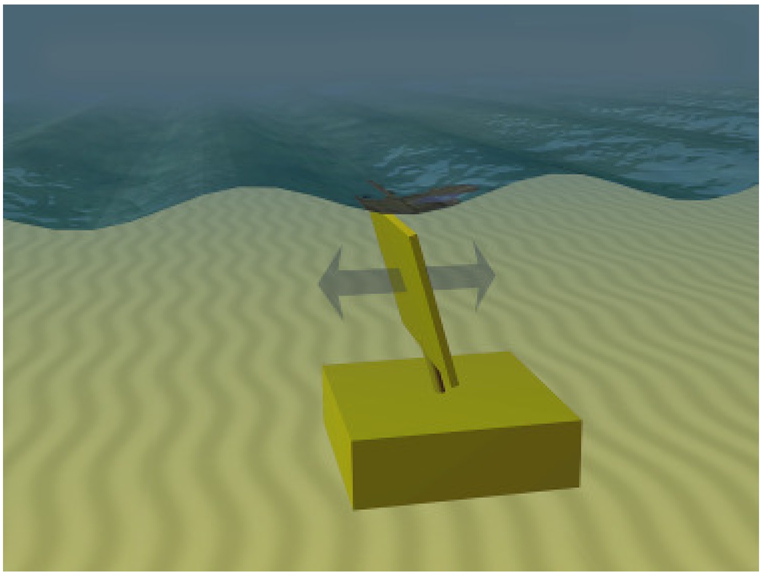
Attenuator – This is a long floating device which is aligned perpendicular to the wave front. The device effectively rides the waves and captures the energy as the wave moves past by selectively constraining the movements along its length. A current example for the attenuator is the Pelamis device, earlier concepts were the McCabe Wave Pump (sea trials) and the Cockerel Raft (concept stage).



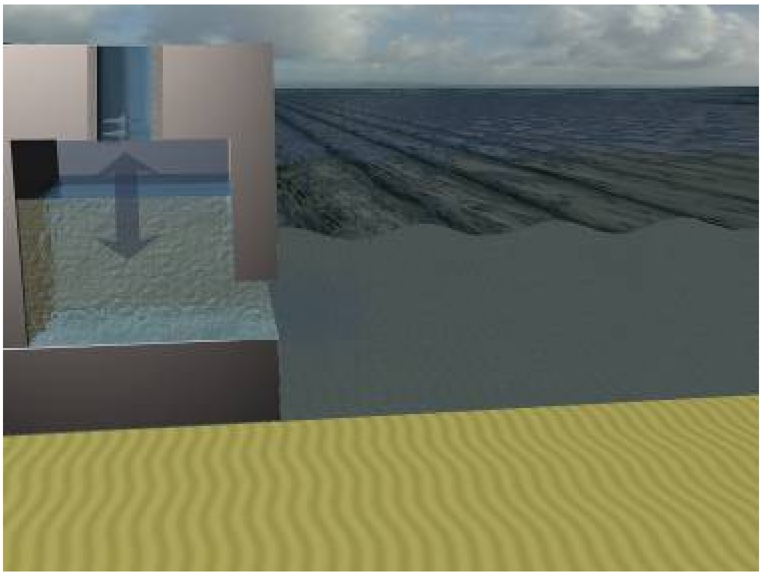
(**Axisymmetrical) Point Absorber** – This is a floating structure that absorbs wave energy in all directions by virtue of its movements at or near the water surface. It has small dimensions compared to the typical wavelength, tending to have diameters of a few meters. The point absorbing characteristic basically means the capacity to absorb energy from the sea area larger than the device dimensions. In reference to the fundamentally same effect in radio (i.e. acoustic) waves, this effect is also called antenna effect. Buoy type designs, for example, act as point absorbers. Typically, but not necessarily, such buoys are axisymmetric. Current examples for this category are the Wavebob, the OPT PowerBuoy and the Aquabuoy. An example for non-axisymmetric point absorber, however with very similar characteristics, is the SeaREV. OWC buoys (OEBuoy, Sperboy, MRC) also have point absorbing characteristics, however they are usually considered under the OWC category.



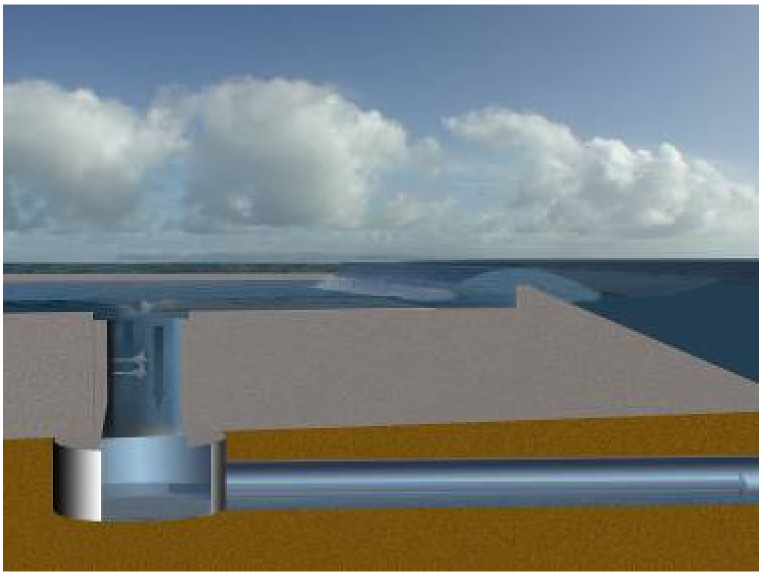
Oscillating Wave Surge Converters (OWSC) – This is a near-surface collector, mounted on an arm pivoted near the seabed. The arm oscillates as an inverted pendulum due to the movement of the water particles in the waves. Current examples for this category are the completely submerged Waveroller and the surface-piercing Oyster. An earlier device of this type, the Japanese Pendulum, had the flap hinged near the surface, hanging downwards, inserted into the caisson structure.



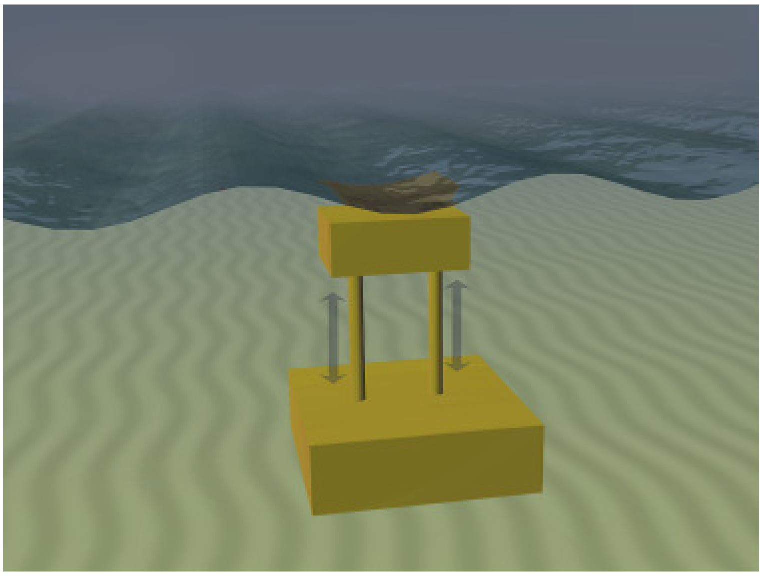
Oscillating Water Column (OWC) – This is a partially submerged, hollow structure, which is open to the sea below the water surface so that it contains air trapped above a column of water. Waves cause the column to rise and fall, acting like a piston, compressing and decompressing the air. This air is channelled through an air turbine to produce power. When properly designed for the prevailing sea state, OWCs can be tuned to the incident wave period in order to resonate. By this means, OWC can actually be quite efficient and present point absorbing characteristics. A particular case of this category is the OWC buoy, which is a floating OWC. Among the currently proposed devices are the Sperboy, the MRC, and the Backward Bent duct type OE Buoy. Classical OWCs are shoreline devices either built directly into the shoreline (Pico OWC, Limpet OWC) or integrated in breakwaters (Mutriko OWC).



Overtopping Device – This consists of a wall over which the waves wash, collecting the water in a storage reservoir. The incoming waves create a head of water, which is released back to the sea through conventional low-head turbines installed at the bottom of the reservoir. An overtopping device may use collectors to concentrate the wave energy. Overtopping devices are typically large structures due to the space requirement for the reservoir, which needs to have a minimum storage capacity. The devices can be floating like the Wave Dragon, currently largest wave energy converter being developed, or fixed, land-based structures, like the SSG (Sea Wave Slot Cone Generator, integrated into a breakwater). An early example for overtopping devices was the TAPChan device in Toftestallen/Norway, where a tapered channel provoked wave overtopping into a reservoir on land.



Submerged Pressure Differential – This is a submerged device typically located near shore and attached to the seabed. The motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential which causes the device to rise and fall with the waves. When properly designed for the sea state, this category also has significant point absorbing characteristics. A well-recognised example for the realisation of this concept to date is the AWS (Archimedes Wave Swing), which also has good point absorbing characteristics. Another device that can be considered under this category is the Waverotor.



There are several categories of wave energy devices by power capture mechanisms, and distinctions are rare. Often, there are only three fundamentally different categories considered, namely OWC, overtopping device, and bodies with wave-induced (relative) motion. Typically, all devices except the overtopping type also have point absorbing characteristics. Point absorption is the ability to absorb power from a larger area than the physical dimension of the device – also known as the antenna effect. There is no common categorisation widely accepted within the international research and technology development (RTD) community, due to different aims. The list above was made with the aim of distinguishing the concepts which are currently the most popular, on basis of their operational principle.

4.3.1. Level 2

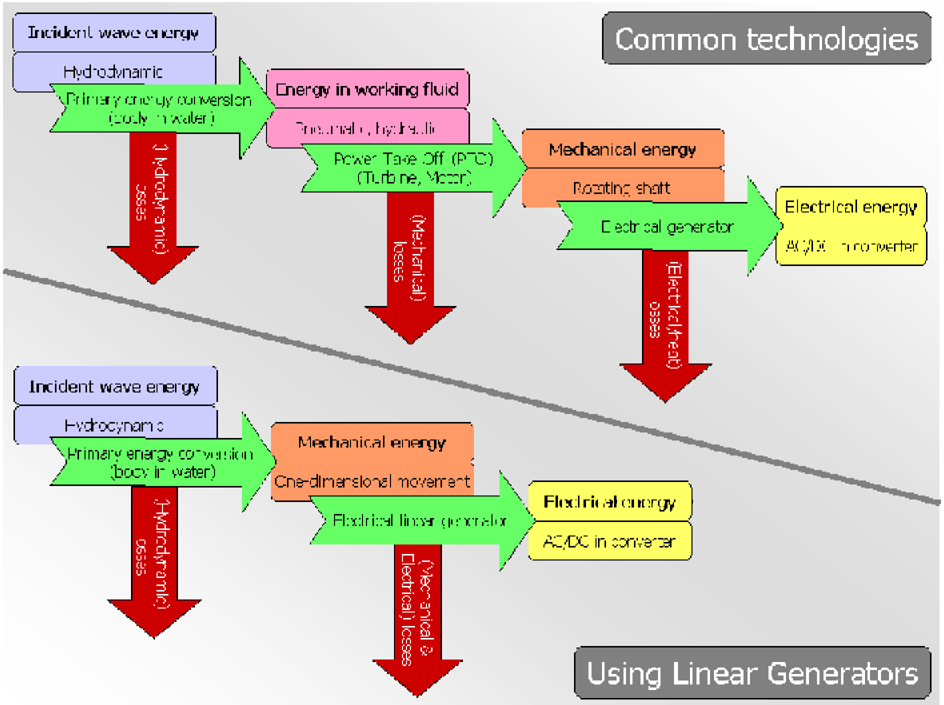
It is unnecessary to provide details of power conversion for each wave energy device at this stage, for two reasons:

The 6 device categories mentioned above may have typical power take off (PTO) options like the overtopping device (water turbines) or the OWC (air turbines), but they may also be suitable for various PTO options.

There are generally 4 types of PTO suitable for wave energy devices, namely the water turbine, the air turbine, the hydraulic motor/generator and the linear generator.

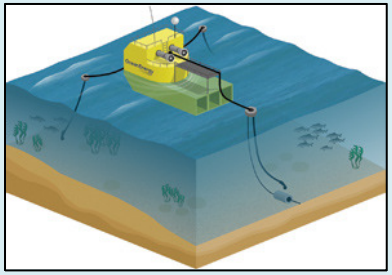
In order to outline the most important aspects of the “wave-to-wire” chain, it is unnecessary to highlight differences between these 4 mechanisms. The horizontal and/or vertical motion of the ocean waves is converted to electricity, typically via relative motion between bodies, but also by other means, for example, air pressure variation (OWC devices) or potential energy accumulation (overtopping devices). Relative motion typically drives high-pressure fluids through hydraulic motors, while pressure variation or potential energy accumulation is converted to electricity via a turbine-generator set. Oscillating bodies with hydraulic PTO (power-take-off) are expected to be the most significant contributors to the wave energy generation. However, there are reasons to assume that in the long-term, other mechanisms can gain relevance as well.

A generic scheme of the wave-to-wire chain is presented below:



The following device list highlights a selection of proposed devices and PTO mechanisms. NB. This list is a limited selection of proposed devices. It does not reflect the credibility, or the opinion, that other devices have less potential. This list includes all those mentioned in Level 1 of Technology Types).

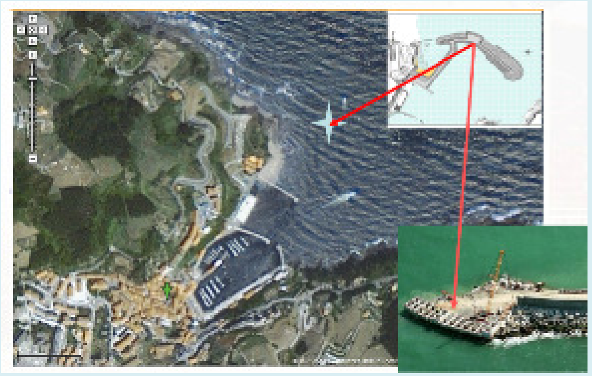
Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
OFFSHORE TECHNOLOGIES:		
AquaBuOY *Finavera Renewables* finavera.com/en/wave Ireland	Offshore; Point Absorber *Integrates 2 technologies originally from Sweden (IPS Buoy and Hosepump)*	 The 'AquaBuOY' point absorber integrates aspects of two previous device designs (the IPS Offshore Wave Energy Converter (OWEC) and the Hosepump) both of Sweden. The device comprises a slack-moored float (buoy) and a submerged vertical tube, which is open to sea at both its top and bottom. Incident waves cause the device to heave up and down creating a damping force that acts on a piston attached to two hose pumps, which contract and expand to provide a pumping effect. The hose pumps and separate water masses contained within them react against the heaving motion and convert the oscillatory motion into a high-pressure water flow to drive a turbine and generator.
AWS (Archimedes Wave Swing) *AWS Ocean Energy Ltd (invented and developed towards pilot plant by Teamwork Technology)* www.awsocean.com UK (Scotland) *(originally Netherlands)*	Offshore; Submerged pressure differential	 The AWS (Archimedes Wave Swing) consists of a large air-filled cylinder which is submerged beneath the waves. As a wave crest approaches, the water pressure on the top of the cylinder increases and the upper part or 'floater' compresses the air within the cylinder to balance the pressures. The reverse happens as the wave trough passes and the cylinder expands. The relative movement between the floater and the fixed lower part or basement is converted directly to electricity by means of an innovative hydraulic system; in the pilot plant in Portugal, 2004, a linear generator was successfully tested. Variable frequency output is converted to utility grade power using an IGBT converter.

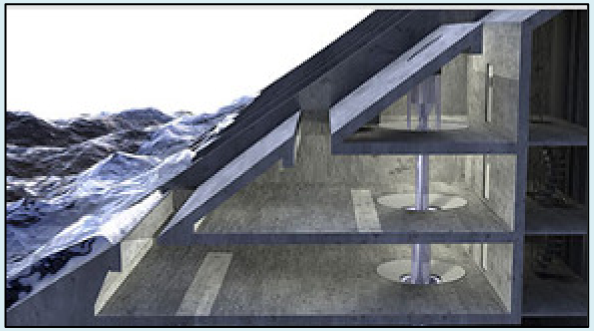
Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
FO3 *Fobox AS* No website Norway	Offshore	 The FO3 has 21 point absorbers mounted in vertical hydraulic cylinders which work in both directions. The vertical movements of the floating point absorbers will be transformed to hydraulic pressure. The hydraulic pressure is used to generate power by generators and numerical calculations.
OE Buoy (Ocean Energy Buoy) *Ocean Energy Ltd.* www.oceanenergy.ie Ireland	Offshore; Oscillating water column	 The OE Buoy is an oscillating water column device, where the air in the chamber is pumped out and drawn in through the turbine duct by the movement of the water free surface within the device. Motions of the hull enhance the relative surface movement and increase the air flow. The power take-off system is an air turbine which converts the flowing air into rotational energy which drives the generator. All of the power take-off is above the waterline and not in direct contact with the seawater.
Pelamis *Pelamis Wave Power Ltd* www.pelamiswave.com UK (Scotland)	Offshore; Attenuator	 The Pelamis Wave Energy Converter 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 rams, which pump high-pressure oil through hydraulic motors. The hydraulic motors drive electrical generators to produce electricity. The Pelamis is designed to be flexibly moored in waters approximately 50-70m in depth.

Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
PowerBuoyTM *Ocean Power Technologies Inc. (OPT)* www.oceanpowertechnologies.com/ USA	Offshore; Point Absorber	 The PowerBuoy is a free-floating point absorber wave energy converter that is loosely moored to the seabed; the buoy's float moves up and down on the central spar as the waves pass. This mechanical movement drives a hydraulic pump that forces hydraulic fluid through a rotary motor connected to an electrical generator.
SperBOY *Embley Energy* www.sperboy.com UK (Cornwall)	Offshore; Point Absorber	 The Sperboy is a floating buoy Oscillating Water Column (OWC) device consisting of a buoyant structure with a submerged & enclosed column. Housed above the OWC on top of the buoy is all the plant, turbines, generators and associated system facilities. The principle of operation is similar to that of fixed OWC's designed for shoreline and fixed installations. Except that a) the device is capable of deployment in deep water to maximize greatest energy source and, b) the entire body floats and maintains optimum hydrodynamic interactions for the prevailing and changing wave spectrum producing high energy capture at minimal cost.

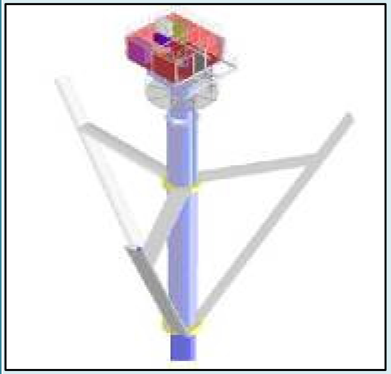
Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
Wave Dragon *Wave Dragon Aps* www.wavedragon.net Denmark	Offshore; Overtopping device	 The Wave Dragon is a slack-moored, overtopping wave energy converter. Two curved arms focus waves onto a central ramp which the waves travel up and 'overtop' into a reservoir. At the bottom of the reservoir is a set of low-head hydro turbines, through which the collected water flows back out to sea. The reservoir has a smoothing effect on the water flow, and the turbines are coupled directly to variable speed generators. Since the head of water in the reservoir accounts for the energy, the concept is similar to a hydroelectric power plant.
Wavebob *Wavebob Ltd.* www.wavebob.com Ireland	Offshore; Point Absorber	 Wavebob is a freely floating axi-symmetric point absorber capable of resonating across any pre-determined range of wave frequencies and band widths. It may then be tuned to the prevailing wave climate using a proprietary system to change the device's natural resonance frequencies without changing draught. This may be set seasonally or much more frequently as may be justified economically. The instantaneous response of the Wavebob is adjusted rapidly and in real time (during each wave) via the hydraulic PTO by an on-board autonomous control system so that useful power output is maximised.

Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
COASTAL & NEARSHORE TECHNOLOGIES		
Energetech OWC *Oceanlinx* www.oceanlinx.com/ Australia	Coastal/near shore Oscillating Water Column	 The Energetech OWC device is a near-shore bottom-standing oscillating water column rated 500 kW, developed by the Australian start-up company Energetech. The device has two particularities, namely the especially developed Denniss-Ault turbine and the structure that was made entirely of steel, including the parabolic-shaped steel arms forming a harbor for tuning the device better to incident waves. The device was placed on the sea bottom in front of the breakwater of Port Kembla, Eastern Australia, where a reef prevents high extreme loads due to wave impacts. The company was re-named into Oxeanlinx and is presently working on the development of an offshore version, apparently resembling a tension-leg platform principle.
LIMPET OWC *Wavegen Ltd (owned by Voith Siemens,)* www.wavegen.co.uk UK	Onshore; Oscillating water column	 The LIMPET OWC is a 250kW onshore oscillating water column device, which was developed as a follow-up for the successful Islay plant at the same location. LIMPET was installed between 1998 and 2000 on the Isle of Islay off the west coast of Scotland. It was initially designed for 2*250kW=500kW. An interesting lesson learnt for OWC operation in general was that in the beginning of operation, the developers were obliged to introduce a sound muffler, as nearby population complained about the noise.

Device Name, Lead Organisation , Website, Country	**Technology Type**	**Brief Description and picture**
Mutriku Breakwater MOWC *EVE (Ente Vasco de la Energia)* www.fedarene.org/publications/Projects/NEREIDA/NEREIDA - 1st e-Newsletter/Nereida - e-Newsletter 1.htm Spain (Bask Country)	Coastal/near shore Multi Oscillating Water Column	 The MOWC project wants to demonstrate the successful incorporation of OWC technology with Wells turbine power take-off into a newly constructed rubble mound breakwater in Mutriku, in the North coast of Spain.
Pico OWC *Wave Energy Centre* www.pico-owc.net Portugal (Azores)	Coastal Oscillating Water Column	 The PICO OWC is a European Pilot Plant based in the oscillating water column principle. The Pico Plant is located in the Pico island, Azores, Portugal. Its construction was concluded in 1999. This plant consists of a hollow reinforced concrete structure – a pneumatic chamber - above the water free surface that communicates with the sea and the incident waves by a submerged opening in its front wall, and with the atmosphere by a fiber duct with a Wells turbine. Up-and down- movement of water column inside chamber makes air flow to and from the atmosphere. The turbine is symmetric and is driven indifferently in which direction the air flows.

Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
SSG *Waveenergy AS* www.waveenergy.no Norway	Coastal or near-shore Overtopping Device	 The SSG (sea Slot-cone Generator) is an overtopping wave energy converter. It consists of three reservoirs on top of each other where the overtopping water from the incoming waves is temporarily stored at a higher level than the sea water level. The potential power of the water in the reservoirs is then transformed in electricity by low-head turbines.
Wave Star *Wave Star Energy* www.wavestarenergy.dk Denmark	Near-shore; multi- Point Absorber	 Wave Star Energy's wave machine is a so-called multi point absorber. That means a machine equipped with a number of floats which are moved by the waves to activate cylinders, which press oil into a common transmission system, the pressure of which drives a hydraulic motor. The motor, in turn, drives the generator of the wave machine. In the event of a storm the floats are lifted to a safe position – on the large-scale machine they will hang 20 metres above the surface. A sensor on the seabed ahead of the machine measures the waves and ensures that the storm security system is automatically activated. The machine can be remotely controlled via the Internet (VPN connection).

Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
Oyster *Aquamarine .* www.aquamarinepower.com Northern Ireland	Near shore; Oscillating Wave Surge Converter	 Oyster is a near-shore bottom-mounted device designed to interact efficiently with the dominant surge forces in shallow water waves. The principle consists of an oscillating module fixed to the seabed in depths of 12m at the mean water level. The module extracts the energy from passing waves and transmits it as seawater hydraulic power to a hydro-electric power conversion unit, located onshore.
Waveroller *AW Energy Oy.* www.aw-energy.com Finland	Near shore; Oscillating Wave Surge Converter	 A WaveRoller device is a plate anchored on the sea bottom by its lower part. The back and forth movement of bottom waves moves the plate, and the kinetic energy produced is collected by a piston pump. This energy can be converted to electricity either by a generator linked to the WaveRoller unit, or by a closed hydraulic system in combination with a generator/hydraulic motor system. A WaveRoller plant is composed by a number of production modules. Each production module consists of 3 wave elements.

Device Name, Lead Organisation , Website, Country	Technology Type	Brief Description and picture
Waverotor *Ecofys.* www.ecofys.nl Denmark	Submerged Pressure Differential	 The Wave Rotor captures wave energy from the circulating water particles in the waves and also tidal currents. The circular currents can directly drive the rotor. The waves turn the rotor with sufficient torque for power to be taken off by a conventional generator coupled via a gearbox to the vertical shaft. This requires the waves to exert forces on the blades and the combination of blades shown (both a Darrieus arrangement and blades perpendicular to the shaft) is intended to optimise these forces. The power is transferred to the rotating shaft directly, albeit at slow speed. Two types of rotors are combined: a Darrieus rotor and a Wells rotor. These are respectively omni- and bi-directional rotors, which can operate in currents of changing directions.

4.4. Lifecycle

There are four lifecycle stages for a wave power scheme. Follow the links provided for the key factors and issues that need to be considered at each stage.

Stage 1 - Design & Planning

Stage 2 - Construction & Installation

Stage 3 - Operation & Management

Stage 4 – Decommissioning

4.4.1. Design and Planning

Offshore technologies:

The operation of several prototypes has lead to a basic design principle: consider first the survivability of the system, and next, the power-capture capability. Even more than operational reliability, survivability is the key challenge for marine renewable energy, and in particular for wave energy devices. By nature, wave energy devices are situated in regions of high incident wave power, which is normally related to rough sea states which has to be considered at design stage.

The absence of clear and reliable design procedures accounting for the harsh environment arising in such an environment makes it difficult to conduct wave energy projects with sufficient planning safety. In almost every case in the past, it was not the wave power extraction technology that failed, but unforeseen problems related to the construction process or the structural stability in extreme conditions. There are no common design procedures or standards yet, but several national and international committees, as well as certification bodies working on proposals for common design guidelines. The variety of systems makes such approaches complex and in some cases generic at the same time.

Coastal & nearshore technologies:

Coastal and near-shore technologies can be subject to harsh conditions because in the shallower water ranges, violent wave breaking can occur regularly. Shoreline devices in depths of 10m and/or breakwater-integrated plants are particularly subject to this situation. Breaking wave impacts can exert high pressure peaks of short duration, as coastal engineering experience has shown. This is why the front walls of wave energy caissons must be very carefully designed.

For coastal and near-shore devices, the aspect of frequent breaking wave loads maybe the most relevant obstacle to their economic viability. Although methods for estimating wave impact loads exist, and at least the order of magnitude can be reasonably estimated nowadays, it remains difficult to interpret the local structural requirements of the cellular walls, when for example a hollow OWC caisson or an overtopping caisson is subject to such loads.

Wave energy technologies have not yet collected sufficient operational data, which is one reason there are no official guidelines available for best practice in design to date.

Safe structural and mooring design is essential for sector credibility – accidents have destroyed devices in the past, due to the aggressive maritime environment, and inappropriate design of structural components, installation procedures or moorings.

Working offshore can also mean a total loss of a device and/or long periods of unavailability. Floating debris can be a shipping hazard, though in some cases the converters will simply sink, therefore not causing a threat to navigation. From an engineering perspective, the technical risks in design, construction, installation and operation can be addressed in two ways. Knowledge and experience from other industry sectors can be valuable, such as offshore oil and gas, including risk assessment procedures (e.g. Failure Modes and Effects Analysis) and engineering standards. Rigorous and extensive testing can also be helpful, including single components, sub-assemblies and complete functional prototypes. The latter will require dedicated test facilities, such as those established at EMEC and NaREC, and supply-chain manufacturers. A combination of the two approaches is likely to expedite development with lowest risks. It could take several years to develop technical evidence to levels comparable with other generation technologies and to satisfy investors and insurers.

In the case of submerged devices, this aspect is less critical; however the sediment transport and local near-shore currents may be critical aspects for the device design.

4.4.1.1. Level 2

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4.4.2. Construction and Installation

It is expected that large-scale implementation will take place by deploying offshore submerged or floating devices at depths around 50-100 m, grouped in wave farms with specific configurations and dimensions to suit the type of technology. While typically the 50m bathymetry is the preferred target zone - due to the best trade-off between resources, length of subsea-cable and mooring expenses - it is expected that the implementation areas will soon extend towards the 100m bathymetry (i.e. the line of 100m water depth).

The mooring technology is normally adaptable to the sea-bottom conditions. For sandy and clay bottoms, suction anchors may be a favoured option. In rocky bottoms, on-site preparation works may be more costly and there may need to be substantial sub-sea drilling. Offshore wave energy devices will most often use slack mooring, allowing the device to orientate towards the waves and to give away in extreme waves, in order to reduce peak loads on the moorings.

Bottom-mounted wave energy devices require, in general, a level sea-bed of sand, gravel or mud. Near-shore devices need the sea-bed to be suitable for laying power cables to shore, with a low level of rock coverage. While near-shore devices will typically be mounted in ca. 20m water depth and can be subject to high waves (H=20m), coastal devices are likely to be installed in water depths of 10m or below. In the case of the OWC, 6-7m is the minimum depth to achieve reasonable performance; overtopping devices might be efficient in more shallow depths.

4.4.2.1. Level 2

Technology Scale and Deployment

Wave energy devices can be located on the shoreline, near-shore or offshore. Shoreline devices are generally single installations. Their size will depend upon the local topography, resources and power demand. A few near-shore and offshore devices are also designed to be large single installations, however most are modular designs which may be installed as single devices or as an array of several modules. Projects may have capacities in the range of a few hundred kilowatts, for small single installations, to several gigawatts, in multiple-module wave farms.

Weather conditions

The installation process will always require a window of time with few waves (i.e. typically Hs < 1.5m). Of importance is the lead-time for the wave climate prediction and its degree of reliability. In general, the approximate wave climate can be reasonably well predicted three to four days in advance on the open (central) Atlantic coastline. Further north, where local and regional weather phenomena can more strongly influence the wave climate, reliability may decrease. Experience has demonstrated the importance of this aspect, and the importance of finding rapid, efficient, and strong, methods of connecting devices to the moorings, which typically are prepared separately before the deployment (e.g. AWS and Pelamis have developed examples of sound procedures). In general, simple vessels or simple anchor handling/tugs suitable for deployment are used; no cranes or special offshore boats are needed. However, in the Pelamis pilot plant, an anchor handler was actually required, substantially increasing the costs and the predictability of schedules and expenses.

4.4.3. Operation and Management

Major maintenance interventions on an annual basis are likely. It is possible that the devices will be removed from the moorings for this. Minor inspections and maintenance actions are performed with rubber boats, remotely operated vehicles (ROVs – such devices are remote-controlled submarine vehicles used in offshore technology for inspection purposes and basic maintenance actions), or special small vessels docking to the plants in calm water. Maintenance will mainly be required on the mechanical and electrical equipment and on the structure; however grid connection and peripheral installations will also require attention, and should be taken into account.

Modular caisson construction of coastline devices will significantly enhance their stability and cost-effectiveness, but on-site works will still be required for sea-bed preparation and in the final construction stage. Maintenance intervals are expected to be similar to offshore devices, however the accessibility issues are much less critical, which makes shore-based devices suitable intermediate solutions for the initial phase of technology development.

4.4.3.1. Level 2

Operation and maintenance of wave energy plants has been a major point of discussion due to the lack of real sea experience and low-budget approaches that have not allowed for proper planning. Most of the issues can be solved with existing technology and equipment from offshore oil and gas technology. However, the means and procedures used in offshore technology are usually cost-intensive, as they were developed in the context of high revenue activities. This and price volatility due to demand variations of the offshore business make the application of these technologies to wave energy unrealistic even in the medium to long term, unless specific cost-efficient solutions are developed. The low revenue density (i.e. slow capital return, high investment costs) of wave energy plants will require new approaches and equipment, in order to compete in the longer term. The rapid acceleration of offshore wind development in the Baltic and North Sea countries (Denmark, UK, Sweden, Germany, and Netherlands) will have some implications for operations and maintenance procedures in the wave sector. Although the operational conditions and maintenance issues are not identical, offshore wind faces the same demand for dramatic improvements in this field, and significant synergy.

4.4.4. Decommissioning

Wave energy devices are typically designed for a lifetime of 20 years according to the device developers. However, on the basis of past experience and the fragility of approaches, this may not be realistic at this stage. Developers are aware that, for a device to be considered commercial, a 20 year lifetime must be guaranteed in order to make the capital-intensive structures and installations feasible. Pilot plants and early stage prototypes may last from several months to 3-5 years. This is a decision taken in order to test the concept and the PTO strategy first.

Depending on the device and the chosen PTO components, major overhauls may be required on an annual basis, often requiring the removal of the device from its moorings and its transport to the next harbour. This removability means that decommissioning of most offshore devices will not be an issue. They will normally be removed from the moorings with relatively little effort, and towed away to shore.

The moorings may be designed for longer life spans, in order to receive the next device. Depending on their design (e.g. concrete base using gravity, hook anchor, suction bucket/anchor) they might be removable with considerable efforts, or they might be considered lost anchors. In this latter case, multi-MW parks with several tens or hundreds of devices might challenge environmental acceptability, which is why removable mooring systems and understanding the impact of systems will be fundamental part of future research and monitoring activities.

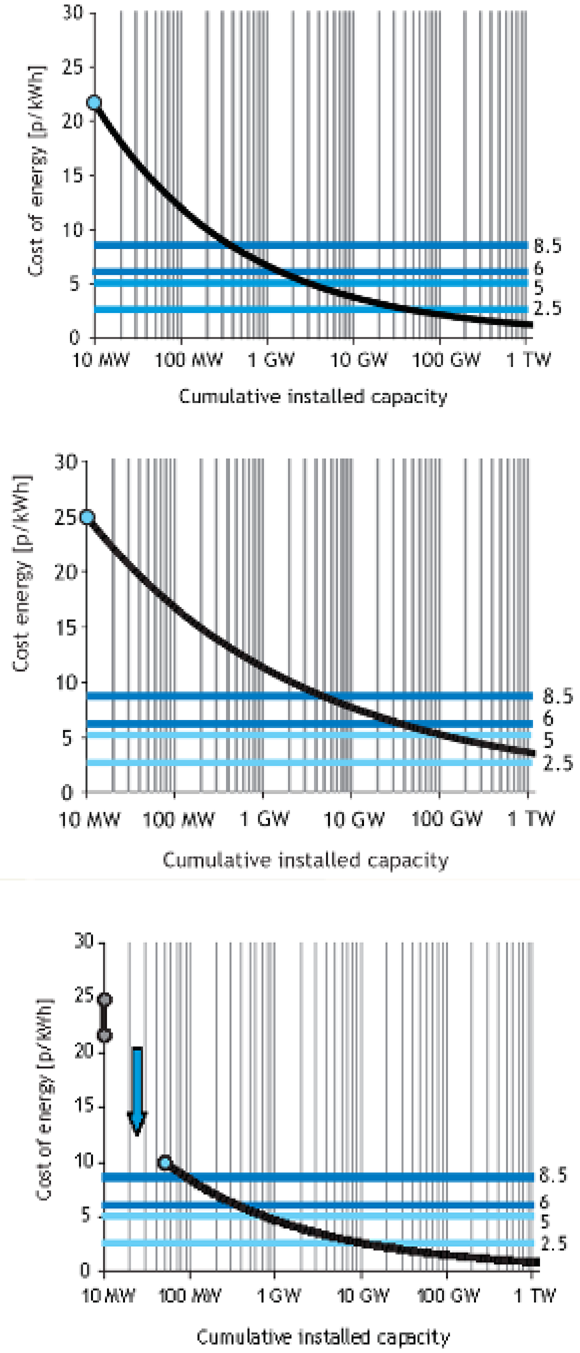
4.5. Economical Factors

In addition to a lack of credibility as a consequence of failures, the main reason for the lack of investment in wave energy is the high capital cost required for development, especially in the early technology phase. Although wind energy has shown how an initially subsidised technology can develop rapidly towards a sustainable industry, wave energy is still being developed on a low-profile basis.

The Carbon Trust (2006) has recently published a set of values (i.e. expected cost of energy; capital investment levels, expected timeline for installed power levels and related capital cost reduction with increasing maturity). This was done using an optimistic and a pessimistic scenario, plus an alternative scenario using a different baseline.

4.5.1. Level 2

The optimistic scenario (left) shows that the value of 12.75 c€/kWh (8.5 p/kWh) could be reached after installing the first 250 MW, whereas in the pessimistic scenario, this will happen in the range of 5 GW installed. The most attractive cost range is from 7.5 c€/kWh to 9.0 c€/kWh (i.e. comparable values to wind energy in the phase when it represents a sustainable industrial sector in Europe). They would be reached after 3 GW and 12 GW of installed power, for an optimistic and pessimistic scenario respectively. In the alternative third scenario, a substantial decrease of initial costs from 33-38 c€/kWh to 15 c€/kWh will be reached after the first 50 MW are installed. Under these circumstances, 9 c€/kWh could be reached after 400 MW has been installed, and 3,75 c€/kWh after 10 GW. These cost levels, measured in c€/kWh, represent the economic feasibility of a power generation technology, by comparing the total investment and operation and maintenance costs to the total produced electricity during the depreciation period of the installation.



Estimated wave energy costs in relation to installed power; a) optimistic estimates based on 33 c€/kWh of initial costs and 15% of learning tax (left); b) pessimistic estimative based on 38 c€/kWh of initial costs and 10% of learning rate (right); in both scenarios a returned tax between 15% (initial) and 8% (final) has been assumed. Source: Carbon Trust (2006).

Such scenarios have to be interpreted with care, as there is a high interdependence in the estimates of initial costs values, and in particular of the assumed learning rate (i.e. rate at which the technology gets cheaper due to the learning effects in the serial production process). Apart from this observation, energy produced from waves will be more expensive until a few hundred of MW has been installed.

For most wave energy undertakings, public support in the following forms have either played an essential role, or are vital for future technology development:

- Research / capital Grants; co-financing of investments, including manpower, equipment and operational costs; public funding levels range from 30% to 75%
- Favourable feed-in tariff for generating wave energy that is fed into the transmission grid; values from 20-25 c€/kWh may be necessary in the demonstration phase and are provided in some countries, such as Ireland, Portugal, and the UK. Other countries provide values from more than 9 c€/kWh, such as Germany, France, and Spain; the feed-in tariff concept is a form of revenue support, in order to enable renewable energy technologies to overcome the initial phase in that they cannot compete with traditional generation technologies. They consist of a premium paid by the grid operators in addition to the regular price per kWh of electricity produced.
- VAT reductions, revenue tax exemptions or reductions and other tax incentives at different levels
- Green Certificates and Renewables Obligations backup industrial investments. While Green Certificates allow to trade renewable electricity in the emission trading scheme, Renewables Obligations establish minimum shares of renewable energy in the portfolio of all electricity producers.

Public funding can only help to overcome some barriers. The main technology development must come from industrial involvement.

The lack of significant industrial involvement in the past may be the major reason for devices not having succeeded earlier. In the absence of market prospects and sufficient vision of relevant industrial players, wave energy projects have been largely dependent on public funding. The result was a strongly academic based development, typically not subject to the natural selection of most successful solutions and resources. The past has shown that public funding is not necessarily the most efficient way, but often the only way to proceed with a concept towards larger scale tests. However in public funded projects, often insufficient flexibility is provided with respect to timescale, milestones and deliverables. This is not well-understood by the public funding entities, in particular on European level. The European "fairness principle" of the process from proposal to adjudication virtually demands a developer to do research and know the exact results and difficulties 5 years ahead of the actual work. But for the early stage of such an unpredictable and capital-intensive sector flexibility is essential. Strictly speaking, one could argue that in its present state, public funding has proven to be incompatible with the needs of wave energy technology developers. This can be demonstrated by the rise of two entirely private-driven approaches, after decades of public-funding-based RTD – examples of these approaches can be found in Pelamis Wave Power and AWS Ocean Energy.

Both devices have been tested at full-scale in real sea conditions, and did not rely on public funding. Still, the examples could not be more different in character. Pelamis benefited from massive private venture capital funding from an early stage of product development, enabling a continuous and stable development process, with a team of several tens of engineers and supporting personnel. AWS was invented and developed from the scratch by the small Dutch innovation company Teamwork Technology towards the 2MW pilot plant deployed 2004 in Northern Portugal. The prototype construction was made possible by private investment from a Dutch utility, which then withdrew in the most critical phase of preparing the deployment. After being unsure of whether the project could continue or not, a Portuguese enterprise invested into AWS, in order to enable the tests. Again the required funding in an essential phase was not made available, and the tests had to be suspended. The assets of the technology went to the newly established company AWS Ocean Ltd, who managed to attract a strong private investor in 2007, allowing for much more stable conditions from then onwards.

4.6. Environmental Interactions

The environmental interactions of wave energy technologies are limited, provided that the site selection is done prudently and a controlled planning policy underlies development in sensitive locations. Noise may be a potential negative interaction in areas with cetaceans, but there is not yet evidence of this, and needs to be a subject of further studies. Other impacts resulting from electrical cables deployment and operation and anchoring systems exist, but are manageable.

The most problematic interaction may be the use of ocean space, which may compete with fisheries and shipping industries. Visual interaction may be significant for shoreline or near-shore devices, but these types of devices are expected to contribute only marginally to the exploitation of the resource.

A potentially strong argument of synergies between wave energy and fishery is that breeding sanctuaries will be a side-effect of large wave energy farms, which typically will be closed to maritime traffic over several square kilometres.

The potential importance of ocean wave energy to a future alternative energy mix is significant, in particular in counties like Ireland, UK, Portugal and Norway, where potential electricity consumption shares of 20-50% could be satisfied by wave energy.

The impact of the wave energy industry on the job market may be of particular interest in countries lacking industrial activity, but also in regions with a shipbuilding tradition, which has been otherwise declining.

Matrices of the key interactions between wave energy installations and the receiving environment can be found on the following pages.

Potential key interactions between offshore/nearshore wave energy installations and the receiving environment

Development phase	Activity	Impact mechanism	Interactions with the physical environment	Interactions with the biological environment	Interactions with conservation (ecological designations, natural heritage, anthropogenic heritage etc.)	Interactions with the socio-economic environment
Preparatory works	Surveying	Disturbance of seabed through sampling	Minor impacts may result from baseline environmental surveys. For example, localised loss of substrates, plants and animals on the seabed through coring, boring and grab sampling, disruption to mammals from seismic and other vessel-based surveys.			Local contractors and scientific experts can be employed to conduct and support baseline surveys for example, vessel operators, consultants and divers etc.
		Noise disturbance through increased vessel activity and sonar / seismic surveying	No key interactions anticipated	Potential harm to fish species	Disruption of marine mammal behaviour	No key interactions anticipated
	Site preparation	Disruption of seabed and water column during and after dredging	Areas of the seabed may be dredged affecting seabed morphology and increasing water turbidity	Plants and animals may be removed and directly impacted by any dredging prior to construction	Protected migratory fish species and protected predatory bird species may be affected.	Temporary disruption to other sea users and navigation resulting from vessel activity and marine works.
Construction and installation	Transporting Wave Device/support structures to site	Physical presence of vessels and associated equipment/structures	No key interactions anticipated	No key interactions anticipated	Potential disturbance to marine mammals	Increased risk to other vessels from slow towing of large objects. Devices may also be transported 'underslung' which may increase maritime risk further.
		Local business and employment opportunities	No key interactions anticipated	No key interactions anticipated	No key interactions anticipated	Potential economic benefits from utilisation of local resources, support companies and services
	Mooring and infrastructure installation	Disturbance to seabed and water column through installation of gravity anchors	Localised impact on seabed morphology – cuttings will become established on the seabed. These may subsequently be distributed over a wider area. Re-suspension of particulate matter into the water column	Direct localised impact on seabed habitats and species Gravity anchors may become colonised	Assuming all the relevant baseline studies have been efficiently completed, no impacts are anticipated	Loss of fishing grounds Fish may aggregate towards structures away from traditional fishing areas Additional hazard to navigation
		Disturbance to seascape and generation of noise through piling (if required)	No key interactions anticipated	No key interactions anticipated	Underwater noise may impact marine mammal species over significant distances	Unfamiliar vessels and superstructures associated with onsite fabricating and installation will be visible within the local seascape for extended periods of time
		Local business and employment opportunities	No key interactions anticipated	No key interactions anticipated	No key interactions anticipated	Potential economic benefits from utilisation of local resources, support companies and services
Operation and maintenance	Extraction of energy from the waves	Reduction in coastal wave action	Impact on coastal processes i.e. erosion and sediment transport	Potential changes to intertidal and sublittoral habitats	Protected intertidal and foreshore community structures may be altered due to reduced wave action and storm effects Protected species foraging and migrating within the water column may be harmed/disrupted Noise from installation during operation may affect the normal behaviour of marine mammals in the area	Reduced wave-reliant amenity value, e.g. surfing Potential reduction in affects of coastal erosion and storm surge damage Potential benefits for intertidal and inshore aquaculture

Potential key interactions between offshore/nearshore wave energy installations and the receiving environment

Development phase	Activity	Impact mechanism	Interactions with the physical environment	Interactions with the biological environment	Interactions with conservation (ecological designations, natural heritage, anthropogenic heritage etc.)	Interactions with the socio-economic environment
		Creation of a wave shadow effect	Localised increased sediment settlement in predominantly down-wave areas	Potential surface smothering of existing seabed species and habitats	No key interactions anticipated	Potential effects on anchoring, sailing and other maritime activities within the wave shadow
	Sustained physical presence of wave device, moorings and support structures at sea	Introduction of structures on the seabed, in the water column and above the surface	Scouring may occur around structures on the seabed	Fish may aggregate around structures. An increase in predator activity may result. Birds may roost on surface piercing structures	Protected marine mammals may be enticed towards wave device installation by aggregating food sources	Sustained presence of device(s) on the seascape Sustained additional hazard to other sea users Sustained exclusion of other vessels including fishing boats from around some installations
	Generation and transmission of electricity	Production of Electro-magnetic Fields (EMF)	No key interactions anticipated	Electrical and magnetic interference with movements of fish species e.g. sharks and rays	EMF may affect protected species passing through the vicinity of the installation	Fisheries dependent on sensitive species may be affected
		Reduction of greenhouse gas and exhaust emissions from fossil fuel combustion	Reduction in air pollution and atmospheric anthropogenic greenhouse gasses	Ecological effects resulting from greenhouse gas emissions and air pollution will be reduced		Local communities may benefit from any revenue generated from the development Employment for maintenance and administrative staff The social and economic impacts of climate change will be mitigated
Accidental events	Incident leading to chemical spill	Chemical pollution	Local/widespread changes in water and sediment chemistry	Species and habitats may be harmed and damaged by chemical pollution		Chemical pollution may affect other estuary users for example; fish farmers, tourists and mariners etc.
	Incident leading to oil/fuel spill	Oil pollution	Transitory oil slicks on surface waters and risk of long-term seabed and shoreline pollution	Species and habitats may be harmed and damaged by oil pollution		Oil pollution may affect other estuary users for example; fish farmers, tourists and mariners etc.
	Loss of equipment / structural components	Disruption to the seabed from sinking debris	Changes to the seabed profile and sediment composition	Localised disruption to seabed species and habitats.		Additional hazard to navigation, disruption of fishing grounds
		Disruption and littering of surface waters and shorelines from floating debris	No significant impact	Disruption to shoreline habitats through smothering and harm to species through ingestion/entanglement		Loss of amenity value, disruption to intertidal fisheries
Decommissioning	Total removal of installation	Reversion to baseline hydrographic conditions	Dispersal of any accumulated sediments around installation Loss of any calming effects around installation and in coastal waters	Potential disruption to ecosystems established and adapted to post-installation hydrographic conditions	Protected intertidal and foreshore communities adapted to post-installation structures may be altered due to increased wave action and storm effects Protected species foraging and migrating within the water column may be disrupted	Increased wave-reliant amenity value, e.g. surfing Loss of benefits gained from wave shadow effects to intertidal / inshore fisheries etc
		Local business and employment opportunities	No significant additional impact anticipated	No significant additional impact anticipated		Potential economic benefits from utilisation of local resources, support companies and services
	Replacement of wave device	Local business and employment opportunities	No significant additional impact anticipated	No significant additional impact anticipated		Potential economic benefits from utilisation of local resources, support companies and services

Development phase	Activity	Impact mechanism	Interactions with the physical environment	Interactions with the biological environment	Interactions with conservation (ecological designations, natural heritage, anthropogenic heritage etc.)	Interactions with the socio-economic environment
Preparatory works	Surveying	Disturbance of seabed / shoreline through sampling	Minor impacts may result from baseline environmental surveys. For example, localised loss of substrates, plants and animals from the seabed / shoreline through coring, boring and grab sampling, disruption to mammals from seismic and other vessel-based surveys			Local contractors and scientific experts can be employed to conduct and support baseline surveys for example, vessel operators, consultants and divers etc. Temporary loss of shoreline amenities Temporary disruption to inshore / shoreline-based fisheries
		Noise disturbance through increased vessel activity, machinery and sonar / seismic surveying	No key interactions anticipated	Potential harm to fish species	Protected bird and marine mammal species may be temporarily displaced from the area.	Noise and increased activity may become a nuisance to nearby residents
	Site preparation	Disruption of seabed, shoreline and water column during and after dredging	Areas of the seabed may be dredged affecting seabed morphology and increasing water turbidity Large volumes of materials may be extracted from shorelines affecting local topography	Plants and animals may be removed and directly impacted by any dredging and extraction prior to construction	Protected bird species may be disrupted	Temporary disruption to other shoreline users, sea users and navigation resulting from vessel activity, marine works and intertidal worksite preparation.
Construction and installation	Transporting Wave Device/support structures to site	Physical presence of machinery / equipment on shoreline/seabed	No key interactions anticipated	Disruption of intertidal and supratidal habitats and species	Protected habitats and species may be affected	Equipment/machinery will be visible for extended periods of time
		Physical presence of vessels and associated equipment/structures	No key interactions anticipated	No key interactions anticipated	Potential disturbance to marine mammals	Increased risk to other vessels from slow towing of large objects. Devices may also be transported 'underslung' which may increase maritime risk further.
		Local business and employment opportunities	No key interactions anticipated	No key interactions anticipated	No key interactions anticipated	Potential economic benefits from utilisation of local resources, support companies and services
	Support structure installation	Disturbance to shoreline sublittoral zone	Localised impact on coastal morphology Re-suspension of particulate matter into the water column Disturbance of nearshore seabed	Direct localised impact on coastal habitats and species Support structures may become colonised	Potential disturbance to protected habitats and species	Loss of recreational coastal areas Localised disturbance to other users
		Disturbance to landscape and generation of noise through piling/drilling	No key interactions anticipated	No key interactions anticipated	Protected bird and seal species may be temporarily displaced from the area	Superstructures associated with onsite fabricating and installation will be visible within the local landscape/seascape
		Local business and employment opportunities	No key interactions anticipated	No key interactions anticipated	No key interactions anticipated	Potential economic benefits from utilisation of local resources, support companies and services

Potential key interactions between coastal and nearshore wave energy installations and the receiving environment

Development phase	Activity	Impact mechanism	Interactions with the physical environment	Interactions with the biological environment	Interactions with conservation (ecological designations, natural heritage, anthropogenic heritage etc.)	Interactions with the socio-economic environment
Operation and maintenance	Extraction of energy from the waves	Reduction in coastal wave action	Impact on coastal processes i.e. erosion and sediment transport	Potential changes to intertidal and sublittoral habitats	Protected intertidal and foreshore community structures may be altered due to reduced wave action and storm effects Protected species foraging and migrating within the water column may be harmed/disrupted	Potential reduction in affects of coastal erosion and storm surge damage Loss of any wave related amenity value at the shoreline
	Sustained physical presence of installation	Introduction installation onto the shoreline and into nearshore waters	Scouring may occur around structures on the seabed	Fish may aggregate around structures; an increase in predator activity may result. Birds may roost on surface piercing structures Installation may become colonised leading to further changes in the local ecosystem	Protected marine mammals may be enticed towards the installation by aggregating food sources	Sustained presence of device(s) on the landscape/seascape Sustained loss of recreational coastal area Sustained disruption wave related amenity at the shoreline and in nearshore waters Nearshore fisheries may be affected for a sustained period
	Production of electricity from renewable energy source	Reduction of greenhouse gas and exhaust emissions from fossil fuel combustion	Reduction in air pollution and atmospheric anthropogenic greenhouse gasses	Ecological effects resulting from greenhouse gas emissions and air pollution being reduced		Local communities may benefit from any revenue generated from the development Employment for maintenance and administrative staff The social and economic impacts of climate change will be mitigated
Accidental events	Incident leading to chemical spill	Chemical pollution	Local/widespread changes in water and sediment chemistry	Species and habitats may be harmed and damaged by chemical pollution		Chemical pollution may affect other area users for example; fish farmers, tourists, beach users and mariners etc.
	Incident leading to oil/fuel spill	Oil pollution	Transitory oil slicks on surface waters and risk of long-term seabed and shoreline pollution	Species and habitats may be harmed and damaged by oil pollution		Oil pollution may affect other area users for example; fish farmers, tourists, beach users and mariners etc.
	Loss of equipment / structural components	Disruption to the seabed from sinking debris	Changes to the seabed profile and sediment composition	Localised disruption to seabed species and habitats.		Additional hazard to navigation, disruption of fishing grounds
		Disruption and littering of surface waters and shorelines from floating debris	No significant impact	Disruption to shoreline habitats through smothering and harm to species through ingestion/entanglement		Loss of amenity value, disruption to intertidal and offshore fisheries
Decommissioning	Total removal of installation	Reversion to baseline hydrographic conditions	Dispersal of any accumulated sediments around installation Loss of any calming effects around installation and in coastal waters	Potential disruption to ecosystems established and adapted to post-installation hydrographic conditions	Protected intertidal, sublittoral and foreshore communities adapted to post-installation structures may be altered due to increased wave action and storm effects	Landscape/seascape reverted back to near original state All amenities associated with the area which were affected by the installation, will mostly be restored to preinstallation conditions

Development phase	Activity	Impact mechanism	Interactions with the physical environment	Interactions with the biological environment	Interactions with conservation (ecological designations, natural heritage, anthropogenic heritage etc.)	Interactions with the socio-economic environment
		Local business and employment opportunities	No significant additional impact anticipated	No significant additional impact anticipated		Potential economic benefits from utilisation of local resources, support companies and services
	Replacement of wave device	Local business and employment opportunities	No significant additional impact anticipated	No significant additional impact anticipated		Potential economic benefits from utilisation of local resources, support companies and services

4.7. Future Potential

There are a number of concepts and ongoing projects that might play a role in the upcoming commercial phase. Similar to wind energy, the kind of incentives granted to developers, in order to survive the pre-commercial development phase, will have crucial impacts on the location and speed of sector development. Typically, the market converges to a few or even only one, concept (e.g. in wind energy, the 3-bladed horizontal axis wind turbine). Therefore, the proposed devices are competing for part of a very limited selection of 'winner technologies' for the later commercial stage. Which technologies succeed will not only depend on the device technology itself, but also on a professional approach and contingency plans for both projects and their promoters. The second aspect is more important than in most other undertakings, due to the highly aggressive and unpredictable marine environment. Although marine and offshore technology can cope with the challenges posed, to date, the projects typically have not had sufficient means for employing the required state-of-the-art technology.

4.7.1. Level 2

Other issues are licensing – ocean space regulations and conflicts of use - as well as environmental impact assessment and performance standards. Difficulties of wave energy technologies, as well as power quality, grid connection and environmental issues must be considered, confirmed by recent due diligence investigations of experienced players in the global offshore business.

The future growth of wave energy could be affected by several factors, including:

(i) Strategic considerations and security of supply

(ii) Financing availability for technology and projects, including public support

(iii) Risk and potential of the technology, seeking to the commercial exploitation of the concept

(iv) Approach in risk management in the development process

(v) Connection to the grid availability

(vi) Grid capacity in accepting irregular sources

(vii) Environmental factors and delay in license processes

Europe could reach several GW of installed capacity for 2020. Carbon Trust (2006) considered that this value will be in the range of 1 GW to 2.5 GW by comparison to the wind energy sector growth in the 1980s. The total capital to be deployed at this stage is estimated to range from 1.5 to 3.75 billion €. After 2020, a faster growth is expected, according to common market experience.

The years 2007-2010 are of fundamental importance to success and pace of ocean wave energy implementation. The prototypes have reached a reasonable level of professionalism, and the first technologies have to prove that they are able to produce electricity on a competitive basis in the longer term. It is vital that the upcoming prototypes and small parks exhibit better reliability and survivability than past systems characterised by strong academic backing, typically very well designed in hydrodynamic or other specific terms, but failing to present a convincing and marketable overall approach.

4.8. Case Studies

There are a large number of wave energy devices, but only some of them will be capable of use in large-scale deployments. Due to the ongoing competition of several devices to be a market leader, and norms of market consolidation, it may be that of the more than 50 concepts proposed, less than five may be "winner" technologies.

Case studies of wave energy technologies and projects are highlighted below, taking into the account the working principle and technology state. This selection includes a wide range of the technology types already introduced (see Technology Types, level 1); all projects have acquired significant experience with real sea installation to date.

* AWS (Submerged Pressure Differential Point Absorber)

* OE Buoy (Floating Oscillating Water Column (OWC) – point-absorbing characteristics)

* Pelamis (Attenuator – point-absorbing characteristics)

* Pico OWC (Shoreline Oscillating Water Column (OWC))

* Wave Dragon (Overtopping Device)

Another factor for the choice of these five devices was that a minimum level of publicly available information exists for these devices, which is not the case for some other projects.

Several Case studies are presented on the following pages.

Case Study – Iberdrola Santoña wave farm

Project Name	OPT - Iberdrola
Location	Santoña (Cantabria/Spain)
Installed capacity	1.39 MW
Technology Type	OPT Power Buoy – Axi-symmetrical point absorber with hydraulic power-take-off
Project Type/Phase	Demonstration wave farm
Year	2008-2009

Project Description

Following a Memorandum of Understanding in March 2004, the Santoña project was the first European commercial wave farm demonstration project to be announced in August of the same year. With the large energy company Iberdrola as major shareholder, a joint venture contract was signed further involving OPT Ltd (a European subsidy of US American company Ocean Power Technologies), the industrial development agency of the Spanish region of Cantabria, Sodercan, and the energy agency of the Government of Spain, IDEA. Later it was reported that Total SA entered into the joint venture.

The objective of the project was to build and operate a 1.25 MW OPT wave power station, consisting of an array of OPT's patented technology PowerBuoy (see below), and to demonstrate the viability of wave power on the northern coast of Spain. The deployment site is 9km offshore from Punta del Pescador in Santoña, which is located on Cantabrian coastline (northern Spain, approximately 20km east of Santander). The deployment site is in approximately 50m depth on a sandy bottom with rock formations.

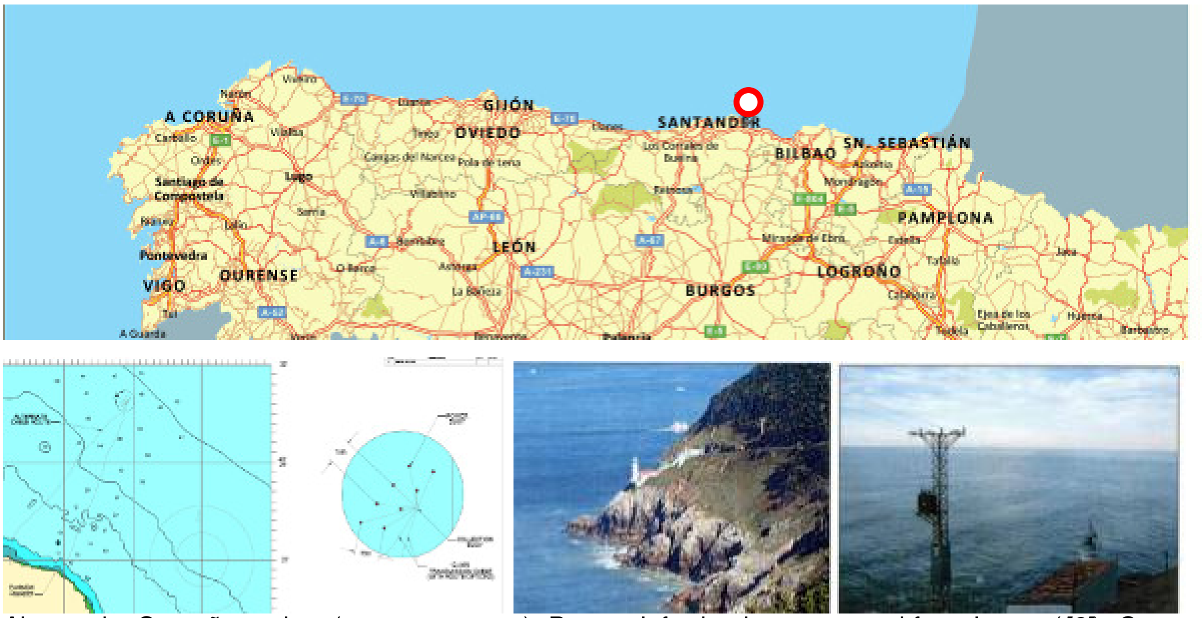
While the initial plan was to deploy a 1.25 MW farm, more recent announcements indicate a rated output of 1.39 MW, consisting of nine 150 kW PowerBuoys (PB-150), plus one 40 kW PowerBuoy (PB-40) to be installed and tested ahead of the subsequent devices. This approach can significantly reduce the financial risk for projects that deal with premature technology.

The power produced by the array of ten OPT PowerBuoys is in the range of 3.5 – 4 GWh per year, based on load factors of approximately 20% in summer and almost 40% in winter (i.e., the relationship of average produced power to the rated power of the device).The combined output of the wave farm will be connected into the Spanish national power grid.

After the contract was signed in 2004, OPT completed the first phases of the project (system design, characterisation of the deployment site, assessment of wave energy resources, determination of the transmission cable route) by 2006, before an EPC contract (engineering, procurement, construction) was signed in July, including the 'turnkey' installation of the PowerBuoys. The EPC contract also includes the subsea power transmission cable, underwater substation and grid connection, all supplied by OPT. By 2007, an agreement was signed for the operation and maintenance (O&M) of the wave power station for up to 10 years.

By the summer of 2008, the first PB-40 device was fully assembled and presented to a selected public.

The support of the Spanish and Cantabrian governments has been an important aspect of the project's success to date.



Above: the Santoña project (*www.mapas.es*); Bottom left: depth contour and farm layout (*[3]*); Coastal connection spot (*www.oceanpowertechnologies.com*)


An artist's impression of an OPT PowerBuoy wave farm (*www.oceanpowertechnologies.com*)

The Technology

The PowerBuoy is a typical ‘axi-symetrical point absorber’ type wave energy device. These are normally buoy-type floating structures, capable of converting a larger amount of incident wave power corresponding to their own width (i.e. antenna effect). The PowerBuoy converts the heave motion through a hydraulic motor system or linear generators into electricity. According to OPT, sensors continuously monitor the performance of the sub-systems and surrounding ocean environment, and data is transmitted to shore in real time.

In the event of very large oncoming waves, the system automatically locks-up and ceases power production. When the wave heights return to normal, the system unlocks and recommences energy conversion and transmission of the electrical power ashore.

Due to their limited power output per device, the buoys are designed for farm deployment (range of several MW to several hundreds of MW), where the spacing of the devices is designed to maximise overall output. The developers state that a 10 MW wave farm with PowerBuoys would cover approximately 0.125 km^2. Each PowerBuoy consists of a relatively simple and strong steel construction using conventional mooring systems, and can normally be deployed by existing marine vessels and infrastructure. When doubling the buoy diameter, the rated power of a device will grow by a factor of 4. Two different PB-40 devices have absolved significant test periods offshore New Jersey and Hawaii, respectively, since 2005.

Deployment of PB-40 in New Jersey (left) and PB-40 deployed in Hawaii (right); *[3]*

The plan was to be ready for large-scale farms by 2006; however, as in other wave energy developments the advances have been much slower than initially expected. OPT is one of the most mature wave energy technologies, together with the Pelamis and possibly the Wavedragon (see according fact sheets). The latter has absolved more than 2000 hours of operation in fourth scale and in a Danish fjord. Pelamis has tested a 750 kW device in Orkney/Scotland and deploys a farm consisting of three follow-up devices in Portugal, in summer 2008.

Very little technical data has been published by OPT, due to a strictly commercial approach to technology development. The Santoña project may be an important milestone to reveal the technology and its performance to a wider public.

OPT expects to deploy their 150 kW device PB-150 in 2009 in the Scottish test centre EMEC, and on the Oregon coast (USA). The use of HTS (High Temperature Superconductors) linear generators as PTO (Power-Take-Off) is being considered.

Related Projects

In Hawaii, where the first PB-40 was deployed in 2005, there are plans to extend a wave farm of up to 1 MW, in 30m water depth.

In 2005, an agreement with Total Energie Development SAS, a unit of Total SA, and Iberdrola SA was signed to develop a wave power station in France [Forbes, June 20, 2005]. This involved identifying potential sites around the French coastline and gaining the necessary consents and permits. The next step was to install a wave power station with a capacity of up to 2-5 MW. No recent news has been found on this undertaking, however reportedly Total holds now shares in the Santoña project.

In May 2008, OPT announced a joint venture agreement between their Australian subsidiary Ocean Power Technologies (Australasia) Pty Ltd ("OPTA"), and Griffin Wave Power Ltd, a subsidiary of Griffin Energy Pty Ltd ("Griffin Energy"), for the development, construction and operation of a wave power farm offshore Western Australia, leading to the development of a wave farm of 10 MW rated power (with potential expansion to 100 MW), feeding into Western Australia's main power grid.

Project Partners

Ocean Power Technologies Inc. / Ltd (USA / UK): technology development of wave energy device and specific components of the power electronics and subsea connection; operation & maintenance.

Iberdrola S.A.: large energy multinational with headquarters in Spain; major project shareholder from the onset

Sodercan, S.A.: industrial development agency of the Spanish region of Cantabria, supporting project development

IDEA – Instituto para la Diversificación e Ahorro de la Energía; agency of the Government of Spain, supporting project development

TOTAL SA: large energy multinational with headquarters in France; project shareholder in later phase

Cost and Financing

The costs for the project are not published; OPT will be able to provide power in remote markets for 5-7 cEUR/kWh with the PB-150, and 2-3 cEUR/kWh with the PB-500 ([3], originally in c$: 7-10¢/kWh and 3-4¢/kWh)

Private investment (Iberdrola, 70%), together with Spanish governmental agencies (initially 2* 10%), as a joint venture. No significant tariff has been published for the project development, but might be implemented when the project is being installed.

Assuming a feed-in tariff of 10 cEUR/kWh, and the indications of OPT regarding the load factor of 30% on average, an annual revenue may be 300-400kEUR for the 1.39 MW Santoña wave farm.

Further Information

Ocean Power Technologies (OPT) develop and commercialise proprietary systems that generate electricity by harnessing the renewable energy of ocean waves. Its PowerBuoy(R) system is based on modular, ocean-going buoys, which have been ocean tested for nearly a decade.

Iberdrola is one of the largest renewable energy utilities in the world, with more than 3800 MW of renewable energy generating capacity and with a commitment to achieve 6200 MW in 2008. Capitalised at more than 14 billion Euros (£9 billion) and listed on Spain's blue chip Ibex 35 index and the Euro Stoxx 50 index, Iberdrola produces power through a combination of hydroelectric, gas, wind power, and nuclear.

Sodercan is the development agency of the Cantabria region of Spain (SODERCAN, S.A.) and is owned by the government of Cantabria, Savings Bank of Santander and Cantabria, and the Chamber of Commerce, Industry and Navigation of Cantabria. Sodercan was formed to encourage regional investment, promote local businesses, sponsor further economic development, and to provide financial resources to entrepreneurial projects.

IDEA is the Institute for the Diversification and Saving of Energy, an entity reporting to the Spanish government's Ministry for Science and Technology. The basic function of IDAE is to promote energy efficiency and the rational use of energy in Spain. It also seeks to promote diversity of energy sources and the use of renewable sources of energy. It promotes these aims through dissemination activities, technical consultancy, the implementation of projects with a technologically innovative component, and financial and technical support for energy efficient installations and diversification of energy sources.

Link to developer/company website

Ocean Power Technologies Inc. (USA): www.oceanpowertechnologies.com

Iberdrola S.A.: www.iberdrola.com

Sodercan, S.A.: www.sodercan.com

IDEA – Instituto para la Diversificación e Ahorro de la Energía: www.idae.es

TOTAL SA: www.total.fr

Sources:

[1] OPT NEWS RELEASE August 04, 2004: Ocean Power Technologies Enters Into Joint Venture To Build Wave Power Station In Spain Ocean Power Technologies, Inc.; Pennington, New Jersey 08534, USA

[2] OPT NEWS RELEASE July 31, 2006: Award Of Contract To Build Wave Farm In Spain; Ocean Power Technologies, Inc.; Pennington, New Jersey 08534, USA

[3] Taylor, G., 2005: Ocean Power Technologies; Hydrokinetic and Wave Energy Technologies

Technical and Environmental Issues Workshop, October 26-28, 2005, Washington, D.C., USA

[4] Renewable Energy Today March 22, 2007: OPT Wave Farm in Spain Gets Operation & Maintenance Contract; http://www.renewableenergyworld.com

[5] Jordan, P., 2008: PowerBuoy Deployments (Present and Future); All Energy'08; 21-22.03.2008; Aberdeen, Scotland/UK

Case Study – Okeanós Pelamis Wave Farm

Project Name	Okeanós: Pelamis wave energy farm Portugal Project Three P1-A Pelamis machines
Location	Aguçadoura/ Póvoa de Varzim, Northern Portugal
Installed capacity	3 * 750 kW = 2.25 MW; plans exist to extend to 30 devices (22.5 MW)
Technology Type	Pelamis: Floating articulated attenuator
Project Type/Phase	Commercial contract
Year	Construction of devices terminated in 2006, later assembly and partly testing by early 2008; installation summer 2008

Project Description

The Aguçadoura wave farm hosts three Pelamis devices and is the first undertaking worldwide as a commercial order of wave energy devices. The 8 M€ purchase of the three Pelamis P-1A machines of 750 kW each by the Portuguese project developer, Enersis, is expected to return the investment, due to the favourable feed-in tariff in Portugal. The agreement dates back to 2005, when Enersis and Ocean Power Delivery Ltd (now Pelamis Wave Power Ltd) signed the agreement of purchase. In July 2006 it was published by Decree-law authorising CEO (Companhia Energia Oceânica, S.A.) to install three machines offshore Aguçadora, Póvoa de Varzim.

The machines were entirely built in Scotland, in order to reduce technical and logistic risks during the manufacturing; Scottish suppliers had a proven prototype. The assembly took place in the Portuguese Peniche shipyard, after the devices were transported in segments to Portugal. The original deadline for deployment was 2006; however several technical issues and the weather delayed the process until summer 2008.

A previous test site of the 2 MW AWS (Archimedes Wave Swing) technology was used. Because of this the deployment site, the deployment license and grid connection, the subsea cable, and the parts of the conversion station on Aguçadoura beach could be re-used. The subsea cable connection and some other pre-installed offshore components were not expected, delaying the installation.

The Aguçadoura wave energy project in Portugal is supported by a specific feed-in tariff currently equivalent to approximately €0.23/kWh.

A letter of intent has been issued to order a further 30 Pelamis machines (for a total 20MW), subject to satisfactory performance of the initial project phase. It is not yet clear whether permission for this extension will be granted, due to some discontent with the exclusive character of the planned Portuguese wave energy pilot zone further south (offshore S. Pedro de Moel). For the Northern Portuguese Pelamis farm, only a substantial extension of 100 or more devices might be profitable; due to current legislation this will not be possible, because the government will grant wave-farm licenses exclusively for the pilot zone for several years, penalising any undertakings outside that zone.

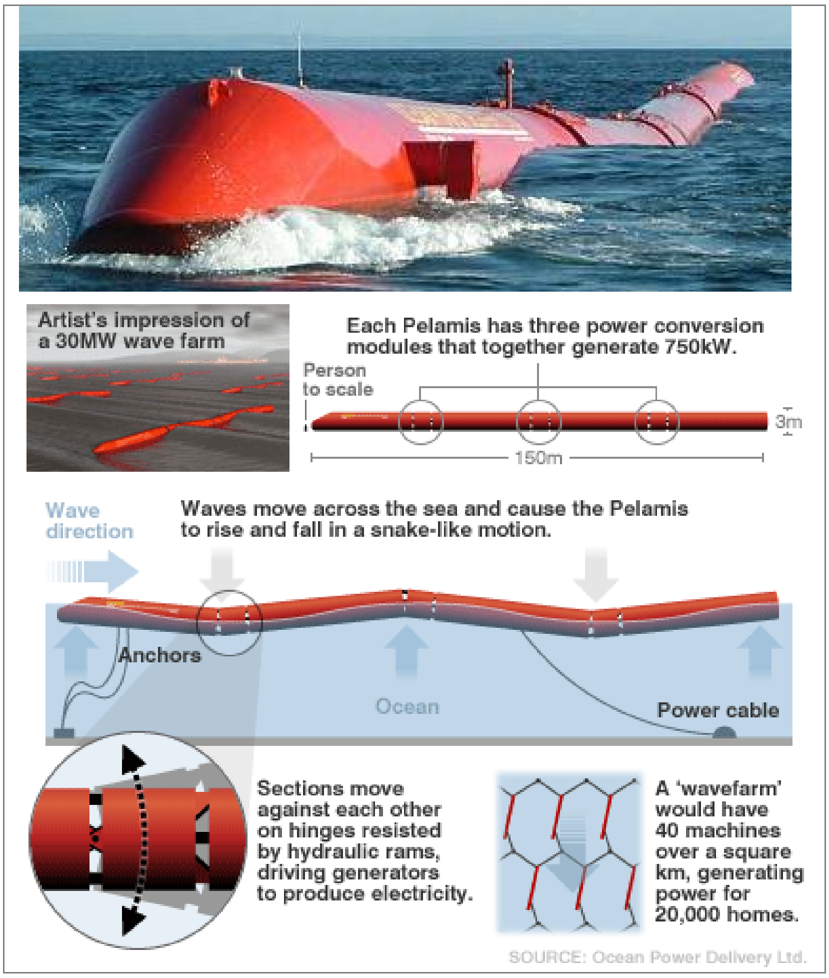
Location of the Aguçadora Wave park (left; *Google Earth*). Constructions of the modules of power take off (top right) and three pelamis machines, 750 kW each (bottom right) in the harbour of Leixões, ready to be deployed *(Pelamis wave Power)*.

The Technology

The Pelamis Wave Energy Converter is a semi-submerged, articulated structure consisting of four cylindrical steel sections linked by three hinged joints. The four sections move relative to each other and the hinges convert this motion by means of a controlled hydraulic power conversion system. Each hinge of the device contains its own hydraulic power take off composed of four hydraulic rams (in each power take off) that resist this movement, pumping high-pressure fluid via smoothing accumulators to hydraulic motors, which drive induction generators to produce electricity. Several devices can be connected together and linked to shore through a single sub-sea cable.

The machine is held in position by a mooring system of floats and weights that prevent the mooring cables from becoming taut. This maintains enough resistance to keep the Pelamis positioned but allows the machine to swing head on to oncoming waves.

The first full-scale pre-production Pelamis prototype was tested at the European Marine Energy Centre in Orkney. The design was independently verified by WS Atkins according to (DNV) offshore codes and standards.



Floating prototype, an artist's impression of a large-scale farm using the principle of the Pelamis device *(Pelamis wave Power)*.

Related projects

The following projects have been proposed, but contracts have not yet been signed:

Orcadian Wave Farm: four Pelamis generators supplied by PWP to ScottishPower Renewables for installation at the European Marine Energy Centre (EMEC). In February 2007 the Scottish Executive announced a funding package for the Orcadian Wave Farm in excess of £4m and in September 2007 the Orcadian Wave Farm received final consent.

Westwave project: up to seven Pelamis generators installed at the Wave Hub facility supplied to E.ON UK & Ocean Prospect. In February 2006 Ocean Prospect secured exclusive access to one of the four Wave Hub's berths for the connection of multiple Pelamis machines.

Project Partners

Pelamis Wave Power; Edinburgh, Scotland: technology development; manufacturer of the Pelamis Wave Energy Converter, which is an in-house product developed since the late 1990s. Starting with mathematical and experimental models with a small core team in Edinburgh, the company name was initially Ocean Power Delivery Ltd, which changed to Pelamis Wave Power in September 2007. Approximately 70 people are employed by the company, with a large number of engineers.

Enersis (CEO - Companhia de Energia Oceânica, S. A); Lisbon, Portugal: Project developer and ownership; Enersis has experience in developing and operating mini-hydropower projects and wind farms in Portugal, and was the first project developer to invest into a wave device, namely the 2MW AWS pilot plant in 2004. Since December 2005 Enersis has been a subsidiary of Australia´s investment bank Babcock & Brown. A Portuguese company, CEO-Companhia Energia Oceânica, S.A. was created under the Enersis group.

Cost and Financing

- 8 M€ for the supply and installation of three Pelamis devices. How these costs correspond to the total costs of the undertaking, has not been published.
- Largely private investment (Enersis-CEO) for capital return with favourable feed-in tariff (> 20 c€/kWh); national demonstration scheme grant of ca. 1.1 M€ awarded
- If predictions on power conversion efficiency and reliability are realised, revenue from electricity feed-in of 800k€ to 1.5 M€ may be expected. As an initial phase of a small series of technology, it is likely that maintenance expenses will be high; during the first years it is not realistic to rely on full temporal availability of the technology.

Further Information

Link to developer/company website

Pelamis Wave Power (former Ocean Power Delivery): www.pelamiswave.com

Case Study – European OWC pilot plant Pico/Azores

Project Name	European Wave Energy Pilot Plant – Pico OWC
Location	Pico Island, Azores/Portugal
Installed capacity	400 kW
Technology Type	Shoreline gully Oscillating Water Column; the wave chamber is integrated in a natural gully, fitted into the rocky coastline.
Project Type/Phase	Pilot Plant testing; preparation of test bed for air turbines.
Year	First installation and punctual operation in1999, partly destroyed Recovery from 2004-2006, first operation October 2005 Continuous and autonomous operation planned for 2008

Project Description

The European Pico OWC plant was built from 1995 to 1998 within the framework of two EC JOULE projects and co-funding from EDP (Electricidade de Portugal) and EDA (Electricidade dos Açores), respectively the national and regional utilities. Instituto Superior Técnico (IST), Lisbon was responsible for the conception and basic engineering studies of this plant and co-ordinated the project. The plant is a bottom-mounted shoreline structure, equipped with a Wells turbine with guide vanes.

The plant was completed in 1999 but flooding and malfunction of the Wells turbine affected the testing program of the plant, leading to long delays (Falcão, 2000). Full scale testing was only performed during a short period in October 1999. In 2003, the Wave Energy Centre (WEC), a non-profit association dedicated to the development and promotion of ocean wave energy, created in Portugal, obtained national funding to proceed with the refurbishment of the plant, under a specific funding scheme for pilot projects related to scientific innovated systems (PRIME/DEMTEC).

In 2004-2006 a set of relevant repair works were undertaken under the co-ordination of the WEC, as part of a national funding scheme and a program of monitoring tests accompanied the commissioning of the plant.

The basic function of the plant was reconstituted in autumn 2005. Substantial limitations of the operation persisted, mainly due to the inappropriate design of the turbine support structure, inherited from the original project. The automatic operational modus was insufficient due to the original plant layout and equipment. Since 2005, three minor accidents (affecting guide vanes, bearing, and glass-fibre of the air tunnel) and insufficient funding prevented the project from a faster and complete recovery. Progress has been made and it is expected that by end of 2008 the plant should be capable of operating at rated power autonomously. EDP provided the investment to refurbish the functional and visual aspects of the Pico OWC.

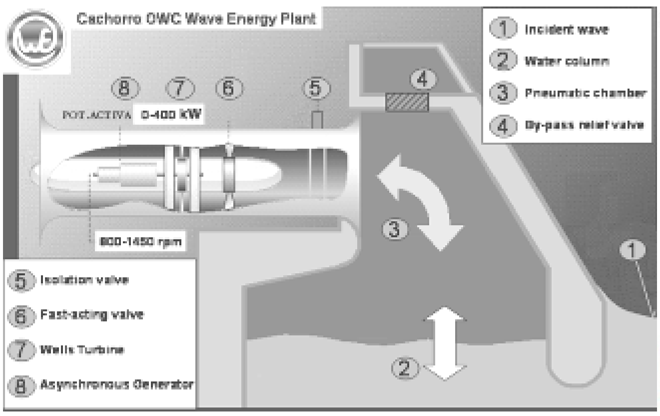
There are plans to prepare the second turbine slot of the structure as a turbine test bed, which is intended to serve as an open air turbine test facility in real-sea conditions.

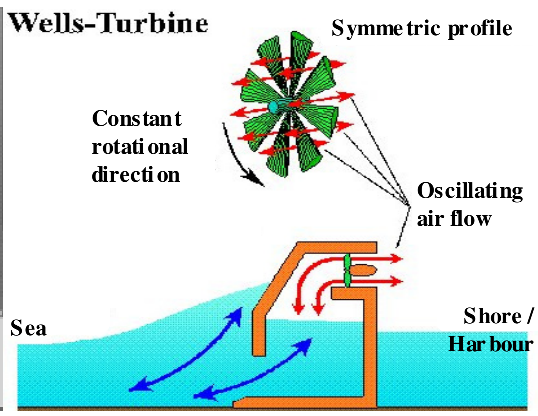
The Pico OWC from the sea (left); plant under heavy sea (centre); the coastline with Pico OWC integrated (right); (*WavEC)*

The Pico OWC has contributed and will contribute substantially to the development of this type of plant, in particular with respect to two issues. The plant has existed for almost 10 years now, of which significant part may be considered as abandoned. The degradation of equipment and components and the moderate efforts necessary to re-activate the plant are unique. As there is no commercial information on the Pico project itself, some data has been revealed to the technical-scientific community as it has become available and open discussion is now being sought.

The Technology

The basic function principle of the OWC is the incident wave motion excites the oscillation of the internal free surface of the entrained water mass inside a pneumatic chamber, which produces a low pressure reciprocating flow that drives the turbine, installed in a duct between the chamber and the atmosphere (see illustration). A detailed description of the design of the Pico plant and electrical-mechanical equipment can be seen at Falcão, 2000.





Cross-section of the pilot plant of Pico, Azores (left) and working principle of an OWC and the Wells turbine (right; *Prof. Graw, Dresden University [6])*

Related projects

LIMPET OWC: The shoreline-based LIMPET device was built in 2000 by the Scottish company Wavegen (now Voith Siemens), in collaboration with Queens University of Belfast (QUB). The LIMPET is a modern sister project of the Pico OWC, as its structural design, construction process and turbine concept were innovative. The device was initially conceived for 500kW (2*250kW counter-rotating Wells turbines). It was downscaled to 250kW, and later used as test facility for smaller turbines. Little data from the LIMPET plant has been published, due to the non-disclosure policy of the developers.

BREAKWAVE project: applied in late 2006 for EU funding, lead by the Portuguese utility EDP, Labelec. It concerns the integration of an OWC plant in a caisson breakwater head in northern Portugal (*Foz do Douro*, Oporto), consisting of two chambers equipped with three (2+1) Wells turbines, resulting in 750 kW installed capacity. In 2001, the plans to build a new breakwater at the Douro estuary ('Foz do Douro') in Oporto, northern Portugal, brought up the possibility of realising the idea of integration of a OWC in a breakwater; the maritime consultant Consulmar asked WavEC for a preliminary study on concerning this possibility in the breakwater head. Using that study as a baseline, the company submitted the proposal to integrate an OWC in the breakwater as part of the public tender, which they later won. After the concession of the breakwater construction in 2004, a consortium has proceeded with preparatory works concerning the integration of an OWC into the breakwater. The project was abandoned due to a non-responsive public body in the critical phase for decisions.

Mutriku OWC Breakwater: Several small OWCs integrated in the new outer breakwater of Mutriku (Basque country, under construction 2007-08) using the technology from Wavegen, form a demonstration project partially funded by the European Commission under Framework Programme 6 with an investment of 3.5M€. The project is promoted by the Basque government and EVE, the Basque Energy Agency. It consist of 16 turbines with a capacity of 20 kW each one (320 kW of total capacity).

Project Partners

Initial project (1992-1998): IST (Instituto Superior Técnico, Lisbon, Portugal); EDA (Electricidade dos Açores, Azores, Portugal); EDP (Electricidade de Portugal, Lisbon, Portugal); INETI (Instituto Nacional de Engenharia Tecnologia e Inovação, Lisbon, Portugal); EFACEC - Sistemas de Electrónica SA (Portuguese supplier and developer of electrical equipment), PROFABRIL (Portuguese designer company of engineering projects), UCC (University College Cork, Cork, Ireland); QUB (Queens University of Belfast, Northern Ireland). A.R.T. (later renamed into Wavegen) subcontracted for the design and manufacture and installation of the mechanical parts.

Recovery Project (2004-2006): the Wave Energy Centre (WavEC) overtook responsibility for the Pico plant, in the context of a recovery project (national funding DEMTEC, EDP and Efacec); main contractors Efacec and Kymaner.

Ownership, operation and maintenance (O&M) until summer 2008: Wave Energy Centre (WavEC); from summer 2008 onwards O&M contract with consortium led by Kymaner.

Cost and Financing

The original project was financed largely by the European Commission; estimated total costs are €2-3M.

The recovery project (DEMTEC national funding, EDP & Efacec) had a total cost of approximately €1M, with the second refurbishment phase financed by EDP

Projected income will be generated by a favourable feed-in tariff of approximately 23 cEUR/kWh. Once the plant can operate autonomously at rated power, the revenue from electricity sale will most likely self-sustain the continuing O&M.

Further Information

Contacts:
Wave Energy Centre, Lisbon: mail@wave-energy-centre.org

Sources:
[1] Falcão, AF de O (2000). "The shoreline OWC wave power plant at the Azores". Proc 4th European Wave Power Conf, University of Aalborg, Denmark, paper B1.

[2] A. Brito-Melo, F. Neumann, A.J.N.A. Sarmento, Full-scale Data Assessment in OWC Pico Plant, Proceedings of The Seventeenth (2007) International OFFSHORE AND POLAR ENGINEERING CONFERENCE. Lisbon, Portugal, July 2007.

[3] Sarmento, A.; Brito-Melo, A, Neumann, F: Results from Sea Trials in the Owc European Wave Energy Plant at Pico, Azores; invited paper for WREC-IX, 19.08-25.08.2006; Proc. WREC IX, ISBN 008 44671 X.

[4] Neumann, F., Brito e Melo, A., Sarmento, A. (2006), "Grid connected OWC wave power plant at the Azores, Portugal", Proc. Int. Conf. Ocean Energy: from innovation to industry, OTTI, ISBN 3-934681-49-2, pp. 53-60.

[5] "CEODOURO project: overall design of an OWC in the new Oporto breakwater" by E. Martins, F. Siveira Ramos, L. Carrilho, P. Justino, L. Gato, L. Trigo and F. Neumann, Proceedings of the Sixth European Wave Energy Conference, Glasgow, UK, August 29 - September 2, 2005

[6] Graw, K.-U. 2004, http://www.uni-leipzig.de/~grw/welle/wenergie_viz.html. Wave Energy information pages of Prof. Kai-Uwe Graw of Leipzig University/Germany (in German). Acessed April 2004 and August 2005.

Case Study – Wave Dragon Milford Haven Project

Project Name	Milford Haven Wave Dragon Pre-Commercial Demonstrator
Location	Milford Haven, offshore Wales
Installed capacity	4-7MW
Technology Type	Wave Dragon – floating overtopping device
Project Type/Phase	Large-scale prototype
Year	2009 (planned)

Project Description

The Milford Haven Wave Dragon Pre-Commercial Demonstrator is a floating slack moored wave energy converter with a rated capacity of 7MW. The demonstrator device will be located 2 - 3 miles off the southwest Wales coast, off St Ann's Head, northwest of Milford Haven, on an area of approximately 0.25 km^2. The deployment of the 7 MW Wave Dragon device is the largest undertaking of wave energy deployment to date, and consists of one single device. Unlike other wave energy converters, the Wave Dragon can be scaled up with relative ease compared to multi-MW devices.

The first objective of the project is to prove the feasibility of installing and grid connecting the device at commercial scale, with the intention of undertaking tests and verifying performance for a period of up to five years. The intention would then be to commercialise the development of multiple devices to be deployed further offshore as part of a wave farm or array.

The second objective of the project is to generate clean electricity from a renewable source of energy. The device is intended to be tested for three to five years, and then removed and the site decommissioned. This demonstrator project has been linked to a further development of a 77MW wave energy farm in the Celtic Sea following the successful demonstrator testing.

The demonstration project is being supported by the Welsh Assembly under the Objective 1 initiative and the Welsh Development Agency (WDA) has been supporting the efforts of the project over the last few years. The Welsh Demonstrator project will also host an EC research and development project funded under the Framework Programme 6. Wave Dragon Wales Ltd is backed by KP Renewables Plc who is providing the required co-funding to deliver the project.

Wave Dragon is the offshore wave energy technology that has endured one of the most extensive consecutive testing periods: "A 1:4.5 scale prototype launched in 2003 was the world's first offshore grid-connected wave energy conversion device. Deployed off the coast of Denmark at Nissum Bredning, this test unit has accumulated over 20,000 hours of experience supplying electricity to domestic homes" (www.wavedragon.net)

Timetable:
Announced in April 2007 (www.wavedragon.co.uk/welsh-pre-commercial-demonstrator/eia-statement.html); May - Dec 2007 - final design and procurement; end 2007 - consent applications; Jan 2008 - constructions (initially planned deployment and grid connection was 2008; now delayed to 2009).

The applications for consent were submitted in April 2007. Pending consent, device construction will start and deployment at site is proposed for summer 2009.

Map of southwest Wales with the proposed project location

The Technology

The Wave Dragon is a slack-moored, overtopping wave energy converter. Two curved arms focus waves onto a central ramp which the waves travel up and 'overtop' into a reservoir. At the bottom of the reservoir is a set of low-head hydro turbines, through which the collected water flows back out to sea. The reservoir has a smoothing effect on the water flow, and the turbines are coupled directly to variable speed generators. Since the head of water in the reservoir accounts for the energy, the concept is similar to a hydroelectric power plant.

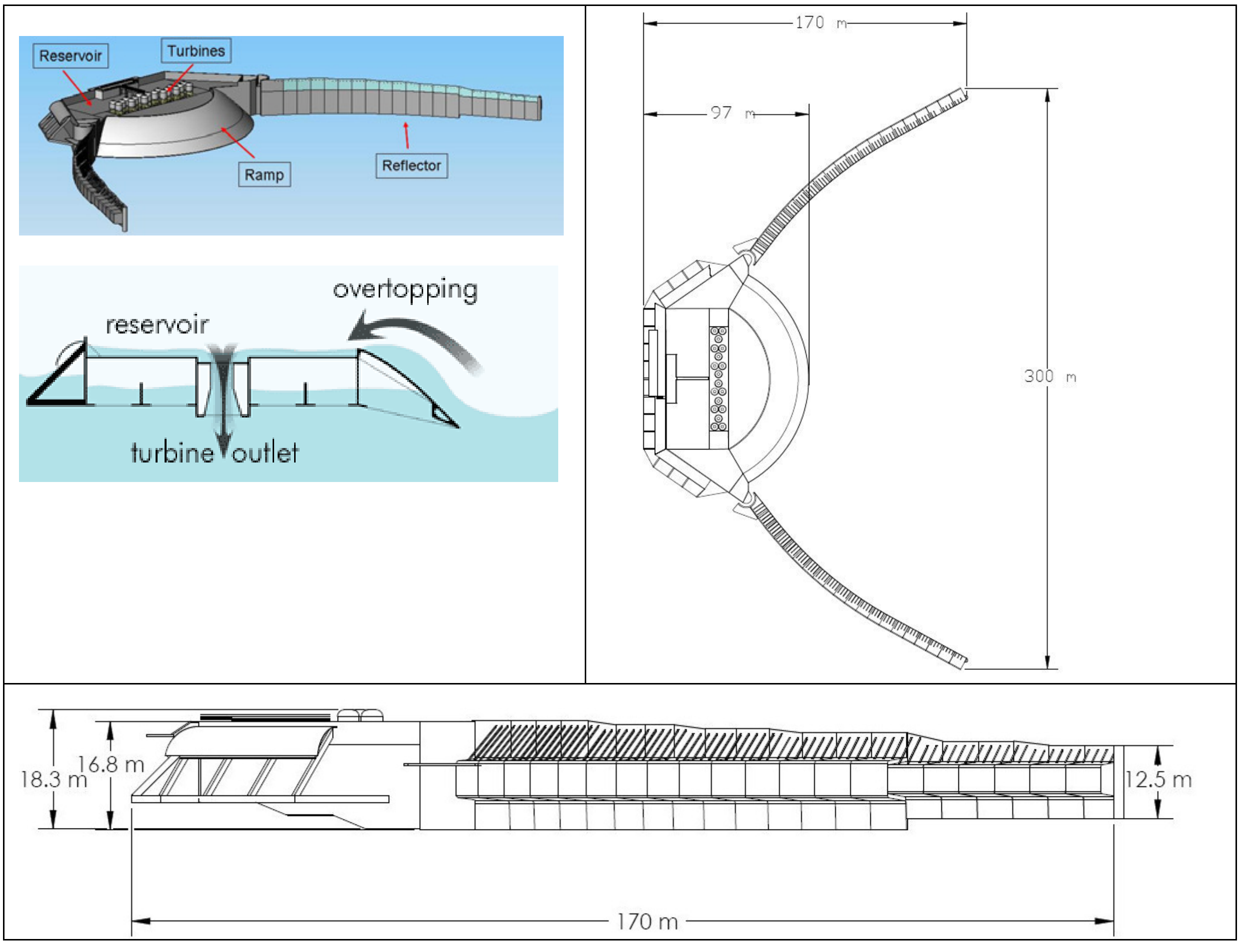
The Wave Dragon consists of three main components:

• Two wave reflectors, attached to the central platform; these act to focus the incoming waves;

• The main platform; a floating reservoir with a double curved ramp facing the incoming waves. The waves overtop the ramp which has a variable crest freeboard 1 to 4 m.

• Hydro turbines; a set of low head Kaplan turbines converts the hydraulic head in the reservoir. These turbines are attached to PMG allowing variable speed operation. The produced electricity is converted using AC/DC/AC power electronic converters to the grid frequency.

Concerns have been raised by potential buyers about the risk associated with the long reflectors and the joint to the platform. The Wave Dragon concept, including the layout of the reflectors and the joint, is well described and tested. To address this concern, however, another reflector layout has been developed. This has an effect on cost and performance profile. This design has shorter reflectors integrated in to the platform structure and has lower energy conversion performance, lower capital costs, and lower risk. These shorter reflectors can be replaced with longer reflectors. This can be done without changes to the Wave Dragon structure or the anchor arrangement and only minor changes to the mooring line arrangement between the CALM buoy and the platform reflectors (see illustration).



Wave Dragon and basic principle of operation (left); Side view of the Wave Dragon (right) and top view (below); *[1]; www.wavedragon.co.uk*

Possible Wave Dragon farm layout (www.wavedragon.co.uk)

Related projects

Wave Dragon Pilot plant 1:4½ deployed in 2003, Denmark, Wave Dragon ApS: a 20 kW, 1:4.5 scale sea prototype launched in Nissum Bredning; power production and O&M tested from 2003 to 2005 and again from April 2006 onwards.

In Portugal, the company TecDragon aims at a 50 MW wave farm composed of Wave Dragon devices in Portuguese waters; advances from this undertaking are not yet known.

The Wave Dragon has similarities with the Swedish technology FWPV (Floating Wave Power Vessel): pilot plant developed and deployed in the 1980s near Stockholm. This project is no longer active. The Norwegian concept WaveSSG (developer Wave Energy AS) is an overtopping concept; prototype only proposed as shoreline-integrated plant. While the current WaveSSG shoreline device might be an interesting niche application for innovative breakwater solutions, the company's statement to develop an offshore (floating) device has not yet been supported by published studies.

Project Partners

Wave Dragon Ltd is the British offspring of Wave Dragon ApS, the Danish company set up for the technology development of the Wave Dragon device. Due to the favourable conditions for prototype development, the activities were shifted to the UK, since the decision for the Welsh demonstrator was made.

Spok ApS is the Danish consulting company whose CEO, Hans Christian Soerensen, has pushed forward the Wave Dragon development to date.

Aalborg University (Denmark) – Civil Engineering Department performed substantial part of modelling and monitoring work, in particular with respect to the Nissum Bredning pilot plant.

Swansea University (Wales) has collaborated in environmental impact and public consultation, as well as electrical issues.

Technica University of Munich (Germany) has been responsible for the development of the special low-head hydraulic turbines used in Wave Dragon technology.

Cost and Financing

To realise this project support has been given from the Welsh Development Agency for three years. Wales has a commitment to renewable energy and to build up experience with this industry. A £5 million (€7.4 million) grant has been awarded by the Welsh Assembly Government as an Objective One project. The project is also supported by the EC 6th Framework Programme.

The Welsh Demonstrator device will initially be deployed in a wave climate much lower than its rated power and size justifies, to allow for proper testing. The demonstrator project has been linked to a 77MW wave energy farm in the Celtic Sea following testing. Significant cost savings can be achieved when a series of reinforced concrete structures and hundreds of turbines are constructed, making it possible to put together a commercial project. The total project investment for this 77MW project is approximately £1,740 per installed kW.

Wave Dragon has been awarded a €2.4 million grant from the European Commission for research related to the Welsh Demonstrator project.

(Friis-Madsen E, Christensen L, Kofoed, JP and Tedd J. Worlds Largest Wave Energy Project 2007 in Wales. Powergen Europe Conference Proceedings, Cologne 2006).

Further Information

www.wavedragon.net

[1] Friis-Madsen E, Christensen L, Kofoed, JP and Tedd J.: Worlds Largest Wave Energy Project 2007 in Wales. Powergen Europe Conference Proceedings, Cologne 2006.

[2] Report prepared by PMSS Ltd to Wave Dragon Wales Ltd, "Wave Dragon Pre-Commercial Wave Energy Device" - Environmental Statement Volume 1: Non-Technical Summary, April 2007

Case Study - The Wave Hub Project (Cornwall/UK)

Project Name	South West England Wave Hub Project
Location	Cornwall cost/ South West of England
Installed capacity	20 MW (4*5 MW)
Technology Type	Electrical grid connection point into which different kind of wave energy technologies can be connected
Project Type/Phase	Dedicated offshore test zone for prototypes
Year	Installation of the Wave Hub is planned for Spring 2010 - a year later than anticipated

Project Description

The proposed Wave Hub infrastructure project is an underwater offshore plug-in facility, to enable wave energy converter device developers to connect their devices to the national grid. The Wave Hub project was proposed by the South West of England Regional Development Agency (SWRDA). It will allow developers the opportunity to test groups of devices over several years to prove the technologies will operate effectively in realistic offshore marine conditions. The Wave Hub approach is expected to bring a number of benefits to developers, including a well defined and monitored site with electrical connection to the onshore electricity grid and a simplified and shortened consent process, reducing the risk for developers of the first pre-commercial wave arrays.

Wave Hub is a sub-sea electrical grid connection point, proposed for installation on the seabed off the north coast of Cornwall on the UK's southwest peninsula. The proposed location for Wave Hub is 20 km northwest of St Ives Bay where the water depth is 50–60m. Wave Hub consists of four separate berths at its offshore site, each capable of exporting 5 MW.

The chosen site is off the North Cornwall coast on the UK's southwest peninsula (see picture), approximately 20 km northwest of St Ives Bay where the water depth is 50–60m. The deployment area occupies an area of 4 km by 2 km. Wave Hub's infrastructure comprises an onshore substation connected to offshore electrical equipment. The offshore electrical equipment includes a termination and distribution unit (TDU; i.e. a 4-way cable splitter), four interconnecting cables, and four power converter units (PCUs; i.e. transformer units) into which devices can be plugged. Wave Hub will be able to generate up to 20 megawatts of electricity; each of the four PCUs can handle up to 5 megawatts.

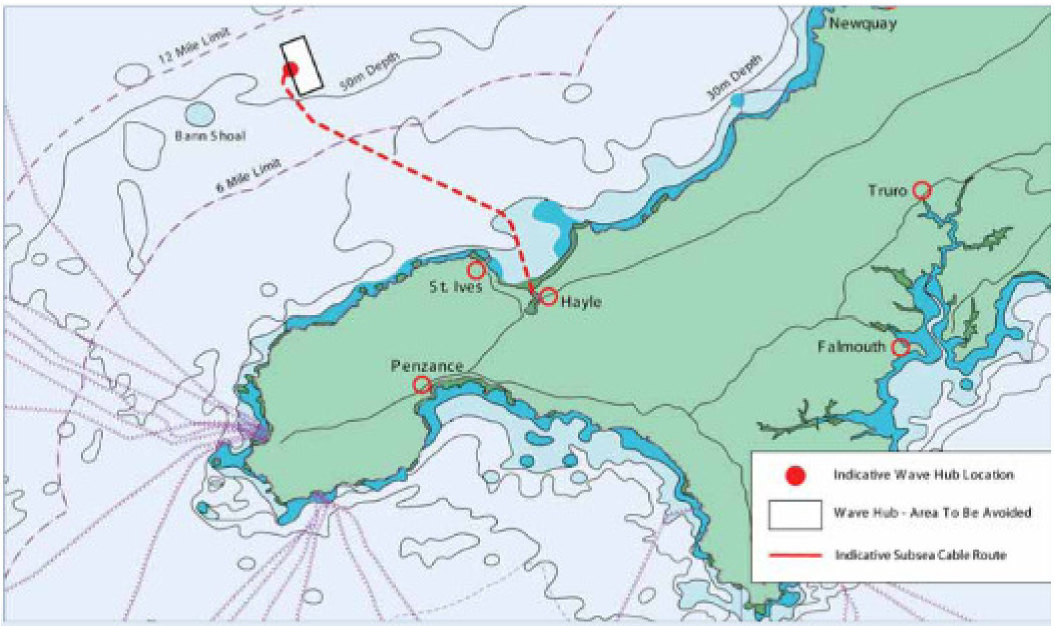
The Wave Hub undertaking is the first initiative of this kind. It is the first large scale wave farm, announced in 2003 and approved in September 2007 by the UK Government, when consent for the Wave Hub was granted.

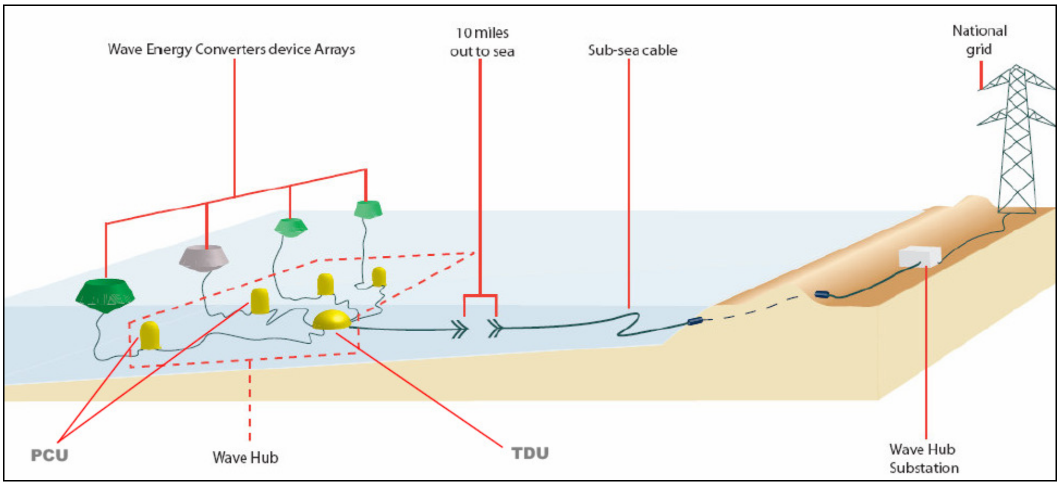
Four device developers have already been selected for deployment Wave Hub; Oceanlinx (Australia; floating OWC), Ocean Power Technologies (USA/UK; heaving buoy), Fred Olsen

(Norway; Multi-point-absorber platforms) and WestWave, a consortium of E.On and Ocean Prospect Limited, using the Pelamis technology of Ocean Power Delivery Ltd.

In April 2008 the SWRDA announced a delay in the Wave Hub implementation schedule. After having received two tenders for supplying and installing the cable and the hub, the offers received were over budget. Construction may now take place in the spring of 2010, with the first power generated by the end of 2010 – one year later than anticipated.

Location of the project (southwest region) and an artist's impression of Wave Hub (*SWRDA - Image by Industrial Art Studio Ltd, St Ives, Cornwall www.ind-art.co.uk)*





Deployment area (above; *South West Wave Hub, Board 5 - SWRDA*) and conceptual illustration of Wave Hub (below; *South West Wave Hub, Board 1 - SWRDA:*)

The Wave Hub project has been supported by a number of studies on the physical environment, environmental impact assessment and conflicts of use. A particular feature of these studies has been to evaluate to what extent the occupied berths might have an influence on the surfing conditions in the nearby coastal areas famous for surf. Intensive discussions with the surfing community have taken place, and although the studies are not yet conclusive, the estimated reduction of wave heights is not expected to have a significant impact on the sport.

Related Projects:

EMEC (European Marine Energy Centre) is the first world-wide offshore prototype test centre, officially opened in Orkney in 2004. EMEC provides multi-berth, purpose-built, open sea test facilities for wave and tidal marine energy converters. The wave test site at Billia Croo, Mainland Orkney receives uninterrupted Atlantic waves of up to 15m, allowing to independently assess devices' energy conversion capabilities, structural performance and survivability. Real-time monitoring of environmental conditions and grid connection and ROCs (Renewable Obligations Certificate) registration are in the scope of EMEC. The Pelamis wave energy converter was tested in 2004 at EMEC, preceding its first commercial contract with the Portuguese project developer company Enersis.

The Portuguese government announced in 2006 the creating of a significant **wave energy pilot zone.** By early 2007, a proposal for a decree-law establishing this zone in central Portugal (offshore S. Pedro de Muel) was released, and finally approved in February 2008. By summer 2008, the market actors were still waiting for the management body to be created, in order to precede the physical establishment of the zone. Using wave hub technology is one possible option for establishing this zone, which is planned to be 80MW (Medium Voltage) as a first phase, in order to be extended by another 170MW (High Voltage), if successful. Updates on the process will be published at www.wave-energy-centre.org .

The Bask Autonomous region is working on the physical establishment of a **real-scale offshore wave test site** with an installed power rating of 20 MW, to be launched by 2009. Further plans for real-scale wave energy test sites exist in **Ireland**, **France** and **Norway**.

Project Partners

The Wave Hub project was proposed by the South West of England Regional Development Agency (SWRDA). The Peninsula Research Institute for Marine Renewable Energy (PRIMaRE), a joint venture between the Universities of Exeter and Plymouth, will also work with the Wave Hub project.

SWRDA:	http://www.southwestrda.org.uk/
PRIMaRE:	http://www.primare.org/
University of Exeter*:*	http://www.exeter.ac.uk/
University of Plymouth:	http://www.research.plymouth.ac.uk/marine/

Cost and Financing

The total project cost is estimated at £28 million for 20MW capacity; BERR has committed £4.5 million to the project, and planning consent was announced by Ministers in 2007.

The South West RDA approved (2007) £21.5 million to construct Wave Hub.

Further Information

Link to developer/company website: www.wavehub.co.uk

Sources:

[1] Press RELEASE April 1, 2008: "RDA sets new timetable for Wave Hub"

[2] Press RELEASE September 17, 2007: "Government go-ahead for Wave Hub project"

[3] South West of England Regional Development Agency Wave Hub, Non-Technical Summary, June 2006, prepared by Halcrow Group Limited for the South West of England Regional Development Agency

[4] South West of England Regional Development Agency: Wave Hub Development and Design Phase, Final design report, June 2006, prepared by Halcrow Group Limited for the South West of England Regional Development Agency

4.9. Test Your Knowledge

Learning Outcomes - Wave

Level	Wave
Basic[1]	On successful completion of this module you will be able to: • Understand the physical processes that result in the formation of waves and the factors which affect this resource (wind speed, its duration, and the distance of water over which it blows (the fetch) • Understand that wave energy is a renewable resource • Recognise that tidal energy resources are widely but not evenly distributed across Europe • Recall the main technology types currently being tested to extract wave energy • Identify the different project phases such as Design and Planning, Construction and Installation, Operation and Management, and Decommissioning • Understand the importance of taking into consideration all of these phases when evaluating the impacts and feasibility of a particular development • Explain how energy extraction leads to a number of possible interactions (both positive and negative) with the surrounding environment • Understand that the surrounding environment includes physical processes, wildlife and habitats, conservation interests, communities and social features, as well as commerce and economic activities • Outline how these negative impacts can be minimised • Name specific examples where wave energy devices are being tested
Intermediate	On successful completion of this module you will be able to: • Describe key developments in the development of wave energy • Describe in general terms the process by which waves are formed • Outline the different categories of wave energy devices • Describe the factors which affect wave resources • Describe the different technology types used to extract energy from tidal streams • Outline the basic steps involved in energy conversion by a tidal energy converter • Outline the important factors in each phase of projects for the different technologies • Describe factors important in the operation and maintenance phase of the project • Describe the various impacts and opportunities associated with the technology • Outline the key types of environmental interactions associated with aquatic renewable technologies • Explain how environmental interactions may change through a project lifecycle, in different locations and at different times • Outline some of the factors which influence the overall cost of the project for the different technologies • Describe specific examples where wave energy devices are being tested

[1] **Basic –** Equivalent to EQF (European Qualification Framework) Level1 and Bloom's Taxonomy "Knowledge" category. This level requires the student to have basic general knowledge of the subject, be able to recall important information.

Intermediate – Equivalent to EQF level 2 and Bloom's Taxonomy "Comprehension" category**.** This level requires the student to be able to explain basic factual knowledge.

4.9.1 Quiz

Answers are given in the footnote[2]

Q1 The use of wave as an energy source has been used:

a) Has been used for thousands of years

b) Is currently been developed as an energy source

c) For hundreds of years and is now a fully commercial scale energy source

d) Has not yet been tested

Q2 Wave energy is derived from:

a) The rise and fall of the tides caused by the gravitational pull of the moon and the sun on the seas

b) The hydrological cycle

c) Winds blowing over the surface of the sea

d) Geothermal energy contained within the core of the earth

Q3 The wave resource is dependent on:

a) The wind speed

b) The duration of the wind blowing over the sea

c) The distance over which the wind blows (the fetch)

d) All of the above

Q4 Choose the two words which best complete this sentence.

Nearer the coastline, wave energy _________ due to friction with the seabed; therefore waves in deeper well exposed waters offshore will have the ________ energy.

a) Decreases, greatest

b) Decreases, least

c) Increases, greatest

[2] 1b, 2c, 3d, 4a, 5b, 6b, 7c, 8b,

d) Increases, least

Q5 The following are types of wave energy device:

a) Venture effect device, reciprocating device (oscillating hydrofoil), horizontal axis turbine

b) Attenuator, point absorber, overtopping device

c) Weir and diversion type plant

d) Solar panels

Q6 An oscillating water column is one which:

a) Has an arm which pivots back and forth like an inverted pendulum due to the movement of the water particles in the waves

b) Uses air trapped above an oscillating water column to drive an air turbine

c) Uses the pressure differential caused by the wave to drive the device vertically in the water column to generate power

d) The waves break over the top of the device into a storage reservoir and the water is used to drive a low-head turbine

Q7 The following is an example of where wave energy devices are being tested:

a) Anatoliki, Greece using a 700kW “Pelton-2” turbine

b) Yell Sound, Shetland Islands, Scotland device using a 150kW reciprocating hydroplane device

c) Aguçadoura, Northern Portugal device using a 3 x 750kW Floating articulated attenuators

d) La Rance Estuary, France using 24 x 10MW low-head bulb type turbines

Q8 The following is an impact associated with extraction of wave energy:

a) Reduced tidal range leading to potential decrease in number of intertidal species

b) Reduced wave action leading to potential changes in intertidal and sublittoral habitats

c) Changes in river flow patterns leading to potential disruption to protected migratory fish routes

d) Reduction on tidal current energy leading to potential increase in sediment settlement downstream of the device

4.10. Further Information

Wavenet - Results from the work of the European Thematic Network on Wave Energy; ERK-CT-1999-2001, European Community, March (2003): very comprehensive but partly outdated document on virtually all aspects relevant to wave end tidal energy implementation in Europe www.wave-energy.net/Library/WaveNet%20Full%20Report(11.1).pdf

Future Marine Energy (2006): with based on the results from the Marine Energy Challenge program (carried out by Carbon Trust): *Comprehensive and actual document on the status and prospects of marine renewable energy technologies in the UK and beyond, focusing on economic factors.*
www.thecarbontrust.co.uk/Publications/publicationdetail.htm?productid=CTC601

Review and analysis of ocean energy systems development and supporting policies (2006): Sustainable Energy Ireland for the IEA's Implementing Agreement on Ocean Energy Systems 28th June 2006. Report elaborated by AEA Technologies. *Compiles some relevant info on the marine energy context country by country within IEA-OES, in a partly comparative way. Contains little details or new expertise, but gives a generic overview of ocean energy systems status.* http://www.iea-oceans.org/_fich/6/Review_Policies_on_OES_2.pdf

Marine Renewable (Wave and Tidal) Opportunity Review (2005) produced by Scottish Enterprise: *Comprehensive but concise description of wave and tidal energy technologies on the background of providing information to potential supply companies.* www.scottish-enterprise.com/publications/marine_renewable_opportunity_review.pdf

IEA-OES Annual Report – Implementing Agreement on Ocean Energy Systems of the International Energy Agency: *Annually updated summary of most relevant activities in the ocean energy sector in the participating countries of IEA-OES* www.iea-oceans.org/publ/index.htm.

Ocean Energy Conversion in Europe (2006), produced by the EU funded network Coordinated Action on Ocean Energy Project (CA-OE): *Descriptive short introduction to wave and tidal energy research and pilot plants activities in the European Union*
http://www.wave-energy.net/index_files/documents/CA-OEBROCHURE.pdf

Performance Assessment for Wave Energy Conversion Systems (2005):, EMEC: *first attempt of a proposal for a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of power performance of wave energy conversion systems, having in view potential demands of purchasers, grid operators, planners and operators*
www.emec.org.uk/pdf/EMEC_Performance_Assessment.pdf

Guidelines on design and operation of wave energy converters (2005), prepared by Det Norske Veritas (DNV) and published by Carbon Trust: *comprehensive document suggesting wave energy standards that has been circulated among the research community before publication. Addresses virtually all engineering fields relevant for wave energy, however must be considered as a first attempt*
www.dnv.com/binaries/WECguideline_tcm4-181675.pdf

Technology White Paper on Wave Energy Potential on the U.S. Outer Continental Shelf (2006): *made by the U.S. Department of the Interior ; showing that wave energy efforts have taken a global dimension by today*
http://ocsenergy.anl.gov/documents/docs/OCS_EIS_WhitePaper_Wave.pdf

Strategic Environmental Assessment (SEA): . *The report produced by the Scottish Executive about the follow-up of environmental impacts studies from Wave Energy in the Scottish West Coast; quite complete, has been in public consultation process*
www.seaenergyscotland.co.uk/