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Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact

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Report on the state of ocean energy in Europe: technologies, test sites, and joint projects

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Report on the state of ocean energy in Europe: technologies, test sites, and joint projects

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Summary

This report aims to draw up the current state of ocean energy in Europe by enumerating the different technologies, test sites, and joint projects that exist today and that are projected for the near future. The introduction will remind the reader of the goals of the Equimar project and the work packages it consists of.

The different technologies that are currently being tested or under development are presented in a table, and although it is difficult to keep such a list up to date, it will be revised as much as possible in order to stay relevent. A list of test sites for ocean energy has also been put together, it shows the growing number of such sites around Europe, and indeed that this number is going to grow in the near future. Finally, joint projects which have taken place between utilities and developpers in Europe are listed and give a sense that the sector does receive some confidence from rather large investors.

CONTENTS

1 ACKNOWLEDGEMENT

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2 Introduction: Objectives of the Equimar Project and Description of Work Packages

Marine energy technologies have not yet reached the commercial stage due to a set of barriers to market penetration of these technologies are challenges of marine energy. For example, lack of experience which limits investment security. However, marine energy could take advantage of the experience from sectors it has some similarity to, for example wind energy, which has long reached market deployment stage, and could thus be a good example of what to do (or not to do) to reach the same stage. Long standing technologies such as offshore oil and gas production could also help the marine energy sector develop its own technologies, and the experience of engineers in that sector could be very valuable for marine energy.

The Equimar projects consists of a group of 23 partners which are active in the field of marine energy research, it is financed by the European Commission under the 7th Framework programme, and will run for three years from 15th of April 2008. The ultimate goal of this programme is to develop a set of norms and standards in order to improve learning and gaining experience for technologies that aim to produce energy from the ocean. This includes site selection, norms for environmental and engineering design, as well as economic issues, such as financing. This project is divided into ten work packages, each of which cover a different aspect of the project.

The first work package (WP1) focuses on the creation of a knowledge base for marine energy, which would be based on the results of the other work packages in the Equimar packages. Its objectives could be summarized in three main tasks: first, gather conclusions and findings from previous research made in the field of marine energy at the national, european and international levels. Second is the task of learning lessons from other sectors, and third, to gather information on the effective needs and technical constraints of stakeholders through a survey.

The first task of WP1 has led to a report which centralises the so-called 'pre-normative studies on ocean energy', and compiles all studies that have been done to date on the topic at the national, european and international levels in the field of ocean energy. This report is subdivided into the sections: Physical Environment and Resource; Specification Concept Appraisal, Device Modelling and Performance Assessment; Sea Trial Testing and Full-scale Design and Deployment; Policy Issues And Environmental Impact Requirements; Economic Assessment of Large Scale Deployment. Developers and researchers will be able to refer to this information and take full advantage of it.

The second task, which aims to learn lessons from other sectors, is subdivided in a number of thematic parts. These are: 'environmental conditions specification; structural design and material selection; components, instrumentation and control systems; reliability and safety requirements; measurements for assessment, grid connection and power quality requirements; and environmental impact requirements '. For all of these topics, the report from WP1 for this second task lists the literature on existing guidelines and norms in these fields, the purpose of this is to facilitate the access to this information and thus the development of marine energy technologies by enhancing learning from other sectors. Even if the guidelines sometimes cannot be used as such for marine energy, they may still be of great help for developers.

Developers can, through this database of references could save valuable time by taking advantage of what has been done and exists, which in turn will reduce costs for marine energy development. This could also help them know what can be done and how, and therefore make the process of development more effective. It will concretely give them tools to conceptualise new devices, but also to foresee what the impact of the device could be on the environment and vice-versa, as well as the potential profitability of devices. And we will hereby summarise the

Research has been carried out for estimating how much energy could be extracted from the ocean, and it is overwhelmingly important in order to assess whether a device will be able to produce energy in a specific location. Developers need to assess the feasibility of specific sites, and this could be made easier by using methodologies for wave modeling and applying them on each potential site and adapting them to the device studied. The same could apply to tidal devices, as tidal range is more easily predicted than wave strength. This data could in particular be adapted from other sectors such as offshore oil platforms, or other offshore industry. Nevertheless, it is important to point out the specificity of marine energy devices and therefore the dire need for specific methods of resource estimation.

Alongside the estimation of a site’s potential power output, related to a particular device, the assessment of a device’s performance is central to its development. Although devices are based on very diverse concepts, and therefore the process for device testing differ accordingly, it is possible to take into account the successive steps of device-testing and apply them to different concepts by adapting them. This could be done at the stages of tank testing, device modeling, and performance assessment.

After site resource and device performance assessment, the step of on-sea testing is crucial to the development of ocean energy devices, as random natural events, which are very difficult to foresee could prevent a device from reaching the commercial stage. Developers could however follow broad guidelines on how to carry out such tests in order to try to minimise the risks of failure. The European Marine Energy Centre, based in Orkney, UK, has been the first body to standardise the procedure of performance assessment of wave and tidal energy converters.

Likewise, guidelines for device design, grid connection and moorings and foundations have already been drafted, they are to be further developed and represent a key asset for developers to take advantage of existing research and development. In fact, standards already exist for components that could come into the assembly and installation of marine energy devices, and that are already used for other marine devices.

Guidelines for the process of manufacturing and assembly have also been put together for marine energy, as well as criteria to assess reliability of devices. The qualification process, which consists in evaluating the reliability of components, exists for other technologies and should be applied to marine energy technologies, which either use new components, or use existing components in an unconventional way. Existing standards could likewise largely be used for failure analysis and reliability requirements. Finally, although ocean energy devices are usually unmanned, safety requirements must be respected and guidelines have also been drafted for them.

Measuring the power output of an electricity producing plant is central to successful grid management, however, due to the early stage of development in which marine energy is, it has not yet been possible to draw guidelines on how to measure this. As a starting point, standards that have been drafted for wind energy could be used to draft guidelines for marine energy to use as a starting point to the establishment of real standards. The same could be said about grid connection and power quality, and especially the integration of marine energy into the grid, which is very hard to assess at the current state of development.

Another overwhelmingly important aspect of developing ocean energy converters are environmental impact assessments (EIA) and other policy issues linked to installation and operation of ocean energy devices. First of all, the developments in the sector of offshore wind should be considered as an example for norms used in EIAs, and even though permitting procedures for installing ocean energy devices differ amongst European states, the existence of an EU directive on environmental impact assessment sets the basis for normalised procedures. However, no specific reference of ocean energy is made in this text, this is why EMEC has issued a guideline on how to undergo an EIA for ocean energy devices. Through setting up 'pilot zones' for ocean energy some European governments have very much simplified authorising procedures, and this could be generalised to other countries. Finally, the use of life cycle analysis to assess environmental impact of ocean energy devices is also very important and should be generalised, as they help predict the total carbon emissions and energy consumption throughout the lifetime of a device.

Studying economic feasibility of industrial scale wave and tidal farms is still a very difficult issue, as very few technologies have reached this stage yet. However, some reports have proposed estimations, but they often fail to provide very specific informations, mostly due to lack of data.

We hereby see an outlook of the stages that marine energy producers must undergo, and it is important that they are supported throughout these stages if they are to reach the stage of commercial scale wave and tidal farms.

3 INITIATIVES FOR STANDARDISATION AND SYSTEMISATION IN THE FIELD OF OCEAN ENERGY DEVELOPMENT

As summarised above, the Equimar project aims to establish procedures and rules for equitable testing of ocean renewable energy devices. It is however not this first intent to move such a framework, and a number of initiatives have been taken and reports produced at the national, European and international levels, these will be refered to as pre-normative studies, as they aim to create a framework for developing the future wave and tidal energy norms. One of Equimar's goals is to make sense and draw conclusions from these various publication and go further in drafting a coherent, stand-alone package of guidelines for ocean energy development. In order to do this, the project looks into identifying the knowledge gaps that exist in the current research and finding the information to fill them.

3.1 PAST STANDARDISATION AND SYSTEMISATION ACTIVITIES IN THE FIELD OF MARINE RENEWABLES

To date, around ten projects, programmes and studies have addressed the subject of standards for wave and tidal energy technologies. In 2003, the WaveNet first aimed to create a network for knowledge sharing and to address key issues in technology development, even though the final report did not directly aim at producing guidelines in the field, it identified some of the main issues faced, most of which are still relevant today. This project looked at some fields relevant to those taken up by the Equimar project, namely 'Social planning and environmental impact', 'Financing and economics', 'Generic technologies', 'Research and development', and 'Cooperation with the power industry'.[1] Thus, whilst this report is largely outdated, the information included in it could be used as a basis for work on the current project.

The same, year, the Sustainable Power Generation and Supply (SuperGen) programme was launched, its first phase lasted 4 years and the second phase is currently ongoing. The aim of the first phase was to bring high level experts together to identify challenges of implementing sustainable power generation and supply, and within it, a significant amount of funding was aimed at marine renewables. The SuperGen Marine research theme aimed specifically at increasing knowledge and understanding of the extraction of energy from the sea; reducing risk and uncertainty for stakeholders in the development and deployment of technology; and enabling progression of marine technology and energy into true positions in future energy portfolios. Whilst this programme provides valuable input for the Equimar project, it lacks the European perspective, as it was solely a UK initiative. This phase was concluded in September 2007, and the second phase is now ongoing until October 2011.

At about the same time the European Marine Energy Centre (EMEC), started draft protocols with recommendation and standards linked to the development of wave and tidal energy. This

[1] WaveNet: Full Report, March 2003, p. i

first started in 2004 with the launch of the draft assessment for testing was launched, its goal was to assess testing of 'Performance of Wave Energy Converters in the Open Sea'.[2] This was only the first in a series of guidelines and assessment procedures addressing multiple aspects of wave and tidal energy development proposed by EMEC.[3]

The Co-ordinated Action for Ocean Energy (CA-OE), which was launched in 2004, also is relevant to the research carried out in the Equimar project, as it aimed to create a knowledge base on Ocean Energy and co-ordinate approches to Ocean Energy research and development. This project brought together a wide range of actors working in the sector of Ocean Energy and aimed to bring together the most up to date research at the European level and create a co-ordinated approach. The outcomes of this project cannot be overlooked today in Equimar, as it focuses on wave and tidal research.

Another report, produced by the US Energy Production Research Institute (EPRI) was effective in proposing methodologies for economic assessment of Offshore Wave Power Plants. This method aimed particularly at determining if devices were ready for full scale testing, or if they required further R&D activities. This methodology could represent a starting point for some working groups in the Equimar project.

An initiative was taken in 2005 in the UK to co-ordinate research and draft a technology road-map. This was done within the framework of the UK Energy Research Centre (UKERC), and involved a number of UK research institutions.

In 2006, the UK Department of Trade and Industry (DTI) launched what came to be known as the 'Marine Renewables Deployment Fund', under which it was required for prototypes and scale models of wave or tidal devices to satisfy a number of criteria in order to have access to funding. The developers where thereby contracted to follow a 'Wave and Tidal Device Performance Protocol', and apply specific methodologies to assess the performance of the devices. Even though these methodologies and protocols were first aimed solely for developers to access funding and to be able to compare the devices tested, they could also be used as a basis for developing some more universal guidelines.

Likewise, the same year, the Irish government launched its Ocean Energy Strategy. A 1:4 scale test site was installed in Galway Bay as a joint project between Sustainable Energy Ireland and the Marine institute, due to the fact that each device must go through independent sea-worthiness evaluation, this lead the University College of Cork to produce a protocol for scaling wave energy converters in different steps, each including specific aims and procedures.

In May 2005, a report commissioned by the UK's Carbon Trust and produced by the Norwegian consultancy Det Norske Veritas (DNV) was published, laying out 'Guidelines for the

[2] http://www.emec.org.uk/pdf/EMEC_Performance_Assessment.pdf
[3] http://www.emec.org.uk/standards.asp

Design and Operations of Wave Energy Converters'[4]. These aim to help developers of wave energy converters to interpret exisitng norms in the offshore and maritime sectors and lays out guidelines for development of such devices. This example could be used and extended to cover tidal devices, and thus be valuable input for EquiMar.

Finally, the UK Carbon Trust's 'Marine Energy Challenge' completed a study in 2006 addressing comparison between of marine energy technologies based on the estimation of the cost of energy.

As we can see, the initiatives, projects, and guidelines that have been developped so far leave some gaps, and thereby room for improvements, this is one of the reasons why the EquiMar project came about and why activities for further standardisation are still being carried out today.

3.2 ONGOING STANDARDISATION AND SYSTEMISATION ACTIVITIES IN THE FIELD OF MARINE RENEWABLES

First and foremost the International Electrotechnical Commission (IEC), the international body that works on setting standards for new technologies, has set up a Technical Committee fully dedicated to ocean energy technologies, except for tidal barrages, which are already included in TC 4. TC 14 was inaugurated in May 2008, and has, up to date, established a number of project teams and an action plan in order to reach its objectives, which are as following, and can be of significant value for the Equimar project, as well as it could provide input to the work of TC 114. The TC 114 Strategic Business Plan (SBP) describes the its goals as follows:

"The standards produced by TC 114 will address:
- system definition;
- performance measurement of wave, tidal and water current energy converters;
- resource characterization and assessment;
- design and safety requirements;
- power quality;
- manufacturing and factory testing;
- evaluationand mitigation of environmental impacts."[5]

Moreover, the TC outlines the importance of collaborating with other projects and organisations on the setting up of these standards. This is why the co-ordinator of the Equimar project Prof. David Ingram has been chosen to establish liaison with this Technical Committee. This will enable to have first had information on its work and provide input from Equimar.

[4] http://www.dnv.no/binaries/wecguideline_tcm155-270406.pdf
[5] Danny Peacock, Strategic Business Plan, TC 114, June 2009, p. 3. http://pubweb-1.iec.ch/cgi-bin/getfile.pl/sbp_114.pdf?dir=sbp&format=pdf&type=&file=114.pdf

So far the IEC TC 114 has produced a number of working documents on various aspects of ocean energy technolgies, and is working to meet the deadlines for 2010. It is very important for all the Equimar partners keep informed of the activities of TC 114 and be ready to provide input to it.

The Wave Energy Planning and Marketing project (Waveplam)[6] is also currently producing studies that could provide input for the Equimar project, and towards the establishment of norms in the field of planning and marketing. Some deliverables have already been published from this project, for example, one regarding a methodology for site selection that could be very useful for some of the Equimar work packages, which aim to tackle similar issues. In general, the Waveplam project's aim to produce studies on how to drive ocean energy technologies from research and development to full scale market development are in line with some of the Equimar project's ultimate objectives.

The Components for Ocean Renewable Energy Systems (CORES) project, is currently ongoing under FP7, and aims to develop new components and concepts and to test them on an offshore platform in order to create a model based on reliable data stemming from these tests. This is extremely relevant to the Equimar project, especially for its work package 4, which aims to tackle issudes related to testing and modeling.

The second phase of the above-mentioned SuperGen program will also be relevant to the Equimar project, as its ultimate goal is to reduce risks and uncertainties linked to ocean energy development. The programme aims at dealing with all the challenges and uncertainties linked to the development of marine energy devices. Many of these fields will be linked to those studied under Equimar.

Finally, the work undergone by the Peninsula Research Institute for Marine Renewable Energy (PRIMaRE) with regards for example to the Wave Hub will also be very important for the Equimar partners, as it could provide data from effective testing, which is the key to creating valid standards.

As we can see, the Equimar project will not start working from scratch and, to some extent, will need to collect and confront data from a rather large number of sources. Apart from this, it will require further research in some areas which have not yet been addressed.

[6] www.waveplam.eu

4 Brief outlook of the different technologies developed in the Ocean Energy Sector

4.1 Introduction

To date, a number of state of the art reports on Ocean Energy have been published, either at the international, European or national level. At the European level, the International Energy Agency's Implementing Agreement on Ocean Energy (OES-IA), produce an annual report that provides an update on the newly developed ocean energy projects. At the European level, some ongoing European projects, such as Waveplam, the European Ocean Energy Association dissemination activities (EU-OEA) Specific Support Action (SSA) project, have developed or are currently developing such documents. At the national level, the Renewable UK Association (formerly BWEA) have produced a state of the industry report in October 2009, which tackles different aspects of ocean energy development in the country, such as devices in the water, test sites, grid connection, financing, etc… In order not to duplicate the work, we will therefore aim to provide an overview of existing technologies and refer our readers to related work for more details.

The great potential for ocean energy has been estimated to up to 20, 2800 TWh/year, according to conservative estimations.[7] This is more than enough to satisfy the world's energy needs, but the main challenge that remains is to harness this energy potential. Nevertheless, current developments show that the industry is moving towards general deployment of proven technologies. To begin, we will seek to present the working principles of all existing technologies and how they could be categorised, as well as examples illustrating the technologies currently being tested. We will then look at the test sites currently developed in Europe, and finally present how private and public actors are currently investing in ocean energy in Europe, making it promising for the sector to reach market state soon.

4.2 Wave Energy Technologies

There is a wide variety of wave energy technologies, which are more different from on another than other types of renewables, such as for example wind turbines or PV panels. This is why there have been a number of intempts to classify them.

The first distinction that can be used to classify wave energy converters is their location: either onshore, near shore, or offshore. This breakup could be further specified through the working principles of the technologies, which are multiple, and make it even more complex to classify these types of technologies. This second level of classification breaks the technologies up into Oscillating Water Columns (OWC), Overtopping devices, and Oscillating devices. Even this

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[7] H.C. Sørensen and A. Weinstein, *Ocean Energy, Position paper for IPCC*, 2008, p. 1, http://www.eu-oea.com/euoea/files/ccLibraryFiles/Filename/000000000400/Ocean_Energy_IPCC_final.pdf

level of classification could be refined, as the oscilating devices category includes what are sometimes refered to as submerged pressure differential devices, oscillating wave surge converters, point absorbers, and attenuators. [8] Please not that these classification are, to some extent, indicative, and other aspects of the devices' working principle could be used to classify them.

Oscillating Water Columns, or OWCs, are technologies that could be installed, either on shore, near shore or offshore, and which rely on the vertical movement of waves to push a column of air up and down, thus spinning an electricity-generating turbine. Examples of this are the onshore Pico OWC, built on the Azores Islands in Portugal, and currently opperated by the Portuguese Wave Energy Centre with a view to optimise components and production of electricity from the device. The Australian Oceanlinx device is an example of a near shore OWC, which uses the same working principle as the Pico OWC for example, but works from a near shore location. The Irish OE Buoy works according to the same principle, but is installed at an even farther location from the coast, it is one of the longest standing wave energy converters in Europe and has undergone extensive testing, particularly under the CORES project.

Overtopping devices could also be installed in the three types of locations mentioned before, though it seems that near shore or off shore devices are somewhat more common. The example of the TAPered CHANnel (TAPCHAN), which was tested during the late 80's and early 90's, is one of an onshore overtopping device. Another overtopping device is the Norwegian Sea Slot-cone Generator (SSG), which could be considered either as onshore or near shore. Unlike the Tapchan, it does not require a channel, but could be included in a breakwater for example, or commissioned on the shore.[9] The Wavedragon is a floating offshore overtopping device which has been undergoing test at Nissum Bredning in 2003 and producing electricity to the local grid. It has now experienced more than 20,000 hours of activity and a full scale prototype should be available by the end of 2010.[10]

Oscillating devices is the most diverse category, but it does not include devices developed to be installed onshore. Among the near shore oscillating devices, the Scottish company Aquamarine's Oyster was recently installed at the EMEC testsite in Orkney, Scotland, it could be described as an oscillating wave surge converter, and is a near-surface device that oscillates according to the movements of the waves. The current device is of a rated power of 315 kW, and a bigger device (Oyster 2) is under preperation, it should have a 2.4 MW installed capacity and be commissioned in 2011.[11]

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[8] Aquaret project: 4.3 Wave technology types. http://www.aquaret.com/index.php?option=com_content&view=article&id=137&Itemid=280&lang=en

[9] L. Margheritini and P. Frigaard, *Subject: The SSG wave energy converter and application on the breakwater of the new Liseleje harbour.* 2007, available at: http://www.liselejehavn.dk/wavenergy_AAU.pdf

[10] Wave Dragon Latest News, retrieved on 2nd March 2010. URL: http://www.wavedragon.net/index.php?option=com_content&task=view&id=42&Itemid=67

[11] Source: Aquamarine Power

The well known Pelamis device, which installed the first array of wave energy converters in the world (three devices were commissioned at the Aguçadoura site in Portugal), could be classified as an attenuator device, it is placed perpendicular to the waves and "rides" them and captures the energy by selectively constraining the movements along its length.[12]

Point absorbers are usually near-shore or offshore devices that have a floating part, and an underwater part. The basic principle is that the floating or near surface part of the device absorbs wave movements in all directions to produce energy. The Ocean Power Technologies point absorber is currently undergoing tests in Spain, financed partly by the utility Iberdrola, as we will see below.[13]

Submerged pressure differential devices are totally underwater devices that move according to pressure differences caused by waves in the near-shore area.[14] Although the work principle exists, no technologies are reportedly being tested at the moment.

To sum up, it is clear that no single wave energy technology stands out at the moment as the most promissing one, and it must be outlined that each type have their own specifications and advantages. For example, Wave Dragon is known to be able to produce more energy from milder wave climates, whilst the Oyster, for example, has the advantage of having all its electricity production components onshore, which makes operation and maintenance easier and more costly. It is still unsure how many devices will make it to commercial stage, but wave energy converters will certainly always be more diverse than, for example, wind energy turbines.

4.3 TIDAL ENERGY TECHNOLOGIES

Energy from tides could either come from the potential energy resulting from the difference in the level of the sea, or from the flow of water in one or the other direction during the flood and ebb tides. Tidal energy, despite having a lower estimated resource potential than wave energy,[15] has the great advantage of providing a predictable and stable electricity production twice a day at least.

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[12] Aquaret project: 4.3 Wave technology types. http://www.aquaret.com/index.php?option=com_content&view=article&id=137&Itemid=280&lang=en

[13] Ocean Power Technologies (OPT) Deploys First PowerBuoy in Iberdrola Wave Energy Project. 2008, http://www.green-energy-news.com/nwslnks/clips908/sep08025.html

[14] Aquaret project, *loc.cit.*

[15] H.C. Sørensen and A. Weinstein, *Ocean Energy, Position paper for IPCC*, 2008, p. 1, http://www.eu-oea.com/euoea/files/ccLibraryFiles/Filename/000000000400/Ocean_Energy_IPCC_final.pdf

4.3.1 Tidal impoundment

In order to harness potential energy from the most widely used and proven method is refered to as tidal barrage. This relies largely on the same principle as large hydropower, except for the fact that the flow of water goes two ways. This is without a doubt the most proven ocean energy technology, as the French utility EDF's La Rance tidal barrage was installed in the late 60's and has been delivering the equivalent of about the quarter of a nuclear powerplant's production to the national grid ever since. Although the output is good, and the environmental impact is relatively high at the local level, and this is why it would be very hard to imagine such plants being commissioned today in Europe, as the environmental requirements are, thankfully, higher than they were fifty years ago. Therefore, new technologies are being developed in order to harness this significant source of energy whilst limiting the environmental impact.

The main alternative to tidal barrages is currently only at the stage of research and development, and is referred to as "tidal lagoon". The idea is to trap the rising water level into a circle shaped impoundment structure located offshore in a high tidal range area, while turbining the water that is flowing into the "lagoon", and then release it as the tide is going lower, and turbine it again. This has the main advantage of not blocking an estuary, thus decreasing environmental impact, especially because these sites usually have very rich eco-systems constructed around the exchanges of seawater and the river. [16]

4.3.2 Tidal Stream

Another form of energy resulting from tides uses the energy from the tides' stream, rather than the tides' range, as seen previously. Tidal Stream devices could be categorised, even though they do not have as many different applications as wave energy, there are: horizontal axis turbines, vertical axis turbines, reciprocating hydrofoils and venturi effects devices.

Horizontal axis turbines are very similar to underwater wind turbines, but they have to be sturdy enough to endure the density of water, which is about 800 times denser than water. This has been a significant engineering challenge, which can be considered as overcome by some of the developpers who have now significant experience in the sector such as Marine Current Turbines, who have had their device installed for some years in the British Southwest, and have recently installed a full-scale, comercial size device at Strangford Lough in Norther Ireland, which is currently connected to the grid and feeding into it. Other examples are the 1 MW Open Hydro turbine, which was installed recently in Nova Scotia, Canada, or Aquamarine Power's Neptune concept, which has not yet been developed in full scale.

Vertical axis turbines rely on the same principle of functioning, except they rotate around a differently oriented axis. One example of this is the Kobold powerplant installed for tests at the

[16] http://www.tidalelectric.com/technology.shtml

straight of Messina in Italy, between the mainland and the island of Sicily. This device has been installed and testing for some years and is effective in harnessing the energy from tidal stream. [17]

The third, less common type of tidal stream energy converter that could be referred to as reciprocating hydrofoils, which have one or more hydrofoils attached to an oscillating arm, which moves up and down due to the flow of water on each sides of the foil. This motion is used to pump a fluid and to run a hydraulic motor and electricity generator. An example of this is the Stingray, a concept developed in Scotland, but which has not yet reached the scale model testing stage.[18]

Finally, Venturi effect devices, are funnel-like shape and use the pressure difference between the inside and the outside of the tube to increase velocity of tidal current's flow. On example of those being developed is the Hydroventuri turbine, that is being made in the UK, by the company of the same name.[19]

These are the main technologies for tidal stream that exist to date, however, it is not impossible that more will come in the future. Now we will se the even less convential parts of ocean energy: Salinity Gradient, Ocean Thermal Energy Conversion (OTEC), and hydrothermal vents.

4.4 SALINITY GRADIENT

Currently, only two companies in Europe develop technologies using the salinity gradient between two sources of water: the Norwegian Statkraft and the Dutch Wetsus. Each of the two companies have opted for one of the two different existing options: Pressure Retarded Osmosis (PRO) and Reverse Electro-Dialysis (RED), respectively.

PRO consists in using the pressure which comes from the salinity difference between fresh water and seawater. This pressure is typically equal to the equivalent of 270 meters high head. In order to obtain this pressure, a semi-permeable membrane is used in order to separate the fresh water and seawater. The first ever prototype plant for this technology was inaugurated at the end of 2009 in Tofte, Norway by Statkraft.[20]

RED also uses membranes, but instead of using the pressure phenomenon, it directly electrifies the membranes, using some cathodes and anodes. The main challenge Wetsus have been

[17] http://www.pontediarchimede.it/language_us/progetti_det.mvd?RECID=2&CAT=002&SUBCAT=&MODULO=Progetti_ENG&returnpages=&page_pd=d
[18] http://www.esru.strath.ac.uk/EandE/Web_sites/05-06/marine_renewables/technology/oschydro.htm
[19] http://www.hydroventuri.com/venturipower-hydroelectric-power-technology.asp
[20] http://www.statkraft.com/energy-sources/osmotic-power/

encountering is to upscale this from 100 mW to 100 MW. To date, no prototype has been installed, and the ongoing tests are taking place at the laboratory level.[21]

4.5 OCEAN THERMAL ENERGY CONVERSION (OTEC)

OTEC has existed for some time now, but was never used for large scale projects. It is often argued that the OTEC resource in Europe is limited, but this is without thinking of the overseas territories that some European states still have. The working principle of OTEC is to use the temperature difference between the surface and the depths of the ocean or sea in order to evaporate and condense again a fluid in order to drive a turbine. There could be two options for this type of technology. Either a closed circuit with a fluid that is at the gas form when at the surface temperature and at liquid form when at depth temperature, or an open circuit using directly the seawater which is criculated through different pressures for it to become gas at the surface and liquid again in the depths. Some applications of OTEC include desalinisation of water for human use.

The French company DCNS has recently announced that it would be developing a 10 MW OTEC project in the island of La Réunion, in the Indian Ocean. This will be the first large OTEC project and will be aiming to contribute to the island's goal to be self-sufficient energetically by 2030.[22]

4.6 HYDROTHERMAL VENTS

Hydrothermal vents are underwater volcanic hot springs, where the temperature goes up to 300°C. Some concepts are currently being researched, for example in Mexico, to look into harnessing this energy potential. In Europe, the best sites for these types of resources would be in the Azores Islands, Portugal. It is fair to say that, to date this is the least developed form of ocean energy.

[21] http://www.wetsus.nl/pageid=119
[22] DCNS Press release: *Ocean thermal energy conversion at Réunion Island: DCNS and Réunion regional council sign demonstrator agreement.* 2009, http://www.epicos.com/WARoot/News/communique234.pdf

5 TEST SITES

5.1 INTRODUCTION

The large number of systems under development at some point needs to be tested at sea. During the last few years, several sites have been developed as test sites for Ocean energy systems. The map below shows some of these sites in Europe.

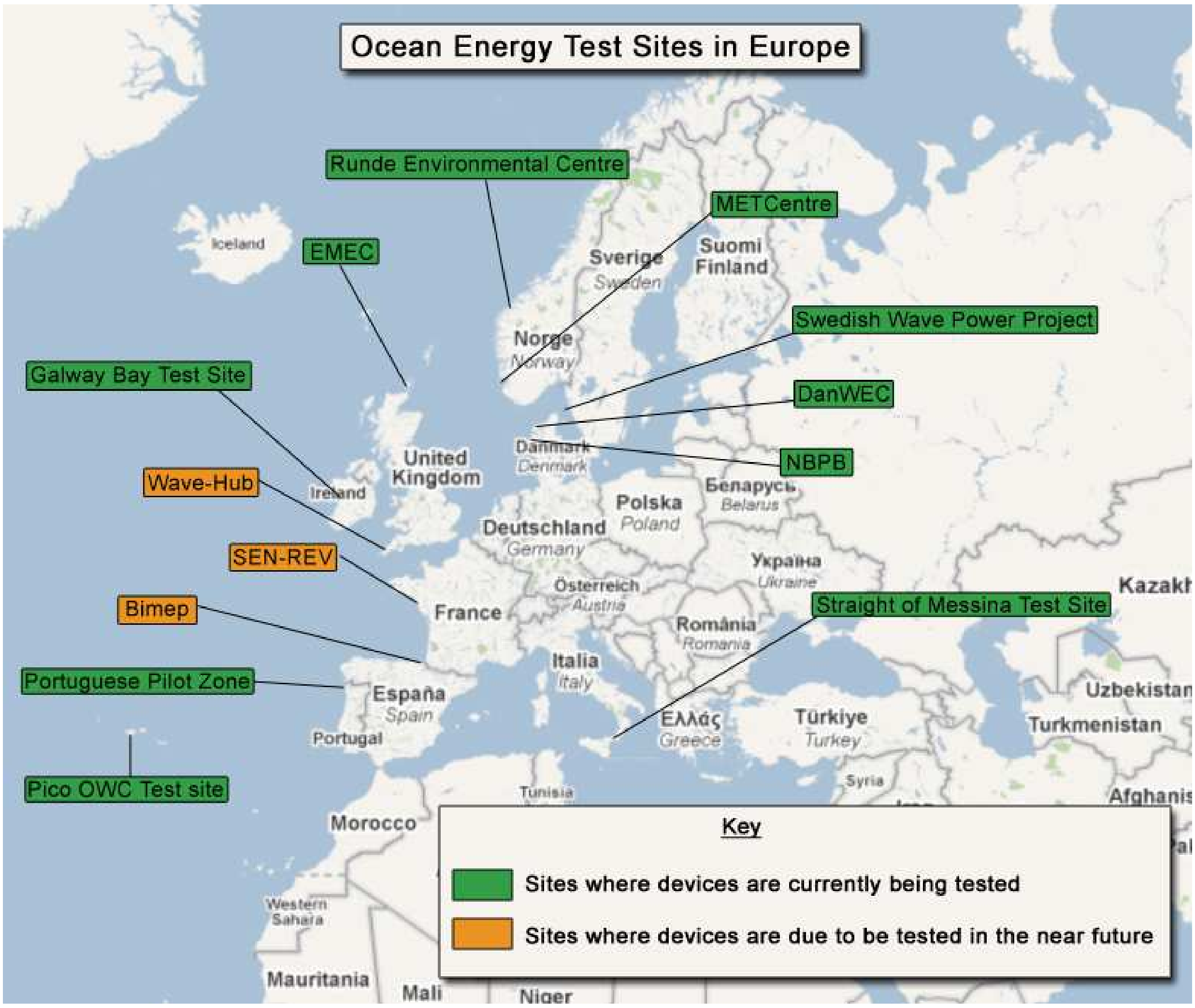


Figure 1 **Test sites for wave and tidal energy systems in Europe**

One of the first installed sites is the European Marine Energy Centre (EMEC) on the Orkney Islands in Scotland. This site is well exposed to the Atlantic waves and tidal streams between the Scottish isles. Therefore, both tidal and wave energy systems can be tested. Systems like Pelamis and Open Hydro have been tested there.

In the UK, arrays of wave energy converters could be tested at the Wave hub - planned to be installed with cables able to transmit the power from several devices to shore.

In contrast with these exposed sites, the sheltered site at Nissum Bredning in Denmark has become well known from the testing of the Wave Dragon and Wave Star projects.

In Portugal the first OWC plant was build on the Azores islands. The milder climate and the favourable feed in tariffs have attracted several developers, pioneered by AWS, and followed by Wave roller and Pelamis. In 2008 a dedicated area called the Pilot zone was established in that country.

These are just a few of all the test sites present in Europe, which we will list below. We will then go on to look at the test sites that are currently under development and that should start being used in the near future.

5.2 EXISTING TEST SITES IN EUROPE

5.2.1 In Scotland (UK), the European Marine Energy Centre (EMEC)

The island of Orkney in Northern Scotland homes the very first test facility for marine energy technologies to be installed: the European Marine Energy Centre (EMEC). Two sites on the island specialise respectively on testing tidal turbines and wave power devices. This site is the first one in the world to have such infrastructure and the only one in Europe to be connected to the grid yet. The two sites each feature excellent conditions for wave and tidal power harnessing, as well as a number of underwater cables which are connected to the grid, and which thereby enable connection of the tested devices.

5.2.2 The Portuguese Maritime Pilot Zone and the Pico OWC

The Maritime Pilot Zone is located off the coast of Aguçadoura in Portugal. This zone stemmed from the difficulty that existed in assessing the environmental impact of marine energy conversion devices. The idea was to create a zone in an area with limited environmental risk, which ensured limited damage, in order to simplify environmental authorisation procedures, and therefore remove some barriers that existed for testing and demonstration of ocean energy converters. Furthermore, this was to eventually include a point of access to the grid. It is in this test zone that the first Pelamis pre-commercial devices were installed at the end of 2008.

An Oscillating Water Column (OWC) wave energy converter had existed on the Azore Island of Pico since 1999, but it was only under a project financed by the Portuguese government that tests and improvements were performed on the powerplant from 2005 to 2008. To day the plant continues operating and belongs to the Portuguese Wave Energy Centre (WavEC). The tests undergone at the central could be applied today on other OWC designs in order to increase efficiency and survivability.

5.2.3 The Danish Nissum Bredning Test Station for Wave Energy (NBPB)

This test station is located at Nissum Bredning in Denmark and was built in 2000. It has in particular hosted the testing of the Wave Dragon device, amongst about 30 others. It enables device developers to test their technologies in sites where the wave power is not too strong as to enable first testings. The test platform is easily accessible by road, and is equiped with cranes, mobile platforms,etc… The test station furthermore offers developers the possibility to hire technicians, contractors, or others.

5.2.4 The Galway Bay Wave Test Site in Ireland

Since March 2006, the Marine Institute and Sustainable Energy Ireland established a Wave Energy Test Site on the North Side of Galway Bay. The site has a size of 37 Hectares and is around 20 meters deep. The wave heights have been monitored and forecast as suitable for prototypes of scales between 1/3 and 1/5. Two developers are currently using the test site, namely Ocean Energy Ltd and Wavebob.

5.2.5 In Norway, the Runde Environmental Centre and the Marine Energy Test Centre (METCentre)

The Norwegian island of Runde, off the western coast of the country hosts a centre for environmental studies, where two Seabased type generators have been installed and connected to an underwater switchgear and a sea-bottom cable linked to the 22kv grid. Though the site still covers just a small area, it is possible that it will expand, and perhaps host more wave energy converters in the future.

The town of Karmøy has also hosted some ocean energy projects in what it calls the METCentre. Amongst these is the Norwegian company Fred.Olsen's project Buldra, which has been in the water for some years, and which will possibly move to the Cornish 'Wave Hub'(UK), after it opens (see below). The METCentre aims to provide developers with the possibility to test devices in real sea conditions, as well as to have an onshore centre for visitors and research. However, it will need financing for this, which it is still looking for. Apart from this wave energy converter, METCentre also tests offshore floating windmills.

5.2.6 The Swedish Wave Power Project in Lysekil

This project aims, like other test sites to provide a site for testing wave energy devices. Here, Seabed devices have been deployed for a few years and are undergoing tests both for their own performances and related to their environmental impact. The local authority has given autorisation for up to 40 buoys and 10 wave power devices on this site, which could be connected to the grid through an underwater cable, itself connected to the grid through an AC/DC converter. The project will end in 2013-2014, when all equipment will be removed.

5.2.7 Testing the Kobold vertical axis tidal turbine at the Strait of Messina in Italy

The technology for a tidal plant called Kobold is being tested at the Strait of Messina, between Italy and Sicily. In this area currents could reach the speed of 2m/s, and are therefore promising for the installation of a tidal energy converter. The site is located at a depth of 20 meters, 150 meters offshore. Although it has not yet hosted other devices, the site could be adequate for other developers to use.

5.2.8 The DanWEC test site in Hanstholm, Denmark

The idea for this test site came from the Climate Commissioner Connie Hedegaard in collaboration with Aalborg University, the leading academic actor in the field of ocean wave energy in the country. The first device that has been installed at this site is the Wave Star Energy test section of a

500 kW. In 2010, the company DEXA wave, have signed up to install one of their devices at this test site.[23]

5.3 Future Test Sites in Europe

5.3.1 In Northern Spain, the Biscay Marine Energy Platform (bimep)

The Basque technological firm Tecnalia is coordinator of the project PSE-MAR, which aims to develop various forms of wave energy convertors (Hidroflot, Pipo systems and Oceantec). In order to do so, the Basque and Cantabria governments have stressed their will to develop the infrastructure for research, development, and demonstration of such technologies. This will be called the Biscay Marine Energy Platform, or bimep, and is expected to be ready to be used in 2010. Both regional governments will hold stakes in this platform.

5.3.2 The French Marine Experimentation Site for Wave Energy Conversion (SEM-REV)

The SEM-REV (Site d' Expérimentation en Mer pour la Récupération de l'Energie des Vagues) test site was developed jointly by the Ecole Centrale de Nantes (ECN), the French National Centre for Scientific Research (CNRS), the Pays de la Loire Region and the French State. This project aims to install single 3-core 20kv/2.5MVA sub-sea cable in order to connect the future test wave energy conversion devices to the local grid, through a newly built local substation. The area chosen for this is 15km off the town of Le Croisic, at a depth of 5 meters. Not only will this test site enable the testing of devices in terms of their efficiency, it will provide for a one stop shop zone, where authorizations will be easier for developers to access. Furthermore, it will aim to assess the environmental impact of devices in order to provide precise figures.

5.3.3 The Wave Hub in Cornwall (UK)

The project for an eight square kilometer wide test site off the coast of the town of Hayle in Cornwall. The site will feature a cable connection to a substation in Hayle that will be built for that purpose, and will initially operate at 11kv, but could be upgraded to 33kv. Each developer could lease a 1km x 2km sea area for testing prototypes for a period of 5 years or more. Funding for the project has been accepted during the summer 2009, and the installation should happen in spring-summer 2010. More than just hosting projects, the Wave Hub will itself collect data on the strength of incoming waves and purchase the electricity from testing developers.

[23] http://www.danwec.com/en/information/about_danwec/

6 JOINT PROJECTS BETWEEN UTILITIES OR ENERGY AGENCIES AND DEVELOPERS OF OCEAN ENERGY TECHNOLOGIES

Europe has recently experienced a number of projects for the development of OE technologies where developers have been supported by big utilities. This is a significant asset for the sector, as it gives it credibility for financing and pushes forward the development of innovative technologies. A Californian developer stated that :*'With [a big utility] behind us, we will be able to go to a bank, if we can show there is no technology risk, to get financing,"* This is the opportunity the developers have in such joint projects. On the other hand, the utilities can contribute to producing clean electricity, reduce carbon emissions, and thereby work towards a more sustainable development.

Here, we will list and present some of the main joint projects that are ongoing in Europe.

6.1 TECNALIA CORPORACION TECNOLOGICA AND IBERDROLA

Tecnalia Corporacion Tecnologica is a technological corporation that arose from the Basque business environment and has become an International benchmark in its field. They particularly specialise in the development of technologies of ocean energy conversion. Iberdrola is Spain's first energy utility and one of the biggest in the world for renewable energy.

The two companies have agreed to invest a total of 4.5 million € in the project Oceantec in the Basque Country in Spain in June 2008. A 1/4 scale model of the device has been put in the water in October 2008. The technology is based on a floating cylinder that is to harness wavepower. The final prototype, which was to be installed in 2009, was planned to produce 500 kWh to the grid and thereby provide electricity to 950 homes.[24]

This was made possible both through the PSE-MAR project managed by Tecnalia technologic Corporation, and Perseo, which is an investment company created by Iberdrola to support high technological value projects in the field of renewable energy and environment.

6.2 E.ON AND PELAMIS

Pelamis announced on the 9th February 2009 that they had concluded a deal with the electricity utility E.ON for a new generation of Pelamis device (P-2) to be installed in the island of Orkney, in Norhtern Scotland.

The new device is 180 meters long (50 m more than the existing P1 device), and it will be the first time such a device is tested anywhere in the world. It is also the first time a major utility orders a wave energy converter in the UK.

[24] http://www.energias-renovables.com/paginas/Contenidosecciones.asp?ID=14&Cod=14770&Nombre=RSS

6.3 SEABASED AB AND VATTENFALL

The Seabased device was developed by the University of Uppsala in Sweden, and funded by the Swedish utility Vattenfall, it is currently being being tested off the west coast of Sweden, near the locality of Islandsberg. The project started in 2004 and should last ten years. This test zone hosts ten buoys which lay on the seabed and will be connected to ten linear generators. Two devices are also being tested under tougher sea conditions on the Norwegian coast off the island of Runde.

6.4 WAVEBOB LTD AND VATTENFALL

The Swedish utility has also signed a cooperation agreement with the Irish developer Wavebob Ltd. The agreement provides for the two companies to help the project mature toward full-scale commercial readiness. Particularly, this should result in the scaling up of the Wavebob technology to be able to produce a large scale 250 MW demonstration project, as well as to develop a methodology of site selection.

6.5 DONG ENERGY AND THE POSEIDON PROJECT

Dong Energy is involved in a number of projects in the field of ocean energy. Amongst these, the Poseidon project, which is owned by the Floating Power Plant company, is very important. The device being developed is a 37 meters-long wave energy converter, which works as a hybrid producing energy from both wind and waves. This promising project could, under its full scale model, reach an installed capacity of 30MW, including the wind energy converters. It is currently being tested in the North Sea in Denmark, off the coast of Lolland.

6.6 DONG ENERGY, VATTENFALL, AND WAVE STAR ENERGY

Wave Star Energy aim to install a full scale prototype of their device off the Danish coast. This comes after more than two years of sea testing a 1/10 scale model, which has successfully resisted several winter storms. The full-scale prototype is to be installed offshore and connected to the grid through an existing offshore wind farm, which belongs to the two Danish utilities Dong Energy and Vattenfall. These will participate in the installation and connection of the Wave Star device to the grid.

6.7 EDF AND OPEN HYDRO

The French utility has appointed the Irish ocean energy developer Open Hydro on the 20th of October 2008 to provide four to ten tidal turbines off the coast of Brittany. This will be an opportunity to monitor environmental impact of the device, and to test it in real life conditions, as well as to test the grid connection of the utility. The devices will be lain on the seabed and use the energy of tidal stream to produce electricity. It should be connected to the grid in 2011.

6.8 VOITH HYDRO BOUGHT WAVEGEN

Voith Hydro, a joint venture between Voith and Siemens, has acquired Wavegen, a pioneer in the field of wave energy, which has developed and is testing its prototype called the Limpet on the island of Islay in Scotland. This prototype has been working since 2000 using the technology of oscillating water column. Wavegen is currently developing new systems to improve its output, and to build and deploy generators for commercial use.

6.9 ROLLS ROYCE HAS STAKE IN TIDAL GENERATION LIMITED (TGL)

The aeroengine manufacturing company have bought a controlling holdingin j' in the privately owned developer TGL, which is working on a prototype it will install in the European Marine Energy Centre in Orkney, Scotland for testing. It aims to produce a device of 500kW to 1MW for demonstration at this site.

6.10 SCOTTISH AND SOUTHERN ENERGY (SSE) AND AQUAMARINE POWER

The subisidiary of SSE Renewable Technology Ventures Ltd (RTVL) and Aquamarine Power have joined forces to create the company Auqamarine Power Ltd. This company will be developing both wave and tidal power technologies. The Oyster hydro-electric wave power device has already been developed and now needs to grow to commercial scale. The new company will develop a system for producing tidal power, which will be an underwater device of 2.4 MW to be installed at the Orkney test site EMEC. A year later the Oyster device should be deployed for demonstration at the same site.

6.11 MARINE CURRENT TURBINES MCT WITH NPOWER

In February 2008, MCT announced it would be launching a project jointly with the renewable electricity producer Npower. The joint venture company between MCT and Npower will be called SeaGen Wales Ltd. The project will consist in a 10.5 MW tidal farm off the Welsh island of Anglesey, this will be made up of seven 1.5MW SeaGen turbines. This farm is estimated to be commissioned in 2011 if everything goes as planned.

6.12 THE BASQUE ENERGY BOARD (ENTE VASCO DE LA ENERGÍA- EVE) AND THE MUTRIKU PROJECT

EVE have, along with the Direction of Harbours of the Department of Transport and Civil Engineering of the Basque Government, launched a project for installing an oscillating water column (OWC) technology developed by Wavegen in Islay in a breakwater at the Basque town of Mutriku. The plant is made of 16 turbines, which build up to an installed capacity of 296 kW, enough to provide electricity to around 250 households. It is provided by Wavegen turnkey to the local government and was to start feeding electricity to the grid in March 2009.

7 ANNEX: A LIST OF OCEAN ENERGY TECHNOLOGIES AND INSTALLATIONS IN EUROPE

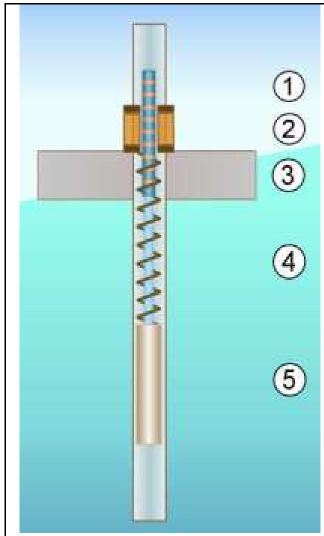
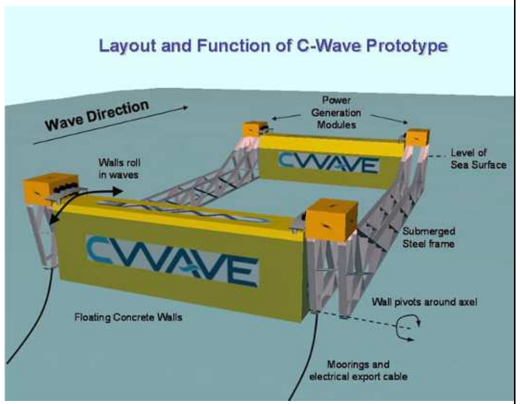
(continuously updated)

The installed kW column includes projects "in the water" but not necessarily grid connected
Given the difficulty of assessing the real state of the project, the installed power data must be considered only approximate
Installed kW = 0 means both no installed power, and unknown status.

NAME	Country base	Type	Rough Description	Current State and rating	Installed kW	Company
1. Aegir Dynamo 	UK	Wave (buoy)	The Aegir Dynamo™ functions in a unique fashion by generating electrical current from the motion of the prime mover in one phase via a direct mechanical conversion and the use of a bespoke buoyancy vessel. Oceannavitas claims 93% conversion efficiency Aegir dynamo can be deployed in coastal sea, shore based, or as affixed structure	NaREC 2kW prototype (New and Renewable Energy Centre in Blyth, Northumberland) EMEC: 1x1MW Wavehub, Cornwall 5x1MW	0	OceanNavitas http://www.oceannavitas.com/
2. Anaconda	UK	A	The system is based on bulge waves traveling along a distensible rubber tube. The tube, typically 7 m diameter and 150 m long and filled with water, is oriented in the direction of wave travel. The	R&D Two different 1:25 scale prototypes have currently been tested, and shown that they could harness wave energy at QinetiQ's	0	CHECKMATE http://www.bulgewave.com/ http://www.checkma

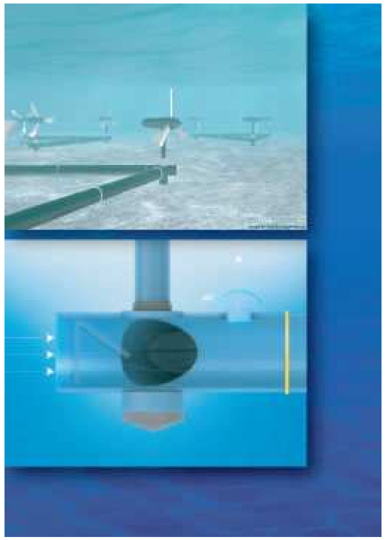
			waves excite a bulge in the tube which travels just in front of the wave rather like a surf-board, picking up energy and increasing progressively in size. The traveling bulge concentrates the energy from the sea and at the end of the tube the energy can be extracted to drive a turbine Joint project funded primarily by the Engineering and Physical Sciences Research Council (EPRSC). The Anaconda has been selected and financed by the Carbon Trust's Marine Energy Accelerator programme.	Haslar Marine Technology Park in Hampshire. The first type of device did not float freely on the wave tank, even though it made measurements possible. The second device did float freely, and was therefore closer to real sea-opperating conditions.		teuk.com/seaenergy/
3. Archimedes Wave Swing (AWS) 	UK	Wave (buoy) B	Cylinder shaped buoy, moored to the seabed. Passing waves move an air-filled upper casing against a lower fixed cylinder, with up and down movement converted into electricity. As a wave crest approaches, the water pressure on the top of the cylinder increases and the upper part or 'floater' compresses the gas within the	Uncompleted prototype phase A 1 MW 1:1 scale model was planned for 2004 Website currently being updated.	250	AWS Ocean Energy http://www.awsocean.com

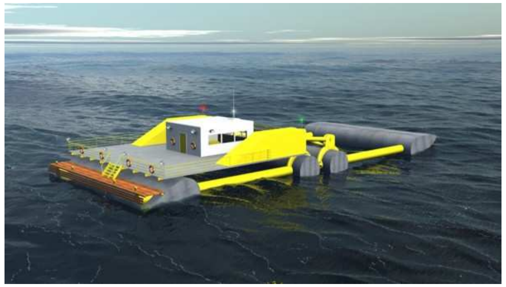
			cylinder to balance the pressures. The reverse happens as the wave trough passes and the cylinder expands. The relative movement between the floater and the lower part or silo is converted to electricity by means of a hydraulic system and motor-generator set.			
4. Atlantisstrom 	DE	Tidal current		Part scale Average capacity 230kW	0	Atlantisstrom http://www.atlantisstrom.de/index_english.html
5. Brandl generator	DE	Wave (buoy) A	Attenuator moored to the seabed A disc, ten metres in diameter and one metre thick, rises and falls with the waves. A pendulum mass hanging beneath a spring moves anticyclical up and down. This mass drives the direct-connected magnets that are inducing an electrical current	1MW R&D	0	Brandl Motor http://brandlmotor.de/brandlgenerator_eng.htm

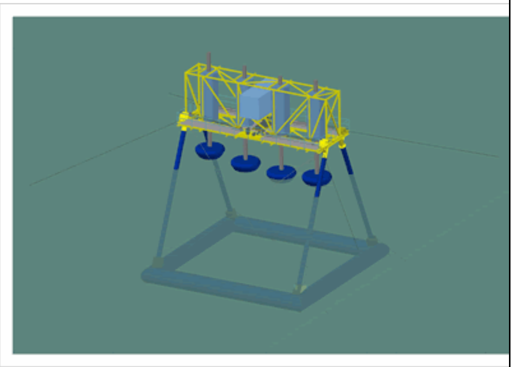
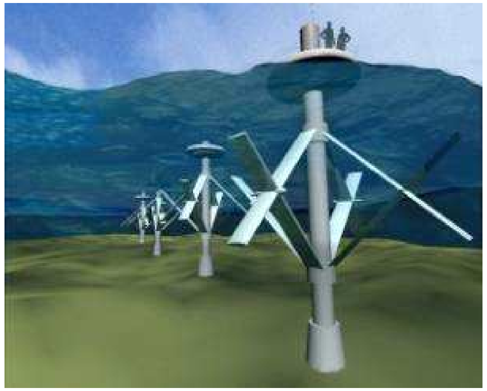
			while moving through the inductance coils.			
6. C-Wave 	UK	Wave A/C	The operating principle of the C-Wave system will have been experienced by anybody who has tried to climb or jump from one boat into another on a wavy sea. As the boats sit next to each other, the gap between them is continually opening and closing requiring a carefully timed jump to get from one to the other. The C-Wave principle uses this a continual movement to drive a generator and produce electricty. The opening and closing of the gap between the boats is a result of the fact that when a	University of Southampton Awaiting development	0	C-Wave http://www.cwavepower.com

			wave passes a boat it doesn't go up and down on the wave as we might think, but in fact it goes round in a circle - up and down and side to side. In fact its not just the boat that is going around, its the water as well. As the wave passes from right to left the water doesn't move from right to left at the same speed as the wave. It goes round in a circle and passes the energy of the wave to the next chunk of water along which goes round in a circle and so on. This is why waves can transmit large amount of energy long distances very quickly.			
7. Deep-gen	Tests planned at EMEC, Orkney, Scotland UK	Current	Horizontal axis turbine - Seabed mounted or gravity base	Tidal Generation Limited (TGL) is developing a 1MW fully submerged tidal turbine lightweight (80 tonnes/MW) support structure (ie 7.7 KW/te) a 500kW machine at the European Marine Energy Centre in the	500	Tidal Generation Limited http://www.tidalgeneration.co.uk

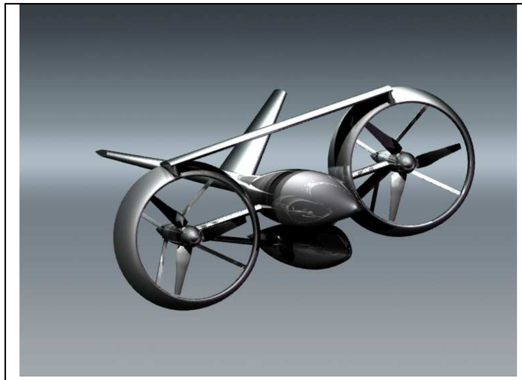
				Orkney Island We believe our device will generate electricity costing 8-9p/kWh for initial farms, falling to 5-6p when the technology is sufficiently well established for projects to attract competitive interest rates		

8. DeltaStream Concept 	UK	Tidal	The DeltaStream device is a nominal 1.2MW unit which sits on the seabed without the need for a positive anchoring system, generating electricity from three separate horizontal axis turbines mounted on a common frame. The use of three turbines on a single, circa 30m wide, triangular frame produces a low centre of gravity enabling the device to satisfy its structural stability requirements including the avoidance of overturning and sliding.	In September 2009, Tidal Energy Ltd was successful in their planning application to install a power conversion compound in the car park of the RNLI car park at St Justinians. They will connect the compound to a DeltaStream generator that will be trialed for twelve months on the seabed of Ramsey	1200	Tidal Energy Ltd http://www.tidalenergyltd.com/

			DeltaStream was conceived by Marine Engineer Richard Ayre with initial research funding from Pembrokeshire Coast National Park Marine Nature Reserve. Experts from Cranfield University in England undertook detailed design and optimisation of the blade design with funding from Carbon Connections. DeltaStream uses the same concept as a wind turbine together with ship propeller technology	Sound.		
9. DEXA Wave energy Cockerell's Raft 	Denmark		The DEXA converter is inspired by the wave extraction system as developed and [patented] in 1980 by the famous inventor Sir Christopher Cockerell. The Cockerell Raft consisted of two buoyant pontoons, hinged together, and dampened with a hydraulic power take-off system. DEXA reconfigured and simplified the basic construction of the Cockerell Raft, and only adopted the use of two pontoons and a hydraulic system from the original technology.	Tank test	0	http://www.dexawave.com

10. Direct Energy Conversion Method (DECM) 	UK	Wave	the system has only one moving part – float / linear generator translator, which is powered by the motion of floats placed in the sea. As waves pass through the wavefarm, so the floats rise and fall. This causes relative motion between the two components of the linear generator (the translator and stator) and electricity is immediately generated. There is absolutely no contact between the two parts of the generator as the energy conversion is entirely electromagnetic.	The 20 kW prototype that was to be installed for tests off the coast of Suffolk, England suffered an accident when it was being taken out for one year sea trial on 20th September 2009. The demonstration WEC was nevertheless recovered and has been transported for reparation back to Lowesoft Harbour, where it was built.	0	Trident Energy http://www.tridentenergy.co.uk/
11. ECOFYS Wave Rotor 	NL	F	In order to tap energy directly from both the up and down and back and forward currents, two types of rotors were combined on the same axis of rotation: a Darrieus rotor and a Wells rotor. These are respectively omni- and bi-directional rotors, which can operate in currents of changing directions	Testing at Nissum Bredning of a 1:10 scale model, which successfully fed electricity into the grid. Expected full scale 500 kW	50	Ecofys http://www.ecofys.com/com/news/pressreleases2002/pressrelease02aug2002.htm
12. Evopod	UK	Tidal current	Evopod is a semi-submerged, floating, tethered tidal energy capture device. It uses a simple but effective mooring	1:10 scale model tested in the Strangford Narrows near Portaferry,	150	OCEANFLOW Energy

			system that allows the free floating device to maintain optimum heading into the tidal stream.	Northern Ireland from June 2008 to 2009. 22 kW 1:5 scale model is being developped		http://www.oceanflowenergy.com/
13. FO3 wave energy converter SEEWEC 	Norway	Wave A	The WEC device looks like a traditional rig, but one striking difference is the floating, egg-shaped cylinders hanging underneath it 1. Energy is absorbed from the waves as they move the cylinders up and down. This linear, vertical motion is then converted to rotational motion by means of a hydraulic system – a hydraulic motor drives a generator to produce electricity. Another important difference is that the rig structure is built using lightweight composite material instead of steel.	Testing 1:3 laboratory rig at Buldra Currently being assessed to see if improvements to the prototype could be made. Full scale 2.52 MW	40	Fred Olsen http://www.seewec.org http://www02.abb.com/global/gad/gad02077.nsf/lupLongContent/D74F5739AAE738F6C12571D800305007
14. GEM-OCEAN'S KITE project	Italy	Tidal current	One of the most attractive project developed during the last 5 years is surely that	Nowadays the real scale prototype, patented and with innovative design, of		ADAG research group of Aerospace engineering dpt. University of Naples

			named GEM (Marine Electrical Generator), developed in collaboration of Parco Scientifico e Tecnologico del Molise (Scientific and Technological Park of Molise). Its patented concept consists of a submerged floating body linked to the seabed by means of a tether. This hull houses electrical generators and auxiliary systems. Two turbines are installed outside the floating body and are exposed to the external currents. Due to a relatively safe and easy self-orienting behaviour, GEM is a good candidate to solve some problems involved with oscillating and reversing streams, typical of Tidal current. An additional advantage of its configuration is related to the possibility of avoiding the use of expensive submarine foundations on seabed,	100 kW with 2.5 knots water current, is being currently designed and it will be installed for the end of next year nearby Venice in a very slow speed current.		“Federico II” www.dpa.unina.it/adag/

			because these are replaced with a flexible anchorage Releasing the anchorage cable allows the system to pop-up for easy maintenance. Special diffuser have been designed to increase the output power for very low speed currents. After several numerical investigations, a series of experimental tests has been carried out in the towing tank of the Department of Naval Engineering at the University of Naples.			
15. Hammerfest Strøm The Blue Concept	Norway	Tidal current	Tidal Stream Turbine Horizontal axis turbine- Seabed mounted gravity base	Full scale, grid connected Kvalsundet fjord (Norway) 1MW prototype planned for 2010-2011, to be installed in Scotland. Pre-commercial t idal farm planned for	300	Hammerfest Strom http://www.e-tidevannsenergi.com/ http://www.hammerfeststrom.com/ Scottish Power http://www.scottishpower.com/

				2012.		
16. Hydro-gen 	France	Marine current	Hydro-gen Horizontal axis turbine – Floating paddle wheel	Hydro-Gen 10: In 2006, a 10 kw prototype (size : 2,3 on 4,5 m) has been engineered, manufactured and tests at sea have started We hope to start at the end of 2008, a 20 kw machine (size: 7 by 3,5 m) which will provide power in remote islands . In 2010 the first 1 Mw class « Hydro-Gen » marine current turbine is expected to start producing.	10	Hydro-Gen http://www.hydro-gen.fr/

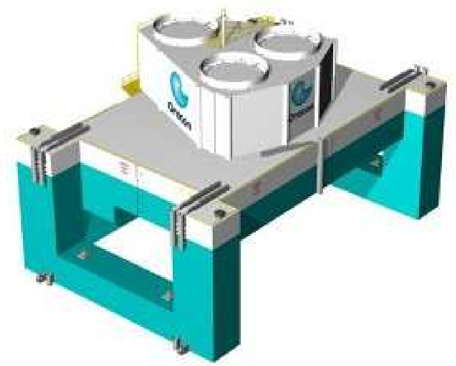
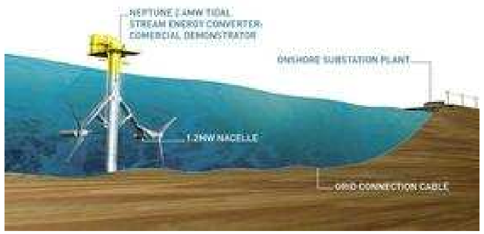
17. Hydro Venturi 	UK	Tidal Stream	Hydro Venturi has been developing a system that works with the Bernoulli principle. This prototype uses the pressure drop in a venturi duct to move a second medium (air). It is claimed that the best site to install the device is where the water is constrained like an inlet or a fjord.	From 2002 to 2005 the company operated a head hydro system in the North of England and in November 2005 they installed an ultra low head hydro demonstration system in the English Midlands. After that, a demonstrator plant was built on the River Derwent, Derby. Since then, they have continued with the development of novel applications for their devices and also, feasibility studies of locations in Canada, Scotland, New York, Iceland, New Zealand and India, for installation purposes. The project has received £2.5m funding to date.	0	Hydroventuri http://www.hydroventuri.com
18. Kobold turbines ENERMAR	Italy	Current	Kobold, a patented turbine, has been the result of such studies. Kobold is able to convert kinetic energy from marine currents into mechanical rotor energy with	Grid connected turbine	40	Ponte di Archimede http://www.pontediarchimede.com/language_us/progetti_det.mvd?RECID=2&CAT=002&SUBCAT=

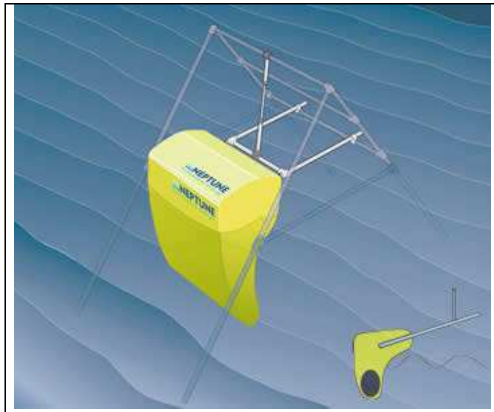
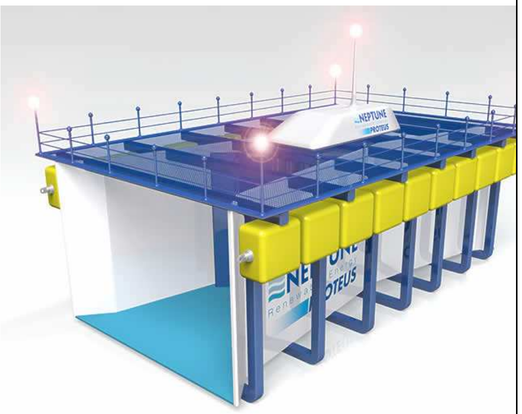
			a high rendering. The Kobold turbine is a rotor mounted on a vertical shaft which produces mechanical energy by exploiting marine currents.			&MODULO=Progetti_ENG&returnpages=&page_pd=d
19. Langlee 	NO	Wave	The Langlee is a submerged wave generator producing electrical energy from the horizontal movements in the waves. Langlee is a patent pending submerged system, operating just beneath the water surface where wave energy is highest, yet where the installation is sheltered from the heavy storms	The Turkish energy company Ünmaksan has signed a letter of intent to finance the development of a pilot facility using this technology along Turkey's coastline, with the ultimate aim to install a 24 MW wavefarm.	0	http://www.langlee.no
20. La Rance 	FR	Tidal Barrage	Installed capacity rating of 240 MW and produces on average 600 GWh/year	Operating since 1966	240 000	
21. Leancon Multi Absorbing Wave Energy Converter (MAWEC)	DK	OWC	MAWEC is an OWC wave energy converter. In working principle it differs from other OWC's in the way that it uses	The next technical step in this project that will take place is a test in a real sea condition.	0	http://www.leancon.com

			pressure and suck at the same time. This gives the wanted effect that the vertical force on the WEC is zero when the WEC streches over more than one wave length. It is the suck forces (F_down) that prevent the WEC from floating up on the top of the waves. In this way it can be made with very low weight which reduces production costs.	A ideal place where the wave conditions fit this 1:40 scale model has already been picked out.		
22. LIMPET 	UK	OWC	The Limpet unit on Islay has an inclined oscillating water column (OWC) that couples with the surge-dominated wave field adjacent to the shore. The water depth at the entrance to the OWC is typically seven metres.□□The design of the air chamber is important to maximise the capture of wave energy and conversion to pneumatic power.□□The turbines are carefully matched to the air chamber to maximise power output.□ giving a nameplate rating of 500kW.	In Islay (Scotland), the commercial scale Limpet produces electricty to the grid since 2000.	500	Wavegen (Voith Siemens) http://www.wavegen.co.uk
23. Manchester Bobber	UK	Wave	A floating mass rises and falls under the action of waves in the water and this causes a	A 1:10 model of the device was tested at the NaREC research	0	http://www.manchesterbobber.com/

			pulley and its shaft to oscillate. A counterweight controls tension in the suspending medium over the pulley and the pulley shaft is connected to an output shaft through a freewheel clutch. As the float descends, the pulley speed attempts to exceed the output speed causing the clutch to engage and accelerating the entire shaft system. At maximum speed the clutch disengages, allowing the output shaft to continue its forward rotation whilst the pulley decelerates and reverses during ascent of the float. Whilst the clutch is disengaged, the output shaft continues to rotate due to the inertia of a flywheel but decelerates due to energy extraction (i.e. the power output). A gearbox is used to increase the output shaft speed hence reducing the size of flywheel and generator required to produce a given output power.	centre during Septembre 05. The next step is to develop a full scale float and to deploy it in open sea conditions for testing.		
24. McCabe Wave Pump	Ireland	A	Pontoons at the front and rear individually are pushed upwards by waves creating high pressure inside cylinders	It is being redesigned and has now submitted to the Irish government for	0	Hydam Technology http://www.wave-power.com

			inside the pump house at the center of the construction	support to construct a 1/4 scale device as part of a development process for a 500kW device.		
25. Morild 	Norway	Marine Currents	Low velocity marine currents The main objective of the MORILD project is to demonstrate the functionality and overall efficiency of a full-scale, operational tidal power plant. The plant will be tested to find out whether it can produce the expected amount of power and whether the structure can endure the severe offshore environment, as well as to uncover areas where further progress can be made to bring down the cost per kWh in a more commercial setting over time.	A full scale prototype is currently being built for deployment	0	Statkraft and Hydra Tidal http://www.statkraft.com/pub/innovation/tidal_power/MORILD_demonstration_plant/index.asp
26. Multi Resonant Chambers	UK	OWC	Oscillating water column – Floating and moored to the sea bottom Orecon has made a technological breakthrough with the MRC (Multi Resonant Chambers) and	1:12 scale model at University of Plymouth The developper Orecon has signed a deal with the Portuguese Eneólica for the first full scale	0	ORECON http://www.orecon.com

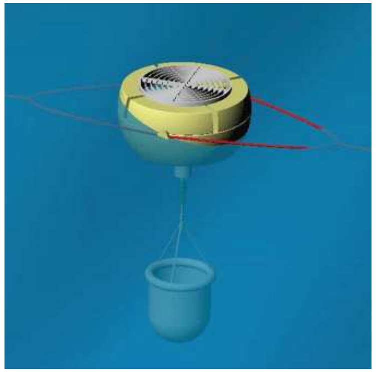
			have delivered the high efficiency implementation of OWC the industry has been waiting for.	1,5MW model. This will be the first phase towards building an array in Portugal. MRC will also be tested at the Wave Hub in Cornwall.		
27. Mutriku 	Spain	OWC	It is the same machine concept operating at LIMPET (Islay, Scotland)	The 16 Wells Turbines are currently being built into the new breakwater.	296	EVE Ente Vasco de la Energia www.eve.es
28. Neptune 	UK	Tidal stream	Horizontal axis tidal turbine the device comprises two horizontal axis tidal turbines, which will be mounted on a single monopile for the commercial demonstrator. The device features bi-directional (flood and ebb) generation,	2.4MW testing at EMEC	0	http://www.aquamarinepower.com/technologies/neptune-/
29. Neptune Triton	UK		The device operates in the nearshore and consists of an axi-asymmetrical buoy attached to an A-frame which would be piled into the sea	No info	0	http://www.neptunerenewableenergy.com

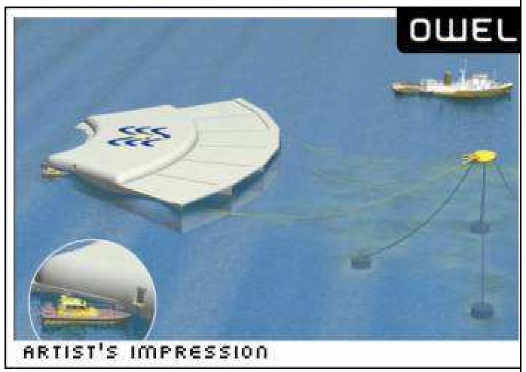
			bed. The axi-asymmetrical buoy is designed to generate a counter phase upstream wave and a much reduced downstream wave; this maximises capture from the wave and improves overall efficiency. In order to tune the buoy to the incident wave regime, the mass can be controlled by pumping sea water into and out of the hollow cavity inside the buoy. Power take off is achieved via a piston and hydraulic arrangement.			
30. Neptune Proteus Mark III 	UK	Tidal current	The Neptune Proteus Tidal Power Pontoon consists of a 6m x 6m vertical axis crossflow turbine mounted within a patented, symmetrical diffuser duct and beneath a very simple steel deck and buoyancy packages. The Neptune Proteus is designed for estuarine sites which can exhibit powerful currents, yet have the advantages of lower access, cabling and maintenance costs than in offshore environments.The vertical shaft connects simply to the gearbox and	Stage IV - Full scale demonstrator at Humber St. Andrews site□Build a full scale demonstrator for the Humber St Andrews site. Design phase expected in Spring 2008, manufacture expected in Summer 2008 followed by deployment, performance monitoring/testing and environmental impact study. Stage V - Develop	0	http://www.neptunerenewableenergy.com

			generator/alternator on the top of the pontoon with associated valves and electrical processing and control machinery. The power pontoon is easily moored in the free stream, thus minimising environmental impact and operates equally efficiently for both flood and ebb currents. The rotor is maintained at optimal power outputs by sets of computer controlled shutters within the duct. Theoretical work and 1/10th, 1/40th and 1/100th scale laboratory experiments suggest an overall efficiency of greater than 45%.	site Manufacture the array of ten Neptune Proteus devices (1,000 MWh/year) and install at the Humber St. Andrews site with full grid connection. Planned at monthly intervals from January 2009.		
31. Ocean Treader WEC 	UK	Point absorber	Point absorber – Moored to the seabed Ocean Treader is a floating device designed to be moored 1 – 2 miles offshore in ocean wave systems, and as such will be largely unobtrusive from the shoreline..	"The theory behind the machine has been proven in wave tank testing and we are now developing a full size machine for offshore testing" Green Ocean Energy Ltd. are currently raising funds to start testing in sea conditions in 2011.	0	Green Ocean Energy Ltd. http://www.greenoceanenergy.com/

32. OE Buoy “Seileán” 	Ireland	Floating OWC	The air contained in the plenum 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 wave energy capture efficiency is high in normal wave conditions. Capture efficiency however, reduces in extreme waves when power levels exceed the capacity of the power take-off system. This makes the device self limiting and will ensure good survivability. The power take-off system is an air turbine, which converts the flowing air into rotational energy, which drives the generator. This air turbine is of the self-rectifying type that is necessary to convert the reciprocating air flow into unidirectional rotation of the generator. The whole power take-off system contains only one moving part.	1:4 scale in Galway 1:1 rated 2Mw could provide power to 1600 homes. The system has successfully undergone 2 and a half years' testing off the coast of Galway, Ireland. It has been producing electricity which was fed into the national grid	20	http://www.oceanenergy.ie/
33. OHEG	UK	Tidal/Wind	Horizontal axis turbine – floating platform 24 hour power is produced by	The first phase of hydrodynamic testing has been undertaken	0	FreeFlow69 http://www.freeflow

			using both the kinetic energy in tidal flow and the potential energy created by tidal height changes. The O.H.E.G. plant is completely independent of the wind farm; however it does make an ideal foundation for offshore wind turbines, combining both tidal energy and wind energy. The O.H.E.G. plant is not detrimental to the surrounding environment or ecosystem and due to its offshore location it will not be visually offensive. Currently the project is on hold awaiting funding.	with the aim of establishing the characteristics of water flow around a solid structure like the prototype Ocean Hydro Electricity Generator plant. A scale model of the plant was used in various depths and velocities of water flow to demonstrate the venturi system in operation and to note the turbulent effects of the structure. The venturi system caused a significant increase in water velocity through the O.H.E.G. channel. It is estimated that the velocity increased by two thirds of the original water velocity.		69.com
34. Open Centre Turbine	Ireland	Current	The Open-Centre Turbine is designed to be deployed directly on the seabed. Permanent Magnet Generator	Orkney EMEC (grid connected) The turbine in Orkney has been installed between a twin-piled structure enabling the	250	Open Hydro http://www.openhydro.com

			Installations will be silent and invisible from the surface. They will be located at depth and present no navigational hazard.	unit to be raised and lowered		
				Other projects: Alderney and Nova scotia. In Nova Scotia, a 1 MW turbine was installed on the 17 November 2009	1000	
35. Oscillating Device 	Norway	A	The oscillating device utilises the movement of ocean waves to create useful energy e.g. electricity. The device is equipped with air pumps that are activated by pivotal and vertical movement between the floater, column and sea anchor. The air pumps are coupled to a turbine that drives other equipment such as an electrical generator. The devices can be arranged in groups to deliver power to a single electrical generator. The system includes energy storage equipment enabling scheduled use of the energy.	Research	0	Ing Arvid Nesheim http://www.anwsite.com/
36. OSPREY	UK		Horizontal axis turbine – floating platform	10 MW	0	FreeFlow69

						
37. Salinity prototype 	Norway	Salinity	The salinity difference between fresh water of a river and salt water in the ocean is used to create a pressure difference equivalent to that present in a water column of more than 120 meters high, this is then turbined in order to create electricity.	Statkraft inaugurated the first prototype osmotic powerplant in the world on the 24th November 2009. A full-scale commercial osmotic power plant could be in place as early as 2015.	0	Statkraft
38. OWEL Grampus Wave Energy Converter 	UK	Wave	OFFSHORE WAVE ENERGY LTD has developed & patented a new concept of wave energy device, which traps and compresses air in successive wave troughs The compressed air is accumulated in a reservoir and is then used to drive a turbine and thus generate power. The devices are inherently robust & are designed to be installed on floating platforms, moored offshore in sea areas where	Demonstrator phase Expected full scale 12 MW	0	OFFSHORE WAVE ENERGY LTD http://www.owel.co.uk

			energetic wave spectra are found			
39. OYSTER 	UK	Wave C	Oyster® is a hydro-electric wave power converter, designed to capture the energy found in amplified surge forces in nearshore waves	The peak power generated by each Oyster® unit is between 300 and 600kw, depending on location and configuration. The capacity of the current device that has been installed at EMEC is 315kW. It has been installed in November 2009 and will have some output data by January 2010. Capacity to build a single onshore generating plant with an installed capacity of 21MW or higher. The Oyster® 2 device should be ready in 2011, it will have an installed capacity of 2.4 MW	315 kW	Aquamarine Power http://www.aquamarinepower.com/technologies/
40. Pelagic Power wave pump	DK	wave	Pumps that are afloat 20-40 meters under the surface of the sea are key elements in Pelagic Power's wave energy concept. In a submerged	A 1:3 scale model was installed on the site of Bjørøya outside Lauvsnes in the municipality of	0	Pelagic Power http://www.pelagicpower.com/

			position, the pumps are not at risk of being exposed to storm waves. Within the new installations lie either so called absorbers or buoys upon the surface. These devices gather energy from the waves and send it to the pumps located further down. The pumps' movement occurs between the absorber and a water anchor placed on each pump. These pumps are called "pelagic wave pumps" and are not anchored to the seabed. Seawater is then pumped to an onshore turbine.	Flatanger in Nord-Trøndelag (Denmark).		
41. PELAMIS 	Agouçadoura, Portugal	Wave	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 fluid through	Not operating.	2.250	http://www.pelamiswave.com/
	EMEC, Orkneys, Scotland			Operating (E-ON test towards commercialization) Fully operational in 2010	750	

				Pelamis wave power are currently developing the P2 device, which is an upgraded version of the first Pelamis device.		
42. PICO 	UK, USA	OWC	Wave enters in the "hydro-pneumatic chamber" (resembling a cave with entry below the waterline). Up-and down- movement of water column inside chamber makes air flow to and from the atmosphere, driving an air turbine. The turbine is symmetric and is driven indifferently in which direction the air flows.	The team working at the PICO OWC are currently looking to solve some problems linked to vibrations, stalling, and trying to develop a way to increase the RPM of the turbine, which is limited. They were happy to announce that the plant was running four days in a row over the summer, which is a record for this type of experimental device. They are furthermore developing a way to detect the size of incoming waves, and to adapt the size of the	400	http://www.pico-owc.net

			Poseidon is a concept for a floating power plant that transforms wave energy into electricity. The power plant furthermore serves as a floating foundation for offshore windmills, thus creating a sustainable energy hybrid. Poseidon has not yet been built at full scale, but has been tested with fine results in scales of 8 meters and 17 meters. A 37 meter off shore demonstration plant was launch in summer 2008. A full scale Poseidon plant can measure from 100 and up to 420 meter depending on wave and wind conditions at the chosen location.			organ.com
44. PowerBuoy Ocean Power Technologies (OPT)	UK, US	Wave (buoy)	OPT's PowerBuoy® wave generation system uses a "smart," ocean-going buoy to capture and convert wave energy into low-cost, clean electricity. The rising and falling of the waves off shore causes the buoy to move freely up and down. The resultant mechanical stroking is converted via a sophisticated	Santoña, Spain: (Customer: Iberdrola) In development; first phase complete; building second phase consisting of subsea power transmission cable, underwater substation, grid connection and the First PowerBuoy unit.	0	http://www.oceanpowertechnologies.com

			electrical generator. The generated power is transmitted ashore via an underwater power cable.	1.39MW		
				Oahu, Hawaii. A Power Buoy was successfuly tested in Hawaii in a US Navy facility from October 2008 on..		
				EMEC, a 150 kW device is to be installed in Orkney by the end of 2009		
				Wave Hub, there is also a plan to install up to 5 MW of PB devices in the future British test site.		
				Reedsport, Oregon. OPT is currently developing the first commercial wave farm off the west coast of the USA. The		

				farm should have an initial installed capacity of 1.5 MW.		
				Coos Bay, Oregon. OPT is proposing the first utility-scaled plant in the USA. It could consist of up to 200 PB devices.		
45. Pulse Generators 	UK	Current	Oscillating hydrofoil - Seabed mounted or gravity base With the conventional approach turbines face into the flow and the swept area over which energy is captured is a circle whose diameter must be significantly less than the depth of the water less than the where which for cross flow turbines in shallow water s directly related to the depth. The hydrofoil approach overcomes this problem because the swept is a rectangle whose length is independent of water depth. At a typical site where depth is limiting a Pulse generator will extract more than 3 times as much energy as a single cross flow turbine.	100kw test rig in the Humber estuary currently feeds power into a chemicals company on the banks of the river. The European Commission has issued a grant to Pulse Tidal in order to deliver a 1000 kW generator by 2012.	100	Pulse Generation http://www.pulsegeneration.co.uk

46. Rotech Tidal Turbine (RTT) Lunar Energy 	Sweden	Current	The RTT is a bi-directional horizontal axis turbine housed in a symmetrical venturi duct. The venturi draws the existing ocean currents into the RTT in order to capture and convert energy into electricity. Use of a gravity foundation will allow the RTT to be deployed quickly and with little or no seabed preparation at depths in excess of 40 metres. This gives the RTT a distinct advantage over most of its competitors and opens up a potential energy source that is 5 times the size of that available to companies using pile foundations.	A 1MW prototype has successfully produced electricity to a simulated grid in May 2009. 8MW by 2010/2011	0	http://www.lunarenergy.co.uk/
47. REDstack 	NL	Saline Gradient	Door middel van Reversed Electro Dialysis wordt uit het in contact brengen van zout en zoet water middels ionselectieve membranen electriciteit gewonnen.	Pilot Plant in Harlingen Full scale final obj: 200MW plant	0	Redstack http://www.redstack.nl/
48. Sabella	FR	Current	SABELLA has developed a specific technology based on	Demonstration 1:3 Estuaire de l'Odet	0	HYDROHELIX ENERGIES

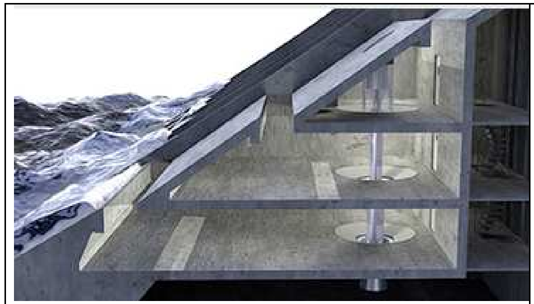
 *Photo Credits: Sabella*			an original concept of a screen of turbines positioned on the seafloor. It is characterised by a configuration of turbines juxtaposed on the seafloor, without impinging on the surface. These turbines are stabilised by gravity and/or are anchored according to the nature of the seafloor. They are pre-orientated in the direction of the tidal currents, and the profile of their symmetrical blades helps to capture the ebb and flow. The rotor activated, at slow speeds (10 to 15 rpm), by the tides, powers a generator, which in turn exports its electricity production to land via a submarine cable anchored and embedded at its landfall.	(Quimper) After two batteries of onsite trials and measurements, “SABELLA D03” was brought up in April 2009. This experiment helped to consolidate experience feedback and to recognise the environmental neutrality and relevance of the solution, giving it a clear competitive edge. Sabella D10, with a 10 meter diameter rotor is currently being designed. It could have a capacity of 200kW to 500kW per unit depending on site.		http://www.hydrohelix.fr/
49. Savonius turbine	UK		Horizontal axis turbine (ducted) - Seabed mounted or gravity base	R&D	0	Rugged Renewables http://www.emat.co.uk

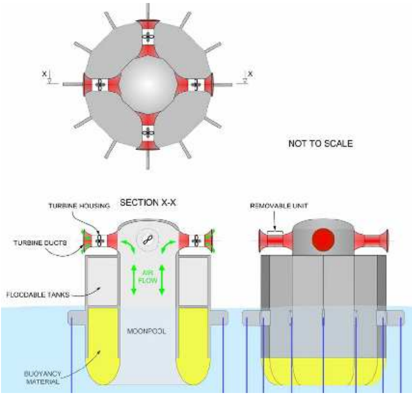
						
50. Seabased 	Sweden /Norway	Wave	The Seabased AB system is based on a three-phase, permanent magnet, linear generator especially developed to be utilised in ocean bed arrays and directly driven by point absorbers (buoys) on the surface. Two devices of 4 meters in diameter have been installed in the water at Runde Environment Centre in Norway.	40 kW	0	Seabased AB http://www.seabased.com http://www.tu.no/energi/article226099.ece
51. SeaPower Project 	Italy	Tidal	Sea Power consists of a vessel or pontoon, moored to seabed, to which several lines of horizontal axis hydro turbines are attached. The same pipes,	After several numerical simulation, a first validation of the studies has been made by testing a prototype of		Fri-El Seapower – ADAG research group of University of Naples " Federico II" www.fri-

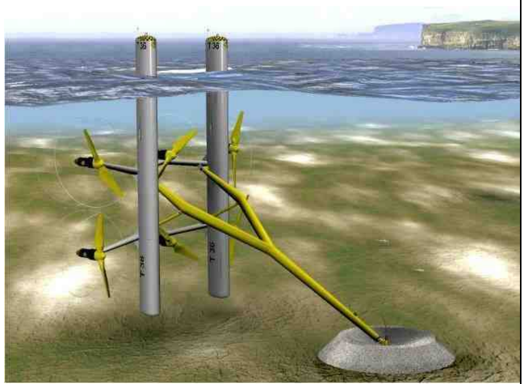
			connecting the turbines through cardanic joints providing the necessary flexibility to the system, transfer the power captured from the water on board of the pontoon. Pipes are here connected to electrical Permanent Magnet Generators – PMG that are kept out of the water in order to simplify and diminish their maintenance. The electric generators transform the power carried by the transmission lines into electrical energy which can be directly fed into the grid through an undersea cable, connecting the individual floating structures to a submarine hub, which in turn is connected to the shore by a single submarine cable. Alternatively the systems can be installed offshore far away from the coasts and hydrogen can be produced with the electricity generated	the system in the water towing tank of the Naval Engineering department of the University of Naples “Federico II”. Soon after the controlled tests, a series of open water prototypes tests has been carried out in the Strait of Messina, in order to check the system well working in real conditions. On July 2008 a reduced scale of Sea Power prototype (6KW at 2.5m/s) was launched and exactly an year later another bigger prototype (20KW at 2.5m/s) was tested in the same waters. The final system has been designed to be installed in Messina Strait and it is conceived to produce up to 500 KW with a nominal		el.it/seapower www.dpa.unina.it/adag/

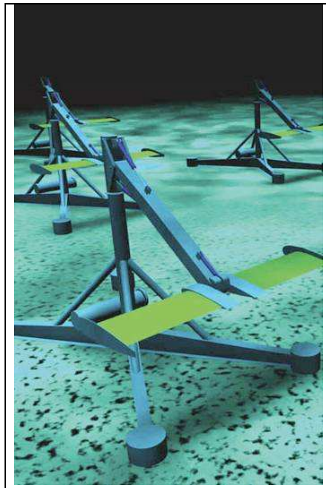
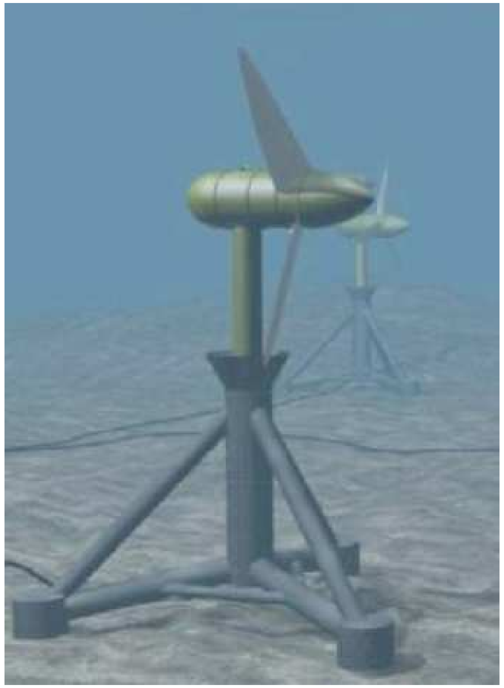
			by the turbines.	flow speed of 2.5 m/s (about 5 Kts).The real scale prototype is not yet realized but several theoretical analysis, numerical predictions, tests in towing tank and real conditions on a scaled prototype have been already carried out. Permits to deploy the final system are expected for the end of the year.		
52. SEAGEN 	UK	Tidal stream	The technology developed by Marine Current Turbines Ltd works much like submerged windmills, but driven by flowing water rather than air. They can be installed in the sea at places with high tidal current velocities, or in places with fast enough continuous	Pre-Commercial Strangford Lough, Northern Ireland	1200	Marine Current Turbines http://www.marineturbines.com http://www.seageneration.co.uk/default.a
				Lynmouth, Devon	300	

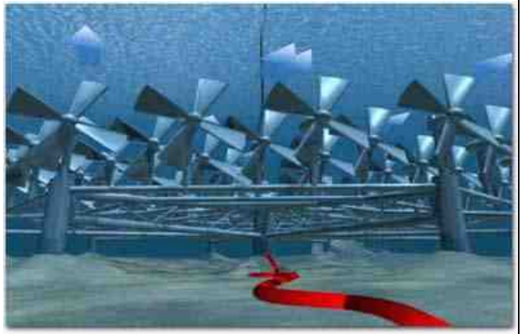
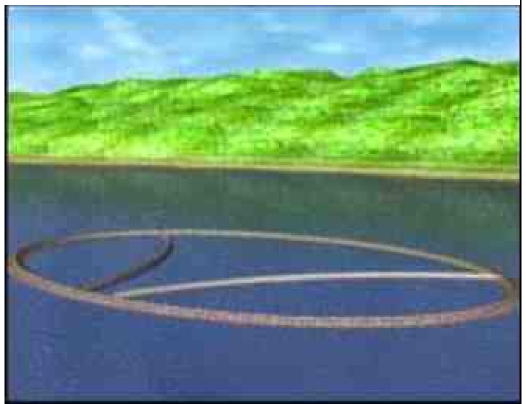
				Anglesey, North Wales, 10.5 MW to be commissioned by 2010-2011	0	
53. Sea Snail 	Orkney, Scotlan[d]	Tidal	Hydrofoil that induces downward force - Seabed mounted or gravity base		150	Robert Gordon University http://www.rgu.ac.uk

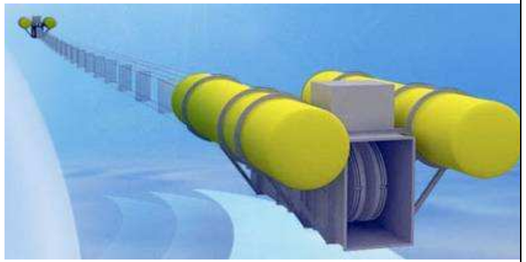
			converter based on the wave overtopping principle utilizing a total of three reservoirs placed on top of each other, in which the potential energy of the incoming wave will be stored. The water captured in the reservoirs will then run through the multi-stage turbine for electricity production. Using multiple reservoirs will result in a high overall efficiency.	Full scale rated 20 MW		
56. The Skerries 	UK	Tidal Stream		Welsh island of Anglesey 10.5MW tidal energy farm (7x1.MW SeaGen urbines): commissioned 2011?	0	Marine Current Turbines http://www.marineturbines.com http://www.seageneration.co.uk/default.asp
57. Sloped IBS Buoy	UK	Wave	Attenuator	Research	0	Edinburgh University http://www.mech.ed.ac.uk/research/wavepower/

							http://www.mech.ed.ac.uk/research/wavepower/sloped%20IPS/Sloped%20IPS%20intro.htm
58. Sperboy Embley Energy  	UK A/D	Wave (OWC Buoy)	SPERBOYTMis 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.	1:100 University of Cork 2007 1:5 University of Plymouth 1999-2001 full scale: 2 MW	0	Embley Energy http://www.sperboy.com

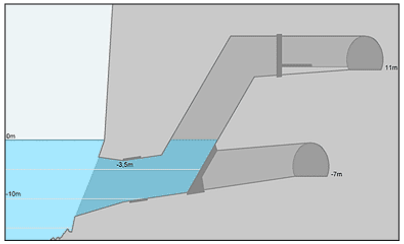
59. SRTT 	Orkney, ScotlandUK	Tidal Current	Horizontal axis turbine - Floating The Scotrenewables tidal turbine (SRTT) system is an innovative free-floating rotor-based tidal current energy converter, which has been under development for over three years.	Full scale 1.2 MW Test at EMEC planned by the end of 2008	0	Scotrenewables http://www.scotrenewables.com/
60. SST Semi Submersible Turbine 	UK	Tidal Current	The TidalStream Semi-Submersible Turbine (SST) concept is designed for deep water, such as the 60m deep Pentland Firth - too deep to mount turbines on towers to the seabed economically and too rough for surface floaters to survive. Instead, the turbines are mounted on semi-submersible spar buoys tethered to the seabed gravity anchorages by a swing-arm	10 MW claimed Pentland Firth (Orkneys) Current state: model testing	0	Tidalstream http://www.tidalstream.co.uk/
61. Stingray EB Frond	Shetland Islands UK	Tidal current	Oscillating hydrofoil - Seabed mounted or gravity base It consists of a hydroplane which has its attack angle relative to the approaching water stream varied by a simple mechanism. This	150 kW machines 500 kW farms On hold for lack of funding	0	The Engineering Business http://www.engb.com/services_09a.php

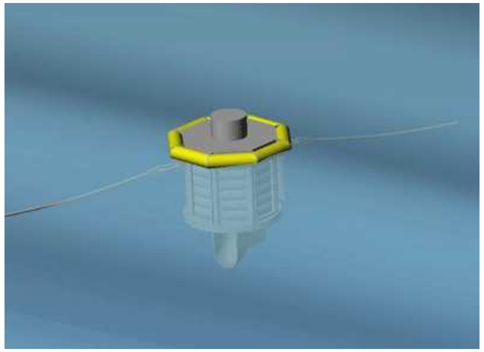
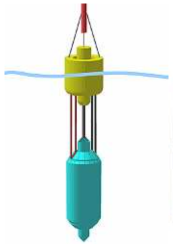
			causes the supporting arm to oscillate which in turn forces hydraulic cylinders to extend and retract. This produces high pressure oil which is used to drive a generator			
62. Swan turbines 	Norway	Tidal stream	A gearless low speed generator offering a high efficiency over a range of speeds with minimal maintenance demands through the use of novel structural and electromagnetic topologies	Swanturbines is surveying several sites around the UK in order to determine the economic viability of small arrays.	0	http://www.swanturbines.co.uk
63. Tidal Current Turbine	NL	MHD	No public info.	NO working	0	Neptune Systems

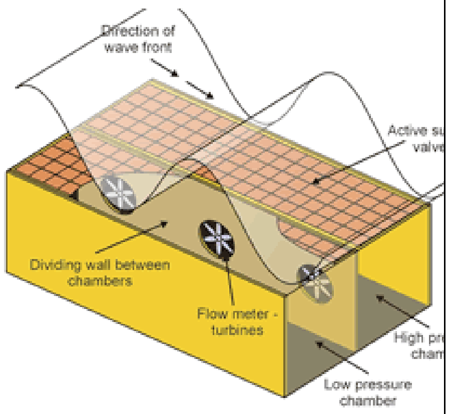
			Quoted in European Commission 6th Framework Programme,Co-Ordinated Action On Ocean Energy, Tidal Renewable Energy , Research, Development And Demonstration Roadmap	prototype, yet		No website
64. Tidal Hydraulic Generators 	UK	Tidal Current	The turbine array is used to generate hydraulic energy that in turn is used to power a generator; electricity can be fed into an existing grid or used to power a single site	THGL has designed, and intends to build a 3.5MW turbine system for the Ramsey Sound in Pembrokeshire, Wales.	0	Tidal Hydraulic Generators Ltd (THGL) http://www.dev.onlinemarketinguk.net/THG/index.html
65. Tidal Lagoons 	UK	Tidal lagoons	Offshore tidal power generation ("tidal lagoons") is a new approach to tidal power conversion that resolves the environmental and economic problems of the familiar "tidal barrage" technology. Tidal lagoons use a rubble mound impoundment structure and low-head hydroelectric generating equipment situated a mile or more offshore in a high tidal range area. Shallow tidal flats provide the most economical sites. Multi-cell impoundment structures provide higher load	Two projects in China and the United Kingdom are mentioned but no information is given about their status.	0	http://www.tidalelectric.com

			factors (about 62%) and have the flexibility to shape the output curve in order to dispatch power in response to demand price signals.			
66. Tidalsails 	NO	Current	The energy converter is a series of underwater sails, affixed to wires strung across the tidal stream at an angle. The sails are driven back and forth by the tidal flow between two stations, at one of which the generator is installed	R&D • Tank test finished in 2006 • 2006 1:40 model • 2008 larger test model in Lukksundet • In the future (not specified) 200-250 meters-long prototype for testing in a river. • Full scale device: 1 km in Kvalsudent in 2010	0	http://www.tidalsails.com
67. TiDEL	UK	Tidal	Horizontal axis turbine – moored to seabed A IMW free-stream tidal generator currently under development.	Testing of 1 MW planned at EMEC 2009	0	SMD Hydrovision http://www.smd.co.uk/

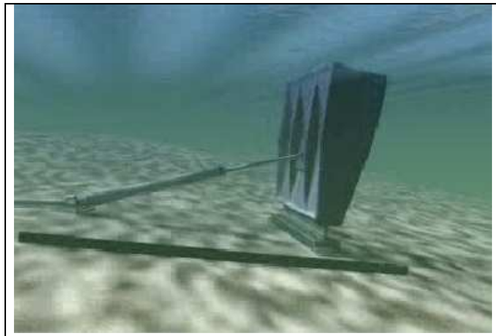
						
68. Tidevannskraft 	Norway	Tidal Current	Horizontal axis turbine - Floating Statkraft is in the process of developing and testing a tidal power plant based on a floating, anchored steel structure which will generate electricity via four large turbines driven by marine currents. The turbines and generators will be placed under the water line and can be easily brought to the surface for maintenance. Because it is a floating power plant, there will be no large-scale permanent disturbance to the sea floor, and the project will have minor environmental impact. The entire plant, complete with	developing and testing	0	Statkraft http://www.statkraft.com/pub/innovation/tecnology/ocean_energy/index.asp

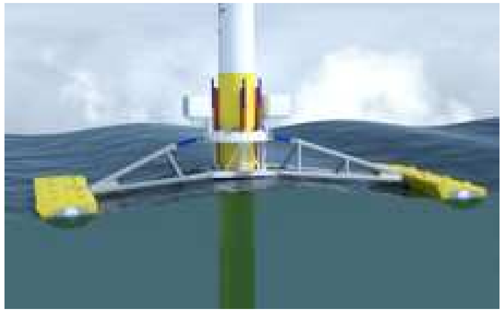
			anchor, can be easily moved or removed.			
69. Tocardo 	Netherlands	Tidal Stream	Horizontal axis turbine - Pile mounted Barrage discharge in the Netherlands	In 2005, a full scale 2.8 metre diameter, 35kW prototype device (Tocardo Aqua 2800) has successfully been tested in the exhaust sluices of the IJsselmeer barrage at Den Oever, the Netherlands. A second demo project on the same location will be implemented in 2008.	35	Tocardo BV Tidal Energy http://tocardo.com/?Tocardo
70. TWEC 	Faroe Islands ?? Ireland/ US???	OWC	A tunneled wave energy plant	Testing Faroe Islands	0	SeWave Ltd http://www.sewave.fo
71. Tidal Delay	Australia / UK	tidal	Standard impulse turbine installed in siphon pipe over/under natural barrier	Tests planned at EMEC, Orkney, Scotland	0	Woodshed Technologies - CleanTechCom Ltd http://www.woodshedtechnologies.com.au
72. University of Strathclyde	UK		Contra-rotating (coaxial) marine current turbine Horizontal axis turbine	Research	0	http://www.strath.ac.uk/na-me/

73. Waterturbine 	Norway		Vertical axis turbine (enclosed) - Floating		0	Ing Arvid Nesheim http://www.anwsite.com/
74. Wavebob  	Ireland	Wave (floating body inertia)	The Wavebob is an axi-symmetric, self-reacting point absorber, primarily operating in the heave mode. It is specifically designed to recover useful power from ocean wave energy, and to be deployed in large arrays offshore.	Galway bay 1:4 prototype Full scale rated 2MW	500	WaveBob Limited http://www.wavebob.com
75. WaveDragon 	Denmark	Wave floating overtopping	Wave Dragon is a floating, slack-moored energy converter of the overtopping type that can be deployed in a single unit or in arrays of Wave Dragon units in groups resulting in a power plant with a capacity comparable to traditional fossil based power plant	1:4.5 Nissum Bredning (Denmark) 1:1 expected 7MW	20	http://www.wavedragon.net
76. WaveMaster	UK	Wave	Point absorber – Moored to the seabed	Prototype	0	http://www.oceanwavemaster.com

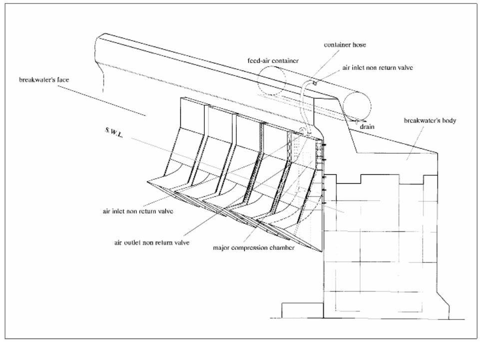
Ocean Wavemaster Limited (OWL)  			A WaveMaster device consists of two pressure chambers connected via a number of turbines and is located under water surface so that, at all times, the device is covered. The upper surface of each chamber is an "active surface" covered with many one-way valves which control the flow of water through the device. The valves on the high-pressure chamber allow the flow of water into the chamber provided the outside pressure is higher than the internal chamber pressure. This typcially occurs under wave crests. If the outside pressure is less than the internal pressure then the valves remain closed and there is no flow. Similarly, the valves on the low-pressure chamber will only allow water to flow out of the chamber if the internal pressure is higher than that outside. This typcially occurs under wave troughs. If the internal pressure is less than the outside pressure then the			

			valves remain closed and there is no flow.			
77. Waveplane 	Denmark	Wave E	Overtopping An artificial beach slows the bottom of the wave, tripping it over, and making it break into the lamellas. The vertical inlets at the rear of the device fill up and feed the flywheel tube, ensuring a smooth and steady vortex is maintained between waves. A series of preliminary tests has been completed to date and shows that the Waveplane is able to divert up to 32.9% of the energy present in regular waves into the rotating water column. Tests have also been undertaken in order to establish the efficiency of a turbine placed in the rotating water column. Results show that approximately 68-78% of the energy can be extracted in this way, which means that in the right wave conditions, as much as 25.7% of the available energy is delivered to the generator	Nissum Bredning, DK DMI, DK Copenhagen Hanstholm expected 2008	4 4 4 100	Caley Ocean Systems http://www.waveplane.com
78. Waveroller	Finland	Wave	Oscillating wave surge converter – Secured to bottom in shallow water	Lena Group, one of the leading business groups in Portugal, through Eneolica,	0	AW Energy http://www.aw-energy.com

			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 by a closed hydraulic system in combination with a hydraulic motor/generator system. WaveRoller is a modular concept. In practice this means that the plant capacity is formed by connecting a number of production modules into a WaveRoller plant. Each module consists of 3-5 wave elements installed into a common generation system.	S.A., one of its companies, and AW-Energy Oy, a Finnish company commercializing it's state-of-the-art technology harnessing near shore bottom wave energy, have entered into an agreement to establish a jointly owned company to produce electricity from ocean waves in Portugal. Parties took a substantial commitment to finance a 1 MW level power plant which will be build during 2008–2009. This plant will be based on the patented WaveRoller technology		
79. Wave Star Multi Point Absorber		Wave	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 pumps, which press oil into a common	1:10 scale model in Nissum Bredning, DK Full scale expected 6 MW	5.5	http://www.wavestarenergy.com

			transmission system, the pressure of which drives a hydraulic motor. The motor, in turn, drives the generator of the wave machine			
80. Wave Treader WEC 	UK	Point absorber	The Wave Treader concept utilises the arms and sponsons from Ocean Treader and instead of reacting against a floating Spar Buoy, will react through an Interface Structure onto the Foundation of an Offshore Wind Turbine. Between the Arms and the Interface Structure hydraulic cylinders are mounted and as the wave passes the machine first the forward Sponson will lift and fall and then the aft Sponson will lift and fall each stroking their hydraulic cylinder in turn. This pressurises hydraulic fluid which is then smoothed by hydraulic accumulators before driving a hydraulic motor which in turn drives an electricity generator. The electricity is	Npower has supported the feasibility study into the commercial application of Wave Treader via their Juice Fund and we expect to build a full size prototype of Wave Treader in 2009 with commercialisation in 2011.	500 kW	Green Ocean Energy Ltd. http://www.greenoceanenergy.com/

			then exported through the cable shared with the Wind Turbine. Periodically the Interface Structure moves vertically to allow for the effects of tidal range, and it also can rotate to ensure that the Sponsons are optimally aligned with the wave direction. An initial study commissioned by us, indicates that the additional loads placed on the foundation of an Offshore Wind Turbine from Wave Treader are relatively small, and therefore Wave Treader will not adversely affect the stability of the Wind Turbine.			
81. WECA Wave Energy Conversion Activator	Greece	Wave D	Oscillating water column - Shoreline The original full-scale model WECA design proposed is made of steel, so as to be suitable for mounting on the run up wall of breakwaters or other rigid or floating structures. It serves the		20	Daedalus Informatics Ltd. http://www.daedalus.gr/DAEI/PRODUCTS/RET/General/RETWW1.html

 WECA early prototypes: Design Details & Mounting on a Breakwater run-up			purpose of absorbing most of the energy of the impacting waves and turn it into compressed air (subsequently converted into electric power or other form of work). Emphasis is given to the development dynamics concerning the behaviour of a hydrodynamic phenomenon, resembling a virtual "Wedge" of kinetic energy rushing into the WECA's interior chamber. The codename nomenclature used for this phenomenon is C.M.W. (Critical Momentum Wedge principle).			
82. Total					9443[25]	

[25] La Rance NOT included