Guernsey Renewable Energy Team

PB & MD 27/07/11

Status of Wave Energy Technology

Executive Summary

Background

The Guernsey Renewable Energy Team (RET) is looking into the possibility of developing renewable energy in the waters surrounding Guernsey. Having released the REA of marine energy and having commissioned a tidal resource assessment it was decide to look in greater detail at the state of the wave industry.

The States of Guernsey have been investigating the potential for renewable energy deployment within its waters since 2008, with the States Energy Report of June 2008 and the subsequent establishment of shadow Guernsey Renewable Energy Commission (GREC) (Now RET). The focus of attention was, initially, the Bailiwick's considerable tidal energy resource.

The main aim of this report is to investigate whether the perception that wave technologies are less developed than tidal is valid by looking at the state of the industries from technological, developmental and financial perspectives.

The Technology

There are numerous possible methods for extracting energy from waves, and very few of them are analogous to familiar energy conversion systems. The number of different technologies and their often unintuitive modes of operation give the impression that the wave energy industry is dominated by eccentric thinkers and there may be a negative reaction to this.

The UK has a current installed capacity of 1.31 MW of wave energy capacity. Whilst this is cause for optimism, the focus is still on individual devices, and not full-scale arrays, and this seems to match the progress being made in the development of Tidal Stream devices although some progress is being made on plans (still not in the water) for small arrays for tidal – e.g. Islay plans for a 10MW deployment.

Most of the wave developer organisations are either in a programme of device testing at EMEC, or have already completed trials there or elsewhere. This gives the impression of an industry that is ready to move from individual prototype device testing to multi-device arrays.

The Crown Estate is owner of the UK seabed out to the 12 nautical mile territorial sea limit. To date, it has "helped establish test and demonstration facilities for wave and tidal energy devices off Orkney (the European Marine Energy Centre) and Cornwall (Wave Hub)" and it has "held a leasing round for sites in the Pentland Firth and Orkney waters, resulting in 1,600 MW of planned projects. This covers both wave and tidal developments.

Current Status of Device Technologies

This review of information indicates that the four front-runners in wave energy development are at a similar stage of development as the leaders in the tidal energy device market; that is, there are several devices that are at the stage of full-scale prototype deployment. The Device Readiness Levels, based on the NASA scale (a recognised technology readiness scale devised by that National Aeronautics and Space Administration (NASA), of each of the lead devices, of lead devices, including both wave and tidal stream devices, may be scored as follows:

Development Organisation	Device	Technology Readiness Level
Wave Energy Development		
Aquamarine Power	Oyster	7
Pelamis Wave Power	P2	7
Ocean Power Technologies	PowerBuoy	7
Voith Hydro Wavegen	Wavegen	9
Tidal Stream Development		
Tidal Generation Ltd		7
Atlantis Resource Corporation	AK1000	7
Open Hydro Tidal Technology	Open-Centre Turbine	7
Marine Current Turbines (MCT)	Sea Gen	9

Risk

There are a number of factors that affect how “risky” a development is in any industry, and Oxera (independent consultants) have undertaken a report into the discount rates for low carbon generation, which in part looks at risk. Both wave and tidal are deemed high risk but Wave (floating) is only slightly higher risk than tidal (stream). The perceived high risk and resultant high cost of capital may be preventing investment in the wave sector. The Oxera report found that generally the most significant factor affecting the perceived risk is the maturity of the technology. With installations planned over the next few years it is likely this risk perception will fall.

Economics of scale

Whilst tidal energy may continue to be perceived as leading wave energy, this may only be a temporary situation, and the eventual emergence of a mature wave energy industry is likely due to the scale of the energy resource available. Globally, the number of exploitable tidal energy resource areas is limited, with many in north-western Europe and Canada. Conversely, the Wave Energy resource is spread throughout the world, and is much bigger. In ‘Renewable Energy: Power for a Sustainable Future – Godfrey Boyle’ (2004) total raw exploitable tidal stream resource in UK waters of 36TWh/yr is indicated, and this should be compared with 260TWh/y for Wave energy. Therefore, any early expansion of tidal energy development must reach a limit long before wave energy has been fully explored and harnessed.

Costs

From recent reports of cost predictions for the wave and tidal industries, it appears that the two technologies are of similar cost magnitudes, with tidal marginally the cheaper in the foreseeable near future. In the medium to long term the gap may reduce, or even favour wave due to the larger resource available globally.

Conclusions

Wave and tidal technologies are not very far apart in terms of technology and costs. Looking at NASA’s Technology Readiness Levels, costs reports illustrate this. Potential deployment times are also similar.

Introduction

The Renewable Energy Team (RET) has been asked to provide a brief report into the current status of the wave energy industry and its relevance to Guernsey's ongoing pursuit of renewable energy. This is against the background of the work undertaken to date that is recorded in the Regional Environmental Assessment (REA) of July 2010.

The REA provided the first stage of the environmental assessment process for both wave and tidal energy within Guernsey's territorial waters. It confirmed that there was, in all probability, an exploitable resource for both types of development.

The development of tidal energy converter devices has made significant steps towards commercialisation. It is possible that there is a perception that the tidal energy industry is closer to full-scale commercial deployment than wave energy, and therefore should be prioritised. This report will consider the perception that wave energy development lags behind tidal energy and whether it is supported by evidence.

The discussion focuses primarily on UK and European technology. Whilst development in marine renewables exists elsewhere in the world, this lags behind Europe and particularly the UK.

Previous Investigations into Marine Renewables on Guernsey

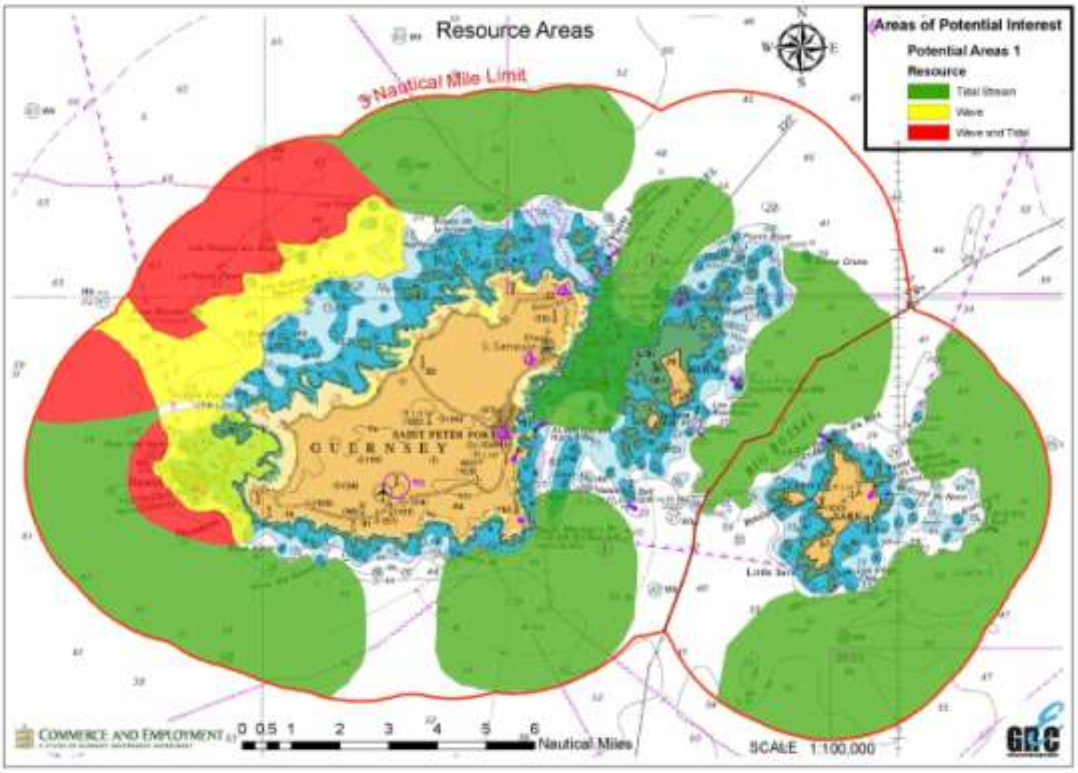
The States of Guernsey have been investigating the potential for marine renewable energy deployment within its waters since 2008, with the States Energy Report of June 2008 and the subsequent establishment of shadow Guernsey Renewable Energy Commission (GREC). The focus of attention was, initially, the Bailliwick's considerable tidal energy resource. Early work included the undertaking of a Regional Environmental Assessment. It was during the scoping of this study that wave energy was also considered within the assessment. It was considered valuable to incorporate wave energy within the scoping because there is likely to be a viable resource available for energy extraction and due to the following aspects that were perceived to be common to both wave and tidal devices:

- The technical and environmental constraints
- The environmental impacts
- The offshore and onshore infrastructure requirements
- Costs of energy
- The progress made by the industry towards commercial scale deployment
- The requirements for port facilities

The conclusions of the REA broadly supported the above perceptions, but with the following exceptions:

- The areas of potential energy resources were different, with the strongest tidal energy resource located east of Guernsey (predominantly in the Big Russel) and the wave energy resource located on the north-west coast.
- Unlike the tidal resource, the wave energy resource has not been proven with any modelling or site-specific data and there is significant reliance on data from remote weather stations.
- At an annual average of 15kw/m length of wave crest, the estimated wave energy resource is at the low end of the range considered appropriate for development.
- Some types of near-shore and onshore wave devices would present a greater landscape impact than offshore types or fully submerged tidal devices.

Figure 1 – Potential Resource Areas



Current Perceptions

It has been acknowledged by the Renewable Energy Team that on Guernsey, with its obvious energy resource located close to its shores, there has been a focus on tidal energy as the main marine source of renewable energy. This has been, perhaps, at the expense of developing opportunities for wave energy production. The remainder of this report will consider the perception that wave energy development lags behind tidal energy and whether it is supported by evidence.

On 19th October 2010, the Institute of Mechanical Engineers (IMechE)[1] held a conference on 'Ocean Power Fluid Machinery' for device developers and academics in London. Tom

1 http://www.imeche.org/Home

Thorpe of Oxford Oceanics presented a lecture on the subject of ‘The status and prospects for Wave Energy Technologies’. Mr Thorpe indicated that there were more than 1000 patents for devices or device components linked to the wave energy industry, and that more than 100 devices are currently in various stages of development.

With regard to tidal devices, there are a limited number of means of extraction, and the majority involve blades on a rotating axle. Of these, the majority operate with an axle that is aligned with the direction of tidal flows and are known as ‘turbines’. Such technology and this mode of operation is very familiar to many people, whether or not they have a scientific or engineering background.

Conversely, there are many possible methods for extracting energy from waves, and very few of them are analogous to familiar systems. The number of alternative technologies may give the impression that the wave energy, industry is dominated by creative thinkers and there may be a negative reaction to this.

Another factor that may add to the negative perception of the marine renewable industry, and particularly wave energy, is the sheer scale of the devices in relation to their energy output. Below is a picture of the Ocean Power Technologies PB-150 Powerbuoy on-shore for maintenance, with a technician on the yellow float unit in the right of the picture. Next to it is a picture of an Audi A4 family car. Both devices have power converters rated at 150kW.

	
Figure 2 - OPT PB-150 Powerbuoy (RenewableUK - 'Wave and Tidal Energy in the UK - State of the industry report'.)	Figure 3 -Audi A4 with 3.0ltr Diesel Engine (www.mtm-online.de)

The remaining sections of this paper will make reference to evidence from a number of respected sources and consider the evidence to support or challenge these perceptions.

Reference Documents and Sources of Information

EMEC Website (www.emec.org.uk)

The European Marine Energy Centre (EMEC) was established by the Scottish Government in 2004 to provide facilities to support the testing of wave and tidal energy converters. EMEC also undertakes research and develops standards on behalf of the industry. It runs a website that is an excellent resource for those studying marine energy. The website identifies the various types of Wave Energy Converter (WEC) that are in development and their mode of operation. Also, it lists the following key stages in the development and deployment of device technology.

EMEC WEC Development Stage	Description	NASA Technology Readiness Level
1	Concept for a Wave or Tidal Energy Converter	1-2
2	Access Kick Off Funding (eg. Carbon Trust Marine Renewables Proving Fund (MRPF))[2]	
3	Utilise Research Providers (eg. University connected research institutes such as the Peninsula Research Institute for Marine Renewable Energy (PRIMaRE) connected with Exeter and Plymouth Universities)[3]	3
4	Access Applied Research Funding (eg The Carbon Trust Applied Research Fund)	
5	Develop Design Utilising Engineering Expertise (eg. Halcrow, Global Marine)	4
6	Access Development and Demonstration Funding (eg. NER 300)	
7	Tank Testing	5
8	Scale Test Facilities (e.g. the National Renewable Energy Centre (NaREC)[4])	6
9	Full Scale Test Facilities (eg. devices installed at EMEC)	7-9
10	Full Scale Semi-Commercial Deployment (e.g. Wavehub)	
11	Full Scale Commercial Deployment (eg. Pentland Firth)	

The numbers in the right hand column above reflect the corresponding Technology Readiness Levels, which is an alternative measurement to assess the maturity of evolving technologies, developed by NASA, and adopted by the marine renewables industry to evaluate progress towards commercial deployment.

[2] http://www.carbontrust.co.uk/SiteCollectionDocuments/Various/Emerging%20technologies/Current%20Focus%20Areas/Marine%20Proving%20Fund/MRPF%20Brochure.pdf

[3] http://www.primare.org/

[4] http://www.narec.co.uk/

NASA Technology Readiness Levels

Applied & Strategic Research

1. Basic principles observed and reported
2. Technology concept and/or application formulated
3. Analytical and experimental critical function and/or characteristic proof of concept
4. Component and/or partial system validation in a laboratory environment

Technology Validation

5. Component and/or partial system validation in a relevant environment
6. System/subsystem model validation in a relevant environment

System Validation

7. System prototype demonstration in an operational environment
8. Actual system completed and service qualified through test and demonstration
9. Actual system proven through successful mission operation

It is important to note that in the UK, due to the historic high risk and low rates of return on investment in research and development of marine renewables technologies, much of the development through readiness levels 1 to 8 has been funded through government grants.

RET Database of Device Developers

Since the production of the REA, the States of Guernsey's Commerce & Employment department has maintained a database of device developers. Information has been gained from reviewing developer websites and the technical press and through correspondence and phone conversations. As such, some of the information records the progress that each of the major developers has made towards commercial production. Some of the information is commercially sensitive and the developers have requested that this remains confidential. The database is summarised as Appendix A of this paper.

RenewableUK

In March 2011, the trade association RenewableUK published 'Wave and Tidal Energy in the UK - State of the industry report'. This provides a summary of progress, with input from many of the leading device developers. In its role as the trade association for marine and other forms of renewable energy, RenewableUK is perhaps duty-bound to promote aspects that imply that an advanced status has been reached. However, the RenewableUK report is still a comprehensive review of the industry and a useful source of information for this brief note.

The Renewables UK report refers to progress in the marine industry with particular mention of:

- testing of full-scale prototype devices (at EMEC)
- significant activity in the R&D of innovative technologies
- some devices maturing to the pre-commercial stage (forthcoming deployment at Wave Hub)

The review was based on a survey of key organisations to understand developer appetite for project development. Wave Energy contributors to the survey included:

- Aquamarine Power
- Pelamis Wave Power
- Ocean Power Technologies
- Voith Hydro Wavegen

The report includes status reports on device development from these and other developers. But, these four developers are perceived as the front-runners that either have already deployed a commercial-scale prototype, or are in the final phases of doing so.

Current and Planned UK Installed Capacity

The UK has a current installed capacity of 1.31 MW of wave energy capacity.

- Scottish Power Renewables has placed an order with Pelamis Wave Power for a 0.75MW P2 second-generation machine at EMEC.
- Aquamarine Power is fabricating an upgraded 0.8MW Oyster 2 device, also for deployment at EMEC in summer of 2011.
- Ocean Power Technologies has developed its PB150 Powerbuoy at Invergordon in Scotland and will conduct preliminary proving trials at a temporary site in the Moray Firth, and this will be the fore-runner to a larger device for use at Wave Hub.

The focus is on individual devices not full-scale arrays, and this seems to match the progress being made in the development of Tidal Stream devices although progress has been reported of plans (still not in the water) for small arrays for tidal and wave.

The 4MW Siadar On-Shore Wave Energy project between RWE npower renewables and Voith Hydro Wavegen, on the Isle of Lewis, is scheduled to be completed by 2013 and a total of 60MW (wave and tidal) is within the various planning application processes for deployment by 2015.

Wave Hub

Many companies are currently developing technologies to extract this renewable energy from the sea. However, the financial capacity of many companies in this development phase is limited and the South West Regional Development Agency (SWRDA) identified the need for assistance during the demonstration stage to ensure that the industry crosses the gap between the development phase and full commercial deployment and reaches maturity.

Wave Hub is intended to facilitate WEC development through final demonstration and pre-commercialisation development stages by allowing developers to install, operate and monitor commercial-scale WECs in realistic offshore marine conditions over a number of years. In this respect, Wave Hub will perform the function of a WEC proving zone. Wave Hub consists of a 20MW rated offshore electrical “socket” connecting wave energy converters to the national grid. It also provides a suitable offshore wave energy deployment site with a fully monitored wave climate and with a simplified route to permitting and consenting. The Wave Hub itself was consented in 2007 and constructed in 2010.

Since completion of construction, only one of the four 5MW rated 2kmx1km berths has been allocated; to Ocean Power Technologies to use with an array of their Powerbuoy WECs. Deployment of devices was scheduled for Autumn 2011, but this seems likely to be delayed due to consenting requirements.

A key driver for the development of the Wave Hub was that it would “Meet a stated market need”. The lack of progress in uptake of places at Wave Hub indicates that something is obstructing further expansion of the wave energy industry. The possible reasons for this obstruction are discussed later in this report.

Crown Estate

The Crown Estate is owner of the UK seabed out to the 12 nautical mile territorial sea limit. Whilst the Crown Estate does not own the seabed around any of the Channel Islands, its attitude towards the development of marine renewables is instructive and the Crown Estate plays an important part in development of the UK’s renewable energy industry.

Its website states that it is “committed to working with industry, government and other stakeholders to realise the UK’s renewable energy targets and as part of this, successfully exploit the country’s significant wave and tidal energy resources.”

To date, it has “helped establish test and demonstration facilities for wave and tidal energy devices off Orkney (the European Marine Energy Centre) and Cornwall (Wave Hub)” and it has “held a leasing round for sites in the Pentland Firth and Orkney waters, resulting in 1,600 MW of planned projects. Further leasing activities are currently underway, including in Scottish waters to give companies further opportunities to compete for the Saltire Prize, unique international challenge that will confirm Scotland’s ambition to become the leading force in clean, green, marine energy. The prize winner will be the team that achieves the greatest volume of electrical output over the set minimum hurdle of 100GWh over a continuous two year period, using only the power of the sea. We are inviting industry views on leasing in Northern Irish waters. Developers planning demonstration projects may also apply to us for demonstration leases.”

Like many organisations, the Crown Estate does not differentiate in its support for both tidal and wave energy. The development of both forms of marine renewables should not be obstructed by a lack of leasing opportunities.

On Guernsey, it is likely that the Commerce & Employment Department will act in a role similar to the Crown Estate in the UK, in that it will manage the seabed and energy resources on behalf of the Crown’s HMRG (Her Majesty’s Receiver General). In Sark, this role may be taken by the Finance and Commerce Committee of Chief Pleas.

Department of Energy and Climate Change (DECC)

A report in October 2010 to DECC by Ernst and Young entitled “Cost of and financial support for wave, tidal stream and tidal range generation in the UK”[5] suggests that both tidal stream shallow (≤30m) and wave devices are, **on a global scale**, progressing at a similar rate, with both anticipated to have large scale demonstration projects installed by 2014. The report also suggests that wave could reach commercial scale in 2016, with 2017 suggested for tidal stream shallow technology. It is also suggested that deep water (>30m) tidal stream could start to play a part by 2018, which would increase the exploitable areas for tidal energy.

BVG Report for the Crown Estate (Pentland Firth)

BVG Associates were appointed by the Crown Estate to assess that impact that the completed leasing round at the Pentland Firth would have on the supply chain. Their report “Wave and Tidal energy in the Pentland Firth and Orkney waters: How the projects could be built”, was published in May 2011[6].

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5 http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Renewable%20energy/explained/wave_tidal/798-cost-of-and-finacial-support-for-wave-tidal-strea.pdf

6 http://www.thecrownestate.co.uk/pentland_firth_how_the_projects_could_be_built.pdf

There has been particular concern in Scotland that suppliers are given ample notification of the planned expansion in manufacturing and deployment activities. The leasing round has led to a firm commitment to deploy 600MW of capacity by 2020.

Capital costs are estimated by BVG to be approximately £3.5M/MW and Operation & Maintenance costs at approximately £220k/MW/p.a (6% of capital cost). These figures are based on large-scale deployment, rather than individual arrays. If Guernsey wishes to progress with a policy of waiting for the marine renewables industry to mature prior to deployment in its waters, then these figures are relevant to its own economic analysis. The reporting of wave energy development was based on the programmed activities of 5 developer consortia at 6 sites.

Most of the developer organisations are either in a programme of device testing at EMEC, or have already completed trials here or elsewhere. This gives the impression of an industry that is ready to move from individual prototype device testing to multi-device arrays.

However, the proposed deployment at Pentland Firth will not be immediate. It can't be, as there is not yet sufficient grid capacity. But also, and importantly, it will take some time for the supply chain to adapt to the workload of manufacturing devices on a large scale. **Serious production-line manufacturing will not start until 2016 and will not peak until after 2019.**

The BVG report does not differentiate between the overall costs of wave vs tidal energy. It is likely that this is because it has been required to present an impartial report into the overall impact on supply chain management, but it is also likely to be the case that wave and tidal technologies will have similar overall costs. It is clear that, per MW installed capacity, Wave devices will be larger and heavier than tidal, but this will be offset by reduced foundation costs and ease of deployment. Furthermore, the costs of infrastructure such as cables, navigational safety measures, landfall and control systems will be similar. For the purposes of this report, it is assumed that wave and tidal energy will be the same through these early stages of the development of the marine renewable energy industry.

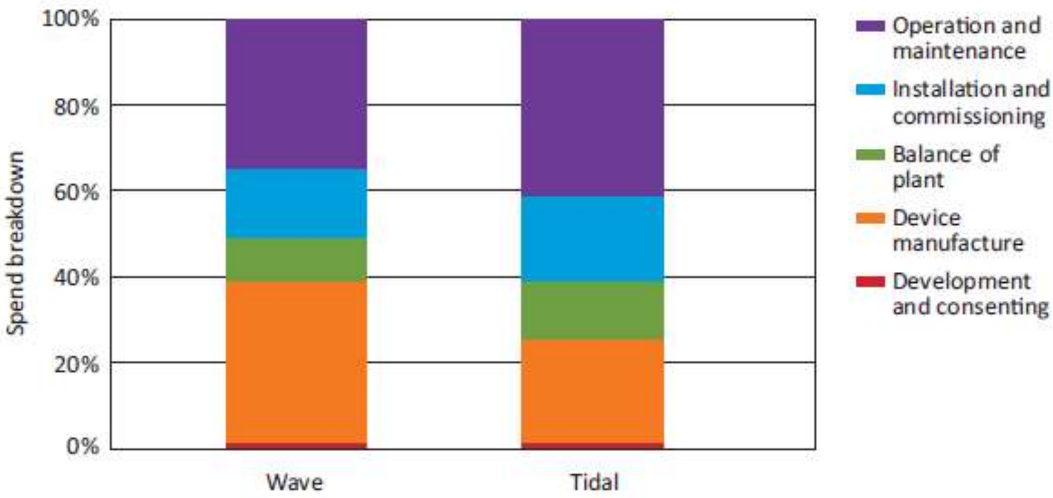

Figure 4 Undiscounted cost breakdown for Pentland Firth and Orkney waters projects

Current Status of Device Technologies

This review indicates that the four front-runners in wave energy development are at a similar stage of development as the leaders in the tidal energy device market, in that there are several devices that are at the stage of full-scale prototype deployment. The Device Readiness Levels, based on the NASA scale, of each of the lead devices may be scored as follows:

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Open Hydro Tidal Technology	Open-Centre Turbine	7
Marine Current Turbines (MCT)	Sea Gen	9

Constraints to Development and a comment on the likely Guernsey position

There has been much discussion in the South West of England as to why the Wave Hub project has firm proposals to fill only one of its four berths for wave energy devices. This reflects a wider concern that development may not have progressed at the speed envisaged when Wave Hub was conceived, despite significant government funding in the UK. This section describes the known potential constraints to development and the actions that have been taken to overcome these.

Test facilities – Prior to the development of the wave hub project, it was considered that there were adequate concept and prototype test facilities in the UK. These included the National Renewable Energy Centre (NarREC) and the European Marine Energy Centre (EMEC). These two facilities allow devices to be tested at all scales up to full-size prototypes. Both centres have expanded recently, with further wave sites established at EMEC and powerful 3MW drive-train test system in planning at NaREC. Further test facilities for early stage development are under construction at PRIMaRE in Plymouth and in an offshore environment at Falmouth.

Grid Connection – Both EMEC and Wave Hub are grid-connected to capacities that are appropriate for their purposes, so this does not limit their use. Elsewhere, grid connection is a limitation to some of the sites being considered for the Scottish Government's £10M Saltire Prize demonstration initiative, and a lack of grid capacity is one of the limitations to early capacity building at Pentland Firth. On Guernsey, a number of possible cable-routes, landfall sites and connecting substations have been identified. With a centre of population located close to the energy resource, grid connection is not considered a constraint on Guernsey.

Consenting – In reaction to criticism from developers, UK environmental consenting authorities have taken steps to streamline their processes to get as close to a 'one-stop-shop' as possible without compromising legal requirements. Despite this, Tidal Energy Ltd have recently taken 9 months to achieve a positive determination for a single-device deployment in Pembrokeshire. The Wave Hub site itself is already consented, and developers only need to provide device specific noise and navigation impact assessments to complete the process. On Guernsey, primary and secondary legislation is being developed to manage a consenting or licensing process, and hopefully will not be a constraint to development.

Knowledge / research – A number of well-funded research initiatives have been established in recent years. These include the Peninsula Research Institute for Marine Energy (PRIMaRE) and The SuperGen Marine Research Programme, funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Low Carbon Research Institute in Wales. It is not likely that a lack of research opportunities presents a constraint to development.

Supply chain – Whilst suppliers engaged with Wave Energy development are limited in number, this may be as a result of constraints, rather than a cause of slow progress. Many organisations within the marine construction industry could quickly adapt to marine renewable energy supply chain availabilities, as has been proven in the offshore wind industry. There is an acknowledged over-capacity in marine engineering throughout the UK, and existing port facilities are actively seeking clients in the renewables sector. Ports that would be suitable for manufacture, assembly and deployment include Falmouth, Devonport and Pembroke. Whilst Guernsey does not and is not likely to have sufficient port facilities to enable fabrication of wave energy devices, Guernsey's harbours will be able to provide for and accommodate inspection and maintenance vessels.

Available deployment sites – The west coast of the UK, Ireland and the Channel Islands have a large wave energy resource, as identified by the Wave Hub project and shown on the Renewable Energy Resource Atlas commissioned in 2007 by the Department of Business, Enterprise and Regulatory Reform (BERR – now disbanded and energy policy handed to DECC). Some of these areas may be partially constrained by other marine activities (e.g. military training areas, shipping routes, etc.) and some may clash with environmental protection areas. However, the successful deployment of the Wave Hub project and two successful planning applications in Wales (MCT Anglesey and TEL in Pembroke) indicates that this is not a significant problem, even in environmentally sensitive areas. On Guernsey, the REA concluded that, in all probability, a suitable wave energy resource does exist. However, further work would be required to properly assess this based on actual site measurements.

Finance – In the UK, electricity distributors are incentivised to purchase renewable energy through the Renewable Obligation system, by which Renewable Obligation Certificates (ROC's) are traded in addition to the actual market price of electricity. The current value of a ROC is estimated as 5p/kWh or £50/MWh. In England and Wales 2 ROCs are issued for each unit (MWh) of electricity produced for both Wave and Tidal energy. RET's own analysis and informal discussions with BVG indicate that, whilst in the long term, 3 ROC's may be sufficient to justify investment in marine renewables, 5 ROC's will be necessary to stimulate the early stages of commercial-scale development. The UK Government is due to review the Renewable Obligation in autumn 2011, and the trade association RenewablesUK has strongly recommended that the rate for both Wave and Tidal energy be increased to 5 ROC's per unit. It is likely that the UK Government, which has proclaimed itself to be the 'greenest government ever' will raise the rates according to the advice given and this should release this significant blockage to development.

On Guernsey, there is currently no mechanism to incentivise the distributor (GEL) to purchase renewable energy. In fact, the existing Merit Order policy acts to prevent this in favour of the cheapest source. Therefore, steps would be required to change energy policy such that some sort of subsidy (e.g. ROC's or a feed-in tariff) could be put in place to provide an incentive for investment in projects.

Project Financing

The Committee on Climate Change commissioned Oxera to investigate how discount rates for renewable and low-carbon electricity generation technologies differ, and what drives investors' perceptions of the riskiness of these technologies. The report is available from:

http://www.oxera.com/cmsDocuments/Oxera%20report%20on%20low-carbon%20discount%20rates.pdf

The discount rates Oxera reports are applied by investors leads to an understanding of the level of risks perceived by these investors.

There are a number of factors that affect how “risky” a development is in any industry, and Oxera have also reported on the discount rates for low carbon generation[7], which in part takes risk into account. The factors that affect risk that are jurisdiction and market led, not technology specific include:

- Wholesale electricity prices and volatility;
- Carbon price levels;
- Electricity demand;
- The direction of energy policy;
- Value of subsidies and other support;
- Public perception.

There are also risk factors that are associated with the technology type:

- Plant load factor;
- Availability of power “on demand”;
- Cost structure – Capital costs and Operational costs;
- Construction lead in times;
- Deployment history
- Maturity of device used.

While all renewable energy production will be affected by fluctuations in the non-technology dependent factors, wave and tidal devices will be affected differently than wind by the technology specific factors. Neither tidal nor wave can guarantee “on demand” power without some form of energy storage. The CAPEX and OPEX split is not well established for either wave or tidal as both are at an early stage of maturity, although it is anticipated that there will be high CAPEX and lower OPEX in the medium to long term, and the early stage of maturity also increases the risk as it is unknown whether the technologies will become commercially self sufficient. Currently, the lead in time for the construction of devices is also quite long, and again this is linked to technology maturity at this stage.

A summary of the discount rates is in the following table (see page 20 of the report)

	Perceived risk category	Discount rate % - low	Discount rate % - high
Nuclear – new build	Medium	9	13
Tidal - stream	High	12	17
Wave - floating	High	13	18

This shows that both wave and tidal are deemed high risk but Wave (floating) is only slightly higher risk than tidal (stream). The perceived higher risk and resultant higher cost of capital

[7] http://www.oxera.com/cmsDocuments/Oxera%20report%20on%20low-carbon%20discount%20rates.pdf

may impede investment in the wave sector. The report found that the most important general factor affecting the perceived risk is the maturity of the technology. With installations planned over the next few years it is likely this risk perception will fall.

Economics of Scale

Whilst tidal energy may continue to be perceived as leading wave energy, this can only be a temporary arrangement, and the emergence of a mature wave energy industry is inevitable due to the scale of the resource available.

In Guernsey it seems likely that the economies of scale are going to be similar, that is tidal stream power may be initially viewed as less risky but wave power may continue to be developed after tidal stream energy has reached its limit. The west coast of Guernsey is open to the Atlantic Ocean, with the prevailing wind and wave direction coming from the West. Tidal energy is currently limited to areas of constriction leading to an acceleration of the water. In Guernsey waters it appears that these areas are restricted to the Big and Little Russels, and south of St Martins Point. There may also be a resource south of Sark, but this does not fall under Guernsey control.

The “Tidal Resource Mapping for the Territorial Waters of Guernsey” by Dr Alan Owen indicates a raw resource of around 700GWh/yr through the Big Russel, but relatively little through the Little Russel. The report also indicates that there is a resource of approximately 2300 GWh/yr to the North West of Guernsey, however this is in deep (>30m) water and so is not, currently, exploitable by any tested devices. The 2011 Cranfield University “A Feasibility Study of Marine Renewable Energy in the Channel Islands” concludes that the Big Russel is the only useable resource in Guernsey waters currently.

RET has not investigated in detail the wave resource off the West coast of Guernsey, however in comparing the wave data from the Channel Light Vessel and the Jersey Buoy there appears to be large similarities in the wave patterns and heights. As Guernsey sits in the middle of the two buoys it would suggest that there is a similar resource off the West coast. The Cranfield University study uses Atlas Numérique d'Etats de Mer Océanique et Côtier (ANEMOC) buoy information from around the Channel Islands and French coast as well as the BERR wave atlas. They identified that the area off the North-West coast of Guernsey is the best wave resource in the Channel Islands with an available power resource equivalent to $15kW/m^{-2}$. While Guernsey’s exploitable area is constricted currently by the 3nm limit, the available resource seems to be there, and if the limit is extended to 12nm in the future then there will be a greater available resource.

Physical Structures and visual amenity

Many wave devices are “surface piercing” and are therefore may be seen when they are deployed and operational. This is in marked contrast to many tidal stream devices which are on the ocean floor and therefore not seen. This visual element may detract from wave energy devices which are deployed closer to shore in places such as Guernsey. The fact that these structures pierce the surface also means they create a greater navigational hazard and pose risk to local fishing industries. However this would also apply to any of the surface piercing tidal technologies.

The UK wave industry is planning on devices being in more remote locations and thus far from where a significant number of people live, navigate or fish. Therefore the visual amenity and physical structures may not be a factor in overall progression of the wave industry but it may be a factor in deployment off Guernsey's coast, especially within the 3 mile zone around the island.

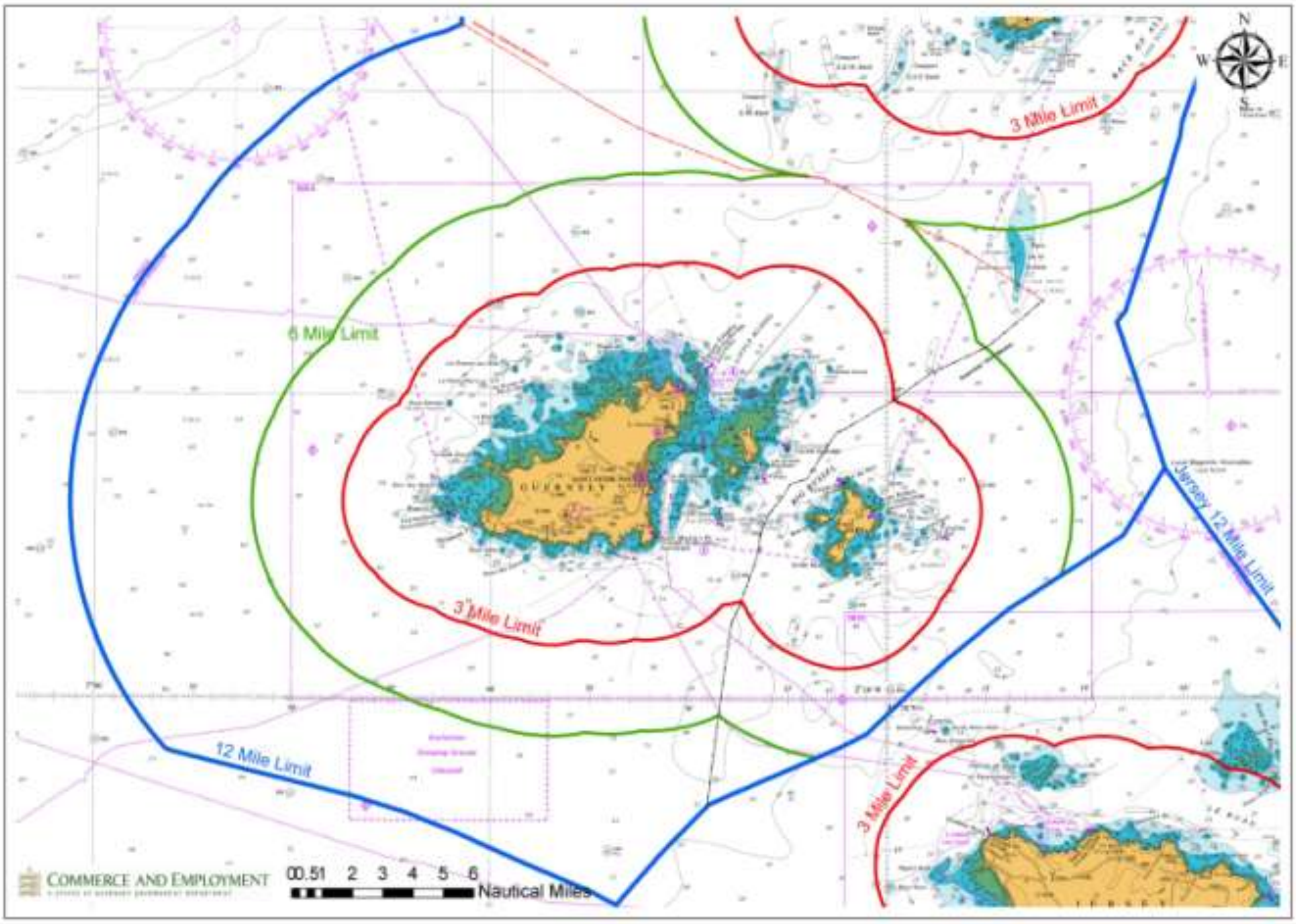

Figure showing the 3 Nautical Mile territorial limit and the 12 Nautical Mile limit

Cost comparison of Wave and Tidal development

Predicting the costs of wave and tidal developments is a difficult task, even without trying to compare them to current generation methods in the future to estimate when they will reach a parity cost wise with established generation. This is because both the wave and tidal industries are in the research and development stage and so predictions have potential for error. However, there have been a number of reports produced in the last year that are looking into the costs of marine renewables to 2050. This section looks at the conclusions reached by the reports to give an indication of the anticipated costs of array scale development.

A report by Ernst and Young (E&Y) for DECC[(4)] outlines that both wave and shallow tidal industries are likely to reduce their costs by around 70% by 2035 for 2 main reasons:

- Expected learning rates in the sector
- A declining rate of increase in underlying costs

DECC produced a report entitled "Review of the generation costs and deployment potential of renewable electricity technologies in the UK"[8], with chapter 7 comparing the E&Y report to a report from RenewableUK (RUK) on marine renewables. This suggests that there is very little difference between the capital expenditure for wave and tidal at demonstration (deployment of 10MW arrays) level. RUK suggests that capital expenditure for tidal will fall between £4.3m and £8.4m/MW, while E&Y suggest that it will be between £3.5m and £5.1m/MW. For wave RUK suggest a slightly lower £4.2m to £8.2m/MW, with E&Y suggesting a slightly higher £4.1m to £5.7m/MW. E&Y then expect that it will reduce to £2.7m to £3.9m/MW for tidal and £2.8m and £3.9m/MW for wave commercial scale development, again very similar. The large ranges for the values per MW are due to the variety of marine devices in development and different devices have different levels of trade off between capital expenditure and operating costs.

In 2020 the DECC report suggests that, using a low, medium and high deployment projections, there is likely to be a £4-12/MWh difference in costs in favour of shallow tidal (deployed in waters less than 30 metres deep) over wave. However by 2025 the report predicts that the situation will have reversed with a capital expenditure advantage of £6-18/MWh to wave, with the gap increasing by 2030. The E&Y report predicts a similar pattern between 2020 and 2050, although this was expected as the DECC report used the E&Y report as a source.

A May 2011 report by the Committee on Climate Change (CCC), The Renewable Energy Review[9], suggests that currently tidal stream is cheaper, as the other reports do, but will also remain cheaper through 2020, 2030 and 2040, although the difference does reduce. The report suggests that costs for both wave and tidal are high at present and are expected to fall, however by 2040 they predict that while neither will have become cheaper than wind both could be cost effective and competitive.

The Offshore Valuation Group (OVG) produced a report in 2010 looking exclusively at the UK's resource[10]. This report contrasts with the others by stating that it is only looking at the UK resource and assuming that there is a greater tidal than wave resource. The report agrees with the CCC report that tidal will remain cheaper up until 2050, potentially because due to the similarities of tidal and wind devices there could be some additional learning gains for the tidal industry from the wind industry.

All the reports admit that there are levels of uncertainty surrounding predictions due to the early stages of the technologies, the uncertainty of the resources, the lack of standardised technology and, in some respects due to the early stage of the

8 http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Renewable%20energy/policy/renew_obs/1834-review-costs-potential-renewable-tech.pdf

9 http://hmccc.s3.amazonaws.com/Renewables%20Review/The%20renewable%20energy%20review_Printout.pdf

10 http://www.offshorevaluation.org/downloads/offshore_vaulation_full.pdf

technology, the lack of available data on the costs of the different devices. Also the reports look at the industries as a whole, while individual technologies may follow different cost patterns, there may be one “winner” for example.

From looking at these four reports it appears that the two technologies are of similar costs, tidal marginally the cheaper at present, with the main differences between the reports seeming to originate from the methodologies employed. The DECC and E&Y reports suggest that there are likely similar amounts of resource around the UK for both wave and tidal extraction, but also look at the global resource, which favours wave. DECC and E&Y therefore take into account possible maturation globally, not just within the British Isles. The OVG report looks exclusively at the UK resource, and also estimates a far higher tidal resource than wave resource around the UK. This is because the report explains that there is no certainty in the tidal estimation of between 33 and 200 TWh so uses the midpoint (116TWh), however only uses the lower quartile estimation for wave resource (40TWh). The CCC report does not state the resources that it is based on, but it is a UK focused document, looking at the potential renewable energy options available to the UK over the next 30 years.

Conclusion

Wave and tidal technologies are not very far apart in terms of technology and costs. Looking at NASA’s Technology Readiness Levels, reports from E&Y, DECC, BVG and CCC illustrate this. Potential deployment times are also similar.

- It was stated in “Current Perceptions” that while both wave and tidal are at similar early stages of development, it is perceived that tidal is the better developed, more advanced and more financially viable option.

- In looking at the leading device developers for both the wave and tidal stream industries in the UK, it appears that they are both industries are at a very similar level of readiness, using NASA’s Technology Readiness Levels. Both Wave and tidal appear to have one developer that has reached level 9 on the NASA scale (system proven through successful operation), with a number of developers scored at 7, but may be close to reaching level 8.

- A number of developers, both wave and tidal, have been installing single devices in research areas such as EMEC in Scotland, as well as around the world in places such as in Canada. It is hoped that some of the developers are close to taking the next step, with Wave hub ready to receive its first array, and positive indications from MCT regarding development off the coast of Wales. However as it currently stands, neither tidal nor wave developers have deployed a large array of devices anywhere in the world. Ocean Power Technologies looks the likeliest to achieve this first with plans to deploy the PowerBuoy in Wave Hub, although this is dependent on consents.

- Both wave and tidal developers have had the option to secure some areas for generation through the leasing of sites in the Pentland Firth and Orkney waters, with a combined total of 1,600MW of planned projects. The BVG report outlines that while this has been secured by some developers, the deployment is not imminent as the grid capacity is not yet in place and the supply chain is not ready for large scale production. This should allow the companies time to gain further understanding of how the devices will work in arrays.

- Investor risk for developing both wave and tidal stream is percieved as high, although slightly higher for wave than tidal, it is possible that with the planned installations over the next few years the risk perception will fall for both technologies.

- The tidal resource in Guernsey is being investigated using tidal modelling with physically measured tidal flow data and currently indicates that there is a raw resource of around 700GWh/yr available in the Big Russel, which would be commercially exploitable with tidal speeds of the order of 1.5m/s. The wave resource has not been investigated by RET in detail, however the Cranfield Report has utilised French buoy data, and overlaid BERR data which indicates that to the West and South of Guernsey there is a potentially exploitable resource.

- There may be some issues surrounding visual amenity of surface piercing wave devices as they may be large structures relatively close to the Guernsey coast.

- Both wave and tidal currently require in the region of 5 ROCs to be a viable proposition to companies in the UK. This high cost reflects the maturities of both of the industries and it is anticipated that costs will reduce by around 70% for both industries over the next 20-40 years, depending on industry growth. CAPEX for wave and tidal are similar, although it appears that it is slightly less for tidal, although this is contradicted by one source, but will depend on a device by device basis.

- Around the UK it appears that there are similar resource potentials for both wave and tidal stream, however globally there is a greater wave resource. This could lead to a larger wave industry and so has the potential to reduce costs further for the wave industries in the long term.

- Both wave and tidal industries should be deploying large scale demonstration arrays prior to 2015 of 10MW.

Appendix A – Device update as of December 2010

Tidal

Manufacture	Partners	Development Installed / planned	Deployment Date	Device	Device rated output	Location	Number of devices	Planned Deployment Duration	Information Source	Source Date	Funding	Progress Update
Open Hydro		Installed		Open-Centre Turbine	250kW	EMEC			Renewable UK – Sate of the Industry report	March 2010		Undergoing testing – connected to the UK grid
MCT		Installed 2008		SeaGen	1.2MW	Strangford Lough			Renewable UK – Sate of the Industry report	March 2010		First **commercial scale** tidal turbine to generate electricity to the grid
Pulse Tidal		Installed may 2009		Pulse Stream 100	100kW	Humber Estuary			Renewable UK – Sate of the Industry report	March 2010	Investors: Marubeni, IT Power, The Viking Fund, LIFE-IC. Also supported by Shell Springboard, The Carbon Trust Incubator, Yorkshire Forward, Future Energy Yorkshire, the NPower Juice fund and the EU	First grid connected **Shallow Water** device
Tidal Generation Limited (TGL)		Planned (possibly installed)			0.5MW	EMEC			Renewable UK – Sate of the Industry report	March 2010		
Atlantis Resource Corporation		Installed		AK1000	1MW	EMEC			Renewable UK – Sate of the Industry report/ press release	March 2010 August 2010		Up to 3 years installation planned Twin rotor fixed pitch blades

Manufacture	Partners	Development Installed / planned	Deployment Date	Device	Device rated output	Location	Number of devices	Planned Deployment Duration	Information Source	Source Date	Funding	Progress Update
Tidal Energy Limited (TEL)		Planned		Delta Stream	1.2MW	Ramsay Sound			Renewable UK – Sate of the Industry report	March 2010	Investors: Eco2 limited, Carbon Connections UK Limited	Tri- Turbine device
Atlantis Resources Corporation		Installed	Aug 2010	Tidal Turbine – AK1000™	1000kW @ 2.65m/s	EMEC	1	3 years	Atlantis Resources Corporation	26/11/10	UK Government, Atlantis	Installed for 3 weeks, retrieved for blade replacement, due for re-installation in 1Q 2011.
Atlantis Resources Corporation	Meygen Ltd Morgan Stanley International Power	Planned	First turbines in 2012	AK tidal turbines	1000kW @ 2.65m/s	Inner Sound, Pentland Firth	Up to 400	20 years	Atlantis Resources Corporation	26/11/10	Partners, shareholders, financial institutions	Seabed lease was awarded by The Crown Estate in Oct 2010.

Wave

Manufacturer	Partners	Development Installed / planned	Deployment date	Device	Device rated output	Location	Number of Devices	Planned Deployment Duration	Information Source	Source Date	Funding	Progress Update
Wavegen (now owned by Voith Hydro)		Installed	2000	Limpet	0.5MW	Isle of Islay, Scotland			Renewable UK – Sate of the Industry report	March 2010		

Manufacturer	Partners	Development Installed / planned	Deployment date	Device	Device rated output	Location	Number of Devices	Planned Deployment Duration	Information Source	Source Date	Funding	Progress Update
Aquamarine Power		Installed	Summer 2009	Oyster	315kW	EMEC			Renewable UK – Sate of the Industry report	March 2010	Funders listed as (from website): Technology Strategy Board, Royal Academy of Engineering, Engineering and Physical Sciences Research Council, The Scottish Government, NPower Juice, Scottish and Southern Energy, Sigma Capital Group, The Norseman.	Previously tested at NaREC where produced and exported electricity to the grid – Operated throughout winter
Aquamarine Power		Planned	2011	Oyster 2	2.4MW	EMEC			Aquamarine Power reply to email	23/11/10	£5.1M Government funding	Appears to be 3 devices linked.
Pelamis Wave Power		Installed at previously Installed		Pelamis	0.75MW	EMEC Portugal			Renewable UK – Sate of the Industry report	March 2010		2.25 MW installed in Portugal – First **multi unit** wave farm and first **commercial order** for wave
Pelamis Wave Power		Underway		P2	0.75MW	EMEC			Renewable UK – Sate of the Industry report	March 2010		Was installed for 4 days in October 2010 as part of the Eon confirm first power from P2 at EMEC (3 year testing)
Ocean Power Technologies		Underway		PB40	40kW	Hawaii and New			Renewable UK – Sate of the	March	US Navy (OPT	First wave device grid

Manufacturer	Partners	Development Installed / planned	Deployment date	Device	Device rated output	Location	Number of Devices	Planned Deployment Duration	Information Source	Source Date	Funding	Progress Update
(OPT)				PowerBuoy		Jersey			Industry report	2010	Website)	connection in USA EIA undertaken
OPT		Underway		PB40 PowerBuoy	40kW	Spain			Renewable UK – Sate of the Industry report	March 2010		A 1.39MW project
OPT		Planned		PB150 PowerBuoy	150kW	EMEC Oregon			http://www.oceanpowertechnologies.com/index.htm	March 2010	US Department of energy	"A 10-Megawatt OPT power station would occupy only approximately 30 acres (0.125 square kilometres) of ocean space."
Wave Dragon				TBC								
Aegir Wave Power Ltd (Vetenfall & Pelamis		Planned	2013-14	P2	0.75MW	West coast of Shetland, Scotland			http://www.aegirwave.com	October 2010		20-30MW farm planned to have a 20 year operational life