Global Status and Critical Developments in Ocean Energy

Ocean Energy Systems Implementing Agreement

OES OCEAN ENERGY SYSTEMS
An IEA Technology Initiative

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SeaGen tidal technology at Strangford Lough, Northern Ireland.
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Tocardo Tidal turbine
Photo courtesy of Torcado tidal turbines

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AWS III - 1/9th version tested in Scotland's Loch Ness in 2010
Photo courtesy of AWS Ocean Energy

Page 112, 2011 Separator
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Photo courtesy of Fred Olsen

Page 139, 2012 Separator
WET-NZ device tested off Oregon coast
Photo by John Huckerby

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INTRODUCTION

Every year since its inception in 2001 the Ocean Energy Systems Implementing Agreement (OES) Executive Committee (ExCo) has published an Annual Report, which details its activities over the previous year and includes on ocean energy activities supplied by each ExCo member country. The 2008 Annual Report started a tradition of including a series of invited articles, on a specific theme, by acknowledged industry experts. These invited articles examine current issues in the development of ocean energy technologies and provide insights into changing circumstances within ocean energy, e.g., forecasting cost of energy for different technologies.

The OES Annual Report is the best guide to recent and current activity in ocean energy technology developments and deployments. The OES ExCo adopted a new 5-year Strategic Plan in February 2012, which has the vision that OES will become the **"Authoritative International Voice for Ocean Energy"**. This vision is being realized by documents, such as the **"International Vision for Ocean Energy"**, published in 2012 and the ongoing publication of Annual Reports. The ExCo is committed to a high standard of content and high production values in the production of these reports. The Annual Reports, which are available on the new OES website – *www.ocean-energy-systems.org* - are widely regarded as one of the key authoritative information sources on ocean energy developments.

In May 2012 the ExCo decided that, with 5 years' worth of invited articles, it would be valuable to collect these articles together into a single volume as a reference source, which documents the recent developments in ocean energy in OES countries. So this volume is intended as an authoritative reference on developments in ocean energy, as they occurred in a year-on-year progression.

2008: Global Status and Perspectives of Ocean Energy Technologies

Fittingly the first set of invited papers was chosen to set a marker for the development of different ocean energy technologies. The OES ExCo chose the six invited authors, because they were each acknowledged experts in their fields and were actively involved in current developments. Five authors provided comprehensive papers on tidal range, tidal stream, wave, Ocean Thermal Energy Conversion (OTEC) and salinity power technologies. The sixth author addressed the utilization of ocean energy to produce drinking water.

2009: Key Technical and Non-technical Challenges for Ocean Energy

The second set of papers was themed around barriers to the uptake and acceleration of ocean energy technologies and how to mitigate these barriers. The papers discussed concepts, such as decarbonization of energy systems, structured development programmes for device developments to mitigate risks, conflicts and synergies in the use of ocean space, international regulatory practices for ocean energy and, finally, the benefits of standardization of ocean energy systems.

The 2009 report was also the first to include statistical tables on R, D and D investment, installed ocean energy capacity and involvement of international electrical utilities.

2010: Key Facilitators for Ocean Energy

The OES ExCo decided to follow the 2009 review of challenges for ocean energy with a set of papers on key facilitators. The first paper addressed the establishment of INORE, the International Network of Offshore Renewable Energy, a group set up by Ph.D. students in NW Europe to provide a forum for younger researchers. OES has become a sponsor of INORE activities, particularly in its expansion into the Asia-Pacific region. A second paper summarized a series of presentations given at the 3rd International Conference on Ocean Energy (ICOE) in Bilbao on moving ocean energy to the industrial scale. Lastly, the third paper analyzed market drivers for investors and policy makers in ocean energy.

2011: Marine Spatial Planning and Ocean Energy

Over the last few years the concept of marine spatial planning (MSP) has become a practice in some countries – an integrated approach to managing and allocating marine resources and space for competing activities. Marine spatial planning uses a map-based methodology to produce an inclusive synthesis to a particular marine area

There are, however, different geographic approaches to marine spatial planning, which are not yet internationally or consistently adopted. Further, consideration of the space/resource requirements of ocean energy has come late to the MSP process. The first paper described the concepts and practices of MSP whilst the remaining invited authors described how MSP was operating in their regions – the European Union, the State of Oregon, the wider United States coasts and New Zealand.

2012: Development of the International Ocean Energy Industry Performance Improvements and Cost Reductions

Although the growth of an ocean energy industry had been identified as a key facilitator for ocean energy in the 2010 Annual Report, the ExCo wanted to refocus on industry development, particularly as there was growing evidence of a broadening of potential investors in ocean energy (particularly amongst the international electrical equipment and turbine manufacturing companies), together with an increasing focus on supply chain developments, rather than device developments.

The four papers looked at disparate industry topics, including cost reduction pathways for wave energy, a utility's perspective on cost and performance of ocean energy technologies, a regulator's view of the development of ocean energy in the United Kingdom and, finally, a Canadian industry perspective on transforming a disparate group of 'technology push' advocates into a 'market pull' industry, resourced to install the first wave and tidal power array projects.

Dr. John Huckerby
OES Chairman (2009 - 2012) and Delegate from New Zealand

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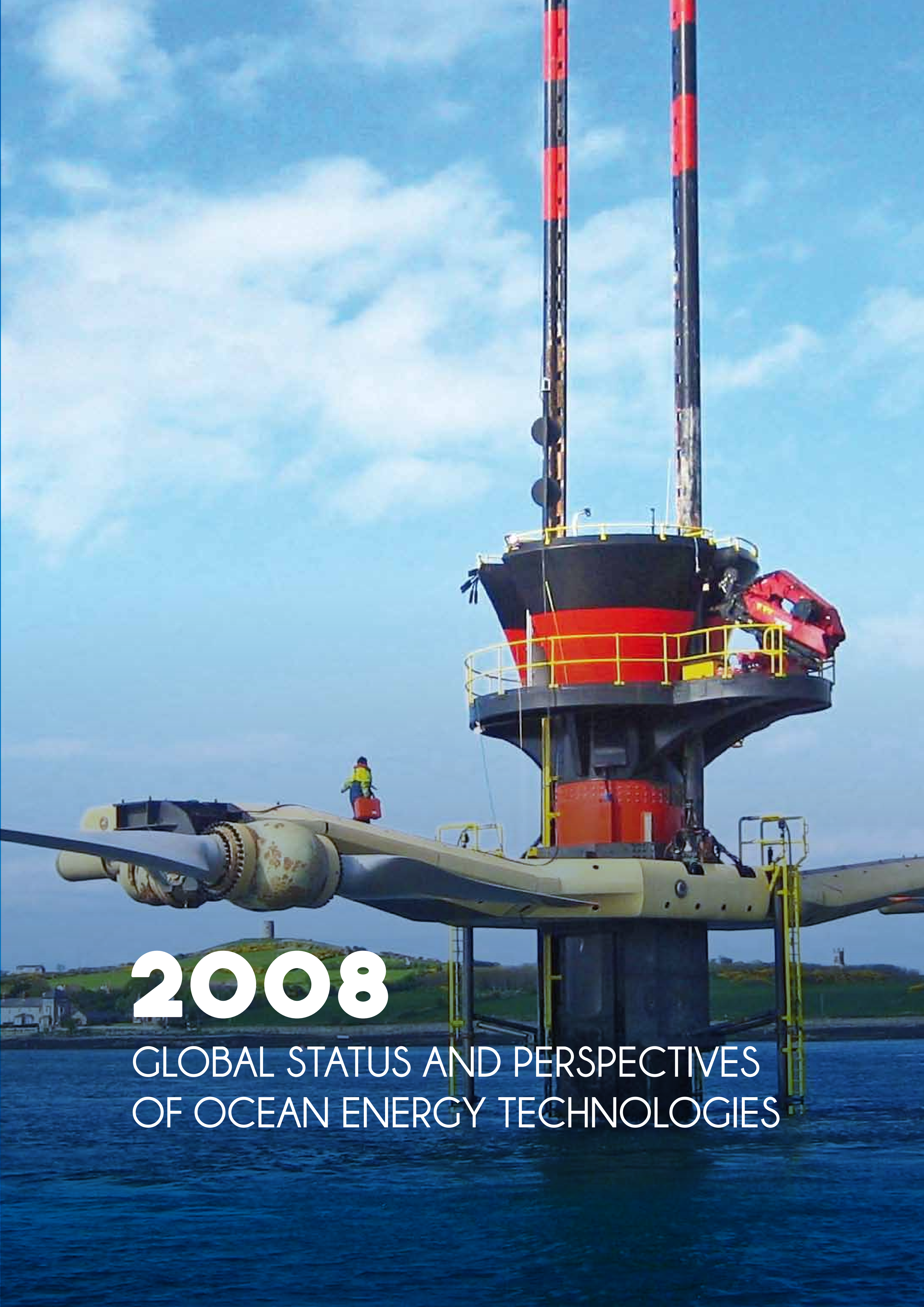

2008

GLOBAL STATUS AND PERSPECTIVES OF OCEAN ENERGY TECHNOLOGIES

2008
GLOBAL STATUS AND PERSPECTIVES OF OCEAN ENERGY TECHNOLOGIES

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TIDAL RANGE TECHNOLOGIES

Gary Shanahan
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There are a number of technologies which can be used to generate power from the tidal range – the difference between high and low tides - of an estuary, bay or river. When the water level outside the impoundment changes relative to the water level inside, the head created enables the production of power from turbines.

The most well understood technology is a tidal barrage in which a barrage spans the estuary, bay or river which can then be considered in a similar way to a hydroelectric dam. Other technologies that are being considered for exploitation of energy from a tidal range are tidal lagoons, tidal fence and tidal reef.

TIDAL BARRAGE

A barrage consists of a number of large concrete caissons built from one side of the water to the other, together with some form of embankment where the barrage is connected to land. The barrage would contain turbines (usually in the deepest water), sluice gates and ship locks to facilitate navigation.

The reservoir (tidal basin) is filled during the rising tide through the sluice gates (and potentially also through the turbine orifices). During ebb tide, when the water level on the seaward side of the barrage is low enough the water behind the barrage is released back to the seaward side through the turbines, generating electricity - ebb generation. So a barrage will maximise its energy in locations with a large basin area and maximal difference between high and low tide. The power generated is proportionate to the square of the tidal range and also to the area of the reservoir. There is the possibility of generating electricity on the incoming tide - flood generation - but studies have shown that this is unlikely to lead to significantly greater generation overall and/or may increase the costs or operational risks. It also needs to be considered whether the value of the energy might be significantly increased by using both ebb and flood generation as opposed to ebb only generation. Pumping or additional basins can also be used to optimise the amount and timing of the energy output, particularly if the geography of the tidal power project permits.

Barrage systems have relatively high civil infrastructure costs associated with what is in effect the placing of a dam across estuarine systems, and also need to take into account the environmental impacts associated with changing a large ecosystem.

The basic concept of hydroelectric dams is well understood and a barrage is the application of mature and commercially available technology. A 240MW tidal barrage (22 km^2 reservoir) has been successfully operated at La Rance, on the Northern coast of Brittany in France since it was first commissioned in 1966 after 6 years of construction using coffer dams. The 24 bulb turbines, each rated 10MW, have a diameter of 5.3m and are capable of operating on both ebb and flood tides and of pumping. The power station has generated around 550GWh a year – enough for a large town of 250,000 households - with high availability in over 40 years of operation. The La Rance barrage has 6 sluice gates and a lifting road bridge over a lock.

FIG. 1: La Rance – courtesy of EdF

The other operational barrage of any real scale is the Annapolis Royal Tidal plant, which has operated in Canada's Bay of Fundy since 1984 and uses a single 18MW Stratflo turbine of 7.6m. The Stratflo turbines are more compact than the bulb turbine for a similar output (rim driven generator) but are only designed for one way (ebb) generation.

A number of other smaller tidal barrages have operated worldwide - including China – where 7 tidal plants have a total capacity of over 5 MW - with the largest being the 3.2MW Jiangxia plant currently using 5 bulb turbines (with an additional 700kW Stratflo turbine scheduled)- and Russia – where a 400kW tidal power plant has operated since the early 1960s, intermittently, at KisloGubskaya. The plant was rebuilt in 2004 to house a new experimental floating 1.5MW orthogonal turbine with a 5m diameter.
http://www.sevmash.ru/?id=3748&lg=en

BARRAGES UNDER CONSTRUCTION

A 260MW tidal power plant is currently under construction at Sihwa in South Korea and is expected to commission in 2010. The plant has been installed in an existing dam and will incorporate 10 bulb turbines, each rated 26MW, with a runner diameter of 7.5m. It will have an estimated output, similar to that of La Rance, of around 550GWh. While relatively small compared to the capacity of the largest hydroelectric dams (10-20GW) this would be the largest tidal facility in the world in terms of installed capacity. However, South Korea has also announced plans for other larger tidal barrages – with, for example, a 520MW barrage planned for Garolim Bay awaiting planning approval.
http://www.westernpower.co.kr/english/business/sub04_01.asp

There are a number of other countries that have reported potential for new tidal range projects such as the US, India, Mexico and Canada. Work in the UK is discussed in more detail below.

TIDAL LAGOONS

Tidal lagoons are free-standing structures built offshore or in a semi-circular type arrangement connected to the shoreline at each end. Unlike barrages, they would not fully cross an estuary or river. They operate on similar principles to barrages in that they exploit the difference in tidal height to generate electricity using low head hydro turbines. They can also operate in both ebb and flood generation modes. A variety of materials have been proposed from which to construct tidal lagoons ranging from rock-filled embankments to gravity concrete walls and geotextiles.

Further study is required to show whether on balance, lagoons have less impact on the environment, shipping and other activity as is claimed. There are no operational tidal lagoons at the moment although a number of projects have been proposed at a variety of scales – particularly in the UK, Mexico and China.
http://www.tidalelectric.com/Projects.htm

SEVERN TIDAL POWER FEASIBILITY STUDY

www.decc.gov.uk/severntidalpower/

FIG. 2: Severn Estuary

The Severn Estuary's 14m (45 foot) tidal range represents a phenomenal source of indigenous, predictable (though intermittent), low-carbon energy. In the 2006 Energy Review the UK Government asked the Sustainable Development Commission to investigate tidal power opportunities across the UK. The

Commission also considered other UK estuaries as well as the Severn. Their report "Turning the Tide, Tidal Power in the UK" *http://www.sd-commission.org.uk/publications/downloads/Tidal_Power_in_the_UK_Oct07.pdf* in October 2007 concluded, with conditions, that there is a strong case for a sustainable Severn Barrage, and also potential for barrages in other locations with smaller natural resources (such as the Mersey, Wyre and Thames).

In response to the SDC conclusions, the Government launched a two-year feasibility study to investigate whether we could support a Severn tidal power scheme and, if so, on what terms. The study is expected to conclude in 2010 and is considering the costs, benefits and impact of the generation of tidal power in the Severn Estuary.

Ten proposals to generate electricity from the Severn Estuary came forward from a public Call for Proposals in May 2008 and a strategic review of existing options used in the Sustainable Development Commission's and previous reports. Proposals are at a variety of scales (from 0.625GW to 14.8GW) and include barrages, land-connected and offshore lagoons, a tidal fence (a continuous line of underwater tidal current turbines), and a tidal reef at a variety of sites along the Estuary.

The tidal reef is a radical new application of existing tidal range technology. The concept, as proposed to the feasibility study, uses fixed flow turbines which operate on a two metre constant head difference, which is maintained by floating concrete caissons or movable 'crest gates'. It would operate on both the ebb and flood tides. In hydraulic terms, the head attained at the reef would be controlled by the rate of flow through the reef and the head differential across the turbines. This proposal is at an early stage of development, with no prototype. A report, commissioned by the Royal Society for the Protection of Birds and published in November 2008 by Atkins Engineering, also considered the tidal reef proposal - *http://www.rspb.org.uk/Images/atkins_tcm9-203975.pdf.* It flagged several technical issues and uncertainties with the concept and proposed a rather different design. The report suggested adapting, and scaling up, very low head hydro turbines such as those being developed at Millau *http://www.vlh-turbine.com/EN/php/News.php* in view of their potential environmental benefits.

These proposed schemes are in varying stages of development, with some using tried and tested technology, and others using tested structures, but completely new materials. Some proposals are based on embryonic technologies which have not been prototyped or deployed, let alone at the huge scale proposed. Locations vary too, with the largest schemes spanning the Estuary from Minehead to Aberthaw (15 miles) and the smallest lying upstream of the Severn road crossings. Energy outputs also vary with the largest option (the Outer Barrage) estimated to generate up to 7% of UK electricity and the smallest generating roughly the same output as a large fossil fuel power plant.

However, careful consideration of the benefits, consequences, risks and costs of any Severn tidal power project is needed. The Severn Estuary is an internationally important nature conservation site for the species that occur there, including migratory fish and over-wintering birds and for its estuarine habitats including mudflat and saltmarsh. The impact of both barrages and lagoons would be to retain water: low tide levels would rise slightly within impounded areas and overall high tide levels would be reduced by about a metre. Some areas of habitat currently uncovered at low tide would be permanently underwater, displacing bird populations. The passage of migratory fish, like eel and Atlantic salmon, would be impeded by any structures that cross the estuary and high mortality rates for some species may be expected without mitigating measures. Impacts on protected sites would need to be compensated for under environmental protection legislation, which safeguards our biodiversity and water quality. The environmental effects of the innovative technology schemes – the tidal reef and tidal fence – are currently unclear as these proposals are less detailed, but they may be less environmentally damaging than barrages or lagoons.

The Severn Tidal Power Study will assess in broad terms the costs, benefits and impact of the schemes, including environmental, social, regional, economic and energy market impacts. It will consider what measures Government could put in place to bring forward a scheme that fulfils regulatory requirements and it will include a Strategic Environmental Assessment to ensure a detailed understanding of the Estuary's environmental resource, recognising the nature conservation significance of the Estuary.

UK PROPOSALS OUTSIDE THE SEVERN ESTUARY

As mentioned above, the Sustainable Development Commission report identified a number of other potential tidal power sites in the UK. A more recent study in the UK looking at tidal potential in the Eastern Irish sea has also set out the potential in the North West of England *http://www.liv.ac.uk/engdept/nwteg_launch_2008_po.pdf.* The study particularly mentions the Mersey Estuary on which a Feasibility Study is currently being carried out. *http://www.merseytidalpower.co.uk/*. Peel Environmental Ltd and the Northwest Regional Development Agency came together to commission a preliminary study that explores the opportunities for renewable energy and embraces the environmental, shipping, and socio-economic aspects of any possible schemes. The largest of a number of options reported to be under consideration is a 700MW tidal barrage.

Other potential tidal energy projects in the North West include the Solway Firth, Morecambe Bay and the Wyre estuary. Regarding the East Coast, projects have been suggested for the Humber, the Wash and the Thames.

THE DEVELOPMENT OF WAVE ENERGY UTILIZATION

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INTRODUCTION

The energy from surface waves is the most conspicuous form of ocean energy, possibly because of the, often spectacular, wave destructive effects. The waves are produced by wind action and are therefore an indirect form of solar energy.

The possibility of converting wave energy into usable energy has inspired numerous inventors: more than one thousand patents had been registered by 1980 and the number has increased markedly since then. Yoshio Masuda may be regarded as the father of modern wave energy technology, with studies in Japan since the 1940s. He developed a navigation buoy powered by wave energy, equipped with an air turbine, which was in fact what was later named as a (floating) oscillating water column (OWC). These buoys were commercialized in Japan since 1965 (and later in USA).

The oil crisis of 1973 induced a major change in the renewable energies scenario and raised the interest in large-scale energy production from the waves. The British Government started in 1975 an ambitious research and development programme in wave energy (followed shortly afterwards by the Norwegian Government), but its funding came almost to a halt by 1982.

In Norway the activity went on to the construction, in 1985, of two full-sized (350 and 500 kW rated power) shoreline prototypes near Bergen. In the following years, until the early 1990s, the activity in Europe remained mainly at the academic level, the most visible achievement being a small (75 kW) OWC shoreline prototype deployed at the island of Islay, Scotland (commissioned in 1991). At about the same time, two OWC prototypes were constructed in Asia: a 60 kW converter integrated into a breakwater at the port of Sakata, Japan and a bottom-standing 125 kW plant at Trivandrum, India.

The situation in Europe was dramatically changed by the decision made in 1991 by the European Commission of including wave energy in their R&D programme on renewable energies. Since then, about thirty projects on wave energy were funded by the European Commission involving a large number of teams active in Europe.

In the last few years, growing interest in wave energy is taking place in USA, Canada, South Korea, Australia, New Zealand, Brazil, Chile, Mexico and other countries.

THE WAVE ENERGY RESOURCE

The main disadvantage of wave power, as with the wind from which is originates, is its (largely random) variability in several time-scales: from wave to wave, with sea state, and from month to month (although patterns of seasonal variation can be recognized).
The studies aiming at the characterization of the wave energy resource, having in view its utilization, started naturally in those countries where the wave energy technology was developed first. This was notably the case of the United Kingdom. The WERATLAS, a European Wave Energy Atlas, whose preparation was funded by the European Commission in the mid-1990s, remains a basic tool for wave energy planning in Europe. More detailed wave energy atlases (including the near-shore and shoreline resources) were produced later in several countries for national purposes.
The wave energy level is usually expressed as power per unit length (along the wave crest); typical values for

"good" offshore locations (annual average) range between 20 and 70 kW/m and occur mostly in moderate to high latitudes. Seasonal variations are in general considerably larger in the northern than in the southern hemisphere, which makes the southern coasts of South America, Africa and Australia particularly attractive for wave energy exploitation.

HYDRODYNAMICS

The study of the hydrodynamics of floating wave energy converters could benefit from previous studies on the, largely similar, dynamics of ships in wavy seas, that took place in the decades preceding the mid-1970s. The presence of a power take-off mechanism (PTO) and the requirement of maximizing the extracted energy introduced additional issues.

The first theoretical developments addressed the energy extraction from regular (sinusoidal) waves with a linear PTO. An additional assumption of the theory was small amplitude waves and motions. This allowed the linearization of the governing equations and the use of the frequency-domain analysis.
Since, in practice, most converters are equipped with strongly nonlinear mechanisms, a time-domain theory had to be developed. The time-domain model produces time-series and is the appropriate tool for active-control studies of converters in irregular waves. However it requires much more computing time as compared with the frequency-domain analysis.

Large numbers of devices in arrays are required if wave energy is to provide a significant contribution to large electrical grids. The hydrodynamic interaction between devices in array is extremely complex and approximate methods have in practice to be devised, like the multiple-scattering method, the plane-wave method and the point-absorber approximation.

The utilization of wave energy involves a chain of energy conversion processes, each of which is characterized by its efficiency as well as the constraints it introduces, and involves control procedures. Particularly relevant is the hydrodynamic process of wave energy absorption. The early theoretical studies on oscillating-body and OWC converters revealed that, if the device is to be an efficient absorber, its own frequency of oscillation should match the frequency of the incoming waves, i.e. it should operate at near-resonance conditions. The amount of absorbed wave energy can be significantly increased by adequately controlling the PTO in order to achieve near-resonance. Phase control (including latching control) in real random waves is a difficult theoretical and practical problem that is far from having been satisfactorily solved.

In the development and design of a wave energy converter, the energy absorption may be studied theoretically/numerically, or by testing a physical model in a wave basin or wave flume. The techniques to be applied are not very different from those in the hydrodynamics of ships in a wavy sea. Numerical modelling is to be applied in the first stages of the plant design. The main limitations lie in its being unable to account for losses in water due to real (viscous) fluid effects (large eddy turbulence) and not being capable to model accurately large amplitude water oscillations (nonlinear waves). Such effects are known to be important (they also occur in naval engineering and in off-shore structures, where more or less empirical corrections are currently applied). For these reasons, model tests (scales 1:80 to 1:10) are carried out in wave basin when the final geometry of the plant is already well established. As the development of the wave energy converter progresses towards the prototype construction stage, the need of large-scale testing requires the use of very large laboratory facilities. This was the case, in Europe, of the large wave tanks in Trondheim (Norway) and Nantes (France).

THE VARIOUS TECHNOLOGIES

Unlike large wind turbines, there is a wide variety of wave energy technologies, resulting from the different ways in which energy can be absorbed from the waves, and also depending on the water depth and on the location (shoreline, near-shore, offshore). Recent reviews identified about one hundred projects at various stages of development. The number does not seem to be decreasing: new concepts and technologies replace or outnumber those that are being abandoned.

Several methods have been proposed to classify wave energy systems, according to location, to working principle and to size ("point absorbers" versus "large" systems). The classification in Table 1 is based mostly on working principle. The examples shown are not supposed to form an exhaustive list and were chosen among the projects that reached the prototype stage or at least were object of extensive development effort.

Oscillating water column (with air tribune)	Fixed structure	Isolated: _Pico, LIMPET
		In breakwater: Sakata, Mutriku
	Floating: Mighty Whale, Ocean Energy, Sperboy, Oceanlynx	
Oscillating bodies (with hydraulic motor, hydraulic turbine, linear electrical generator)	Floating	Essentially translation (heave): Aquabuoy, IPS Buoy, FO3, Wavebob, Powerbuoy
		Essentially rotation: Pelamis, PS Frog, SEAREV
	Submerged	Essentially translation (heave): AWS
		Rotation (bottom-hinged): WaveRoller, Oyster
Overtopping (with low-head hydraulic turnbine)	Fixed structure	Shoreline (with concentration): TAPCHAN
		In breakwater (without concentration): SSG
	Floating structure (with concentration): Wave Dragon	

TABLE 1: Wave energy technologies

FIRST GENERATION DEVICES

Most of the first prototypes to be built and deployed in open coastal waters are or were located on the shoreline or near shore, and are sometimes named "first generation" devices. In general they stand on the sea bottom or are fixed to a rocky cliff. Shoreline devices have the advantage of easier maintenance and installation and do not require deep-water moorings and long underwater electrical cables. The less energetic wave climate at the shoreline can be partly compensated by natural wave energy concentration due to refraction and/or diffraction (if the device is suitably located for that purpose). The typical first generation device is the oscillating water column (OWC). Another example is the overtopping device Tapchan (Tapered Channel Wave Power Device), a prototype of which (rated 350 kW) was built on the Norwegian coast in 1985 and operated for several years.

The oscillating water column (OWC) device comprises a partly submerged concrete or steel structure, open below the water surface, inside which air is trapped above the water free surface. The oscillating motion of the internal free surface produced by the incident waves makes the air to flow through a turbine that drives an electrical generator. The axial-flow Wells turbine, invented in the late 1970s, has the advantage of not requiring rectifying valves. It has been used in almost all prototypes.

Full sized OWC prototypes were built in Norway (in Toftestallen, near Bergen, 1985), Japan (Sakata port, 1990), India (Vizhinjam, near Trivandrum, Kerala state, 1990), Portugal (Pico, Azores, 1999), UK (the LIMPET plant in Islay island, Scotland, 2000). The largest of all (2MW), a nearshore bottom-standing plant (named Osprey) was destroyed by the sea (in 1995) shortly after having been towed and sunk into place near the Scottish coast. Smaller shoreline OWC prototypes (also equipped with Wells turbine) were built in Islay, UK (1991), and more recently in China. The Australian company Energetech developed a technology using a large parabolic-shaped collector to concentrate the incident wave energy (a prototype was tested at Port Kembla, Australia, in 2005).

In the present situation, the civil construction dominates the cost of the OWC plant. The integration of the plant structure into a breakwater has several advantages: the constructional costs are shared, and the access for construction, operation and maintenance of the wave energy plant become much easier. This has been done successfully for the first time in the harbour of Sakata, Japan (in 1990), where one of the caissons making up the breakwater had a special shape to accommodate the OWC and the mechanical and electrical equipment. The option of the "breakwater OWC" was adopted in the 750 kW OWC plant planned to be installed in the head of a new breakwater in the mouth of the Douro river (northern Portugal) and in the newly built breakwater at Mutriku port, in northern Spain.

OSCILLATING-BODY SYSTEMS

Offshore devices (sometimes classified as third generation devices) are basically oscillating bodies, either floating or (more rarely) fully submerged. They exploit the more powerful wave regimes available in deep water (typically more than 40m water depth). Offshore wave energy converters are in general more complex compared with first generation systems. This, together with additional problems associated with mooring, access for maintenance and the need of long underwater electrical cables, has hindered their development, and only in the last few years some systems have reached, or come close to, the full-scale demonstration stage.

There is a substantial variety of typically offshore wave-energy devices, some of which reached, or are close to, the prototype stage. In most cases, there is a mechanism that extracts energy from the relative oscillating motion between two bodies.

This is the case of the Pelamis, developed in UK, a snake-like slack-moored articulated structure composed of four cylindrical sections linked by hinged joints, and aligned with the wave direction. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors driving electrical generators. Sea trials of a full-sized prototype (120m long, 3.5m diameter, 750 kW rated power) took place in 2004. A set of three Pelamis devices was deployed off the Portuguese northern coast in September 2008, making it the first grid-connected wave farm worldwide (Figure 1).

Several concepts use the heaving motion of a slack-moored axisymmetric buoy reacting against the inertia of another body (Figure 2). In the case of the Powerbuoy (developed in USA) the second body is a submerged disc, whereas the Wavebob (an Irish concept) consists of two co-axial axisymmetric floating bodies oscillating differently. In both cases, the PTO consists of a high-pressure-oil hydraulic circuit, with rams and a hydraulic motor. The Aquabuoy is a device that combines two concepts developed in Sweden: the IPS buoy and the hose pump, which were tested in the sea at about half-scale in 1982. The Aquabuoy consists of a buoy, whose heave oscillations, by reaction against the inertia of the water inside an acceleration tube (located beneath the buoy), produce high-pressure water flow by means of a pair of hose pumps. This is converted into electrical energy by a conventional Pelton turbine driving an electrical generator. A prototype was built and tested in 2007 off the coast of Oregon, USA.

In some cases, the device consists of a set of heaving buoys reacting against a common frame and sharing a common PTO. This is the case of FO3 (mostly a Norwegian project) in which the frame is a large floating structure with very low resonance frequency, of the Danish Wave Star (the frame stands of the bottom) and the Brazilian hyperbaric device whose frame is a breakwater. These are recent devices equipped with pressurized hydraulic systems, the first one having been tested at 1/3 scale and the last two at 1/10 scale.
The Archimedes Wave Swing (AWS), basically developed in Holland, is a fully-submerged device consisting of an oscillating upper part (the floater) and a bottom-fixed lower part (the basement). The floater is pushed

FIGURE 1. The three-unit 3×750 kW Pelamis wave farm in calm sea off northern Portugal, 2008.

down under a wave crest and moves up under a wave trough. This motion is resisted by a linear electrical motor, with the interior air pressure acting as a spring. A prototype, rated 2 MW (maximum instantaneous power) was deployed and tested in 2004 off northern Portugal. The AWS was the first converter to use a linear electrical generator, a technology that is being developed by other teams (University of Edinburgh, UK, Uppsala University, Sweden, and Oregon State University, USA) for wave energy applications.

▲
FIGURE 2. Heaving point-absorber prototypes: Powerbuoy, Wavebob and Aquabuoy.

Except for the Pelamis, the oscillating-body devices mentioned above absorb energy essentially from the heaving mode of oscillation. Other modes, namely pitching and surge, can also be used. This is the case of the French system named Searev, a large floating device enclosing a heavy horizontal-axis wheel behaving like a mechanical pendulum. The rotational motion of the pendulum relative to the hull activates a hydraulic PTO.

The Oyster (UK) and the Waveroller (Finland) are devices based on the inverted pendulum, designed to be located near-shore in water depths of 10-12m. The concept consist of a flap-shaped buoyant body hinged at the sea bottom, whose pitching motion, activated by the waves, drives a hydraulic ram that pumps high-pressure fluid (sea water in the case of Oyster, oil in Waveroller). A 10-15 kW prototype of Waveroller was tested in the sea in Portugal in 2007. A full-sized prototype of Oyster (300-600 kW) was recently built in Scotland.

FLOATING OWCS

The early OWCs developed in Japan before 1980 by Yoshio Masuda were floating devices. Interest in the floating OWC has not died out. The so-called Mighty Whale, built in Japan in the 1998, and tested in the sea for several years, is in fact a floating version of the OWC (50m-long, 30m-wide structure), equipped with three Wells turbines, each driving a 30kW electrical generator.

The Backward Bent Duct Buoy (BBDB), originally a Japanese concept, has been object of more recent interest in Europe, under the name OE buoy: a 15m-long 1/4-scale pilot plant, equipped with a Wells turbine, has been built in Ireland and is being tested since November 2006 in the sheltered waters of Galway Bay (western Ireland).

The Sperboy is a floating OWC being developed in UK that uses several vertical columns of different lengths to more effectively capture energy from a range of wavelengths. A 1/5th scale pilot unit has been deployed at sea in southern England.

OVERTOPPING DEVICES

The working principle of overtopping devices is very different compared with OWCs and oscillating bodies. Overtopping or run-up is a non-linear phenomenon that cannot be modelled by linear wave theory, and so requires different modelling tools. An overtopping device acts basically as a pump that converts wave energy into potential energy in a water reservoir whose main function is to provide a stable supply to a conventional low-hear hydraulic turbine (or a set of turbines).

In the Tapchan (mentioned above), the run-up effect is produced by a gradually narrowing channel with wall heights equal to the filling level of the reservoir (about 3 m in the Norwegian prototype) such that as the waves propagate down the channel their height is amplified until the wave crests spill over the walls and fill the water reservoir.

In other devices, the run-up effect takes place along a sloping wall or ramp, as is the case of the Wave Dragon, an offshore floating system developed mostly in Denmark. The Wave Dragon consists of a floating slack-moored platform with two long arms acting as wave reflectors to focus the waves towards a ramp. A 1:4.5-scale model, 57m-wide, equipped with seven turbines, was deployed in 2003 off the Danish coast in the North Sea and tested for a couple of years. Plans to construct of a multi-MW full-sized device have been announced.

The Seawave Slot-cone Generator (SSG) is a Norwegian breakwater-version of the run-up concept that utilizes multiple reservoirs placed on top of each other, into which the water overspills through slots spaced at different levels on the sloping sea-facing side of the breakwater. The device is equipped with a special multi-stage vertical-axis turbine.

EQUIPMENT

The energy of sea waves can be absorbed by wave energy converters in a variety of manners, but in every case the transferred power is highly fluctuating in several time-scales, especially the wave-to-wave or the wave group time-scales. In most devices developed or considered so far, the final product is electrical energy to be supplied to a grid. So, unless some energy storage system is available, the fluctuations in absorbed wave power will appear unsmoothed in the supplied electrical power, which severely impairs the energy quality and value from the viewpoint of the grid. Besides, that would require the peak power capacity of the electric generator and power electronics to greatly exceed the time-averaged delivered power. In practice, three methods of energy storage have been adopted in wave energy conversion.

An effective way is storage as potential energy in a water reservoir, which is achieved in overtopping devices, equipped with more or less conventional low-head hydraulic turbines, capable of attaining a peak efficiency close to 90%.

In the oscillating water column type of device, the size and rotational speed of the air turbine rotor make it possible to store a substantial amount of energy as kinetic energy (flywheel effect); this is particularly true for the Wells turbine, whose rotor diameter and blade tip speed are both substantially larger compared with the self-rectifying impulse turbine (that has been proposed as an alternative to the Wells turbine). These self-rectifying air turbines are relatively robust and mechanically simple pieces of equipment. However, they are subject to much more demanding conditions than the turbines in any other application, including wind turbines. Indeed the flow through the turbine is reciprocating and is random and highly variable over several time scales, ranging from a few seconds to seasonal variations. It is not surprising that the time-average efficiency of an air turbine in an OWC has been found to be relatively low, in general not exceeding about 50%. This is a technical area with substantial room for improvement.

In a large class of devices, the oscillating (rectilinear or angular) motion of a floating body (or the relative motion between two moving bodies) is converted into the flow of a liquid (water or oil) at high pressure by means of a system of hydraulic rams (or equivalent devices). At the other end of the hydraulic circuit there is a hydraulic motor (or a high-head Pelton water-turbine) that drives an electric generator. The highly fluctuating hydraulic power produced by the reciprocating piston (or pistons) may the smoothed by the use of a gas accumulator system, which allows a more regular production of electrical energy. Naturally the smoothing effect increases with the accumulator volume and working pressure. High-pressure oil is the working fluid in the Pelamis, Wavebob, Powerbuoy, Wave Star devices, whereas sea water is used in the PTO of Aquabuoy and the Brazilian multi-body hyperbaric device. This type of PTO may be regarded as unconventionally using conventional equipment. Hydraulic motors (including variable displacement versions, particularly suitable for oil flow control) are commercially available up to several hundred kW, while Pelton turbines exist that cover a very wide range of power levels. In both cases peak efficiencies can reach close to 90%, although the efficiency can drop significantly at partial loads. The gas accumulator system may represent a substantial part of PTO cost.

In most wave energy devices, a more or less conventional electrical generator is used to produce electricity. Variable rotational speed is frequently adopted, the technology (and the power range) being basically similar to wind energy applicactions.

Some devices use direct electrical energy conversion by means of linear electrical generators (this was pioneered in Holland for the Archimedes Wave Swing device). These machines are still at the development level. Such PTO systems do not require an intermediate mechanical system and may attain a high efficiency. On the other hand, the energy storage capability is small (or very expensive) which may result in a high peak-to-average power ratio and in poor quality of the electrical power supplied to the grid.

CONCLUSION

Unlike in the case of wind energy, the present situation shows a wide variety of wave energy systems, at several stages of development, competing against each other, without it being clear which types will be the final winners.

In general, the development, from concept to commercial stage, has been found to be a difficult, slow and expensive process. Although substantial progress has been achieved in the theoretical and numerical modelling of wave energy converters and of their energy conversion chain, model testing in wave basin a time-consuming and considerably expensive task is still essential. The final stage is testing under real sea conditions. In almost every system, optimal wave energy absorption involves some kind of resonance, which implies that the geometry and size of the structure are linked to wavelength. For these reasons, if pilot plants are to be tested in the open ocean, they must be full-sized structures. For the same reasons, it is difficult, in the wave energy technology, to follow what was done in the wind turbine industry (namely in Denmark): relatively small machines where developed first, and were subsequently scaled up to larger sizes and powers as the market developed. The high costs of constructing, deploying, maintaining and testing large prototypes, under sometimes very harsh environmental conditions, has hindered the development of wave energy systems; in most cases such operations were possible only with substantial financial support from governments (or, in the European case, from the European Commission).

Unit costs of produced electrical energy claimed by technology development teams are frequently unreliable. At the present stage of technological development and for the systems that are closer to commercial stage, it is widely acknowledged that the costs are about three times larger than those of energy generated from the onshore wind (the gap is smaller in comparison with offshore wind). It is not surprising that the deployment of full-sized prototypes under open ocean conditions has been taking (or is planned to take) place in coastal areas of countries where specially generous feed-in tariffs are in force, and/or where government supported infrastructures (especially cable connections) are available for testing.

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THE STATUS OF TIDAL STREAM ENERGY CONVERSION

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INTRODUCTION

Energy and climate change are currently two of the most important issues facing society. Many governments around the world have set targets for emission reductions and the production of electricity from renewable resources. The development of low carbon technologies that can result in reductions in emissions whilst contributing to energy security - especially if derived indigenously - occupy the centre ground in the policies of many governments. However, most policies are highly reliant on the expansion of large scale wind energy supply with little attention paid to other areas of renewable energy.

Ocean energy, in the form of tidal stream (or marine current), tidal range and wave resource exploitation can, in addition to wind energy, deliver large amounts of power that could contribute to national and international targets. Globally, tidal dissipation on continental shelves has been estimated at 2.5 TW [1]. If 1-2% of this could be tapped for power generation, tidal power could deliver 200-400 TWh/annum. The global wave energy resource has been estimated by the European Thematic Network on Wave Energy at 1.3 TW, with a technically exploitable resource of 100-800 TWh/annum [2, pages 289-290].

Marine current energy conversion devices are currently being tested at the prototype and pre commercial demonstration stage at sea. There is also a thriving research and development community around the world undertaking both fundamental and applied research to support tidal and wave energy development. However, at present most technological innovation to exploit such resources is currently at an early stage of development, with only a small number of devices approaching the commercial demonstration stage. In addition, there is plethora of conversion philosophies that seem to dilute the available financial resources resulting in inertia in technology progression to commercialisation.

This report provides a summary of the current status of the development of tidal stream energy conversion technologies, relevant research and development areas and some insight into other related issues as permissions, consents, finance and infrastructure.

Prior to presenting the status update, it is worth stating some of the important issues that arise when undertaking work in this area. Table 1 summarises some of these in the context of marine current device development. Resource assessment is one of the essential components of any development project. Obviously a site could be selected due its partially known energetic potential - high or moderate flow velocity. However, there are many additional factors which also need consideration - proximity to a grid connection and ports, availability of vessels and an understanding of sea-bed conditions. Unlike fossil fuel electricity generation, the fuel in tidal stream electricity conversion - flow in the sea - is free and the revenue stream from a particular development is governed by the energy yield of the project. Furthermore, the overall cost of a tidal stream project is totally dominated by capital and operating costs. Since the revenue is mainly dependent on flow conditions, the profitability of a project is highly dependent on clear understanding of the site conditions including fluid flow characteristics. Hence, resource assessment is crucial task to arrive at the required economical analysis that will indicate the viability or otherwise of a tidal stream project. Therefore, in addition to giving the technology and research and development status, this report will also briefly give some consideration to one of these issues – resource assessment.

DEVICE SPECIFIC ISSUES	PROJECT SPECIFIC ISSUES
• Energy capture	• Resource assessment
• Power take-off	• Economics modelling & Financing
• Control systems	• Consents & Permits
• Electrical conversion	• Environmental Impact Assessments
• Cable connection to sea-bed	• Stakeholder consultation
• Fixing/Moorings	• Cable-routing
• Testing at scales	• Deployment & Maintenance
• Economics and financing	

TABLE 1. Important issues in device and project development

RESOURCE ASSESSMENT

Resource assessments produced by developers are in many cases subject to commercial confidentiality. Recently, work has started to standardise resource assessment methodologies through the drafting of new protocols [3, 4]. However, these are still in the early stages of development. The gathering and analysis of field data on tidal streams is an ongoing process with Acoustic Doppler Current Profiling (ADCP) surveys carried out in many favourable locations [5].

In many locations, available data on tidal streams is sparsely distributed and is rarely in primary form. Simple interpolation is an option in such cases, as used in resource assessments such as [6], but may be inaccurate where there are significant changes in topography and flow velocity in space.

Before an expensive hydrographic survey is commissioned - which is limited to a small area of sea and carries the risk of no data return - it would be desirable to obtain a first estimate of the resource over an area wide enough to include all possible generator locations, but with resolution detailed enough to include details of the flow at spatial and temporal scales relevant to an array of turbines.

Numerical modelling of tidal flows can constrain sparse data with the known dynamics of fluids, giving a high resolution picture of the available resource. It also offers the potential to examine the effects of arrays of turbines on the flow itself, providing the turbines can be adequately represented. As an example, such an approach has been attempted for the Portland Bill site in the South of the UK, parameterizing the turbine array as added roughness [7]. Fig.1 (a) indicates the results in terms of speed-difference when energy extraction is included, at a particular time-step during the simulation, while Fig.1 (b) shows the percentage change in tidal ellipse magnitude, superimposed on bathymetry contours. The latter indicates that measurable changes may persist for some kilometres downstream of an array.

TECHNOLOGY STATUS OF DEVICES

This section reviews current projects and their development giving brief highlights of front-runner devices which are approaching the commercial demonstration stage; also mentioning prototype and laboratory scale devices. Most of the sources of the information presented are web pages, published articles and from presentations at conferences and meetings.

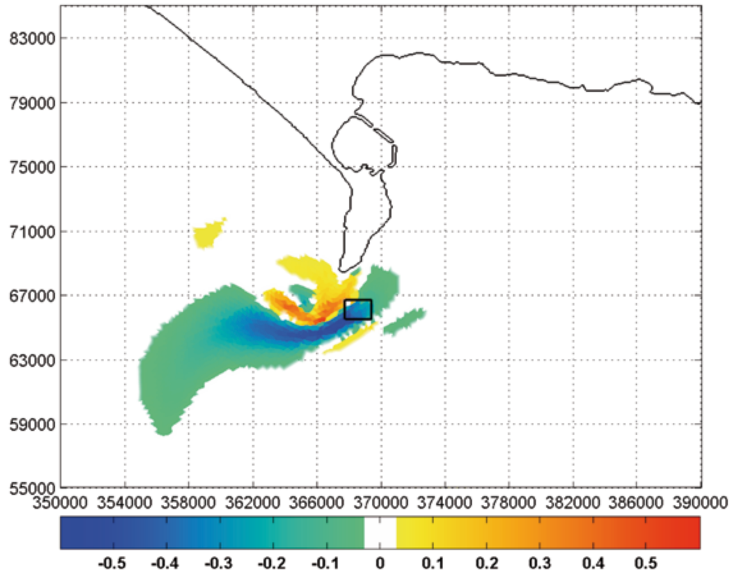

FIGURE 1. (a). Difference in flow speed with respect to natural state, when energy is extracted. Portland Bill, UK, [7].

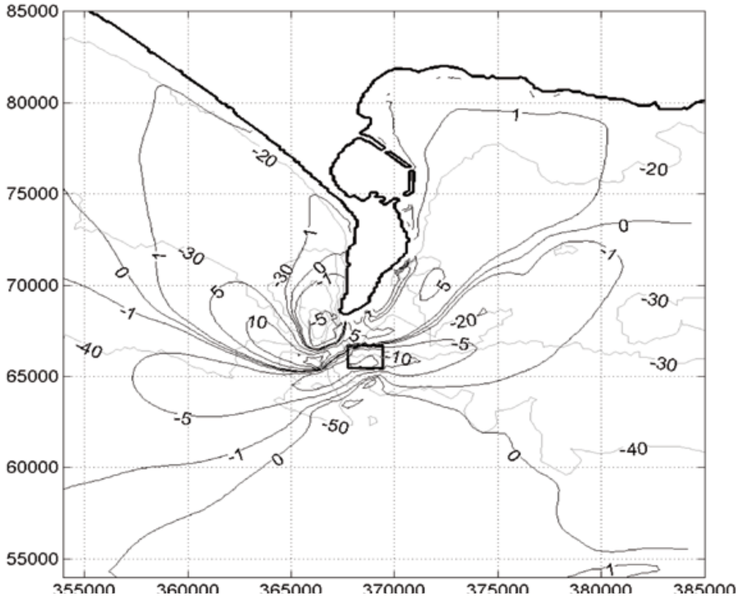

FIGURE 1. (b). Percentage decrease in major axis of tidal ellipse with energy extraction. Portland Bill, UK, [7].

Commercial and Prototype Devices

Currently available information on commercial, prototype device development and deployment plans are summarised below and builds on last year's OES report [8]:

Project SeaGen (Marine Current Turbines Ltd, (MCT Ltd)) at Strangford Lough, Northern Ireland, UK has successfully deployed a second generation device consisting of a piled twin horizontal-axis two-bladed turbine converter of capacity 1.2 MW [9]. This project builds on experience gained over last five years with the 300 kW device installed at Lynmouth in the Bristol Channel UK [10]. Initial indications from the Seagen project are that the systems are working well, with power being exported to the grid. The deployment apparently went well, in spite of delays and re-design of the piling process. A blade failure was reported during commissioning in July [11]; re-fitting of a new blade was achieved in Nov 2008 [12].

Over the last 12 months, the Irish company Open Hydro has been testing their open centred, rim generator device, capacity 250 kW, at the European Marine Energy Centre (EMEC) in the Orkneys.

At the recent ICOE conference in Brest (Oct 2008), the two companies indicated that they are the front runners in tidal stream technologies, having devices in the sea and producing electricity, with Open Hydro being the first to export electricity to the UK grid [13]. However, in spite of some months in operation, neither Open Hydro nor MCT Ltd were in a position to present to the audience either operational or performance data on their devices.

Several new tidal stream devices have also entered the field in 2008: Hydrohelix have tested a 3 m diameter device in Brittany [14]; OceanFlowEnergy have deployed a 1/10 scale floating device in Strangford Narrows [15]; Pulse Tidal have recently started the installation of their 100 kW oscillating hydrofoil generator in the River Humber [16]. Meanwhile in Canada, Clean Current has re-deployed their 65 kW device after a refit due to initially disappointing performance of water lubricated bearings [17]. In the southern hemisphere, Atlantis Resources Corporation has achieved what they claim is a world record of towing tests in the sea of their 400 kW Nereus II and 500 kW Solon prototype turbines [18]. ScotRenewables SRTT, a 1.2 MW floating device, will be tested at EMEC in 2010 [19]. Verdant Power, had six of their 35 kW turbines installed in the East River NY, USA, in 2006/7. Reports indicate multiple failures but a retrofit with new blades was accomplished in Sept 2008 [20]. The Netherlands-based company Tocardo BV have this year established a subsidiary in Wick, Scotland with a view to developing a 10 MW farm in the Pentland Firth. Meanwhile, they have begun production of three pre-commercial 35 kW units for testing in a sluice gate intake on Den Oever, Netherlands, the same location that the original 2.8 m prototype was tested in 2005 [21].

A number of large tidal stream developments are planned over the next five years. Lunar Energy and E.ON are developing a farm of eight 1 MW turbines off the coast of Pembrokeshire, Wales, UK [22]. Meanwhile, further north, but still in Welsh waters, MCT Ltd and Npower will be working to install a tidal farm of seven of the third-generation SeaGen 1.5 MW turbines off the coast of Anglesey to enter operation by 2012 [23]. In September 2008, it was announced that Hammerfest Strøm, who have been quietly testing their turbine in northern Norway for the past four years, have partnered with ScottishPower and plan to develop 60 MW at three sites in the UK [24]. Across the Channel (or La Manche), Open Hydro have been selected by EDF to install four to ten of their scaled-up 1 MW turbines off the coast of Brittany [25].

Several developers are eyeing the Pentland Firth for commercial scale deployments; Atlantis Resources Corp are looking for a partner in an innovative project to develop a 20 MW tidal farm to power a proposed new data-centre located in the far north of Scotland [26].

Both the east and west coasts of Canada hold enormous potential for tidal stream generation, but planned developments have been slower to progress than on the other side of the Atlantic. This is changing, with MCT Ltd and British Columbia Energy Corp planning to deploy at least three SeaGen units in Discovery Passage [27]. On the other coast, in the famous Bay of Fundy, up to three turbines are to be installed from 2009 by Open Hydro in partnership with Nova Scotia Power [28]; Clean Current [29] with a scaled up version of their device installed at Race Rocks; and Minas Basin Pulp and Power Co, possibly with a UEK device (although the latter is in doubt partly due to the death in November 2008 of the founder of UEK, Philippe Vauthier).

Looking further into the future, it was announced in March 2008 that Lunar Energy had signed a Memorandum of Understanding with Korean Midland Power to develop a 300 MW farm in the Republic of Korea by 2015, which - if it goes ahead - will be by far the largest tidal stream development in the world [30]. Larger even than the newly installed 254 MW tidal scheme retro-fitted into an existing 11 km barrage in Sihwa Lake, Korea, due to be completed late 2009 [31]. Three further 'converted barrages', totalling 1.8 GW, are proposed to be built in Korea by 2014 [32]. Together, these developments will launch Korea well ahead of France as the world's leading nation for tidal generation.

The UK may not be far behind, however, as MCT Ltd has recently indicated that it intends to apply for a lease from the UK's Crown Estate to deploy its technology in to Scotland's Pentland Firth. The potential capacity figures quoted are up to 50 MW by 2015 and up to 300 MW by 2020 [33]. This is subject to securing the required finance, meeting the necessary approvals and the availability of an appropriate local grid connection at the site. Several consortia are also in the running for a tidal generation scheme on the River Severn, with proposed capacity varying from to 1-8 GW [34]. Not strictly in the UK, but closely related, Open Hydro and Alderney Renewable Energy plan to develop a 285 MW array in the waters of the Channel Island of Alderney [35].

All the above is extremely good progress with some welcome large projects being highlighted for development in the not too distant future. These are not only important for the maturity of the technology but also for providing the needed experience of operating in the sea. However, it remains to be seen how the current financial turmoil and bleak outlook for the world economy will impact upon the progress of the proposed large schemes.

RESEARCH AND DEVELOPMENT

Fundamental research and development are the backbone of both generating new knowledge and assessing devices at their early stage of development. This section aims to give some of the highlights in this area, by summarising new advances that are relevant to the development of tidal stream energy conversion.

In parallel with the developments in the commercial sector, many aspects of tidal stream power remain active areas of research. This research divides naturally between individual devices, device interactions and resource assessment. In the former category are the tests of the University of Strathclyde 2.5 m CoRMaT contra-rotating turbine and its smaller 0.92 m cousin, both major highlights at the tenth World Renewable Energy Congress in Glasgow in July 2008 [36]. Also in 2008, The University of Southampton has carried out extensive tests on side-by-side dual 0.8 m rotors, as part of a UK, Technology Strategy Board funded programme to determine wake interactions; publications will follow in due course [37]. Several teams are working on CFD simulations of tidal turbines, using developments of blade element momentum theory [38]; nested rotating reference frames within conventional RANS solvers [39, 40]; boundary element methods more commonly used to design ship propellers [41] and more exotic vortex methods [42, 43]. When considering the interaction of multiple devices, scale effects make experimental work challenging; nevertheless work has progressed through the use of porous disk simulators and artificial roughness to physically model the evolution of the far wake of a tidal turbine influenced by the vertical flow profile [44, 45]. Multiple rows of tidal fences have also been tested in a similar fashion, and initial comparisons with CFD simulations have been made [46]. Resource assessment is necessarily more theoretical and uncertain in nature than the previous topics, as arrays of turbines are yet to be constructed. Research has been focussed on the limits to energy extraction in channels and bays [47]; on GIS mapping of the available resource taking into account the multitude of constraints on development [48]; the interaction of turbine performance with resource assessment [49]; and learning lessons from wind in how to parameterize the effects of large arrays on the flow [50].

Protocols

There have been a number of recent attempts at drafting protocols for fair evaluation of the tidal stream resource and the performance of tidal stream turbines at different stages of development [51, 52, 53]. It is the aim of the IEA and other stakeholders, after wide international consultation, for some of these to form the basis of international standards [3]. The standards will be assessed and propagated through the newly-formed Ocean Energy IEC committee (IEC TC 114) [54]. A major EU FP7 project entitled "Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact" (EquiMar, of which the Author is a member), will further develop the protocols and best practice guidance, as data and experience from full-scale testing in the sea becomes available [55].

PLANNING, CONSENT AND FINANCING

Most countries have their own processes for project approval. These vary and the number of stages needed to achieve approval or consent for a project is highly complex. Taking the UK as an example, there are a number of hurdles for developers to leap in order to install their device on the sea-bed. The sea-bed itself is the property of the Crown Estate (a government agency) who plan to grant exclusive leases over portions of it to tidal stream developers, provided certain conditions are met. To secure site leases from the Crown Estate requires the project developer to carry out comprehensive environmental impact assessments and monitoring, as well as assuring the Crown Estate of the appropriateness of the design, technical and operational integrity of the technology. On the 17 November 2008, the Crown Estate announced a first round of development in the Pentland Firth, inviting developers to apply for pre-qualification [56]. Once the option to lease the sea-bed has been obtained, developers must obtain consents from either the Marine and Fisheries Agency (in England and Wales), or the Fisheries Research Services (Scotland), or the Northern Ireland Environment Agency. These consents include a licence under the Food and Environment Protection Act (mainly concerning drilling and foundations) and the Coast Protection Act (mainly for the electrical connection to shore). Obtaining these consents would involve at the least a detailed environmental statement based on survey data and possibly an Appropriate Assessment if required by the Habitats Directive. In the process of obtaining the consents a wide variety of bodies would consulted, a process taking at least six months [57]. In addition, for developments greater than 1 MW, consent is required from BERR (possibly now DECC) under the Electricity Act. Local planning permission is also likely to be necessary for any onshore works, for example cable-routing to and construction of substations.

Finance is another major hurdle for both prototype development and project implementation. For example, in the UK some of the tidal stream technology variants (e.g. Lunar and SMD Hydrovision) which have market potential, and were supported under the previous BERR technology programme, are rumoured to be awaiting co-financing to support development of full scale prototypes. Meanwhile, BERR's GBP 42M Marine Renewables Deployment Fund, offering 25% capital grants up to GBP 5M and revenue support of GBP 100/MWh, has – so far - had no takers [58]. Many countries have now introduced schemes to support new renewable technologies, including ocean energy or marine renewables; selected schemes are included in Table 2.

COUNTRY	POLICY NAME	YEAR	COMMENTS
Canada	EcoENERGY for Renewable Power	2007	Incentive of CDN 1 c/kWh for up to 10 years
France	Renewable Energy Feed-In Tariff (IV)	2007	
Ireland	Renewable Energy Feed-In Tariff (REFIT)	2005	Fixed price for ocean energy (wave and tidal) is EUR 22c/kWh
Korea (Rep. of)	• Extension of Renewable Energy Subsidy • Renewables Feed-in Tariff for (Electricity Business Law)	2002 2001	• Compensation for the difference between the base price and the system marginal price • Tidal/ocean: 62.81 KRW/KWh (0.061 USD/KWh)
Portugal	Modified feed-in tariffs for renewables	2007	Demonstration wave power up to 4 MW: EUR 260/MWh; decreasing to EUR 76/MWh for greater than 250 MW
UK	• Marine Renewables Deployment Fund • Renewables Obligation Certificates (ROCs) Scheme extended in November 2008 to 2037.	2005 2002	• Capital grant 25% eligible costs up to GBP 5M. Revenue support GBP 100/MWh independent of ROCs. • ROCs trade at up to GB £51/ROC. Renewable generators currently awarded 1ROC/MWh. Likely 2009, scheme banded to give wave and tidal 2ROCs/MWh.
USA	Grants for Developing New Energy Technologies	2005	Grants of up to USD 100k for small businesses

Table 2. Selected financial incentives relevant to marine renewables (source [59])

CONCLUSIONS

Tidal stream technology and the associated industry are still in their infancy. Some people believe that the current status of the technology is comparable with that of the emerging wind energy development in the 1980s. However, as shown above, given the availability of favourable regulatory regimes, the progress should be much faster than that of wind. However, the most important issue for the technology is to prove itself within the operating environment. There is now an urgent need to have operational experience in the sea. This experience is paramount as it gives confidence to investors, the power utilities and governments in the viability of the technology. In addition, technology developers and stakeholders will need to establish a robust supply chain for design and manufacture, transport to site and appropriate installation vessels. The viability of the technology will depend, in the long term on operational reliability of the devices, their maintenance and operating costs, permitting and consent for projects, availability of grid infrastructure and most importantly (in the age of the current credit crunch) the availability of finance. There are however, many drivers that are likely to play a major role in assisting the development and the roll out of tidal stream technology. These initiatives are mostly related to new energy and climate change legislation in many countries, the prevalence of feed in tariffs in many EU countries, the change in policy in the USA, the requirements for energy security and fulfilling internationally negotiated carbon reductions.

In summary, 2008 is an important milestone for tidal stream energy conversion. We have seen the first deployment of two grid connected, large scale pre-commercial devices in the sea, albeit limited to sheltered test sites. Nevertheless this progress is extremely important for the technology as it has stimulated many activities including joined-up thinking for developing sites with arrays. The change of administration in the USA, and the ambitious funding of USD 15 Billion for renewables, may help to awaken other countries to invest in such areas for the creation of jobs and the exploitation of non-fossil fuel sources for electricity production.

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OCEAN THERMAL ENERGY CONVERSION (OTEC) AND DERIVATIVE TECHNOLOGIES: STATUS OF DEVELOPMENT AND PROSPECTS

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INTRODUCTION

Ever since Georges Claude conducted his pioneering work on Ocean Thermal Energy Conversion (OTEC) nearly 80 years ago [1, 2], generations of engineers have dreamt of tapping this enormous renewable resource. Considerable work was initiated after the oil price shocks of the 1970s, but these efforts waned within the following two decades under less favourable political and economic conditions. In the meantime, OTEC advocates and researchers realized that the ocean thermal gradient could be used not only to produce electricity, but also in derivative technologies like desalination, cooling and aquaculture. These other deep ocean water applications (DOWA) were often envisioned as co-products that could help OTEC break its economic glass ceiling. In time, they would follow their own separate development paths.

A good synopsis entitled OTEC Economics was published in 1992 by Luis Vega [3], who had been instrumental in the execution of some of the most significant OTEC field demonstration projects ever conducted [4, 5]. The emphasis on economics in his brief article certainly was not meant to belittle other challenges faced by OTEC promoters, of which he was well aware, but it does reflect a fundamental need for very heavy financing. Given the sharp rise in the cost of primary energy over the past few years and a renewed interest in renewable energies, it is timely to examine the current status of development of OTEC and its derivative technologies. This summary will include a brief discussion of prospects, technological or other issues, and activities.

OTEC

Long-term opportunities

The OTEC resource covers an area exceeding 100 million km^2 across tropical oceans. Unlike most renewable energy conversion systems, OTEC could deliver power at very high capacity factors and offer baseload capabilities. The overall sustainable size of the resource is limited by the rate of formation of deep cold seawater, although unrealistically high estimates based on solar fluxes are often suggested. Orders of magnitude between 3 and 10 TW appear likely, i.e. a range approximately ranging from twice today's overall electricity consumption to about half of today's primary energy needs [6-8]. The lower bound reflects a possible degradation of the local thermal gradient under very intensive OTEC scenarios.

Favourable OTEC regions are for the most part far offshore from any land. This suggests that a substantial development of OTEC would necessitate floating systems rather than land-based plants. In either case, tropical locations with steep bathymetries remain the best candidates. They include countless small islands as well as some large, sometimes heavily populated island nations (Indonesia, the Philippines, Papua New Guinea, Taiwan). Brazil has extensive coastlines with excellent ocean thermal gradients, while the Gulf of Mexico could provide the U.S. with good opportunities.

Any significant OTEC development is not likely a) to take place where logistical difficulties are excessive (e.g. lack of infrastructure) and b) to be spearheaded by countries that may not easily bear the risk and burden associated with novel capital-intensive technologies. In a more distant future, a systematic development of remote OTEC regions would probably require the manufacture of energy vectors such as liquid fuels rather than direct power transmission to shore.

Issues

In the standard formulation of OTEC, electricity would be produced by circulating a working fluid through a Rankine thermodynamic cycle. Because of the moderate temperatures involved, ordinary refrigerants such as ammonia typically have been considered for such systems. Available seawater temperature differences dT, of the order of 20°C, must be used not only to define the boundaries of the cycle (evaporation and condensation temperatures), but also to maintain adequate temperature differentials between seawater streams and working fluid as heat is transferred. Hence, the Carnot efficiency of OTEC cycles is based on a fraction of dT, and is at most a few percent. All issues related to – and hurdles impeding the development of OTEC stem from this fact.

OTEC systems require cold seawater flow rates of about 2.5 to 3 m^3/s per net megawatt, with usually greater warm surface seawater flow rates. Large and efficient heat exchangers are thus necessary. Because of a need to also minimize seawater pumping losses, very large conduits also must be envisioned. The Cold Water Pipe (CWP) in particular represents a technological frontier, at least for OTEC plant designs beyond 10 MW [9]. Difficulties with the OTEC power block have been tackled differently. To be able to replace costly metal heat exchangers with simple hardware, Claude invented the Open-Cycle (OC-OTEC) [1] where steam generated from surface seawater in a low-pressure chamber continuously provides the working fluid. Unfortunately, the benefits gained with simpler robust evaporator and condenser designs are offset by the needs for very large low-pressure turbines and multi-stage vacuum compression systems. This would effectively limit OC-OTEC to plants smaller than 10 MW.

More recently, there have been efforts to improve the low efficiency of OTEC Rankine cycles by using a mixture of ammonia and water through the heat exchangers. This concept is embodied in the Kalina and Uehara cycles. The behavior of the mixture during evaporation and condensation differs from that of pure fluids. It theoretically allows a better match of heat loads during heat transfer since the temperatures of working fluid and seawater can remain closer. A plant based on this cycle requires additional hardware, i.e., a separator before the turbine inlet and an absorber after the turbine outlet. Also, the heat carried by the water in the mixture can be partly recuperated through a regenerator. The Kalina cycle reportedly can boost the Carnot efficiency of an OTEC system by 50% or so, but it also imposes increased demands on the evaporator and condenser. Hence, the viability of OTEC cycles departing from the standard Rankine cycle probably hinges on the availability of better heat exchangers [10].

The greatest technological (and credibility) challenges facing OTEC remain in the realm of ocean engineering, as OTEC field experimentation critically depends on whether a CWP can be deployed and how long it survives. From Claude's hardships in the 1930s [1, 2] to recent trouble in Indian waters [11], the history of OTEC development is rife with CWP failures. The state-of-the-art for operating deep cold seawater pipelines consists of seafloor-mounted high density polyethylene (HDPE) conduits. The largest to date (1.4 m in diameter and 2.8 km long) was deployed off the west coast of Hawaii to a depth of 900 m in 2001 [12]. While HDPE CWPs would be ideal for small megawatt-class systems, OTEC plants of much greater capacity would have to rely on other choices. On the other hand, the exploitation of vast remote offshore areas with floating platforms poses specific challenges that are not addressed with land-based systems.

The most ambitious programme designed to resolve ocean engineering problems specific to large floating OTEC plants remains the comprehensive effort led by the U.S. National Oceanic and Atmospheric Administration (NOAA) in the late 1970s and early 1980s. This included the development of computer simulation tools, model basin tests of potential platforms and pipes, and an at-sea test of a 120 m long2, 2.5 m diameter CWP suspended from a small barge. The pipe was made of two layers of fibreglass-reinforced plastic (FRP) separated by syntactic foam. Manufactured in Washington State, it was shipped to Hawaii in 24 m sections. A field experiment took place for three weeks in the spring of 1983 off of Honolulu.

The large size of OTEC components and the demands imposed by offshore environments on equipment survival and power production logistics result in high projected capital costs. From an economic point of view, this is exacerbated by relatively low power outputs so that standard analyses based on the levelized cost of electricity generation have consistently resulted in uneconomical projects. Even though the cost-effectiveness gap between OTEC and the most expensive fossil-fuel power generation technologies (e.g., oil) has steadily declined, OTEC market penetration has not yet succeeded. When considering estimates of capital costs per unit power as a function of rated power, OTEC systems exhibit a considerable expected economy of scale as one would move from small pilot plants to larger commercial units. Because of a lack of experimental and operational data in running OTEC systems, however, taking advantage of this purported economy of scale has not been possible. Various strategies aimed at leveraging market resources have been attempted. A common approach has been to identify niche markets where the local cost of electricity is sufficiently high and the overall power demand sufficiently low to make OTEC potentially attractive at the modest power outputs suitable for first-generation projects (e.g. 1 to 10 MW). In the best scenarios, a Power Purchase Agreement (PPA), perhaps indexed on a high Avoided Energy Cost (AEC), may be secured with a local utility. While addressing the demand-side aspect of the problem, a favourable PPA has proved insufficient to persuade investors that the risk associated with OTEC is acceptable, with capital outlays as high as $300 million for power outputs of the order of 10 MW. Hence, it remains likely that any meaningful demonstration of scalable OTEC systems will be accomplished with a strong commitment of public funds.

Activities

Recent efforts have shown a widespread interest in reviving OTEC, but remain subject to formidable funding hurdles. Accordingly, a number of partnerships were established this year that seek to leverage the necessary technical and financial means to build OTEC pilot plants. In August, Xenesys Inc. of Japan and Pacific Petroleum Company formed a joint venture for the industrialization and commercialization of OTEC in French Polynesia. They are seeking support from local authorities to proceed. In October, a consortium of French industrial and public partners launched the initiative IPANEMA aimed at facilitating the emergence of marine renewable energy technologies. In November, Lockheed-Martin (LM) and the Taiwan Industrial Technology Research Institute (ITRI) pledged to collaborate on a 10 MW plant project in Hawaii. Significant monies have already been committed by LM on initial design and R&D activities, but the completion of the project will necessitate a substantial commitment by the U.S. Government.

SEAWATER DESALINATION

Long-term opportunities

While fresh water is a valuable commodity worldwide, the future of seawater desalination utilizing the ocean temperature gradient is hard to evaluate, either in conjunction with OTEC electricity production, or as a stand-alone technology. In the former case, it depends on the development of OTEC with specific additional constraints (e.g., low vacuum components, water transmission to market). In the latter case, it must compete with other desalination technologies. On the bright side, the temperature differential sufficient to generate steam can be much smaller than for OTEC systems that require a turbine. At this juncture, it is likely that any advance in the development of this technology will hinge on the identification of specific niche markets or on some definite progress in deploying OTEC systems.

Issues

The concept of producing fresh water from seawater streams of different temperatures emerged as a logical consequence of OC-OTEC. In such a cycle, about 0.5 % of the warm surface water is converted into steam in a low-pressure vacuum chamber; this steam can be recovered as potable water by condensation as long as a Direct-Contact Condenser (DCC) is avoided. From this basic idea, numerous hybrid cycles were devised to preserve advantages afforded by a DCC in OC-OTEC systems (with the addition of a freshwater-seawater liquid-liquid surface condenser), or by other more general OTEC Rankine cycles (with electricity and desalination modules in series, or in parallel with double heat exchangers). The next conceptual leap was to forego OTEC electricity production altogether. This led to the additional consideration of more typical, though more complex desalination technologies such as Multistage Flash (MSF) distillation or Multiple Effect Desalination (MED). The latter relies on using heat from condensing vapour at a given temperature in order to produce vapour at a lower temperature in a series of vacuum chambers (effects). It was identified to be potentially well suited for low-temperature applications, at least in small systems [13]. In all cases, non-condensable gases released at low pressures need to be continuously removed.

Activities

Ocean thermal gradient desalination on the floating barge Sagar Shakti has been successfully demonstrated in 2007 by India's National Institute of Ocean Technology (NIOT) [14]. The project was designed to produce 1000 m^3/day by converting about 1% of the pumped surface seawater into steam. It extends NIOT's previous experience with smaller land-based low-temperature thermal desalination plants (e.g. Kavaratti).

SEAWATER AIR CONDITIONING

Long-term opportunities

Seawater air conditioning (SWAC) is the only technology using a thermal property of the oceanic water column that has reached commercial maturity. It is essentially a land-based technology that relies on a close access to cold water from population centres on shore. Hence, cost effectiveness critically depends of favourable siting. In spite of such limitations, there remain a great many attractive locations to further expand SWAC systems.

Issues

The success of SWAC rests on the direct cooling of A/C fluids with available thermal energy rather than with the mechanical energy expended in typical chillers. It is thermodynamically efficient as long as seawater pumping power requirements remain modest. In practice, available HDPE pipes a few kilometres long are generally adequate.

Activities

Many SWAC systems are currently being considered, e.g. in French Polynesia where existing projects have already proved successful. The largest venture with a marine SWAC system to date is planned for Honolulu, Hawaii by Honolulu Seawater Air Conditioning, LLC. The 25000 ton (A/C) project will utilize nearly 3 m^3/s of 7°C seep seawater pumped from a depths of about 530 m via a 1.4 m diameter HDPE conduit. Planners have released their Draft Environmental Impact Statement (EIS) to the U.S. permitting authorities in October and no roadblock is anticipated [15]. At the other end of the scale, 'mini-SWAC' systems based on small pressurized pipes conveying the coolant directly to submerged heat exchangers have recently been suggested to serve the needs of the smallest remote island communities [16].

SEAWATER ENRICHMENT

Long-term opportunities

High nutrient concentrations are found in deep seawater. Its use in land-based mariculture operations was spearheaded at the Natural Energy Laboratory of Hawaii Authority (NELHA) in the late 1970s. Many similar facilities have been developed elsewhere since then. The production of high-value nutraceuticals and additives (e.g., spirulina, astaxanthin) and of seafood for local niche markets has typically been targeted. The deep seawater needs of land-based mariculture, however, are projected to be exceeded by those of even modest land-based OTEC plants, especially if land availability (e.g., for raceways) is limited.

Just as long-term opportunities for OTEC lie offshore, the most tantalizing prospects for seawater enrichment are embodied in the concept of Artificial Upwelling (AU). With its high deep cold seawater intensity, OTEC seems ideally suited to be a generating technology for AU. Moreover, OTEC relies on strongly stratified tropical waters where the upper layer tends to be depleted of nutrients. Hence, if large floating OTEC plants are built, it might be possible to adjust the release of the effluents to deliberately produce significant artificial upwellings. The success of this approach hinges on achieving effluent neutral buoyancy well within the photic layer. Different stand-alone AU concepts have also been formulated and partially tested, but their practical viability remains to be established.

Issues

The most obvious strategy to potentially boost the oceanic food chain with OTEC deep seawater effluents is to release them at a shallow depth (without interference with the OTEC warm seawater intake). This would generate a negatively buoyant plume that would entrain ambient water until it stabilizes. The process is strongly site specific (e.g., local density stratification, cross currents) and very sensitive to scaling effects. All other things being equal, larger plumes sink to deeper waters but undergo less dilution. Time scales of minutes involved in plume stabilization are too fast to allow immediate nutrient utilization. Instead, primary production (and subsequent trophic enhancement) would take place in the 'far field', over time scales of days. In Low Nutrient Low Chlorophyll (LNLC) waters, the upper ocean is so depleted in essential nutrients that constraints on plume dilution should be less critical than constraints on stabilization depth.

The Japanese developed a concept that would make the stabilization of upwelled water independent of AU scale by pumping both lighter surface seawater and deeper nutrient rich seawater in a prescribed ratio corresponding to neutral buoyancy at a targeted release depth. Successful tests were initiated in Sagami Bay, Japan in the TAKUMI experiment [17, 18]. Simple plumes released from the surface as well as the TAKUMI concept were later analyzed for oligotrophic waters [19]. It was confirmed that TAKUMI represents an optimal limit for desirable AU characteristics. It was also shown that in the presence of deep permanent pycnoclines typical of LNLC oceanic regions, the amount of surface water that would have to be pumped for a prescribed mixing ratio with deep seawater rapidly would make TAKUMI impractical for desirable stabilization depths. Additional results suggest that the presence of moderate ambient cross currents may dramatically improve the physical behavior of AU for simple plumes, with deep seawater flow rates about an order of magnitude higher for a given combination of neutral-buoyancy depth and dilution.

The high flow rate AU configurations discussed so far rely on hard pipes and powerful pumps. There are low flow rate alternatives that would require minimal or no pumping mechanism and could possibly use soft flexible conduits. In one case, the heaving motion of a buoy induced by surface waves would control a valve in a connected vertical pipe; this would allow the upward flow of seawater within the pipe [20]. In another system, less saline deep water brought inside the pipe slowly warms up; as a result, density differences with the outside water column allow a sustained ('perpetual') upward flow of a few millimeters per second [21]. Slowly upwelled water would be quite stable near the ocean surface and therefore correspond to optimal conditions for enhanced photosynthesis. Aside from specific engineering challenges and issues of survival at sea, the low flow rates associated with these concepts would necessitate the deployment of arrays of considerable extents to be quantitatively significant.

Activities

The most significant endeavour is the sustained operation of TAKUMI since May 2003 in Sagami Bay, Japan, where 100000 m^3/day of 200 m deep water is stabilized relatively close to the surface. TAKUMI has been organized by MARINO-FORUM 21, a subsidiary of the Fisheries Agency of the Government of Japan. Notable as well, although less successful is an attempt this year to deploy novel wave-driven AU pumps off of Hawaii during the first Ocean Productivity Perturbation Experiment (OPPEX-1) led by the University of Hawaii.

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STATUS OF TECHNOLOGIES FOR HARNESSING SALINITY POWER AND THE CURRENT OSMOTIC POWER ACTIVITIES

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THE POWER OF OSMOSIS

It has been known for centauries that the mixing of freshwater and seawater releases energy. For example will a river flowing into the salty ocean releases large amounts of energy. The challenge is to utilise this energy, since the energy released from the occurring mixing only gives a very small increase in the local temperature of the water. During the last few decades at least two concepts for converting this energy into electricity instead of heat has been identified. These are Reversed Electro dialysis and Pressure Retarded Osmosis. With the use of one or both these technology one might be able to utilise the enormous potential of a new, renewable energy source. On global basis this potential represents the production of more than 1600 TWh of electricity per year.

The Reversed Electro dialysis (RED) is a concept where the difference in chemical potential between both solutions is the driving force of the process. The chemical potential difference generates a voltage that with the use of membranes for electro dialysis is converted into electrical current. This concept is under development in the Netherlands and there are preparations for the first prototype to be build.

For Pressure Retarded Osmosis (PRO), also known as osmotic power, the released chemical energy is transferred into pressure instead of heat. This was first considered by Prof Sidney Loeb in the early 70's, when he designed the world first semi permeable membrane for use in desalination trough reverse osmosis. In osmotic power one can utilise the natural occurring osmosis, which relates to the difference in concentration of salt between two liquid, for example sea water and sweet water. Sea water and sweet water have a strong force towards mixing, and this will occur as long as the pressure difference between the liquids is less than the osmotic pressure difference. For sea water and sweet water this would be in the range of 24 to 26 bars based on the salt concentration of sea water.

In a PRO system filtered sweet water and sea water are led into the system. Before entering the membrane modules the sea water is pressurised to approximately half the osmotic pressure, approximately 12-14 bars. In the module sweet water migrates through the membrane and into pressurised seawater. This results in an excess of diluted and pressurised seawater which is then split in two streams. One third is used for power generation in a hydropower turbine, and the remaining part passes through a pressure exchanger in order to pressurise the incoming seawater. The drain from a plant will to the main extent be diluted seawater that will be led either back to the river mouth or into the sea.

An osmotic power plant will to a large degree be designed of existing "off the shelf" technology. The two unique components are the pressure exchanger and the membrane. The majority efforts in order to commercialize osmotic power are the improvement and scale up of these components.

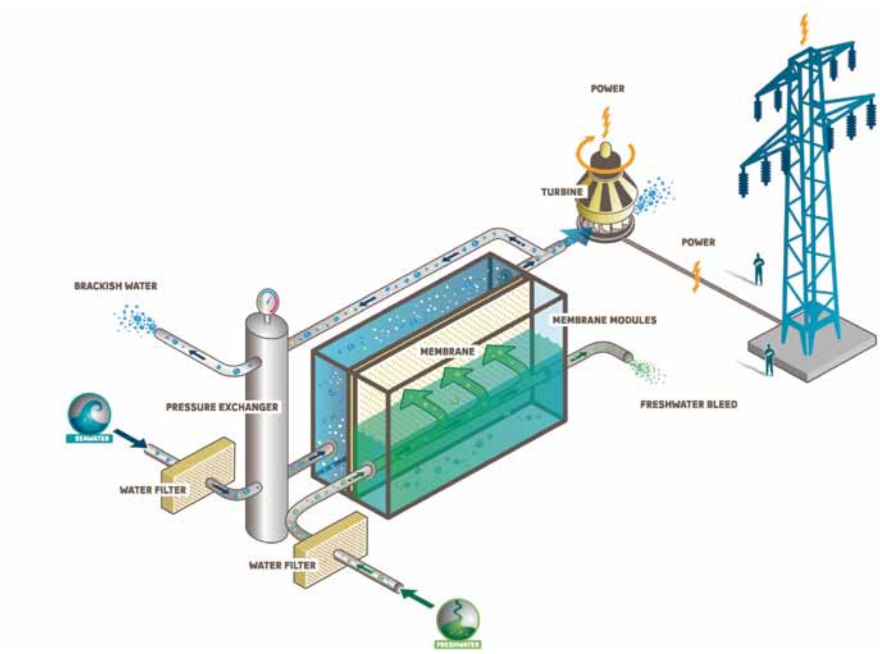

FIGURE 1: The principle of osmotic power is utilising the entropy of mixing water with different salt gradients. In the process the water with low salt gradient moves to the side with the higher salt concentration and creates increased pressure due to osmotic forces. Given the sufficient control of the pressure on the salt water side, approximately half the theoretical energy can be transformed to electrical power, meaning that the operating pressure are in the range of 11-14 bars enabling the generation of 1MW per m³ per sec fresh water.

CURRENT ACTIVITIES

After the idea of using PRO was developed in the early 70's, limited effort has been made to bring this technology to a commercial level. There have been some minor studies and testing, but it was not until Statkraft started working with PRO that the development picked up momentum. Since this work started around 1996, research has been focused on designing a suitable membrane for PRO, and at the same time one has worked with system design and several studies of the feasibility of the concept as a commercial source of energy.

The development of an efficient membrane for osmotic power has been the major focus of the efforts made by Statkraft. The current power density of the membrane is approximately 3 W/m², which is up from less than 0.1 W/m² a few years back. This research has for most part been done in Germany, Norway and the Netherlands, there are however other groups working on similar topics both in North America and Asia.

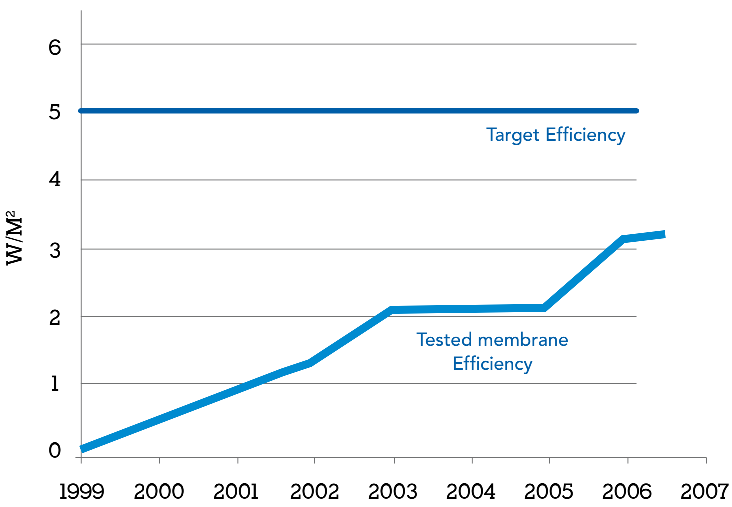

FIGURE 2: The power efficiency of membranes has been increased from 0.1 to approximately 3 W/m².

The world's first prototype of osmotic power is now under construction and the plant will be put into operation in January 2009 in the southeast of Norway.

FIGURE 3: The Prototype at the East coast of Norway.

The main objectives of the prototype are twofold. Firstly, confirming that the designed system can produce power on a reliable 24-hour/day production. Secondly the plant will be used for further testing of technology achieved from parallel research activities to substantially increase the efficiency. These activities will mainly be focused on membrane modules, pressure exchanger equipment and power generation (turbine and generator). In addition there will be a focus on further development of control systems, water treatment equipment, as well as infrastructure with regards to water inlets and outlets.

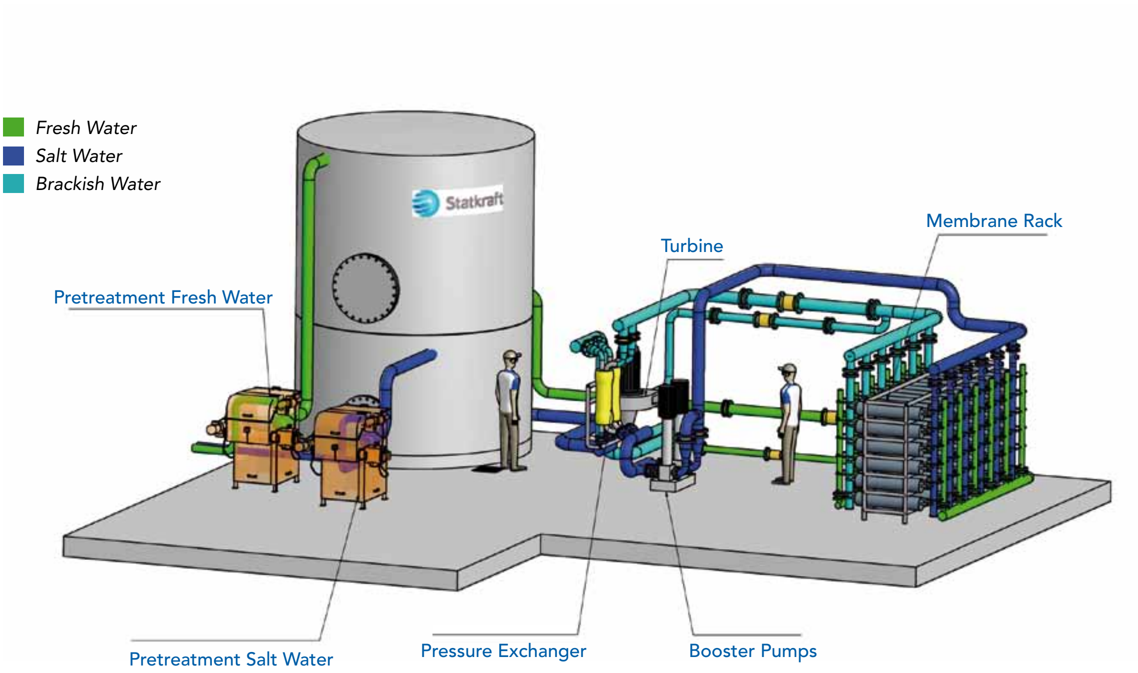

FIGURE 4: Prototype illustration.

The main objectives of the prototype are twofold. Firstly, confirming that the designed system can produce power on a reliable 24-hour/day production. Secondly the plant will be used for further testing of technology achieved from parallel research activities to substantially increase the efficiency. These activities will mainly be focused on membrane modules, pressure exchanger equipment and power generation (turbine and generator). In addition there will be a focus on further development of control systems, water treatment equipment, as well as infrastructure with regards to water inlets and outlets.

ENVIRONMENT AND MARKET POTENTIAL

Osmotic powers excellent environmental performance and CO_2-free power production will most likely qualify for green certificates and other supportive policy measures for renewable energy. The estimated energy cost is comparable and competitive with the other new renewable energy sources, such as wave, tidal and offshore wind being in the range of 50-100 €/MWh.

With a potential of more than 1600 TWh a year world wide, where 170 TWh a year is in Europe, this will likely prove to be a major contribution to the growth of renewable energy, and to represent a new attractive business potential for both the commercial power companies and technology suppliers.

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UTILIZATION OF OCEAN ENERGY FOR PRODUCING DRINKING WATER

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Abstract

Wave, thermal gradient and tides are some of the common forms of renewable energies available from the ocean. Even though the understanding on each of these forms has matured over the last few decades, harnessing these ocean energies itself is still in initial stages around the globe. With the growing demand for fresh water around the globe and ocean being a natural source for water, the need for the desalination of ocean water has attained increasing relevance for the present day policy makers. The use of ocean renewable energies to desalinate the water presents a viable alternative for the generation of fresh potable water. This paper discusses the efforts made by the National Institute of Ocean Technology towards this goal.

INTRODUCTION

The ocean can be huge source of energy in a variety of ways. The most commonly known and studied form is wave energy, next is the ocean thermal energy and also ocean currents. Today renewable energies are being studied extensively due to the slow attrition of the natural non-renewable sources. Additionally the acute drinking water shortage in some countries is making seawater desalination more relevant. If seawater desalination is powered by a renewable energy the method becomes economically more viable and also environmentally friendly. Utilization of these energies to produce drinking water is an important area of study, research and poses lot of challenges for implementation.

The use of Ocean Thermal Gradient for power generation has been thoroughly investigated following the works of Claude (1930). A few of the subsequent studies like Kalina (1984), and Uehara (1999) addressed the production of water as a by-product. Apart from few works that established laboratory scale models, as those of the 210kW rated operational OTEC plant (Vega and Evans, 1994) that worked for five years during 1993-98, the research has not progressed to operational plants. One of the main challenges associated with the operationalization of the OTEC based power systems was the design of the required system with the added constraint of making the end product economically viable.

The National Institute of Ocean Technology (NIOT) also embarked on the Ocean Thermal Energy Conversion program in early 2000 (Ravindran and Raju Abraham, 2003). The objective was to commission a floating OTEC plant of capacity 1MW. Though components were realized, due to poor infrastructure and limited ocean installation experience in the country, problems were encountered in the deployment of the large cold water pipeline due to which the program was suspended. Thus the experience gained has been effectively utilized in putting up the first ever land based and floating low temperature thermal desalination plants which are discussed in a later section.

Presently the NIOT has deployed and recovered several pipelines and small contractors in the country have been groomed to carry out these tasks with ease. Offshore handling equipments and vessels have been procured which can facilitate offshore operations. Parallely along with offshore experience, studies are being carried out on turbines and heat exchangers for furthering OTEC research. India being a tropical country blessed with a large temperature difference between surface and deep sea water cannot afford to ignore OTEC activities and efforts are on to incorporate a small OTEC plant to power a desalination plant as will be discussed later.

The Indian wave energy plant at Vizhinjam in Kerala was commissioned in the early 1990s. The OWC based plant has been generating power for several years. Several power modules were tested and in comparison with the common Wells turbine, an impulse turbine was found to give the highest efficiency (Sharmila et. al, 2004). The wave energy generated continuously at this plant was utilized to power a Reverse Osmosis plant to generate fresh water from seawater. This will be discussed in a later section.

OCEAN THERMAL GRADIENT BASED DESALINATION

As mentioned earlier after the setbacks suffered in the OTEC program NIOT decided to attempt to utilize the thermal gradient for generating potable water. The low temperature evaporation of surface water at a reduced pressure generates water vapor and this can be condensed using deep-sea water. This method is called Low Temperature Thermal Desalination (LTTD). After several experiments in the laboratory the NIOT installed the first ever land based LTTD plant (Kathiroli and Purnima Jalihal, 2008) at an island in the Lakshadweep islands in western India (shown in Fig. 1). This plant is of a capacity of 100m^3/day. The bathymetry near the plant is such that the 400m water depth is available within 500m from the shore. The plant is located on the shore. A pipe of length 600m draws 12oC cold water continuously to feed the condenser.

The plant was commissioned in 2005. It has been continuously operating for all these years providing good quality drinking water to the local community. The impact on the life and health of the islanders has been simply remarkable. Along with stomach disorders, various ailments related to dietary salt excess like hypertension, etc., have reduced. The environmental friendliness of the method is very beneficial and attractive in the fragile coral environment. Additionally the deep sea cold water is being used to run the air conditioning system in the entire plant building saving power costs.

FIGURE 1: Land based LTTD plant at Kavaratti, with an inset of the Local Users

The success of the island plant led to the thought of scaling up for mainland requirements. The deep water however is available very far away from the coast hence to cater to the mainland, offshore plants become necessary. To demonstrate that an offshore desalination plant is feasible, a barge mounted LTTD plant of capacity 1 million liters per day was installed and commissioned about 40km offshore from Chennai in Southern India.

The first ever barge mounted LTTD plant (Kathiroli et. al, 2008) was commissioned successfully being moored in 1000m water depth with a single point mooring (shown in Fig. 2). A long, 1m diameter HDPE pipe was vertically suspended below the barge to draw the cold water. Fresh water of excellent quality was generated for several weeks.

FIGURE 2: Barge Mounted LTTD Plant

The success of the island LTTD plant has led to the island authorities requesting NIOT to put up more such plants and work towards commissioning them in mid 2009 is in progress. The success of the offshore plant has led policy makers towards the idea that the technology needs to be scaled up and commercialized. A larger plant of capacity 10million liter per day is being taken up. This will involve challenges like design, fabrication and installation of the offshore platform with large cold water pipes. Studies are underway currently.

WAVE POWERED DESALINATION

The power generated at the wave energy plant at Vizhinjam was used to drive a Reverse Osmosis (RO) based plant of capacity 10000 liters per day. The method involved the use of a special variable speed alternator made indigenously for the Indian Railways. This alternator gave a DC output within a range of speed of the impulse turbine. The power generated was fed to the RO plant (Fig. 3). A battery was also introduced in the circuit for charging when the wave power was high and discharging when it was less. The concept was successful and led to the first ever wave powered desalination system. The system generated fresh water out of seawater using the power from the sea. Since studies are being focused towards floating wave powered devices application of this system to such a device is yet to be studied.

FIGURE 3: Wave Energy Plant and the RO Desalination System at Vizhinjam, India

As mentioned earlier three more LTTD plants are being put up in the Lakshadweep islands. In the next phase attempts are being made to put an OTEC module in one of the plants just large enough to power the pumps in the desalination system. Powering the LTTD plant with OTEC will result in 'free' water generation which is season independent and will be a boon to the island communities that depend on diesel generators for power. Currently studies on the working fluid to be used and the design of the turbine for the same are under progress. For the larger capacity LTTD plant the use of OTEC to generate the fresh water will make the technology really viable since diesel need not be transported from mainland. The challenge would be to make the turbines and integrate OTEC and LTTD components on a compact offshore platform.

CONCLUSION

LTTD has been amply understood and fine tuned through the various plants put up by NIOT. The challenge now is to make them self powered using OTEC and demonstrate sustainable generation of power and fresh water in the field.

Acknowledgements

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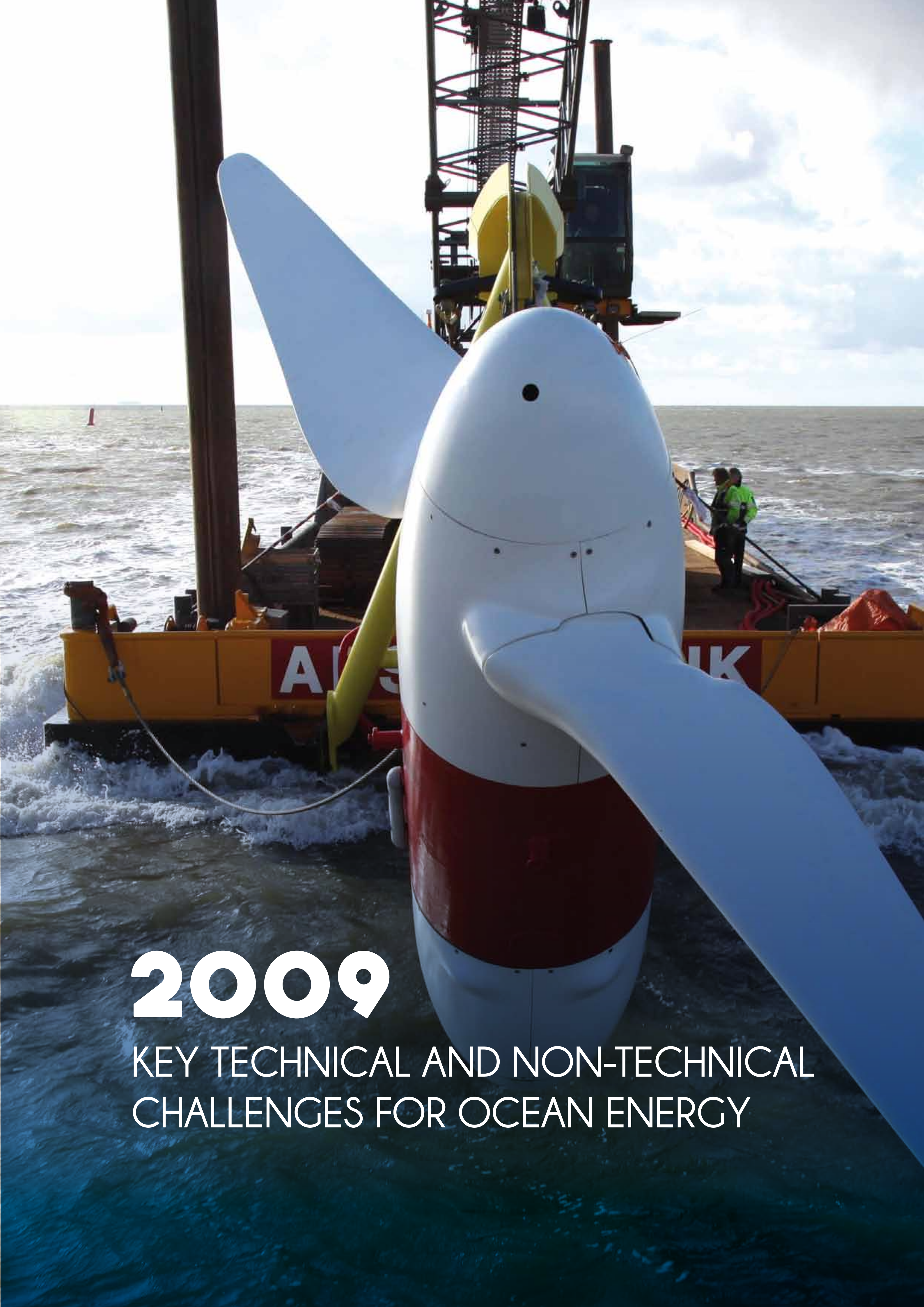

2009

KEY TECHNICAL AND NON-TECHNICAL CHALLENGES FOR OCEAN ENERGY

2009
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The Opportunity and Challenge for Ocean Energy as Part of Energy System Decarbonisation: the UK Scenario
Henry Jeffrey and Mark Winskel
UK Energy Research Centre (UKERC), Edinburgh University, United Kingdom

Marine Energy Device Development: A Structured Programme to Mitigate Technical & Financial Risk
Brian Holmes
Hydraulic Maritime Research Centre (HMRC), University College Cork, Ireland

Ocean Energy as Ocean Space Use – Only Conflicts or Also Synergies?
Frank Neumann
Wave Energy Centre, Portugal

Overview of Global Regulatory Processes for Permits, Consents and Authorization of Marine Renewables
Carolyn Elefant
Law Offices of Carolyn Elefant, Ocean Renewable Energy Coalition (OREC), USA

The Standardization of Marine Renewable Energy Conversion Systems
Melanie Nadeau
CanmetENERGY, Natural Resources Canada, Ontario, Canada

THE OPPORTUNITY AND CHALLENGE FOR OCEAN ENERGY AS PART OF ENERGY SYSTEM DECARBONISATION: THE UK SCENARIO

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THE CHALLENGE OF DECARBONISATION

This is a time of unprecedented attention on energy systems, certainly since the energy crisis of the 1970s. The broad acceptance that carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions are responsible for climate change has made decarbonisation of the economy an international policy priority (IPCC, 2007). Ambitious targets for economy-wide decarbonisation and low carbon technology deployment are being established across international policy, industry and research communities.

As part of this, the UK has set out a legally binding framework for decarbonisation from now to 2050. Following a recommendation by the UK Committee on Climate Change, the UK's reduction target for all greenhouse gases (GHGs) is at least 80% below 1990 levels by 2050, with a recommended interim target of at least 34% by 2020 (CCC, 2008).[1] These targets – some of the most ambitious legally binding levels of GHG reductions anywhere in the world – have been incorporated in the UK Climate Change Act (UK Government, 2008a). Ocean energy is one of a number of emerging low carbon supply options that has the potential to help meet these targets.

Alongside major deployments of more mature low carbon supply technologies over the next decade, there is an opportunity for currently less mature emerging technologies, such as ocean energy, to contribute significantly to deeper decarbonisation over the medium to long term. Realising this potential will involve a complex interplay between technology *development* (and learning-by-research) and technology *deployment* (and learning-by-experience).

This paper begins by highlighting the specific technical challenges associated with the development of ocean energy. It will then use the UK as a case study to illustrate and discuss the potential deployment that could be achieved if these challenges are overcome and ocean energy competes in the overall energy mix. Building on the results from this case study the paper will culminate by laying out and summarizing the high level challenges associated with the large scale international deployment of ocean energy.

OCEAN ENERGY

Ocean energy (defined here as wave and tidal current technology[2]) is an emerging technology field with considerable promise. For example, it has been estimated that around 15-20% of UK electricity demand could be met by ocean energy (Carbon Trust, 2006). This said, ocean energy innovation and industrial systems are at a relatively early stage of development as compared, for example, to wind power, and this is reflected in a wide variety of prototype device designs.

For example, there is still a wide range of engineering concepts for capturing wave energy, including oscillating water columns, overtopping devices, point absorbers, terminators, attenuators and flexible structures. Tidal current energy exhibits less variety, with most prototype designs based on horizontal axis turbines, but vertical-axis rotors, reciprocating hydrofoils and Venturi-effect devices are also being developed. Two UK based companies (Pelamis Wave Power and Marine Current Turbines) have recently installed full-scale devices that are representative of the sectors' progress, Figure 1.

[1] *The UK Climate Change Committee recommended that the decarbonisation targets be applied to all greenhouse gases, and not just CO_2 emissions. This was subsequently accepted in the UK Climate Change Act (CCC, 2008; UK Government, 2008). Non-CO_2 emissions accounted for 15% of total GHG emissions in 2006 (CCC, 2008). The modelling scenarios presented in this report only consider CO_2 emissions.*

[2] *Tidal barrages, lagoons or ocean thermal circulation technologies are not addressed here.*

FIGURE 1: Full Scale Marine Energy Devices: Pelamis Wave Power (left) and Marine Current Turbines Seagen Device (right); (Sources: PWP, MCT)

In the wake of the 1970s energy crisis, a number of wave energy Research & Development (R&D) programmes were established internationally, but – in contrast with wind energy – these efforts were not sustained, and there was very limited innovation in the ocean energy sector from the mid-1980s to late 1990s. Renewed policy interest (and public and private funding) over the last decade has provoked a resurgence in innovation activity, and the emergence of multiple device designs. These more recent efforts have been led initially by small and medium enterprises (SMEs) and university consortia, although large power companies and large scale public-private programmes are increasingly involved.

International interest and development activity has grown rapidly in recent years, and over a dozen countries now have specific support policies for the ocean energy sector. Additionally, full scale ocean energy test centres have been established in the UK and continental Europe, with new centres being built in the United States and Canada. Additionally, this international interest and growth has lead to the development of international standards specifically for ocean energy.

The nascent status of ocean energy technology creates considerable challenges for its development. In particular, there is a need to strike a balance between trials of the most advanced prototype devices, and also research on more radical but less developed designs and components. The Carbon Trust have indicated long term learning rates for wave and tidal energy of up to 15% and 10% respectively, but also highlighted the importance of taking advantage of step change improvements (Carbon Trust, 2006).

RESEARCH CHALLENGES AND PRIORITIES

As indicated in the previous section, both wave and tidal current energy still face a number of significant technology challenges in order to reach fully commercial status. A representative, but by no means exhaustive, summary of the general challenges for the sector is provided below:

- At present ocean energy innovation activity is spread over a wide variety of concepts and components, and at the highest level, wave and tidal current have distinctive innovation needs. Although this variety of device design and experimentation is important, it may create problems in terms focussing R&D investment and the speed of commercialisation. Across the sector as a whole, there is a need to strike a balance between prototype design variety and consensus, and to manage the selection processes for linking between the two. While resources and effort tend to focus on a few large-scale wave and tidal current prototypes (up to around 1MW), and more conventional designs and components, there is a parallel need to explore more radical options which may offer step-change cost reductions or performance improvements. This can be understood as a balance between early-stage learning-by-research and later-stage learning-by-doing.

- At the same time, a number of generic technologies and components – such as foundations, moorings, marine operations and resource assessment – offer opportunities for collaborative learning, although the transfer of generic knowledge and components within the developer community is limited by commercial competition (Winskel, 2007).

- Given limited full scale experience in real operating conditions, there is a need for more data on prototype performance and operating experience to feed back into the overall Research, Development & Demonstration (RD&D) cycle.

- There are significant opportunities for knowledge transfer from other sectors, such as offshore engineering. Enabling this transfer will involve better understanding of the 'adaption costs' of transferring components and methods to the marine environment, and identifying opportunities for collaboration with other industries and supply chain partners.

CASE STUDY:

Potential Development and Deployment of Ocean Energy in the UK

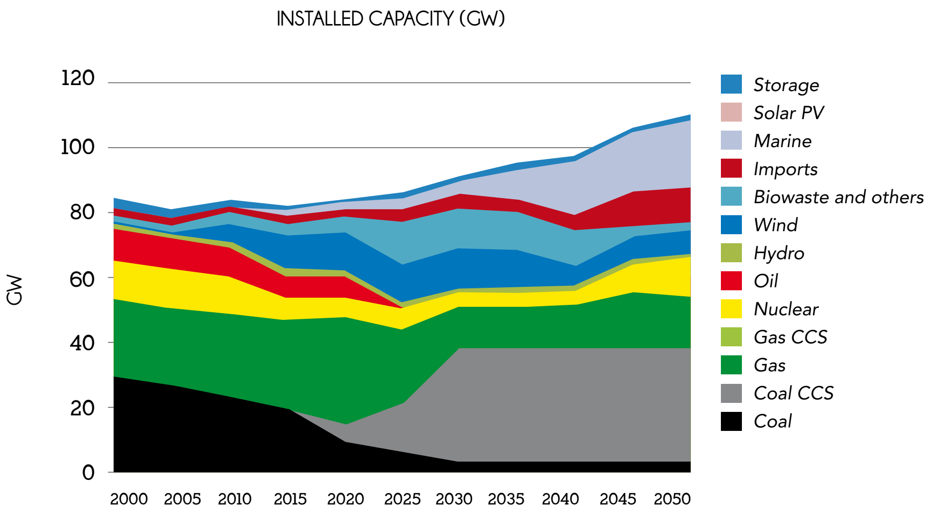
This case study investigates the prospects for accelerated development of a range of ocean energy supply technologies, and the impact of this acceleration on the decarbonisation of the UK energy system. Technology acceleration is analysed firstly by devising detailed single technology scenario (ocean energy) of accelerated development, and then system-level modelling of the potential impacts of this acceleration on the UK energy system from now to 2050. The results of the case study highlight the potentially important role for ocean energy technology acceleration in the transition to a low carbon energy system in the UK, and also its wider international significance.

Input Assumptions

Given the leading position of the UK in the ocean energy sector, domestic innovation support policies are potentially able to influence the progression of the sector internationally over the short to medium term. Using plausible deployment figures for the period to 2015, and international learning rates and initial capital cost figures derived from the Carbon Trust (Carbon Trust, 2006), 'accelerated' learning curves for wave and tidal were produced. (Note that this analysis is based on the continuation and expansion of tariff and capital support mechanisms in the UK and elsewhere to support niche deployment and learning).

Results: Single Technology Scenario

In the single technology scenario (Figure 2), with ocean energy technologies accelerated alone (and all other technologies under non-accelerated 'business as usual' assumptions), technology acceleration makes a substantial difference to the deployment of ocean energy technology in the UK, with over 20 GW of installed capacity by 2050.



▲
FIGURE 2: Indicated impact of ocean energy acceleration in the UK (2000-2050)

Results: Aggregated Scenario

In the aggregated scenario case, all low carbon energy supply technologies are accelerated in parallel and compete for market share. In this case ocean energy continues to make a significant contribution to the supply mix (see Figure 3, here ocean energy supplies almost 15% of all electricity generated in 2050, i.e. over 240PJ (67 TWh)).

ELECTRICITY GENERATION MIX

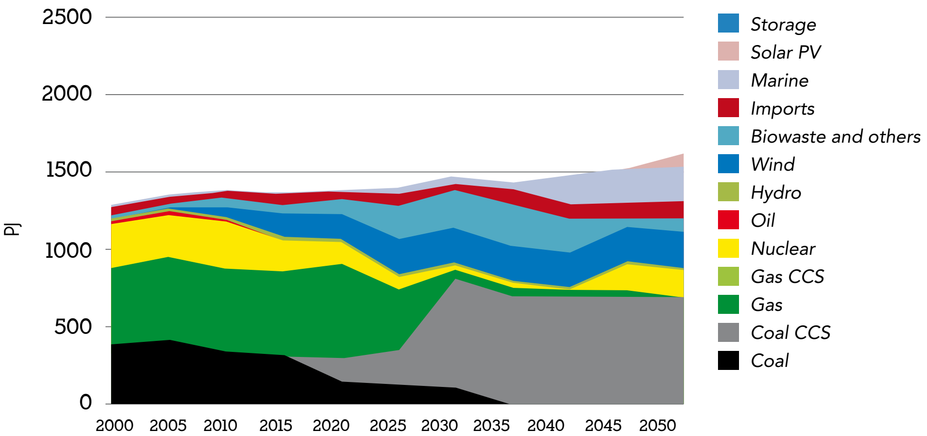


FIGURE 3: Indicated impact ocean energy in a UK aggregated scenario

DISCUSSION OF RESULTS

These scenarios provide only possible illustrations of the future. In practice the feasibility of their implementation depends on many issues beyond the relative costs and performance of different supply technologies, such as raw material prices, supply chain capacities and investment risks. In addition, energy system change is also affected by patterns of energy demand, the networks used to transfer energy between production and consumption, and many other regulatory, organisational and political interests and pressures.

For this scenario to be realised, over the period to 2020 there is likely to be a progressive device design consensus, with a distinct group of wave and tidal designs becoming 'industry standards'. Consolidation in the marketplace is also likely, with mergers and acquisitions allowing hybrids of the best technologies to emerge and reduce overall costs. Up to and beyond 2020, it is conceivable that disruptive technologies, embodying novel approaches to energy extraction, will be introduced, allowing for accelerated cost reduction, although the timing of these breakthroughs is difficult to predict. UKERC's Marine Energy Technology Roadmap (UKERC, 2008a) details the technology and commercial challenges involved in establishing a deployment strategy for the ocean energy sector up to 2020.

Beyond 2030, it is implausible to speculate in any detail as to the future direction of the industry; however, given continued publicly and privately funded development programmes, and associated learning effects, device costs are likely to decrease, and performance increase. While an accelerated development trajectory for the ocean energy sector involves some degree of design consensus over the medium term, there is a danger that if this consensus is imposed too early it may lead to 'lock-in' around devices with less scope for development in the longer term.

SUMMARY OF INTERNATIONAL CHALLENGES

Realising ocean energy development scenarios will depend on a co-evolution of accelerated development and deployment, with ocean energy technologies benefiting from learning-by-experience associated with early deployments, in conjunction with learning-by-research to enable step changes in technology performance and cost.

The significant levels of deployment indicated in the case study scenarios, when replicated internationally, are unlikely to be met with the existing international supply chain infrastructure, and will require considerable investment in specialised and dedicated installation equipment. Some of this investment is already underway: for example, some technology developers have already taken delivery of dedicated installation vessels. Additionally, technology acceleration will involve measures to address the generic technical challenges highlighted in the UKERC Marine Technology Roadmap (Figure 4).

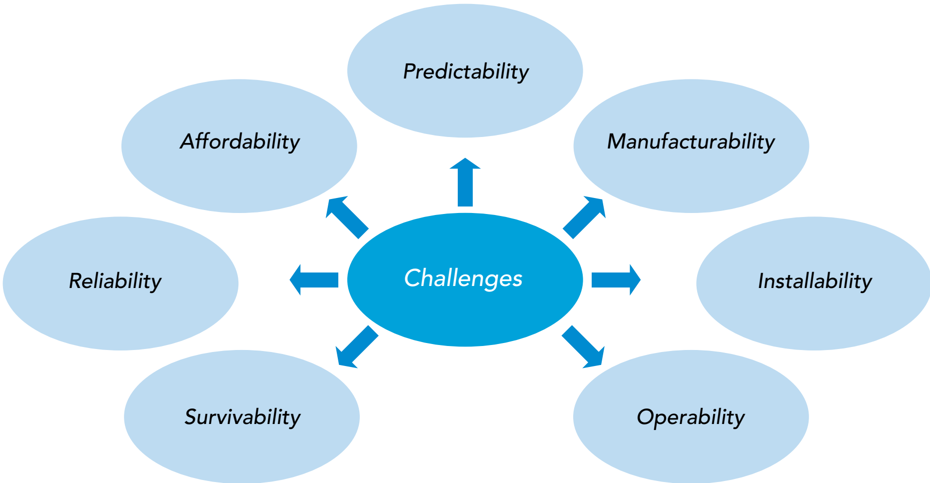


FIGURE 4: Generic Technical Challenges involved in Marine Energy Technology Acceleration

A coherent and adaptive approach to policy, across international energy arenas, will be needed to provide an appropriate combination of support mechanisms, and ensure effective distribution of investments as the sector matures.

Overall, in the short term, there will be considerable deployment challenges for the sector, with planning and legislation, human resource skills shortages, and availability of installation vessels all being significant hurdles. Despite a certain level of existing headroom, grid reinforcement will also be a significant challenge for many countries during this period.

In the medium term the challenges of planning and regulation should have been largely addressed. Despite the capacity that will have been built up in the preceding period, skills shortages and availability of vessels will still be a challenge to the sector due to the ramp-up in build rate in this period. Given the remote nature of many of the ocean energy resources, major grid reinforcements will be a major challenge during this period, with the need for an offshore grid highly likely. International initiatives, such as the "European Supergrid", are already beginning to address this issue.

The long term appears less challenging for the sector, to the extent that many earlier limitations need to have already been managed (such as supply chain constraints, planning constraints and grid implications). However, additional capacity may be exploitable by this time, so that deployment may continue increasing beyond, for example that indicated in the UK case study, above. In addition, competition for resources from other energy and non-energy sectors could have significant impacts on their availability to the ocean energy sector across all time periods.

CONCLUSION

Ocean energy is an emerging technology field with considerable promise over the medium and longer term. The industry has just started demonstrating full-scale devices and device arrays. The nascent status of ocean energy technology creates considerable scope for accelerated development. In realising this potential, however, there is a need to allow for parallel progress in demonstration trials of the most advanced wave and tidal prototype devices, and also research on more radical but less developed designs and components.

The case study scenario described here indicates that technology acceleration has the potential to make a substantial difference to the deployment of ocean energy technology in the UK, with initial deployments starting soon after 2010, and rapid expansion after 2030. Under these accelerated development assumptions, ocean energy supplies almost 15% of all electricity generated by 2050, and additional exploitable resource may allow for further increases to this figure.

Accelerating ocean energy to achieve these deployment levels will require sustained support for its development over time. A coherent and adaptive approach to policy, in the UK and internationally, will be needed to ensure effective investments as the sector matures. In particular, there is a need to strike an effective balance between technology-push and market-pull mechanisms, to allow for design consensus, but at the same time avoiding 'lock-out' of breakthrough technologies which may allow for step-change improvements. There are also considerable associated investment needs in supply chains, installation capacity, and electricity networks. With these in place, the work here indicates that ocean energy can become a significant contributor to low carbon energy supply systems in the UK and beyond.

Acknowledgements

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More specifically, the research reported here has been supported by energy systems analysis using the UK MARKAL elastic demand (MED) model. The operation of the UK MARKAL MED model is detailed in the report (Anandarajah et al., 2008).

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MARINE ENERGY DEVICE DEVELOPMENT: A STRUCTURED PROGRAMME TO MITIGATE TECHNICAL & FINANCIAL RISK

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Note: The phased development schedule & test programmes described in this article are appropriate to both wave and tidal devices. However, the details will be specific to the different technologies so for clarity only the application to wave energy is covered. A full description for tidal device progression is under review for inclusion in the OES-IA Annex II.[1]

1. INTRODUCTION

Volatile primary fuel prices, climate change, diminishing raw fossil fuel stocks and security of supply are some of the reasons National governments and international organisations are looking seriously at alternative energy source for electricity generation. This article describes a systematic approach to developing one of those renewable, sustainable options, wave energy.

A great deal has already been learned about the requirements for extracting energy from ocean waves, both at a fundamental physics level and the heavy marine engineering necessary for safe operation at sea. However, at the current stage of technical advancement the development of ocean energy devices must, inevitable, be a careful, patient and reasonably expensive process. As the knowledge base expands from further experiences and understanding the required rigorous approach may be relaxed but for now a cautious and measured methodology should be followed if the reward of economically exploiting the vast amounts of energy contained in the world's oceans and seas is to be achieved in an accelerating time frame.

Persuading technology developers to follow a controlled and careful approach is becoming even more important at the present time since there seems to be an urgency setting in, manifesting as a rush to launch devices in the sea regardless of their Technology Readiness Level (TRL)[2]. Although marine energy can only become a reality following full scale testing of wave energy converters (WEC) at sea it is important that the correct engineering procedures are followed leading up to the first sea trials. Although difficult, political and business concerns must resist applying pressure to deploy new devices prematurely.

However, a cautious approach should not be regarded as a slow advance, indeed evidence shows that by following a structured programme device development is quicker since the unexpected problems some meteoric rising companies are encountering can be avoided. Most of the current leading pioneers of wave energy devices have been astute and followed a development schedule of some description, which is one reason they are the most advanced. Figure 1 shows the development profiles of some devices. If early tests were rushed the device can become delayed in later stages. This is because the ocean is not a place to investigate options but rather somewhere to verify designs proven in a more controlled environment.

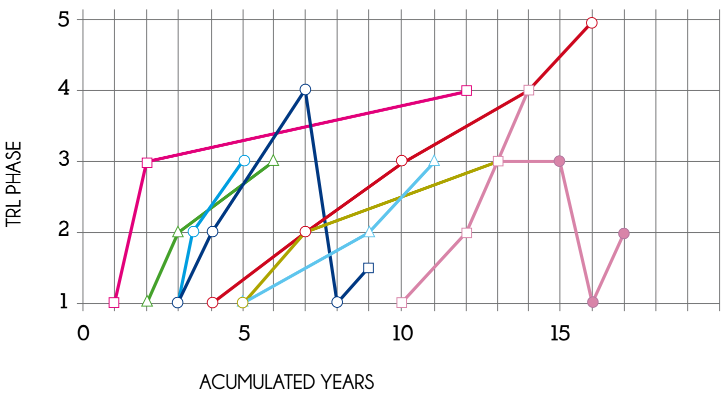

FIGURE 1: WEC Development Profiles

[1] http://www.berr.gov.uk/files/file48401.pdf
[2] http://en.wikipedia.org/wiki/Technology_readiness_level

The systematic programme presented here is now becoming accepted as the best practice and it is being formalised in a document under production by the Annex II of the Ocean Energy Systems Implementing Agreement. The purpose of the programme is to reduce the technical and financial risks encountered during the development process by investigating engineering elements at the appropriate time and cost.

It should be stated, however, that even following an organised and well planned test programme is no guarantee of success but not following one is probably a pathway to disappointment, lost time and wasted resources.

2. CHRONOLOGY

Even though wave energy research began seriously following the oil crisis of the late 1970s no formalised guidelines, recommended procedures, or best practice manuals that developers could reference and follow appeared until 2003. Until that time the vanguard companies had to design their own development schedules and test programmes on an ad hoc basis, and usually in isolation from each other.

Most of the initial investigation took place in the UK but in the early 1990s the European Union [formerly the European Economic Community] became interested in the potential of ocean power supplying electricity into the member states energy portfolios. One of the first proposals supported was the Offshore Wave Energy Converter Project (OWEC1)[3]. A section of the review sketched out a test programme which was documented in 1995. However, nothing was advanced on this report and the schedule did not become a standard approach to be applied throughout the member states researching the area.

The OWEC1 development schedule was used as the framework for the *Irish Wave Energy Development & Evaluation Protocol* published and implemented in 2003[4] and the Danish wave energy programme, 1998-2002.[5] Since the development schedules were supported by both countries funding agencies, wave energy converter (WEC) companies soon followed the recommended phased approach based on a Technology Readiness Level method. Perhaps not totally supportive at the time these companies would now be key endorsers of the staged approach.

2.1 Increased Awareness

Since the turn of the Millennium many other influential and authoritative groups have become interested in establishing a series of standard, equitable approaches for both the development schedule and the test programmes that should be adopted during the progress of wave energy devices from concept to demonstration. The list below includes the main bodies pursuing this objective.

- the International Electrotechnical Commission's Technical Committee 114 (IEC TC114)
- the Ocean Energy Systems Implementing Agreement (OES-IA)
- the UK Department of Climate Change (DECC), via European Marine Energy Centre (EMEC)
- Sustainable Energy Ireland (SEI), via Ocean Energy Development Unit (OEDU)
- the UK Carbon Trust via Det Norske Veritas (DNV)
- the International Standards Organization & British Standards Institute (ISO & BSI)
- the UK Engineering & Physics Research Council (EPSRC) via SuperGen Marine Consortium
- the European Union, via Seventh Framework Programme (FP7) project EquiMar (Equitable Testing and Evaluation of Marine Energy Extraction Devices)
- the US Department of Energy (DOE) via National Renewable Energy Laboratory (NREL)

It has, therefore, become important not only to establish agreed and accepted procedures but also to synchronise the different group's documentation. Ideally this will lead to a complimentary and co-ordinated programme and certainly ensure they are not contradictory.

[3] The Offshore Wave Energy Converter Project-1, Danish Wave Power APS, 1996 (EU JOULE contract no. JOU2-CT93-0394)
[4] *http://www.sei.ie/Renewables/Ocean_Energy/OceanEnergyIndustryForum/Forum_Archive/Development_and_Evaluation_Protocol.pdf*
[5] The Danish Wave Energy Programme, Nielsen K, Meyer N, Proc of the 3rd European Wave Energy Conference, 1998

3. THE TECHNOLOGY READINESS LEVEL SCHEDULE

Technology Readiness Level (TRL) development programmes are standard approaches for product advancement in established industries. They are particularly important in American military equipment design and were the cornerstone in NASA's very successful moon landing programme[6]. More important perhaps than the overall budget!

The principle of such a schedule is to sequence the design development so the required knowledge is obtained at different stages to enable the safe transmission along a path of increasing technical complexity and investment requirements. In the case of ocean energy device development the stages can be linked to different model scales by following Froude Similitude Laws and geometric similarity rules[7].

These accepted and proven modelling laws correctly scale the various important physical properties such that results at one size can be confidentially extrapolated to larger and full prototype scales. This in turn means important information and design criteria can be investigated at appropriate stages of development to optimise the time and costs involved in the evolution of taking a design from concept to market. However, as with all engineering solutions there are practical considerations. Not all physical processes scale as precisely as it would be convenient, and some components can not be physically modelled, which leads to the proposed staged programme, designed to enable all factors to be studied at the correct time. To accommodate all requirements a 5-stage TRL schedule has evolved as the optimum for the development of ocean energy extraction devices. Figure 2 shows the overall structure of the programme. Although presented as a linear path device development should not be regarded as a straight line process. Feedback loops and repetition of stages should not be unexpected. The 5 stages basically align with small (1:50 - 100), medium (1:10 - 25), large (1:3 - 8) and full (1:1 - 2) scale models that can be tested initially in hydraulic laboratories and, at later stages, in the open ocean.

The test programme applied at each TRL is very important but, of equal merit, is the stage gate decision procedure that should be implemented at the end of each test programme. In many ways these essential due diligence processes are the most difficult parts of the schedule to establish, and achieving agreement on the recommended evaluation criteria is not a trivial task.

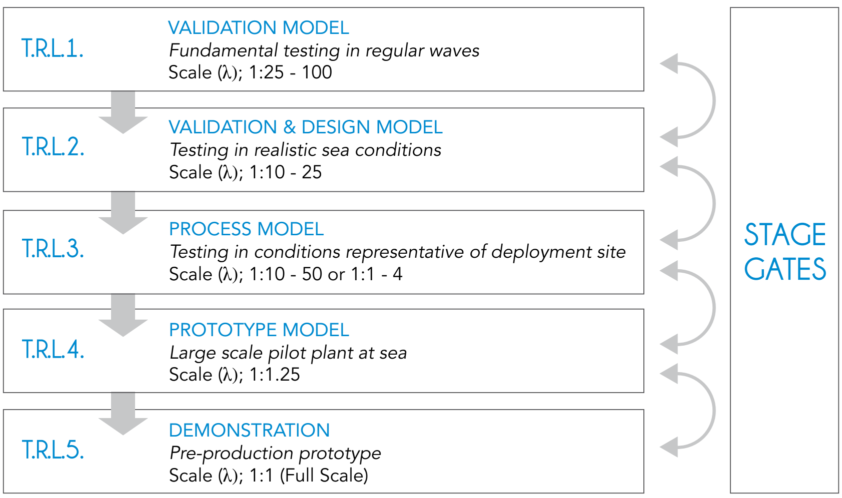

FIGURE 2: WEC TRL Development Programme

3.1 Stage Gates

At present it is often left to individual marine energy device developers to set their own design acceptance parameters since no consensus on robust, generic or standard evaluation procedures has been established. This has lead to the situation where the only measure often applied is the extrapolated estimated cost per kilowatt (c/kW) of electricity generated. Obviously, this value is an important criteria but it is difficult to apply with any confidence in the early stages of development, though essential in the later TRLs.

[6] *http://history.nasa.gov/apollo.html, http://en.wikipedia.org/wiki/Apollo_program*
[7] Physical Models & Laboratory Techniques in Coastal Engineering; Hughes S., World Scientific Publishing, 1993

Other factors such as the size, weight, manufacturing, deployment and operational complexity, power take-off (PTO) survival, hull seaworthiness and station keeping matters can also be considered. The numbers can be summarised into evaluation parameters such as electrical production per dwt (Δ) (kW/tonne) or per displaced volume (∇) (kW/m^3). [These project continuation criteria are currently under review by several of the bodies listed in Section 2].

As stated above using alternative, robust benchmarks to compare devices, or even assess a single unit against threshold values, is not a simple, or clear, undertaking but such a system is necessary if funds and time are to be focused on the devices offering the greatest potential of large scale deployment. This evaluation is particularly relevant to ocean energy, and in particular wave power, since the possibility of extracting the resource seems to have captured the imagination of inventors and engineers as much as the early days of flight did at the turn of the last century. At present, over 100 designs are being investigated at the various TRLs.

4. TEST PROGRAMMES

The actual test programme required for each WEC is, inevitably, a bespoke plan appropriate for each TRL stage. However, the overall approaches for each of the 5 stages are generic as described below. It should be noted that an important element of the stage development is that conditions are controllable and repeatable in hydraulic facilities for TRL1 & 2 but only acceptable as they occur for TRLs above this. Programmes have to be structured to accommodate this loss of control. The boundaries between TRLs are not sharp and can often merge but this should not lead to missing a stage completely.

4.1 Technology Readiness Level 1 [addressing the Unknown – Unknowns]

The primary purpose of TRL1 is to prove the basic concept of the proposed WEC in regular waves and obtain an estimate of its power performance in irregular, real sea waves.
At the beginning of the process most devices have many design variables that can influence the behaviour and performance under wave excitation. For this reason the stage is divided into 3 sections of small (scale = 1:25 - 100) scale testing as summarised in Table 4.1. Budget and durations estimates for TRL1 are also indicated. A typical idealised physical model is shown in Figure 4.1.

Once the design variables have been individually investigated in regular wave to optimise the machine, it is tested in irregular seas to evaluate the performance potential. To conduct this process fully a specified number of sea states are run extending from calm to storm conditions but focussing on the design seaways. A typical selection of design criteria to be investigated in all sections of the TRL is shown below.

VALIDATION MODEL: PHASE 1	SCALE: 1:25-100	
SECTION	TIMETABLE (Including Analysis)	BUDGET (€000)
Idea	1-5 Days	1-5
Concept	1-3 Months	25-75
Performance	1-3 Months	
Optimisation	1-3 Months	25-50

TABLE 4.1: TRL 1 Format – schedule & budget

FIGURE 4.1: Idealised TRL 1 Model [courtesy Oceanlinx Ltd]

TRL1 – Pre-design stage gate requirements

- Linear monochromatic waves to validate or calibrate numerical models of the system (25 – 100 waves).
- Finite monochromatic waves to include higher order effects (25 – 100 waves)
- Hull(s) sea worthiness in real seas (scaled duration at 3 hours).
- Restricted degrees of freedom (DoF) if required by the early mathematical models.
- Provide the empirical hydrodynamic coefficient associated with the device (also mathematical modelling).
- Investigate physical process governing device response. May not be well defined theoretically or numerically solvable.
- Real seaway productivity (scaled duration at 20-30 minutes)
- Initially 2-D (flume) test programme
- Short crested seas need only be run at this early stage if the devices anticipated performance would be significantly affected by them.

4.2 Technology Readiness Level 2 [addressing the Known – Unknowns]

If the WEC satisfies the stage gate criteria applied at the conclusion of TRL1, a larger model (circa 1:10) is constructed. There should now be fewer design options to investigate but rather TRL2 concentrates on specific component testing in more seaways, including those expected at future external sea trial sites.

Since the TRL3 requires a fully functional large scale device deployed in open water a complete engineering study should be undertaken in this TRL2. Table 4.2 shows the expected budget and duration breakdown for this phase and a typical model in Figure 4.2.

Of particular importance is the evaluation of control strategies to be applied on the power take-off system. Models should be physically large enough to incorporate the equipment and sensors required to conduct these tests.

The anticipated mooring arrangement should be deployed so the corresponding forces can be monitored to verify the design prior to later sea trials. Failure modes should be included.
Besides producing accurate results that will reduce the error band applied in the stage gate criteria, the rationale for TRL2 is to verify all the data generated in TRL1. This validation is required to justify the design decisions transferred between the TRLs.

A list of some of some of the factors to include in TRL2 is shown below.

VALIDATION MODEL: PHASE 2	SCALE: 1:10-25	
SECTION	TIMETABLE	BUDGET (€000)
Performance	1-3 Months	25-50
Survival	1 Month	15-25
Mathematical Model		10-20
Hull Design		15-25
Power Take-Off		25-75
Control		
Generator & Power Elecs		25-50
Mooring & Anchor		15-25
Preliminary Site Selection		10-25
Project Supervision	6-12 Months	25-50

FIGURE 4.2: Practical TRL 2 Model
[courtesy Ocean Energy Ltd]

TABLE 4.2: TRL 2 Format – schedule & budget

TRL2 – Pre-sea trial stage gate requirements

- Accurately simulated PTO characteristics
- Performance in real seaways (long and short crested)
- Survival loading and extreme motion behaviour.
- Active damping control (may be deferred to Phase 3)
- Device design changes and modifications
- Mooring arrangements and effects on motion
- Proposed power take-off design and bench testing (Phase 3)
- Engineering design (Prototype), feasibility and costing
- Site review for Phase 3 and Phase 4 deployments
- Over topping rates

4.3 Technology Readiness Level 3 [addressing the Known – Knowns]

There is a growing agreement that before full scale pre-production prototype WECs are built and deployed, a large scale unit in the region of scale =1:4 should be tested at a benign outdoor site. [N.B. The waves are not benign relative to the model]. This step would be a main contributor to the title of this article since the machine should be a fully operational unit but the required budget an order of magnitude less.

The practical rationale for TRL3 is that sea states are lower, the test sites involve shorter boat trips and the support services required (harbours, support vessels etc) are also more readily available. The technical motivation is that it is very difficult to bench test the device's individual sub-systems, assemblies or components so this approach enables the machine to become a serviceable test rig.
An estimate of this TRL's time and budget is shown in Table 4.3 together with a model, or device, at sea (Figure 4.3). The people on deck indicate the device physical size.

Because these are fully operational electricity generating machines being tested in realistic conditions, TRL3 offers the opportunity for more that just power and technology proving. Not only can project management, manufacturing, deployment, servicing and maintenance techniques be practiced but also certification and insurance requirements, licensing and permitting issues together with environmental requirements will be experienced. Listed below are some of the key aspects of TRL3 activity.

It is essential that funding mechanisms to enable this TRL are included in country support policies. To reduce the fiscal risk it is recommended that this phase is conducted at an established test site.

PROCESS MODEL: PHASE 3	SCALE: 1:10-15 or 1:1-4	
SECTION	TIMETABLE (Including Analysis)	BUDGET (€000)
Large Scale Facility	3-9 Months	500-1,000
Benign Site	6-18 Months	1,000-2,500

TABLE 4.3: TRL 3 Format – schedule & budget

FIGURE 4.3: Operational TRL 3 Model
[courtesy Ocean Energy Ltd]

TRL3 – Pre-prototype stage gate requirements

- To investigate physical properties not well scaled & validate performance figures.
- To employ a realistic/actual PTO and generating system & develop control strategies.
- To qualify environmental factors (i.e. the device on the environment and vice versa.
- 1 (Marine growth), 2 (corrosion), 3 (windage and current drag).
- To validate electrical supply quality and power electronic requirements.
- To quantify survival conditions, mooring behaviour and hull seaworthiness
- Manufacturing, deployment, recovery and O&M (component reliability)
- Project planning and management, inc licensing, certification, insurance, etc

4.4 Technology Readiness Level 4 [addressing the Knowns]

Prototype scale testing commences in TRL4. The importance of these sea trials cannot be over stated since they must progress the device from a pre-production to a pre-commercial machine. It can also be seen that both the required budget and duration increase significantly in line with the shear scale of operations. This can be seen by the device in Figure 4.4 where offshore operations are now very serious activities. It would be expected that a utility or other large financial backer would be involved by this TRL.

It is not possible to cover all the requirements necessary for proving the device at TRL4, since it involves a full pre-production process verifying that the completed device is fit-for purpose under all headings. These would range from the overall design to individual component suitability, through to electrical production and quality of supply. Effectively, the machine has to satisfy the complex 'wave-to-wire' performance WECs must achieve if they are to be successful. However, it should not be expected that single units could ever repay the project cost; therefore a funding mechanism to support this period of development is extremely crucial to allow devices to successfully complete TRL4.

A testing centre infrastructure to support TRL4 is currently under development (see Section 5), especially in Europe. If these establishments expand with supply and support services, as it is expected, it would be (strongly) encouraged that sea trials are conducted at one of the centres to reduce the challenges facing heavy engineering operations at sea. As well as alleviating permitting, licensing and other ocean use issues the sites should offer easier grid connection that includes performance monitoring instrumentation. It is anticipated that service vessels and support industries will set up in these areas and quickly gain important experience in their fields, which device developers should then benefit from.

The list below provides a summary of some of the key performance elements to be considered during TRL4 testing. The list is by no means complete.

PROTOTYPE DEVICE: PHASE 4	SCALE: 1:25-100
TIMETABLE (Including Analysis)	BUDGET (€000)
6-12 Months	10,000-15,000
1-5 Years	~20,000

TABLE 4.4: TRL 4 Format – schedule & budget

FIGURE 4.4: Pre-production TRL4 Device
[courtesy AWS Ocean Energy}

TRL3 – Pre-production stage gate requirements

Hull seaworthiness and survival strategies
- Mooring and cable connection issues, including failure modes
- PTO performance and reliability
- Component & assembly longevity
- Electricity supply quality
- (Absorbed/pneumatic power-converted/electrical power)
- Application in local wave climate/conditions
- Project management, manufacturing, deployment, recovery, etc
- Service, operational and maintenance experience [O&M]

4.5 Technology Readiness Level 5 [addressing the future!!]

When a device successfully completes the rigorous technical sea trials the solo pre-production converter should have evolved into a pre-commercial machine ready for economic demonstration in TRL 5. By this stage matters have advanced to project rather than product development and will involve groups specialising in this work.

The technical risks in this TRL should be contained since it mainly involves combining several machines that have already been proven. However, although the likelihood of major failures is reduced the consequence of breakdowns can be considerable. The financial risks are less certain since it is the economic prospects that are under review. Business forecasts indicate that ocean energy parks will only become commercially viable when large arrays of devices (50 -100 MW) are deployed. The purpose of this phase is, therefore, to test small groups of devices that, if successful, can be expanded into a full electricity generating station.

There are two main technical components under investigation during this time. Firstly, can the intelligent power electronics controlling the output from each individual unit combine the supply in a way that stabilises the exported supply to the grid. Many theoretical studies have been conducted on this subject and comparison made with wind park output. However, only one wave energy array has been in operation for a limited period, so no empirical evidence yet exists to validate or verify the theories.

Secondly, the physical influence of one machine on another by the interaction through the medium they operate in. This can be particularly important in wave energy arrays since the radiated wave from a single device spreads radially along the ocean surface. To some degree this interaction will be specific to a particular type of machine so generic studies should have been conducted in one of the earlier TRLs to estimate the optimal spacing and layout criteria for the park if the issue is found to be important.

The stage gate evaluation criteria requirements at this time are extensive so just a key summary list is presented below.

TRL5 – Pre-commercial stage gate requirements

- Multiple units performance
- Device array interactions
- Power supply interaction
- Environmental impact issues
- Full technical & economic due diligence

5. INFRASTRUCTURES

A strong technical support structure is advantageous to implement the TRL schedule efficiently. However, as with the device development guidelines, until post-2000 there existed few large-scale sites where wave energy machines could be tested.

Indoor hydraulic tank facilities for TRLs 1 & 2 investigations were less of a problem but few centres specialise in ocean energy testing for either wave or tidal models. Even today there is no single establishment with whom a device developer can work to move efficiently and cost effectively through the early stages of development. This situation may improve over the next few years as disparate European testing centres are attempting to form a distributed network through which a developer may progress the design of a WEC through all TRLs. A similar co-ordination of effort is under review in the USA.

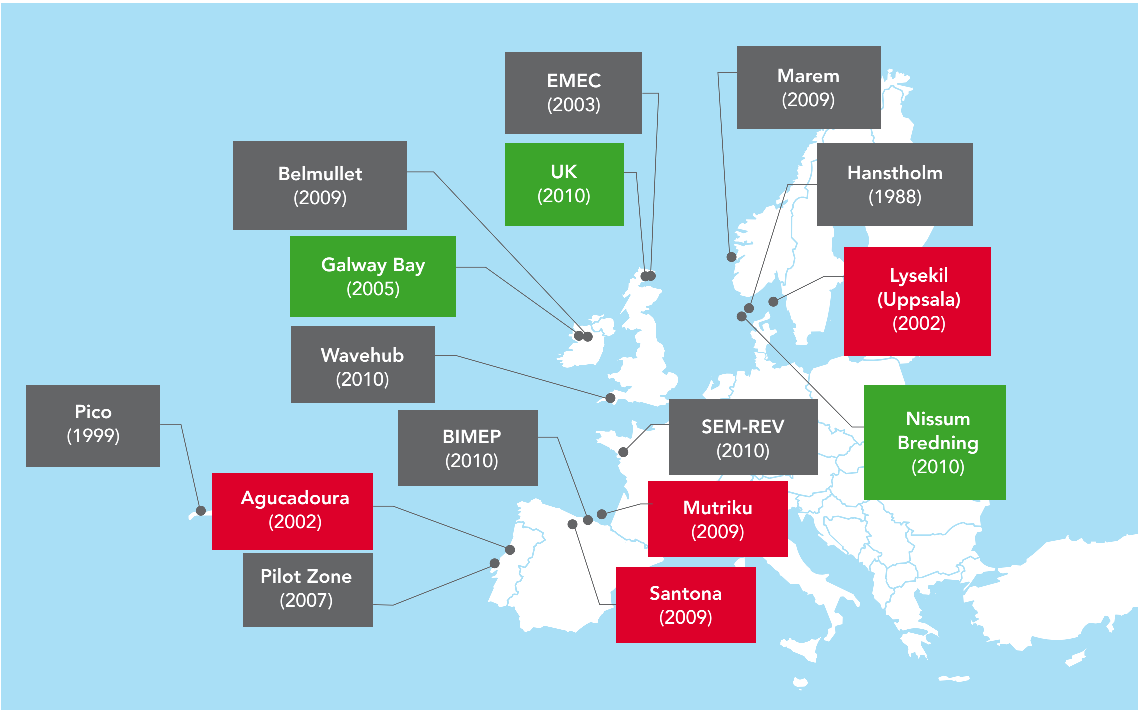

FIGURE 5: Outdoor Test Centre Infrastructure

There would be several advantages to such a technical network but, of particular merit, would be the implementation of the established testing programmes as outlined above. At present there is no universally established test protocol so testing centres apply their own. Projects, such as the EU-supported EquiMar consortium and a US Department of Energy's initiative (through NREL) are attempting to correct this deficiency, by drawing up details for each TRL, including the continuation stage-gate criteria. Eventually such documents can reside with the centres to ensure consistent and comparable results.

Prior to the new Millennium there was certainly a dearth of outdoor test areas where the later and larger size TRL trials could be conducted. Only two sites were available pre 2000 (Figure 5). Both of these were in Denmark and at that time they were not registered externally as official test centres.

There may still be a shortage of large-scale TRL3 test sites (GREEN boxes) though some of the continental full-scale pilot zones now offer the opportunity for short-term testing of quarter-scale machines in the calmer seasons.

There is also only one pre-production sea trial site for small array testing, the Wavehub in Cornwall, England, which will become operational in 2011. However, the sea areas marked in RED represent early pre-commercial wave parks, where device interaction investigation can take place. Unfortunately the public availability of the data is uncertain.

6. Towards the Future

There is good reason to be cautiously optimistic about the prospects of marine energy technologies supplying significant amounts of clean electricity.

This optimism can be supported by the number of devices that are progressing through a development programme to begin sea trails at, or close to, full-size prototype scale. If only one or two achieve expectations at the pre-production stage the objective of harness the world's ocean power potential should become achievable.

The caution is based on the funding mechanisms. Although the current set of pioneering devices must be the units that prove the technical and practical possibility of extracting ocean energy they may not be the machines that are finally deployed on a wide scale. It is important therefore to maintain support systems that will allow the companies to re-investigate fundamentals or enable new entrants into the industry.
The stage-gate application through the Technology Readiness Levels should assist the process as an evaluation methodology that will enable funding to be appropriately focussed at each of the TRLs.

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OCEAN ENERGY AS OCEAN SPACE USE ONLY CONFLICTS OR ALSO SYNERGIES?

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THE FUTURE OF OCEAN SPACE: A CROWDED USAGE?

The increasing ambitions of implementing ocean energy technologies on a large-scale have led to discussions about the conflicts of use of the ocean space, mainly with respect to traditional competing uses, but also among the new 'competitors' in the field of maritime renewables. To date, this situation has been generally recognised at a generic, but not detailed, level (see e.g. Waveplam, 2009).

With terrestrial resources approaching their physical limits, ocean space has increasingly been considered as a last resort for a number of vital resources of modern society, in particular for energy conversion, minerals, biomass and food. Territorial waters are subject to increased economic interest, which is why tools like Marine Spatial Planning (MSP) and Integrated Coastal Zone Management (ICZM) have become major issues on the political agenda in the European Union (EU) and beyond. While ICZM has been implemented for a long time in most developed coastal areas, future-oriented and consistent decision-making needs to be extended towards the offshore region in the present context. Instead of some usages replacing others, it is likely that traditional usages of ocean space continue or even increase, while new and competing uses will equally require large areas.

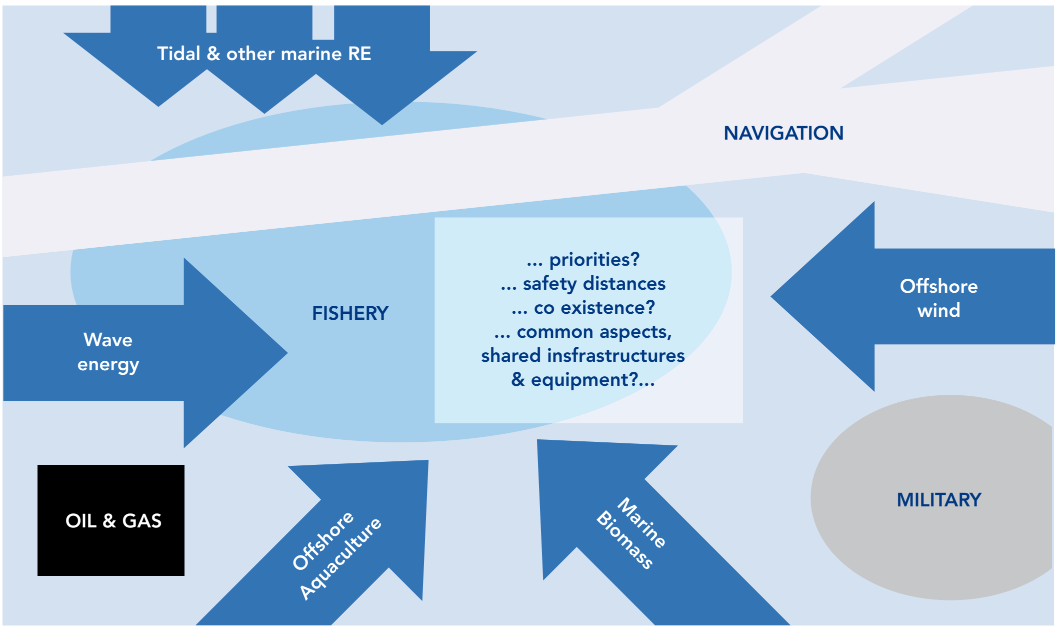

FIGURE 1: Sketch Of Increasing Density And Variety Of Ocean Space Uses: The New 'Competitors'

Such a scenario requires a new level of sensibility on the decision-making level, both with respect to priorities, possible co-existences and cross-border aspects. On the national level, some countries have started to implement detailed and structured approaches to regulation and avoiding conflicts of ocean space use, including the emerging sector of electricity generation from marine renewables. In particular in the UK, the Department for Environment Food and Marine Affairs (DEFRA) has established a widely accepted definition of the term Marine Spatial Planning, showing the ambitious targets of the process:
"Marine spatial planning provides an opportunity to take a strategic plan for regulating, managing and protecting the marine environment that addresses the multiple, cumulative and potentially conflicting uses of the sea".

The process of yielding a binding legal framework to this extent, originated in the year 2002 (DEFRA, 2002), has recently yielded the Marine and Coastal Access Act in 2009 (DEFRA, 2009).

The rapid increase of large-scale offshore wind farms contributed to the importance that this issue has been given in the UK, and certainly the existence of high-level discussions involving several public documents and consultation periods has, in turn, been beneficial for the acceptance of large-scale offshore wind farms. However, each technology has its own specific coastal and maritime space issues, and geographic factors strongly influence the usage scenarios involving marine renewables.

Therefore, there is a strong need for more detailed technical inputs for such documents, as well as for an integration of cross-border relevant aspects and a global understanding of priorities and co-existence.

THE NEED FOR MORE STRUCTURED PLANNING & CONSENTING

Every sector considers its own performance and contribution as the most relevant to society, and as long as its economic activities remain autonomous, the requirement for co-existence or even synergies with other sectors, potentially competing for access to the same areas, is not a priority. In this context, ocean energy will not only 'compete' with existing ocean uses but also with other new activities considered vital for modern society. Therefore, quantitative and objective means of measuring the (socio) economic value and consequently attributing priority usages for certain areas will be an important tool for future marine spatial planners. Socio-economic evaluations exist for traditional sectors (e.g. fishing), but others are difficult to quantify (e.g. military uses). The socio-economic value of marine renewable energies still has to be evaluated, although conventional offshore wind (bottom-fixed farms in shallow water; <40m) provide some evidence. If an acceptable approach for such quantification can be found for the entire range of competing uses, the most optimal and beneficial uses of ocean space can be guaranteed.

Given the scenario of potentially 'crowded' territorial waters, the most interesting areas for marine renewable energy conversion, namely shallow to intermediate water depths (30 - 200m) relatively close to the coast, are intrinsically subject to the highest competition. From the perspective of ocean energy and its comparatively weak lobby, it is vital for the emerging sector to create awareness of its needs, and to procure strategic allies since there are no presumed preferential rights. Further, the high capital-intensity connected with moderate revenue and capital return performance in the early years of development make it vital for ocean energy to be proactive in highlighting and pursuing potential synergies with other sectors. In addition to direct economic benefit in case of synergetic co-existence, ocean space can be used in a more efficient way, which in turn should count in favour of such combinations in the process of MSP. A good example of the growing interest in such synergies is the recent call of the European Commission for projects that address combined platforms for wave and offshore wind energy.

Overall, more detailed consequential investigations are needed in order to yield a reasonable and efficient co-existence of future sea uses. Thus, MSP should be enabled and take into account the following aspects:
(i) Quantified (socio) economic value (e.g. per square km) of different usages; the outcome must be a directly comparable quantity, however local and regional priorities and in particular environmental acceptance must be taken into account;

(ii) Existence of synergy potential between different usages based on their space use and technical characteristics with respect to dimensions, materials, installation and O&M needs (increase in value for any combined uses).

The remainder of this article is an attempt to outline the needs for ocean space and characteristics of the most likely major potential 'rivals' of ocean energy (in particular wave energy, due to its expected large-scale implementation in territorial waters) for future ocean space use, as well as to highlight some potentially important synergies. Simultaneously, it is a call for more detailed and pro-active investigations on technical and procedural synergies of ocean energy with other usages.

EXISTING USES OF TERRITORIAL WATERS

In the following section, the expected usages of the ocean space are briefly outlined, in particular with respect to their characteristics regarding potential conflicts and co-existence, or even synergies, with ocean energy. It should be noted that typical 'conflicts of uses' are no-go areas, some of which are not generally linked to a certain usage or not easy to evaluate on the background of the purpose of this article. Such obstacles can be existing cable routes (mainly for telecommunication but also electricity transmission cables), pipelines, scientific research areas, including sites of (potential) archaeological interest and specific biosphere reserves, as well as dredge spoil disposal sites and their safety perimeter. Such conflicts are not the scope of this discussion, as there is neither a way to reasonably quantify their comparable benefits, nor to procure synergies with ocean energy.

NAVIGATION & SAFETY

Large-scale wave energy farms might be planned in areas that are intensely used for navigation purposes. The characteristics of commercial ship traffic and leisure or small craft interaction are distinct:

- Maritime Transport / Cargo

In busy navigation routes, any obstacle increases the potential hazard of ship collisions and, based on the present mindset of shipping authorities, ocean energy would be considered a danger within a rather large perimeter around shipping routes - even outside the main routes. In particular in the North Sea and in the vicinity of more industrial regions with major ports, this may become a major constraint for ocean energy.
On the other hand, advances in control and navigational warning systems can significantly improve this situation, once the navigational sector gets accustomed to the additional infrastructures at sea. At such a stage, even positive effects may arise regarding navigational safety and even maritime control issues: the marker systems of wave farms could incorporate modern communication systems, and assume the function of navigational guidance. Further, farms distributed relatively widely over the open ocean could play an important role in better controlling the common practice of illegal discharges of cargo ships, or even in ad-hoc actions in oil spills, preventing major damages to the environment.

- Leisure/Recreational Boating:

Leisure boat (yacht) traffic can be difficult to tackle, also due to a lack of regulation and lower levels of professionalism (e.g. lower standard of navigational discipline and technical equipment), compared to commercial navigation. On the other hand, if active safety and communication capabilities are incorporated in the marker systems, even an improvement of yachting safety can be achieved (see above). For small crafts in general ocean energy infrastructures may provide an additional item for emergency assistance, several miles out in the sea.

FISHING

Fishing is by far the most widespread and well-established usage of ocean space, and, due to the strong traditions of the sector and the constantly increasing need for seafood, it is considered a vital activity. In addition to the same navigational risks as for other ships, the opposition of fishermen communities to potential no-go areas due to ocean energy farms is a widely discussed issue.

- Industrial/Trawling:

In wide areas of the coastal and territorial waters, the dominant use of ocean space is commercial fishing, often by trawling fleets. In some regions considered appropriate for ocean energy, such as the Portuguese coast, the only traditional ocean space use has been fishing, so the fishing industry might have difficulties to accept other new and competing uses. The opposition of the commercial fishermen community to marine renewables could arise from the potential requirement for relatively large no-go areas for trawling, because of the specific potential damage of anchors, mooring lines, measurement devices and other infrastructural elements by the fishing nets.

On one hand, a certain opposition is comprehensible if looking at short-term and company-specific economic profit. On the other hand, independent evaluations have to reason whether or not such opposition is justified and how priorities should be fixed. Such a process should take into account (i) the direct economic benefit of each activity, and (ii) whether there is in fact a conflict, or whether synergies between these uses could even outweigh the conflict potential. From a pragmatic viewpoint, an increased presence of 'smart' offshore infrastructures would also benefit the fishing community, as verification of catch quota and mutual respect of boundaries increases the fairness of this activity. It is further likely (though not yet proven) that large no-go areas caused by the ocean energy farms function like sanctuaries and actually improve the habitat to an extent that livestock may recover significantly. Based on the continuous decrease of livestock of important fishing species, such a scenario would directly benefit the fishing sector.
In any case, there will be the need to reconcile large-scale ocean energy with the fishing industry, and synergy potential does not seem to be significant from a technical viewpoint.

- Artisanal Fishing:

Issues like ocean space access restrictions for the 'general public' in order to enable an economic activity are usually emotive and in particular local fishing communities can have strong lobbying capacity. On the other hand, the artisanal fishery as trade is factually threatened with extinction in many coastal areas, and due to the profound knowledge of the marine environment and navigation equipment, affected communities have an excellent potential for employment in the rising marine energy industry after slight retraining actions.
If active and early dialogues with such artisanal fishing communities succeed, wave energy farms might not be perceived as a threat but, in the best case, as an opportunity.

MILITARY AND SURVEILLANCE

The existence of designated areas for military use typically excludes the implementation of marine renewables. On one hand, it must be verified - on a case-to-case basis - to what extent such areas need to persist in the same dimensions and, to the same extent, as compared to times where no other large-scale uses than fishing existed. In many cases, a possible relocation of such areas further offshore might be a valid option. On the other hand, with ocean energy installations becoming a reality along large parts of the coastlines, military field exercises should also recognize this reality, so in some cases superposition might be acceptable.

Certainly there is synergy potential for other military uses, namely related to surveillance of traffic and intrusions, including the increasing problem of drug traffic. Properly instrumented (radar, visual and acoustic devices), offshore wave energy farms can substantially contribute to monitoring territorial waters. It should be reminded that some wave energy applications have been supported in recent past having in view autonomous military uses.

OIL & GAS EXPLORATION & PRODUCTION

To a similar extent to fishing, oil & gas exploration and production activities have dominated some areas of ocean space. The relationship between these activities and ocean energy is two-fold:
(i) In active production areas, there may be a restriction on ocean energy farm density (due to exclusion zones), but no general exclusion of such installations. In fact, the offshore oil & gas sector initially looked into marine renewables for autonomous power supply. For example, the Beatrice (*www.beatricewind.co.uk*) offshore wind farm project was mainly driven by this idea. So ocean energy and hydrocarbon production may have some attractive synergies.

(ii) In case of exploration activities in areas where no resources have yet been detected, the priorities need to be re-evaluated, as it is certainly unacceptable to reserve such areas for several decades, thus excluding other uses. However, even in case of later detection, a co-existence may be possible, if taken into account early.

In both cases, ocean energy can contribute to fulfil the high-energy demands of offshore oil & gas activities, partially offsetting the rivalling factor of ocean space use.

OCEANOGRAPHY AND OTHER MARINE R&D

Provided that ocean energy does not significantly impact with the physical and biosphere environment, more synergies than conflicts can be expected for oceanographic and other R&D activities. Except for specific large-scale baseline studies, where a native environment is required for proper results, marine renewables infrastructures can serve as monitoring stations for meteorology, water properties and livestock survey, among others.

COMPETING NEW USES (ASPIRANTS)

MARINE RENEWABLE ENERGY - OFFSHORE WIND

Offshore wind energy has been the fastest growing renewable energy source and is a reality in relatively shallow waters, mainly in the UK and the Baltic regions. The expansion of the 'shallow-water' technology is somewhat limited and many coastlines are too deep for further growth. On the other hand, particular floating wind farms are likely to become a major contestant for areas that are suitable for wave energy. Several technologies (Hywind, *www.statoil.com*; Sway, *www.sway.no*; *www.bluehgroup.com*; WindFloat, *www.principlepowerinc.com* (Figure 2)) have reached a credible development status, and their technical properties indicate large potential for combined use with ocean energy devices.

Floating wind farms are typically moored in 50 - 200m deep water, and their distance would generally allow wave farms to be installed in-between (in an advanced stage, once mooring systems of different floating devices might be combined). There are further possibilities of direct integration of Oscillating Water Columns (OWCs) in the structures of floating wind farms, and floating and submerged point absorbers might be used for catenary mooring systems. In addition to the more efficient use of materials and equipment, common installation and O&M activities can be explored.

FIGURE 2: Artist's Impression of Windfloat Concept: Various Technical Synergies with Wave Energy Devices (Picture Courtesy of Principle Power Inc.)

MARINE BIOMASS

Marine biomass is often included in the term of 'aquaculture' (see next section), while biomass itself is a term usually connected to renewable energy. However, in this article it is considered separately, being aquaculture related to fish and seafood (livestock) farming. Recently the large-scale 'farming' of marine biomass in offshore installations has become the subject of substantially increased interest, partly as a consequence of its potential for CO_2 sequestration. The development of industrial-scale algae bio-reactors is starting to be planned for production of carbon-neutral bio-fuels, high value food colourings, pharmaceuticals, cosmetics, dietary supplements, edible seaweed, animal feed, soil improvers, and fertiliser. Ultimately, area-wide implementation of algae cultivation has been proposed for direct CO_2 sequestration.

Among other research activities world-wide, the German Alfred Wegener Institute (AWI) (*www.awi.de*) has investigated offshore cultivation of marine macro-algae under harsh environmental conditions since the mid-nineties, and already proposed multifunctional ocean space use in connection to offshore wind farms several years ago, including solutions for traffic organisation in such areas (Figure 3; Buck et al., 2004).

FIGURE 3: Example Of Multifunctional Maritime Traffic Zones As Proposed By AWI
Picture from *www.awi.de/en/research/new_technologies/marine_aquaculture_maritime_technologies_and_iczm/*

In addition to low potential competition for ocean space, since marine biomass cultivation could be implemented further offshore, marine biomass production has an obvious synergetic potential in connection to ocean energy, in particular with respect to the joint use of offshore infrastructures (e.g. mooring lines, monitoring devices) and joint O&M. Further, marine biomass cultivation could potentially be incorporated in ocean energy installations, due to the large variety of potential technical requirements. Finally, ocean energy devices could be used to provide energy for the marine biomass cultures, which was recently announced as one of the commercial approaches to synergetic marine biomass and ocean energy production by the Marine Sector of the British C-Questor group (*www.cquestor.com*).

OFFSHORE AQUACULTURE

Open water offshore aquaculture for fish and seafood production on a large-scale has been increasingly considered a sustainable alternative for satisfying the massive needs of human consumption. While open-ocean fishing is reaching physical limits and some species are moving towards extinction, pond aquaculture is land-intensive and expensive, and the quality of the products is questionable. Due to being in open waters, offshore cages are subject to natural water circulation and quality, health and environmental issues are drastically reduced. Offshore aquaculture had been a vision for more than a decade, however only in recent past significant advances have been made, for example through the Hawaii Offshore Aquaculture Research Project (HOARP, see Billig, 2009 & Figure 4) that uses a large bi-conical steel cage for survivability in waves up to 8m.

FIGURE 4: HOARP Demonstration Project.
Picture from *www.oar.noaa.gov/spotlite/archive/spot_hawaii.html*

Meanwhile, credible commercial approaches to submerged offshore cages have been developed, for example the OceanGlobe from the Norwegian company Byks (Figure 5; *www.byks.no*), the Aquapod from the US company Oceanfarmtech (*www.oceanfarmtech.com*), and the Sea Station from the US company Oceanspar (*www.oceanspar.com*).

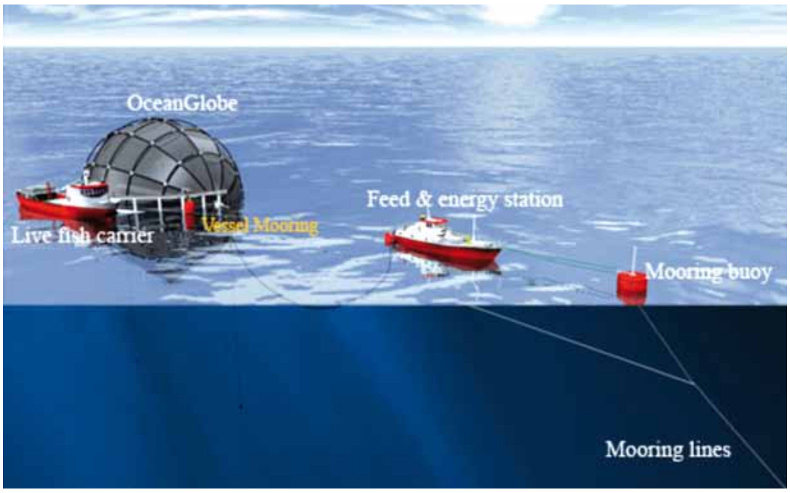

FIGURE 5: Artist's Impression of OceanGlobe Installation
Picture from *www.byks.no*

Goudey (2008) and Kite-Powell (2008) give a comprehensive overview of the state of the art and currently most relevant issues of the sector. Despite its large potential and technical viability, offshore cage aquaculture faces a dilemma similar to offshore renewable energies: costs are still multiples of costs for aquaculture in nearshore protected waters, mainly as consequence of the high mooring and O&M costs. Successful implementation of automated operating procedures for minimising labour, improved safety and further reduction of environmental impacts are the most relevant items for making offshore aquaculture viable, and this could well be possible by sharing ocean space and infrastructures with ocean energy, in particular large-scale wave energy farms. To a similar extent like marine biomass, ocean energy can equally be used to power large-scale open water aquaculture.

CONCLUSIONS

The increasing density of ocean space use and the relatively low priority ocean energy has experienced in the political agenda to date call for improving the growing sector's positioning for future implementation phases. In order to ensure strong, sustainable growth of ocean energy, its secondary uses, and synergies with existing and other new activities, have to be fully explored. In particular, wave energy and floating offshore wind farms appear suitable to coexist; in addition, marine biomass farming and/or large-scale offshore seafood aquaculture hold a large potential for technical synergies with wave and/or offshore wind farms. In general, these synergies consist of common use of mooring systems, installation processes, O&M equipment and personnel. In the early implementation phase of marine energy farms such synergies can naturally not be exploited, as survivability and other technical issues need to be fully addressed first. However, once technical solutions for such combined uses are developed, the viability and acceptance of ocean energy and other uses will be substantially increased. Therefore, such synergies must be investigated at an early stage and stakeholders from different fields should be incentivised to collaborate on this issue.

In this context, current legislation and consenting procedures appear biased towards traditional, or simply the most capital-productive uses, which calls for correction towards more objective and neutral evaluation procedures for deciding upon priorities for ocean space use. Such procedures should include a quantification of the weighted socio-economic benefit of each use. Further, the factor of secondary uses and synergy potential should be accounted for by default in future actions of marine spatial planning. Finally, a much stronger international collaboration must be enforced to enable an integrated approach, not limited to European waters.

Acknowledgements

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OVERVIEW OF GLOBAL REGULATORY PROCESSES FOR PERMITS, CONSENTS AND AUTHORIZATION OF MARINE RENEWABLES

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Note: The views discussed in this paper are entirely the author's own, and do not represent the official position of OREC.

EXECUTIVE SUMMARY

Within the past two years, a number of first generation, commercial marine renewables projects came online, delivering power to the grid. These projects include: Verdant Power's RITE project,[1] Pelamis' Aguçadoura Wave Park,[2] Marine Current Turbines' SeaGen Project at Strangford Lough,[3] and Aquamarine's Oyster.[4]

Unfortunately, international regulatory processes for siting marine renewables have not kept pace with technological advancements. In many countries, deployment-ready projects face costly and protracted permitting procedures by multiple agencies, each with their own unique legal and regulatory requirements. Few regimes provide an expedited system for deploying smaller or early stage commercial arrays. In addition, most marine renewables find themselves in a "Catch-22" situation: regulatory bodies are reluctant to grant authorizations without information about project impacts, but developers cannot provide this information without first getting projects into the water to gather data on impacts. Finally, marine spatial planning (MSP) – a tool designed to facilitate coordinated decisions about use of marine resources on a programmatic level rather than case-by-case basis – is gaining traction, and raising questions about whether MSP will expedite marine renewables development through advance planning or interfere by potentially delaying near term development or putting promising sites off limits.

This paper provides an overview of the regulatory process and unique challenges for marine renewables in different parts of the world. The first part of this paper surveys the regulatory process in various countries governing permits, consents and other necessary authorizations for marine renewables projects. As Part I will discuss, most countries' existing regulatory systems share features such as environmental review, opportunities for stakeholder input, examination of competing uses and a method for acquisition of site access and adequate property rights to construct the project. Likewise, in recent years, many countries have enacted legislation to facilitate renewables' ability to secure grid access, which is another necessary component of the regulatory process. Part II will discuss obstacles to expedited permitting – such as lack of co-ordination between agencies or "regulatory overkill," *i.e.*, where projects are subject to extensive review and mitigation conditions disproportionate to the potential harm. Part II briefly evaluates various options to advance marine renewables development such as marine testing beds with blanket consents, pilot project licensing and adaptive management, strategic environmental assessment and coastal and marine spatial planning.

[1]Verdant Power Website, *http://verdantpower.com/what-initiative/* (last visited December 4, 2009) (describing two year demonstration operation from 2006-2008 of 6 unit Roosevelt Island Tidal Energy project in East River, New York).

[2] The Aguçadoura Wave park, comprised of 3 x 750 kW units operated from September through November 2008, before being removed. Due to financial difficulties of the parent company, the project remains out of commission. See *http://en.wikipedia.org/wiki/Aguçadoura_Wave_Park*

[3] Marine Current Turbines 1.2 MW Seagen unit was deployed in Strangford Lough in April 2008 and remains in operation. See *http://www.marineturbines.com/18/projects/19/seagen/* (accessed December 4, 2009).

[4] In November 2009, Aquamarine Power launched the Oyster at EMEC, which is feeding power to the grid through a shore-based hydropower project powered by water pumped from the Oyster wave energy device. See *http://www.aquamarinepower.com/news-and-events/news/latest-news/view/112/scotland-s-first-minister-launches-oyster/* (accessed December 4, 2009).

SUMMARY OF REGULATORY PROCESS

This section will describe the following components of the regulatory or process: (1) legislation or regulations that govern the consent or approval process (including any special processes for demonstration projects); (2) procedure for obtaining a lease or rights to use lands for the project, (3) review of project impacts, including environmental, navigation, fishing and recreational use and (4) grid access. The table below summarizes the discussion:

COUNTRY	AUTHORITY FOR CONSENTS	SPECIAL PROCESSES	LEASE	EA	GRID ACCESS
US	FERC issues permits and licenses under Federal Power Act	Pilot project license for small (< 5 MW) demonstration projects; one year processing time.	State leases w state submerged lands, MMS lease on Outer Continental Shelf	Yes, by FERC for licenses and MMS for leases.	Yes, under FERC Interconnection Rules
Canada	Varies by province; Ontario establishes Renewable Energy Facilitation Office (REFO) for review	Renewable Energy Approval (REA) can issue in 6 months time.	Granted by provinces	Yes, though varies by province. Nova Scotia has SEA for tidal projects.	Yes, under Ontario Green Energy Act
UK	Marine and Coastal Access Bill for projects <100 MW; Planning Act for projects > 100 MW Scotland is developing similar bill.	Consolidated process by Marine Management Organization (MMO) for smaller marine renewables projects	Seabed lease or site option agreement from Crown Estate	Required for all marine renewables. Scotland, Northern Ireland preparing SEAs for marine renewables	Department of Energy is developing new regulations for grid access for offshore renewables.
Portugal	Decree Law No. 5/2008 for Pilot Zone	Pilot Zone for demonstration, pre-commercial and commercial wave energy devices up to 250 MW	Pilot Zone access	Environmental Incidence Study for Pilot Zone	Yes, in Pilot Zone
Denmark	Not discussed	One stop shopping	Not discussed	Yes	Yes
Australia	Authorization under Coastal Management Act	Not at present	Not discussed	Yes	Not discussed
NZ	Authorization under Resource Management Act, with regional councils issuing consents	Yes, 2009 amendments include streamlining decisions	Not discussed	Yes, all applications require Assessment of Environmental Effects of project impacts	Not discussed

A - UNITED STATES

1. Authority for consent

In the United States, the Federal Power Act (FPA), 16 U.S.C. 791 *et. seq.* governs licensing of marine renewables projects. Under the FPA, Federal Energy Regulatory Commission (FERC) may preliminary permits and licenses for marine renewables. A preliminary permit enables a developer to study a site for three years and maintain priority to apply for license over competing applicants but does not authorize construction of a project (Federal Power Act, 16 U.S.C. sec. 800). As a result, a preliminary permit does not provide any opportunity to test projects in real world conditions. A FERC license, by contrast, allows a developer to construct and operate a project, generally for a term of up to 50 years. But the process for obtaining a license is lengthy (as long as three to seven years) and requires data on a project's potential impacts, which are often unknown until a project is deployed and observed.

Recognizing the limited options for demonstration projects, FERC developed two alternatives. The first alternative, known as "the Verdant exception"[5], allows a developer to deploy and operate a small (less than 5 MW) project for 18 months or less to gather data to support a license application, so long as the developer agrees not to sell power to the grid during the test period.

The second alternative is the FERC created "pilot license process" for new technologies in 2007. A pilot license has a five-year term, a processing time of one year, limited study requirements up-front but rigorous post-deployment monitoring requirements. At the end of the five-year pilot license term, a developer has the option of removing the project or applying for a long-term license at the site. See FERC Hydrokinetic Pilot License Process at *http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/energy-pilot.asp.* Presently, three United States developers – Verdant Power, Snohomish Public Utilities District and Ocean Renewable Power Corporation – are pursuing pilot licenses for tidal sites in Washington State and Maine. See *http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp*

2. Property Interests/Site Access

The FERC process authorizes project operation but does not confer property rights for constructing the project. For projects located on "state submerged lands" – that is, lands up to three miles off shore (with the exception of Texas and the West Coast of Florida where states own lands up to ten miles offshore) - a developer will typically obtain a land lease or rights of usage from the state. Projects beyond these limits are located on the Outer Continental Shelf, where a developer must obtain a lease from the Minerals Management Service (MMS). In April 2009, MMS issued rules for grant of leases and also entered into a Memorandum of Understanding (MOU) with FERC to coordinate the leasing process with the licensing process. Under the MOU between FERC and MMS, a developer must secure a lease from MMS, before it can receive a FERC license.

3. Environmental Review

In the United States, federal agencies that issue a license must prepare an environmental analysis to assess the impacts of a project on the surrounding environment and other uses. The FPA also requires FERC to review the effect of a project on navigation and to consider whether it makes best use of the waterway (FPA, Section 803). Projects must also comply with a variety of federal environmental laws, such as the Endangered Species Act (protects endangered species), the Coastal Zone Management Act (CZMA - ensures that project is consistent with state plans for use of coastal areas), the Clean Water Act (protects water quality), whilst abiding by state environmental regulations as well. In addition to the FERC license and a land lease, developers must also obtain authorizations from the agencies that administer these federal statutes. There is no process for coordinating issuance of a FERC license and issuance of a CZMA authorization (issued by the state) or a water quality certificate and, as a result, the license process is quite lengthy.

4. Grid Access

For projects that connect to the interstate grid, FERC has power, under the Federal Power Act and FERC's own regulations, to oversee interconnection. FERC established a straightforward protocol that developers must follow to obtain grid access; the rules for smaller generators are not complicated and the process is relatively quick. [See FERC Regulations on Interconnection, *http://www.ferc.gov/industries/electric/indus-act/gi.asp*]. As marine renewables projects expand in size, they will impose greater demands on the grid.

Marine renewables projects may face longer "queues" for access, as the utility or the regional transmission system operator[6] evaluates how to incorporate large amounts of new and variable power into the system.

B. CANADA

1. Consents and Environmental Review

In Canada, projects are approved and monitored by a series of federal and provincial environmental agencies and laws. Permitting processes differ by province, with regulations too varied to summarize in detail. Generally, projects are subject to some type of environmental assessment – either an individual Environmental Assessment (EA) (for larger projects), a class EA (evaluates impacts of classes of activity) or screened EA (where projects falling below certain impact levels are exempt from further review. An

[5] Verdant Power, FERC Decision, 111 FERC para. 61,024 (2005). The Verdant exemption was named for Verdant Power, which first asked for this policy. Now established, it is available to all developers.

[6] In some parts of the United States, the grid is operated by a regional transmission authority, rather than an individual utility)

Environmental Assessment includes an evaluation of effects on fish habitats under the Federal Fisheries Act and on endangered species under the Species at Risk Act. Navigational impacts are also evaluated by the Navigable Waters Protection Division.

Some provinces have made modifications to these general practices. In September 2009, Ontario's new Green Energy Act took effect, with significant improvements for streamlining of siting of tidal energy projects. The Green Energy Act establishes a Renewable Energy Facilitation Office (REFO) to assist renewable developers by connecting them with resources in other government ministries and agencies and providing information on government incentive programs. The Act creates a comprehensive "renewable energy approval" (REA) which consolidates environmental review processes, creates procedures for stakeholder input and exempts renewables projects from municipal zoning requirements, which had previously thwarted expeditious permitting.[7] As a result of the changes, developers can obtain required permits in six months' time.[8] There is even discussion of a six-month guarantee for processing approvals.

In Nova Scotia, tidal project development begins with a strategic environmental assessment of a site, after which access is awarded to a company through a competitive process.[9] The developer must then obtain all necessary permits to site the project, with fewer rigorous up front requirements for test facilities (which are subject to post-deployment monitoring).

2. Property Rights

In Canada, offshore Crown lands are controlled by the adjacent coastal province, which has powers of disposition. Provinces have different policies for granting use of Crown lands for marine renewables projects, with eased requirements for test or demonstration projects.[10] Most provinces require developers to pay a fee for leases for commercial tidal projects.

3. Grid Access

In Ontario, the Green Energy Act established a feed-in tariff, which also provides access to the grid. In other provinces, standard offer contracts for power purchases are available.

C. EUROPE

1. United Kingdom

a. Consents and Environmental Review

In November 2009, the United Kingdom's Marine and Coastal Access Bill received Royal Assent. The new law consolidates licensing of marine renewables of 100 MW or less within the newly created Marine Management Organization (MMO), thus eliminating the need for multiple consents under both the Food and Environmental Protection Act and the Electricity Act.[11] For projects larger than 100 MW (known as "nationally significant infrastructure projects"), the 2008 Planning Act establishes an Infrastructure Planning Commission to streamline the licensing process.[12]

[7] See Green Energy Act (September 2009) (online at *http://www.elaws.gov.on.ca/html/statutes/english/elaws_statutes_09g12_e.htm*; additional information at *http://www.greenenergyact.ca/Page.asp?PageID=122&ContentID=1360&SiteNodeID=243)*

[8] See *http://greenenergyreporter.com/2009/02/ontario-introduces-sweeping-green-energy-reforms/* (describing that elimination of municipal regulations will allow for six month processing).

[9] See *http://www.gov.ns.ca/energy/resources/EM/tidal/Tidal-Policy-Framework-Nova-Scotia.pdf.*

[10] See e.g., New Brunswick Policy for Allocation of Crown Land for instream tidal projects at *www.gnb.ca/0078/policies/clm0192007e.pdf* Ontario crown land policy, *http://www.mnr.gov.on.ca/en/Business/CrownLand/2ColumnSubPage/STEL02_165785.html.*

[11] See Marine and Coastal Access Act (2009) online at *http://www.opsi.gov.uk/acts/acts2009/pdf/ukpga_20090023_en.pdf*, BWEA Summary Report (October 2009) at www.bwea.org.

[12] See Planning Act, *http://www.opsi.gov.uk/acts/acts2008/ukpga_20080029_en_1.*

In the UK, there are two types of environmental review: strategic environmental assessment (SEA) prepared by the government to evaluate impacts of marine renewables on a system wide basis, and an Environmental Impact Assessment (EIA), prepared by the developer addressing site specific impacts.
All marine renewables projects require an EIA. At this time, the UK does not prepare a SEA for marine renewables, because the impacts are yet unknown that the SEA would not produce any definitive data to inform siting decisions. The UK prepares a strategic environmental assessment (SEA) for offshore wind, and will likely prepare an SEA for marine renewables prior to the siting of large scale arrays.[13]

The Marine and Coastal Access bill has limited applicability in Scotland, Northern Ireland and Wales. Scotland is developing a similar a Marine Bill that will also streamline the licensing process and adopt a one-stop shopping approach.[14] In contrast to the UK, both Scotland and Northern Ireland are preparing SEAs that will include marine renewables.[15]

b. Property Rights

Developers wishing to deploy a wave or tidal device or small array of up to 20 devices with capacity of less than 10 MW in UK waters or Renewable Energy Zone (REZ)[16] beyond 12 nautical miles, must obtain a seabed lease or site option agreement from the Crown Estate.[17] To obtain a lease, developers must show that the site is suitable for deployment of a marine energy device/array and provide a business plan, with a timetable of steps leading to deployment. Currently, the Crown Estate is opening large swaths within the REZ for offshore wind development off the coast of the UK. In 2008 the Crown Estate opened the first competitive bidding round for acreage to deploy wave and tidal energy projects in the Pentland Firth off the NE Scottish mainland.

Leases for test and demonstration projects will be short term, generally up to seven years. Rent will be discounted for the initial term of a demonstration lease.

c. Grid Access

The Department of Energy is developing a new regulatory regime for offshore electricity transmission, exploring ways for the capital cost of grid connection to be borne by the offshore transmission owner, rather than the marine energy project developer, who would just pay an annual charge.[18]

2. Portugal

a. Consents and Environmental Review

In Portugal, Decree Law No. 5/2008 establishes a Pilot Zone for the installation of demonstration, pre-commercial and commercial wave energy devices with rated capacity of up to 250 MW. The Pilot Zone is located 120 km north of Lisbon, off Sao Pedro de Moel and covers 320 km^2.[19] The Pilot Zone will be connected to the grid and will be managed by REN (*Redes Energéticas Nacionais* - National Energy Networks, S.A.). REN is responsible for licensing in the Pilot Zone, with regulatory processes varying, dependent upon whether a project is a pilot or commercial project. The licence process should be accompanied by an Environmental Incidence Study that is a less demanding administrative instrument than the Environmental Impact Assessment.

3. Denmark

Denmark's consent process for wave energy projects follows a one-stop shopping procedure used for offshore wind.[20] In issuing permit for wave projects, the Danish Energy Authority followed the consent procedures for offshore wind, with approval given based on a project's location, the results of an environmental impact assessment and plans for decommissioning. Denmark's system also allows for grid access.

[13] See *http://www.offshore-sea.org.uk/site/scripts/documents_info.php?categoryID=39&documentID=5*
(January 2009)(describing SEA process).
[14] See *http://www.scotland.gov.uk/News/Releases/2009/04/29162907* (describing introduction of Scottish Marine Bill) (April 2009).
[15] See *http://www.sei.ie/Renewables/Ocean_Energy/Offshore_Renewable_SEA/*
(describing Irish SEA); *http://www.seaenergyscotland.net/ (Scotland's Marine Renewable SEA).*
[16] The UK declared a Renewable Energy Zone (REZ) in 2004. The REZ extends up to 200 nautical miles form shore and within the REZ, the UK has claimed exclusive rights to production of energy from wave and wind. See Section 84, Energy Act (UK) 2004.
[17] See Crown Estates Website,
http://www.thecrownestate.co.uk/our_portfolio/marine/wave-tidal/application_process.htm
[18] BWEA Report (October 2009).
[19] See International Energy Agency, Global Renewable Energy: Policies and Measures database,
http://www.iea.org/textbase/pm/?mode=re&id=4249&action=detail.
[20] See Wave Energy Centre Paper, Uppsala (September 7-10, 2009).

D. AUSTRALIA

In Australia, wave and tidal project developers can obtain consent to use and develop Crown lands under the Coastal Management Act (CMA). However, the process is imperfect.[21] First, the consents available under the CMA are subject to a company's ability to define a specific location for a specific unit. But most companies would prefer a consent that covers a broader area to allow for additional exploratory activities to identify the optimal location for the units. Second, the CMA is administered by different states, and there is much uncertainty at the departmental level.

Despite barriers, Carnegie successfully obtained a consent for its CETO I wave project prototype.[22] According to the PB Power Report (previous footnote), the project was subject to environmental review including impacts on marine flora and fauna observed at the site. However, it was also recommended that the developers conduct further studies to support project expansion, including studies of shoreline, bird and marine mammals, subsea and terrestrial acoustic surveys and wave monitoring ahead of and behind units. The developer also worked with many different stakeholder groups, and consulted with the State Government of Western Australia, the Department of Land Administration, Sustainable Energy Development Office, Fremantle Port Authority and Yachting Association of Western Australia for approvals for deployment.

E. NEW ZEALAND

In New Zealand, developers must obtain authorization for a project under the Resource Management Act (RMA). Regional councils and territorial authorities issue the required consents. All applications for a consent must include an Assessment of Environmental Effects (AEE) of likely project effects and mitigation strategies.[23]

In September 2009, the RMA was amended, largely to expedite and improve the resource consent process.[24] Changes include:

- Deterring frivolous, vexatious and anti-competitive objections that can add tens of thousands of dollars to consent applicants
- Streamlining processes for projects of national significance
- Creating an Environmental Protection Authority
- Improving plan development and plan change processes
- Improved resource consent processes
- Streamlined decision making
- Strengthening compliance by increasing penalties and proving for a wider range of enforcement
- Improvements to national instruments[25]

In 2008, two projects received approval under the former version of the RMA. Consents were issued to Neptune Power Limited by Greater Wellington Regional Council allowing it to deploy a 1 MW prototype tidal turbine in the Cook Strait. The environmental review for the Cook Strait Neptune Project examined impacts on marine mammals and whales, sedimentation, visual impacts, and navigation.[26] Consents were also issued to Crest Energy Kaipara Limited by Northland Regional Council for a 200 MW tidal project but these were immediately appealed by four groups, including Crest Energy itself (which objected to some of the consent conditions). The appeals were heard by the Environment Court in June 2009 and an interim decision published in late December 2009 indicates that the judge is minded to grant consents subject to conditions and an approved environmental monitoring plan.

[21] Transcript, Environment and Natural Resources Committee, September 29, 2009.
[22] PB Power Report on CETO Technology, *www.ceto.com.au/ceto-technology/pdf/pb-report-full.pdf* (2007), (describing permit process).
[23] Wikipedia, "New Zealand Resource Management Act",
http://en.wikipedia.org/wiki/Resource_consent#Plan_classificationshttp://en.wikipedia.org/wiki/Resource_consent#Plan_classifications
[24] See *http://www.scoop.co.nz/stories/PA0909/S00123.htm (summary of RMA amendments).*
[25] See *http://www.scoop.co.nz/stories/PA0909/S00123.htm*
[26] Development of Marine Energy in New Zealand, Power Projects Limited (June 30, 2008).

REGULATORY TRENDS AND CHALLENGES FOR MARINE RENEWABLES

Having described the regulatory regime for licensing marine renewables in various locations in Part I, it is now possible to identify options for addressing problems and discuss future regulatory trends.

A. THE CHALLENGE: DEPLOYING DEMONSTRATION AND EARLY-STAGE PROJECTS

Advancement of the marine renewables industry depends on projects getting into the water so that developers can observe operation and impacts in real world conditions. Up until recently, many pilot projects have been subject to crippling environmental review disproportionate to predicted impacts, which increases the costs and delays associated with deployment.

1. Pilot Licensing Programs: A special "pilot project" authorization might cure this problem. In the U.S., FERC's pilot license process takes one year by replacing extensive environmental review up front with rigorous post-deployment monitoring. Meanwhile, the short term of the pilot license (five years) and application of principles of adaptive management (whereby developers must modify or cease project operation to address any observed adverse impacts) ensure adequate environmental protection. Unfortunately, the FERC pilot license program is still slow to reach its intended one year process goal since some regulatory agencies are requesting two years worth of data collection, thereby extending the one year process.

2. One-Stop Shopping: A streamlined, one-stop shopping process can also reduce licensing costs and delays. Some of the countries discussed – such as the UK or Canada (Ontario) have attempted to create a one-stop shopping approach to licensing. For example, in the UK, smaller projects are sited by the MMO, which helps with coordination, while Ontario's Renewable Energy Facilitation Office does the same. One-stop shopping reduces developer costs and cuts down on the complexity of permitting. Moreover, a one-stop approach puts one agency in the lead, and forces the others to cooperate. Unfortunately, in the U.S., one-stop shopping would require additional legislation to give the lead agency jurisdiction over other federal agencies. Moreover, without set deadlines, even a one stop process can be lengthy. But one-stop shopping apparently worked well for Denmark's offshore wind program and certainly deserves additional discussion inasmuch as the process could assist in siting marine renewables.

3. Test Centers and Pre-Screened Test Sites A third option for expediting deployment of pilot projects is creation of pre-screened test centers or sites. Though projects located in test sites may require additional environmental review, it is generally less extensive because the sites have been pre-screened. Test sites are also connected to the grid, so that developers can potentially sell power and earn revenues to offset development costs. Portugals's Pilot Zone is one example of a test site, as is the European Marine Energy Center (EMEC) in Scotland (for smaller projects) and the U.K.'s anticipated Wave Hub (*http://www.wavehub.co.uk/*) (for larger projects). In Ireland, the Galway Bay test facility is used for smaller devices in a less robust wave environment protected by the bay and Irish authorities have started developing a larger open ocean test facility. The Galway Bay facility benefits greatly from a collaboration with IBM and its SmartBay program, which has installed sensors throughout the Bay, which can measure sedimentation transport, turbine efficiencies, environmental impacts, fish and marine mammal behavior, and data for other industries and sea uses.

Test centers will play an important role in the marine renewables industry since they allow for expeditious deployment of demonstration and smaller projects. Even when marine renewables projects outgrow the capacity of the test center, because they provide a readily accessible site that will support ongoing innovation.

B. THE CHALLENGE: MOVING BEYOND PILOT PROJECTS TO LARGER PROJECTS AND A MARINE RENEWABLES INDUSTRY

Once marine renewables move past the pilot phase to commercial operation, it will be necessary to explore ways to facilitate deployment on a systemic, rather than case by case basis. Strategic environmental assessments (SEA) and marine spatial planning (MSP) offer two options.

1. Lack of data on impacts

The SEA is a legally enforced assessment procedure required by Directive 2001/42/EC (known as the SEA Directive). The SEA Directive aims at introducing systematic assessment of the environmental effects of strategic land use related plans and programs. Both Scotland and Northern Ireland are preparing SEAs that will include marine renewables. Though the UK has been unable to perform an SEA for marine renewables for want of data, it will likely prepare one for prior to siting of larger arrays.

The U.S. has a similar concept to the SEA, known as a programmatic environmental impact statement (PEIS). In December 2007, MMS released a PEIS for development of alternative energy on the Outer Continental Shelf which mentioned marine renewables, though also noted that these technologies were not likely to be deployed for another five to eight years.[27]

2. Marine Spatial Planning

Many countries are exploring ways to manage competing uses in oceans through Marine Spatial Planning (MSP). The European Union (EU) has directives which require an examination of MSP issues, while the Obama Administration just released a draft report endorsing the adoption of MSP in U.S. waters up through the limit of the Exclusive Economic Zone (EEZ). Finally, a cursory review of the UK's Marine and Coastal Access Bill suggests that it adopts a version of marine spatial planning by allowing for creation of marine conservation zones.

Marine spatial planning can assist marine renewables by creating a system to deal with overlapping uses and competing claims. In addition, data collected using the MSP process can inform developers' siting decisions and thereby speed the license process.

Despite potential benefits, some developers in the United States remain wary of MSP, fearing that it might put off limits areas with prime wave or tidal power, which could constrain growth of the industry. In addition, there is concern about "zoning" the ocean without adequate data, or putting a moratorium on existing development while MSP is implemented. Whether MSP will help or hinder the marine renewables industry, at least in the short term, is a topic that will certainly generate much discussion in the year ahead.

[27] See MMS PEIS at *http://ocsenergy.anl.gov/documents/index.cfm*

THE STANDARDIZATION OF MARINE RENEWABLE ENERGY CONVERSION SYSTEMS

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Summary
Wave, tidal and water current energy conversion systems are at the early stages of development with only a few technologies approaching full-scale commercial deployment. There are over 100 prototype technologies that are being developed world-wide to harness the potential and kinetic energy produced from waves, tidal and water currents. The resource opportunity for these technologies is substantial with energy estimates ranging between 8,000-80,000 TWh/yr for ocean waves and greater than 800 TWh/year for marine currents. Whilst the opportunity is enormous, there remain significant challenges facing this emerging industry. The development of well designed standards will assist in mitigating the technical and financial risks to move this technology into the commercial market space. This paper will discuss the role that international standards will play within this industry and the activities of IEC/TC 114, a committee mandated to develop marine energy standards.

INTRODUCTION
In comparison to other more established renewable energy technologies, there has been only modest investment in marine energy. Although there has been on-going research in this field for the last 30 years, technologies to harness the energy from waves, tidal and water currents are still at early stages of development. More focused attention has been given to this technology in the last few years, as countries explore alternative options to increase the amount of renewable energy in their power production mix, to reduce emissions affecting climate change, and to seek regional solutions to meet rising energy demands.

Today, the marine energy industry is characterized by a high number of prototype technologies with the first entering the commercial-deployment stage. The first commercial-scale multiple-unit array installation occurred in 2008. There is continued interest from governments and utilities wanting to see wave and tidal current energy as a viable source of electrical power, capable of being connected to the grid and contributing to the overall renewable energy supply in their respective countries.

With the diversity in configurations of the various technologies, particularly for wave energy devices where several power take-off systems exist, it becomes difficult to assess and compare the performance of one technology versus another. These variations may be a result of differences in technology but can also be attributed to methods in which technologies are being tested. For instance, two tidal turbines can have very different energy conversion efficiencies, but without standardized testing methodologies it is unknown which of the technologies is actually more efficient. Figures 1 and 2 illustrate two types of tidal energy converters.

A report, prepared for the International Energy Agency's Ocean Energy Systems Implementing Agreement (OES) in 2006, noted that the absence of technical standards was one of the main barriers restricting the development of ocean energy technologies [1]. Furthermore, the lack of internationally recognized standards for development, testing and measurement has a negative effect on the credibility of the performance stated by technology developers. This becomes a very critical problem when developers are searching for investors that have a multitude of technologies from which they can choose to invest. Standards can provide investor confidence that a return on their investment, within a pre-determined level of uncertainty, will be achieved.

FIGURE 1: Open-centre, horizontal axis tidal current turbine (Courtesy: OpenHydro)

FIGURE 2: Vertical axis tidal current turbine (Courtesy: Ponte di Archimede International)

While developing national standards provides a foundation for technology comparisons, experience has shown that international standards offer industries greater technology mobility. Meeting international standards gives technology developers access to a global market. For instance, if a manufacturer were to build products conforming to various national standards, it would quickly lose the economies of scale having to produce products that conform to individual country standards requirements. Far from becoming trade barriers, standards promote international trade [2].

With this in mind and the recognition of a flourishing marine energy industry - with the potential for a significant global impact, the International Electrotechnical Commission (IEC), the organization that leads the standardization of electrotechnical equipment, established a technical committee to address the standardization of marine energy conversion systems (IEC/TC 114). This committee was formed in the fall of 2007 with the United Kingdom holding the Secretariat and Canada as Chair. The IEC has been establishing standards for over 100 years and is also the responsible body for international standards for other renewable energy technologies such as wind turbines, hydraulic turbines and fuel cell technologies.

In parallel to the activities of IEC/TC114, the development of standards for marine energy converters has been occurring at a more national and regional level. Most notable are the standards and guidelines that have been produced by the European Marine Energy Centre (EMEC) in the United Kingdom. A suite of thirteen documents have been produced by a working group with individuals representing technology developers, regulators, academia, utilities and project developers [3]. In April 2008, a project entitled *Equitable Testing and Evaluation of Marine Energy Extraction Device in Terms of Performance, Cost and Environmental Impacts* (EquiMar) was launched with 23 partners from 11 European countries. Funded by the European Commission, EquiMar will deliver a suite of protocols for the equitable evaluation of marine energy converters (based on tidal and wave energy) [4]. Close collaboration with these national and regional organizations will be important as IEC/TC 114 begins to develop international standards.

INNOVATION AND THE ROLE FOR STANDARDS

Concerns have been raised that while marine energy technologies are at an early stage of maturity, early development of standards may stifle technical innovations. This risk can be mitigated by the development of 'performance-based' standards rather than 'design' or 'prescriptive' standards. The difference between these forms of standards is that performance-based standards focus on the behaviour of the object or its purpose while prescriptive standards generally specify dimensions and materials of the technology being standardized. For obvious reasons, performance-based standards provide more flexibility to technology developers without comprising safety issues.

The standards produced by IEC/TC 114 will be performance-based to provide the necessary guidance required to produce a product without limiting innovation within the industry. Moreover, in recognition of the embryonic state of technologies, standards currently being produced by the committee are Technical Specifications (TSs). Technical Specifications are used for pre-standardization purposes when the subject matter is still under technical development [5]. They are not considered International Standards, but serve as prospective standards for provisional application [6]. The review of the TS is required every 3 years, at a minimum, where it can then be withdrawn or further converted into an International Standard. This step aims to ensure that the specifications do not prohibit future technological innovation and that they remain current with state-of-art technology.

Independent of the industry, standards are critical in moving technologies forward by providing concise guidelines for device developers, manufacturers, regulators and users. They also serve to promote safety, reliability, and efficiency within an industry that relies on engineering components or equipment.

ON THE PATH TO STANDARDIZATION

The objective of IEC/TC 114 is to prepare international standards for marine energy conversion systems. The primary focus of the committee is to address standards relevant to the conversion of wave, tidal and other water current energy into electrical energy. Other conversion methods relevant to electricity production from a marine environment (e.g. Ocean Thermal Energy Conversion (OTEC)) will be included within the scope of IEC/TC 114, but addressed as a secondary priority. Mature tidal power technologies, such as tidal barrage or dam installations, have been specifically excluded from the scope of this committee. This exception is explicitly stated as tidal turbines and the civil infrastructure surrounding these forms of ocean energy extraction are covered by IEC/TC 4, a committee that addresses standards relating to hydraulic turbines. As IEC/TC 4 focuses on hydraulic rotating machinery and associated equipment related to hydropower development [7], tidal power/barrages fall under the suite of standards offered by this committee. Technologies extracting the kinetic energy from rivers, also known as in-river or hydrokinetic, are included in the remit of IEC/TC 114, because of their similarity to technologies developed for tidal current applications.

IEC/TC 114 will produce standards that address diverse subjects, such as system definition, performance measurements, resource characterization and assessment, design and safety requirements, power quality, manufacturing and factory testing and the evaluation and the mitigation of environmental impacts.

THE COMMITTEE: ITS STRUCTURE AND WORK PROGRAMME

An IEC/TC consists of National Committees (NCs) who are members of the IEC and have a particular interest in a subject matter. Each NC represents its nation's electrotechnical interests and can consist of manufacturers, consumers and users, government agencies, professional societies and trade associations and standards developers. In some countries, national committees are public or private sector only, while others are a combination of both.

Today, IEC/TC 114 has fifteen NCs that are participating members of the committee. Participating members must actively vote on documents, attend and contribute to plenary meetings, and nominate experts to each working group and project team that formulate the work programme of the committee. National committees have discretion as to which activities they choose to take part in. There are also four observer national committees, who are interested in keeping abreast of the activities involved in the standardization of marine energy, but do not take an active role in the committee's activities.

To allow for a formal collaboration with other organizations pertinent to the TC's subject matter, IEC encourages the implementation of liaisons. To this end, IEC/TC 114 has established formal liaisons with the IEC/TC 4 and IEC/TC 88, a committee that develops standards for wind turbines. In addition, liaisons have been formalized with the IEA's OES Implement Agreement as well as EquiMar. These liaisons allow IEC/TC 114 to exchange basic documents with these organizations and allow for observers to follow the work of the committee or vice-versa. Liaison organizations do not possess the right to vote but they can contribute to and participate in working groups or project teams. These liaisons have already been valuable to IEC/TC 114, as experience from more mature committees has provided insight to the work programme of our committee.

Standards produced by IEC/TC 114 are denoted by the 62600 series, a number assigned by the IEC. To manage complexity regarding the annotation of the various standards being produced by this committee, a numbering system or nomenclature has been devised. Standards produced with a single digit suffix (i.e. 62600-1, 2, 3, etc.) will address issues that focus on more than one type of energy conversion system (i.e. wave and tidal energy). The dash 100 series (i.e. 62600-100, 101, etc.) will address issues particular to wave energy conversion while the dash 200 (i.e. 62600-200, 201, etc.) will be specific to tidal energy conversion. The rest of the centennial numbers, such as 300s and 400s, will be left open to allow for flexibility to address other types of technology standards that may be included as part of the future scope of this committee. For example, the 62600-300 series could potentially address standards that are specific to the conversion of water current energy into electricity.

IEC/TC 114 is currently developing five technical specifications, which have been identified as key priorities for the first suite of standards to be delivered. Discussions remain underway on other possible technical specifications such as moorings and tank-testing. Additional standards will be initiated, based on interest and availability of experts, taking into consideration overall industry requirements as well as the sustainability of the committee.

The five technical specifications are discussed in more detail below. The IEC standards development process is illustrated in Figure 3. It is worthwhile mentioning that these documents take, at a minimum, three years to reach publication.

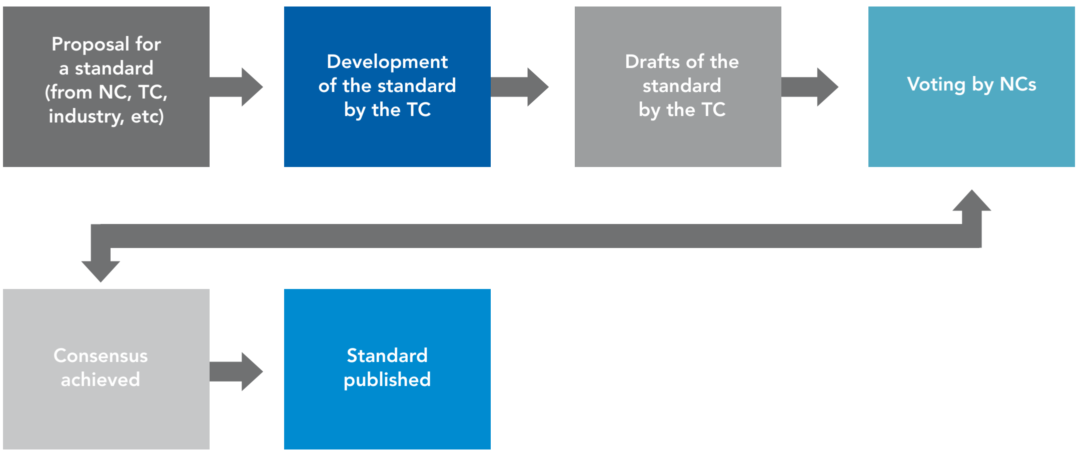

FIGURE 3: Standards Development Process

Terminology for Marine Energy (IEC TS 62600-1)

This TS defines terms related to marine energy converters and will provide uniform terminology in the form of definitions as they relate to wave, tidal and other water current energy converters. This specification will serve as a resource for the working groups and project teams as well as users. The establishment of defined terms early in the standard development process will ensure that uniform terminology is being applied to all future standards developed by this committee. Consistency is essential to remove any potential confusion related to existing multiple meanings for terms currently used within this industry. [8]

Design Requirements for Marine Energy Converters (IEC TS 62600-2)

This TS provides the essential design requirements to ensure the engineering integrity of wave, tidal and other water current energy converters for a specific design life. Its purpose is to provide an appropriate level of protection against damage from all hazards that may lead to failure of the primary structure (e.g. the collective system comprising the structural body, foundation, mooring and anchors, piles device buoyancy, and attachments). This specification will include requirements for subsystems of wave, tidal and other water current converters such as control and protection mechanisms, electrical systems, mechanical systems and mooring systems only as they pertain to the structural viability of the device in an open water site. [9]

Wave and Tidal Energy Resource Characterization and Assessment (IEC TS 62600-3)

This TS will provide uniform methodologies for the consistent and accurate characterization and assessment of both wave and tidal energy resources. This TS will enable marine energy project developers to characterize the wave/tidal resource and assess the potential of sites for deployment. It will enable the comparison of resources at different sites for both wave and tidal energy projects, a requirement that project developers will have and which device developers will be concerned to meet. This specification is intended to be applied to national, regional, areal and site-specific scales to enable a high-level screening as well as site-specific evaluations. Figure 4 provides a graphical representation of the densities available for tidal power.[10]

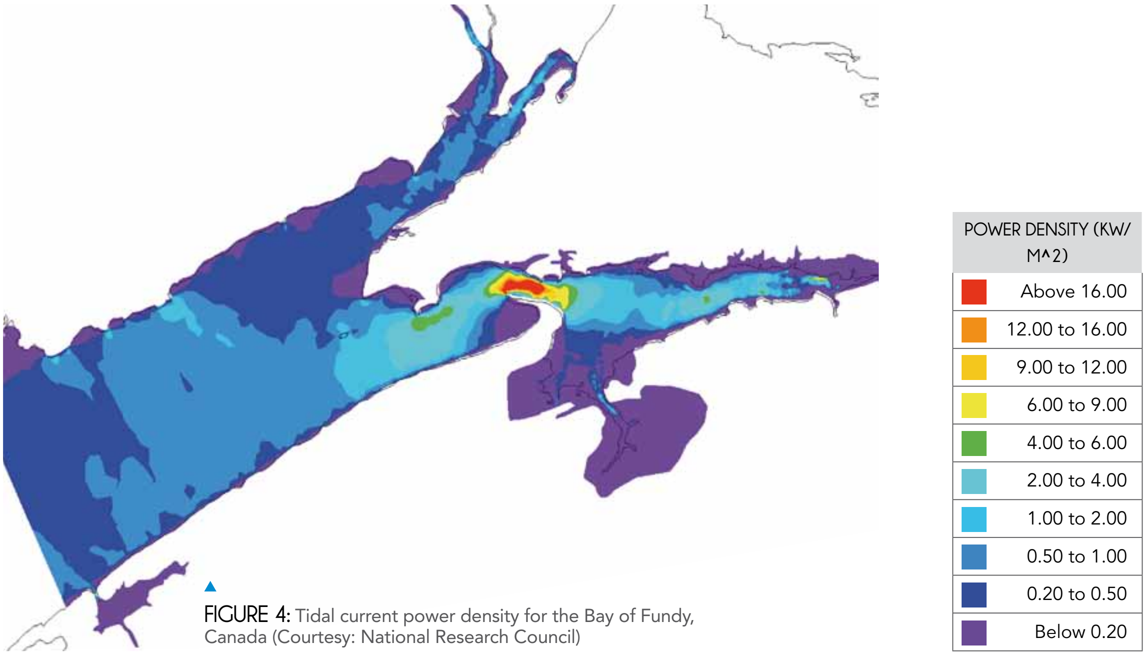

FIGURE 4: Tidal current power density for the Bay of Fundy, Canada (Courtesy: National Research Council)

Performance Assessment of Wave Energy Converters (IEC TS 62600-100)

This TS establishes the general principals for assessing the power production performance of wave energy converters (WECs) when deployed in the open sea. The TS is applicable to WECs which generate electricity using the wind-generated waves in order to deliver that electricity to an onshore grid by means of a cable connection. It is applicable to floating WECs both compliantly moored and taut-moored, and bottom-moored WECs. It is not intended to apply to tank testing or test basins. WECs have various configurations as shown in Figures 5 and 6.

FIGURE 5: Oscillating water column (Courtesy: Oceanlinx)

FIGURE 6: Oscillating body (Courtesy: Pelamis Wave Power)

Performance assessment will ensure that that there is an agreed methodology for the measurement of the power output of a WEC in a range of sea states, as well as provide a framework for the reporting of the results of these measurements. It will also enable the estimation of an annual energy production of a WEC at a prospective site where there is wave power resource information of sufficient detail and quality. [11]

Performance Assessment of Tidal Energy Converters (IEC TS 62600-200)
This TS establishes the general principles for assessing the power production performance of tidal energy converters (TECs) when deployed in open seas. It is applicable to TECs that generate electricity using the action of the tide in order to deliver electricity to the onshore grid by means of a cable connection. It is applicable to both floating and bottom mounted TECs. It is not intended to apply to testing in enclosed flumes or rivers. This specification will enable the performance of devices to be effectively validated, and consequently enable government, industry and the finance/investment community to form soundly based judgements of the commercial prospects of the technologies being demonstrated. Device performance will be characterized by using (but not limited to) a measured power curve, measured annual energy production and a continuous record of operational status. [12]

CONCLUSION

History has shown that companies involved in standards are more competitive and better equipped to meet market demands for new technologies [2]. Developing standards is a long-term investment that requires the collaboration of developers, manufacturers, regulators, international organizations and experts. As the industry is in its infancy, it is challenged by the lack of available resources, both in human and financial capital, to support the development of standards. It is apparent that a country that is interested in developing a marine energy market and technology capacity must take part in this effort, providing a solid foundation for technologies with a superior performance that are cost-competitive and reliable.

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11. IEC TS 62600-100 Ed. 1. The Assessment of Performance of Wave Energy Converters in Open Sea (to be published)
12. IEC TS 62600-200 Ed. 1. Performance of Tidal Energy Converters (To be published)

2010

KEY FACILITATORS FOR OCEAN ENERGY

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Why Wave Energy - Market Driver Analysis for Investors and Policy Makers
Gordon Dalton,
Hydraulic Maritime Research Centre (HMRC), University College Cork, Ireland

International Network on Offshore Renewable Energy (Inore): Realising the Potential of Young Researchers and Offshore Renewable Energy
Peter Johnson (University College London)
Angus Vantoch-Wood (University of Exeter)
Eric Stoutenburg (Stanford University)
Izan Le Crom (Wave Energy Centre)
Julien Cretel (Hydraulics and Maritime Research Centre)
and João Baltazar (Instituto Superior Técnico)

ICOE 2010 – Moving Ocean Energy to the Industrial Scale
John Huckerby, AWATEA, New Zealand
António Sarmento, Wave Energy Centre, Portugal
Jochen Bard, Fraunhofer Institute, Germany
Chris Campbell, Ocean Renewable Energy group, Canada
Henry Jeffrey, UK Energy Research Centre (UKERC), Edinburgh University, United Kingdom
Eoin Sweeney, Sustainable Energy Authority of Ireland, Ireland
Jose Luis Villate, Tecnalia, Spain

WHY WAVE ENERGY - MARKET DRIVER ANALYSIS FOR INVESTORS AND POLICY MAKERS

Gordon Dalton,
Hydraulic Maritime Research Centre (HMRC), University College Cork, Ireland

This paper will address the topic of 'Why wave energy' by analysis the factors for consideration from two perspectives:

- Factors for consideration by an investor in wave energy.
- Factors for consideration by a policy maker in wave energy.

1. WHY WAVE ENERGY – FOR AN INVESTOR

The first section of this paper discusses why an investor would consider wave energy as an investment option. Investors today have the option of investing their finance in an enormous range of products/companies/ventures. The principal criteria which will determine their decision to invest will be the expected return on their investment (some investments are driven by personal or philanthropic reason, but these are a minority). With return on investment as the driving force, an investor will compare wave energy projects to a host of other possible ventures. Investors usually specialise in certain product or industry sectors, determined by their past experiences and expertise. Thus, investors in wave energy will be familiar and interested in the energy sector in general, and more than likely have an interest in renewables.
This paper investigates 'why wave energy for a investor' by assessing all the criteria and facts that an investor will need to investigate in order to make a decision on the viability for investment in either wave energy research, development, manufacture or deployment sectors.

1.1 Supply Analysis

1.1.1 Global Fossil Fuel Deposits

The level of global fossil fuel reserves will have a direct bearing on the future attractiveness and viability of renewable energy. Accurate forecasting of this trend will dictate investment in renewables.
Statistics presented in Table 1 indicate that there is ample coal reserves left for nearly 200 years. Thus an investor could be wary of investing in wave energy technologies or wave farm development in countries that have large deposits of coal, or access to cheap coal. On the other hand, oil reserves have less than 50 years left. Thus countries heavily dependent on oil imports would be countries most likely to require high renewable energy targets in the near future to offset the high price of oil which will inevitably result from future limited supply. In summary, countries that have limited fossil fuel reserves and large wave energy capacity are the optimum countries on which to focus investment.

FOSSIL ENERGY SOURCE	RESERVE (RESOURCE) (GTCE)	PRODUCTION RATE (GTCE)	STATIC DEPLETION TIME (YEARS)
Total	1279 (6224)	13.1	98
Oil (conventional)	233 (118)	5.5	42
Natural gas (conv)	196 (230)	3.0	65
Coal (hard and lignite)	697 (3541)	4.1	170
Uranium, Thorium	56 (293)	0.5	101

* *Expected additional resources*

▲

TABLE 1: Fossil reserves, resources, consumption rates, depletion time, and solar delivery times [1]
(Giga tonnes coal equivalent (1 Gtce) = 29 EJ = 8,140 TWh thermal = 5 Billion bbl)

1.1.2 Cost of Fossil Fuel Deposits

High and fluctuating fossil fuel prices are a major driver for the competitiveness and utilisation of renewable energy technologies [2]. Since 2000, the prices of fossil fuels, and in particular oil prices, have increased significantly by approximately three times (Figure 1). Oil prices are forecast to continue to increase in price for the foreseeable future. These price fluctuations may provide an essential driver for investments in renewable and wave energy technologies.

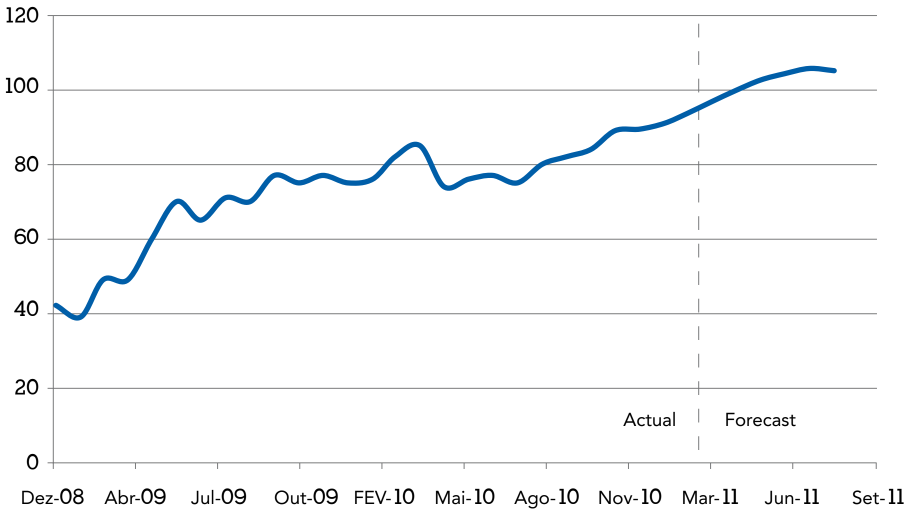


FIGURE 1: Crude oil past & future projection. West Texas Intermediate in US Dollars per barrel.[1]

1.1.3 Supply Predictions for Wave Energy

An investor will need to assess the predicted maximum capacity that wave energy can produce given ideal conditions, and compare these to exiting onshore and offshore wind competition. Wave energy is predicted to supply 188GW of renewable power to Europe by 2050, and will have a similar proportion of the renewable energy mix as offshore and onshore wind (Figure 2) [3]. An estimated 150 GW of wave energy production by 2030 would contribute 11-14% of total electricity consumption In Europe[2].

In 2007 the countries of the European Union consumed 2,926 TWh of electricity [3]. Ocean energy generation has a potential to reach 3.6 GW of installed capacity by 2020 and close to 188 GW by 2050. This represents over 9 TWh/ year by 2020 and over 645 TWh/year by 2050, amounting to 0.3% and 15% of the projected EU-27 electricity demand by 2020 and 2050 respectively. The numbers presented are achievable targets for ocean energy at the European level.

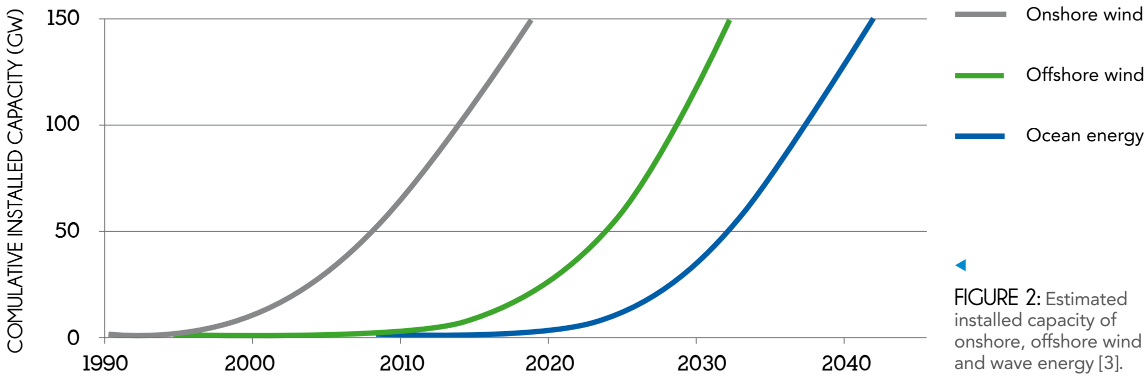


FIGURE 2: Estimated installed capacity of onshore, offshore wind and wave energy [3].

[1] http://www.forecasts.org/oil.htm
[2] http://www.ewea.org/index.php?id=60&no_cache=1&tx_ttnews%5Btt_news%5D=1361&tx_ttnews%5BbackPid%5D=1&cHash=a082035a00
[3] http://www.eia.doe.gov/oiaf/ieo/electricity.html

1.2 Demand Analysis: Fossil Fuel and Green Energy

Investors interested in the energy supply market will need to do a full assessment of future demand for the following:

- General energy consumption and electricity consumption.
- Green energy/electricity consumption.

1.2.1 General Energy and Electricity Demand

The German government's scientific advisory board on global energy consumption assumes a rise by a factor 4 to 1,600 EJ or 55 Gtce (Giga tonnes coal equivalent, 1 Gtce = 29 EJ), respectively, from the year 2000 until 2100 [4]. Forecasts from the US indicate the energy demand will double until 2030 and electricity demand will triple (Figure 3).

In conclusion, investors should view the strong forecasted demand growth for energy and electricity as positive indicators for future investment consideration in the energy sector.

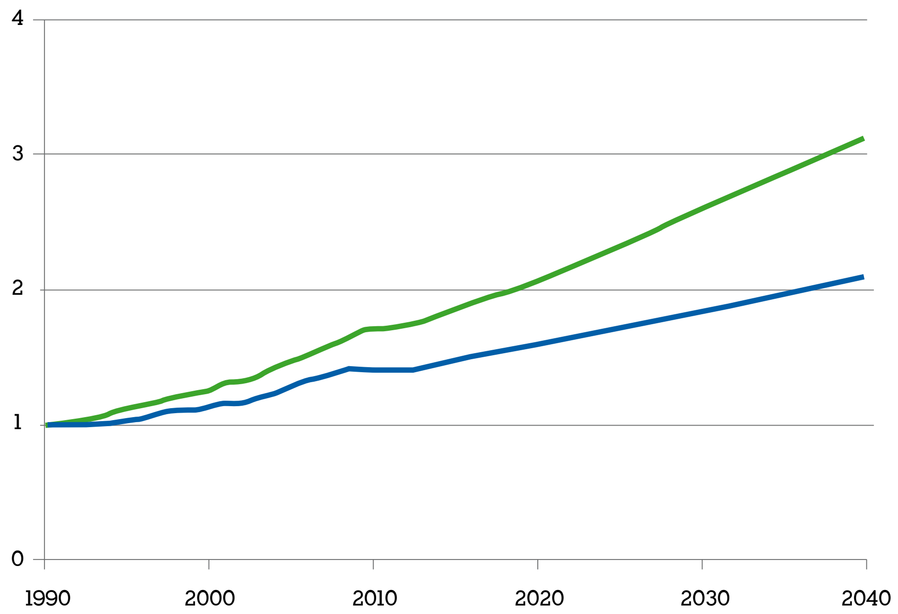


FIGURE 3: Growth in world electric power generation (green line) and total energy consumption (blue line), 1990-2035. Index, 1990 = 1. (Energy Information Agency, US)[3]

1.2.2 Renewable Energy Demand

As fossil fuel resources are facing depletion, it is anticipated that the deficit can be filled in part by renewable sources of energy.

Predictions by the US Energy Administration Bureau [5] indicate the renewable energy has a strong growth market increasing at the same rate as the other fuel types (Figure 4). Figure 5 splits the renewable portion of the fuel mix into its constituents. Knies [4] reports from a German study that solar will be the most prevalent renewable energy form by 2050 and ubiquitous by 2100. 'Others' described in the graph could refer to wave energy, but is not qualified. A more conservative report from EC.Europa [6] sees a modest growth of all fuel types with biomass as the greatest growth fuel. Wave energy is not described in any graphs of the types, however it is assumed that it forms some portion of the "others". The current market proportion is certainly small in comparison to other renewables, but one can assume that it will be a growing one if it follows the trend that other renewables have taken, such as offshore wind [7].

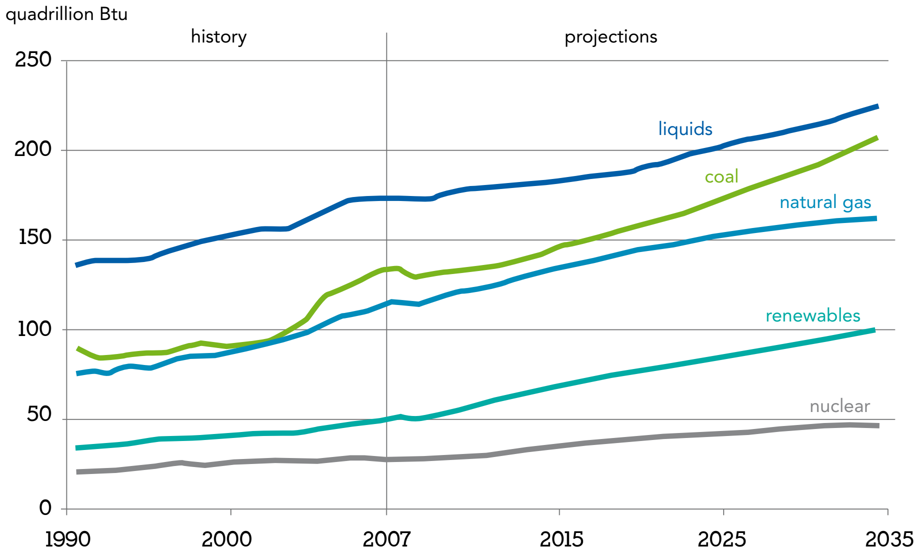


FIGURE 4: Energy fuel mix predicted for 2015, 2025 and 2035 (Energy Information Agency, US) [5]

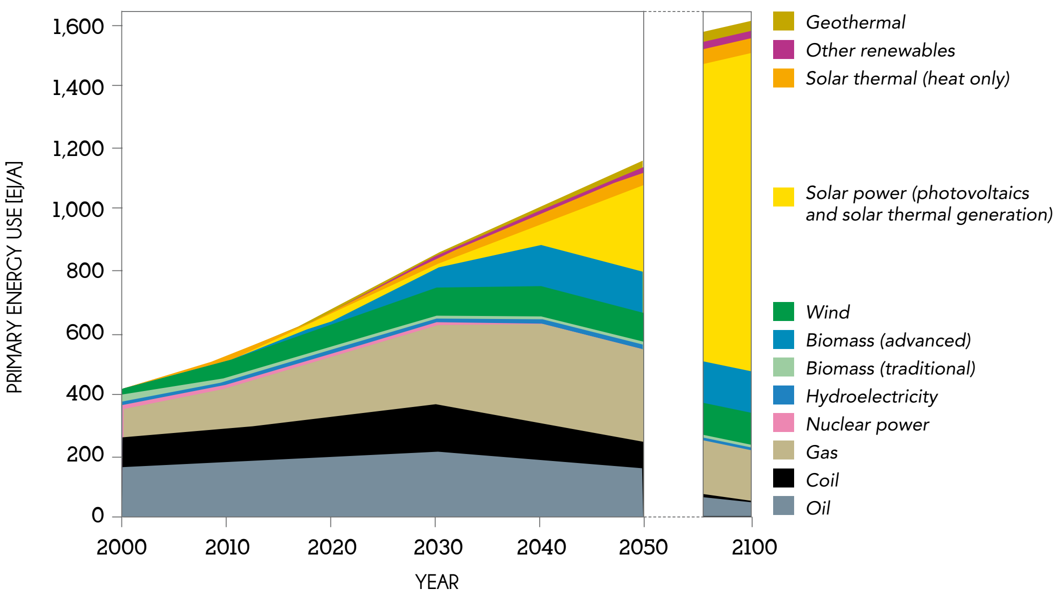


FIGURE 5: Development of global primary energy demand according to the scenario "exemplary path" by the scientific advisory board (WBGU) to the German government [4].

1.3 Target Penetration of Green Energy

Investment in renewable energy technologies in certain countries will be directly proportional to the strategic plan of the national government of the country. National targets have been set in most European countries for:

- Renewable energy- general targets.
- Wave energy specific targets.

	SHARE OF ENERGY FROM RENEWABLE ENERGY (%), 2005	SHARE OF ENERGY FROM RENEWABLE ENERGY (%), 2020
Malta	0	10
Luxembourg	0.9	11
Belgium	2.2	13
Cyprus	2.9	13
Czech Republic	6.1	13
Hungary	4.3	13
Netherlands	2.4	14
Slovakia	6.7	14
Poland	7.2	15
United Kingdom	1.3	15
Bulgaria	9.4	16
Ireland	3.1	16
Italy	5.2	17
Germany	5.8	18
Greece	6.9	18
Spain	8.7	20
France	10.3	23
Lithuania	15	23
Romania	17.8	24
Estonia	18	25
Slovenia	16	25
Denmark	17	30
Portugal	20.5	31
Austria	23.3	34
Finland	28.5	38
Latvia	32.6	40
Sweden	39.8	49

FIGURE 6: EU national targets for the contribution of electricity produced from renewable energy sources in percent (%) of gross final consumption, comparing 2005 to 2020[4].

1.3.1 Renewable Energy - general

National renewable energy targets for European countries are displayed in Figure 6. The countries with the highest targets are Denmark, Estonia, Spain, France, Austria, Portugal, Finland and Sweden.

1.3.2 Wave Energy Targets

The UK has the highest wave energy target for 2020, at 2GW (Figure 7). This is double that of France and 4 times that of Ireland, Portugal and Denmark. However, it must be remembered that the UK has 10 times the population of these countries, so for per head of population perspective, Ireland, Portugal and Denmark are setting very high targets. Thus the investment made by these countries as a percentage of the total budgets in renewable energy is high, and can be taken as a positive indicator for investors as attractive locations for investment.

[4] *http://ec.europa.eu/energy/renewables/targets_en.htm*

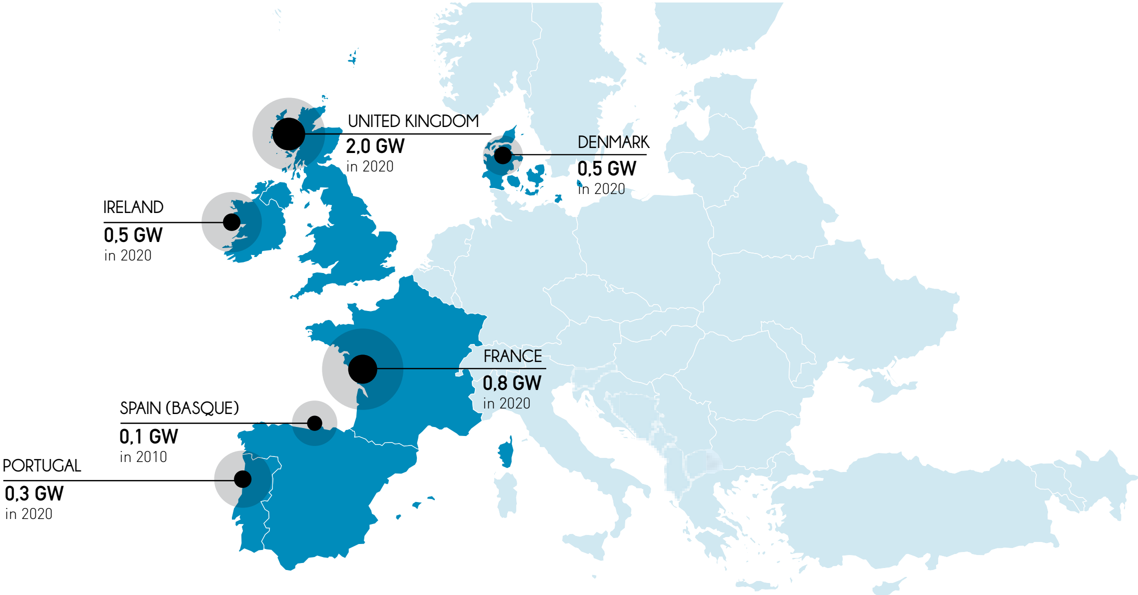


FIGURE 7: Current and future targets for ocean energy for European countries [3].

1.4 Capex and COE

An investor needs to ask "is the cost of renewable (and wave energy) competitive with other forms of energy"? The costs ultimately must be as attractive as fossil fuel prices to be worthy of investment consideration in the long run.

1.4.1 Capital Expenditure (Capex)

Capex is cost per kW (€/kW) or per MW (€/MW). This metric gives a direct relationship between the initial cost of the device and its rated power. It is neither location specific nor account for revenue. Statistics available for the Nuclear Association [8] show that that there is a wide range of Capex for various energy sources. Onshore wind is still more expensive than conventional fossil fuel sources such as coal and gas but cheaper than nuclear power (Figure 8). A more detailed literature review costs for offshore wind is displayed in Table 2 indicating that moving offshore incurs a higher cost than onshore wind, with Capex as high as €4500/kW. Wave energy also is predicted to have a high Capex, ranging from a low of €1400/MW to a high of €8-10,000 by Dalton [9] and Cameron [10]. These very high Capex costs will require substantial support mechanisms to make wave farm ventures viable. It would also be assumed that learning curve and market demand will help reduce the Capex over time to similar levels of onshore wind. However, this cannot be assumed or expected, as per the example of offshore wind, where the price per MW doubled from year 2000 to 2010 [11], due to supply not meeting demand, as well as price increase in raw materials.

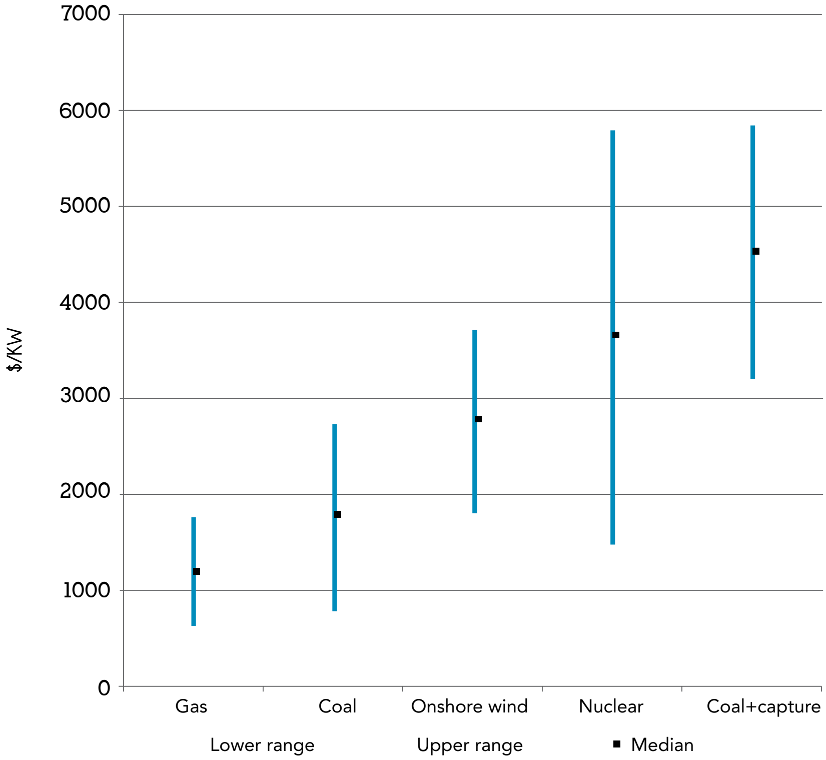


FIGURE 8: Cost per kW for various technologies, showing upper, lower and median value ranges. [8]

TECHNOLOGY	AUTHOR	YEAR	REFERENCE	TURBINE OR FARM SIZE	€/KW
OFFSHORE WIND	Snyder and Kaiser	2009	[12]	1-2MW turbines	1500-3000
				2-5MW turbines	2000-3000
				1-50MW farms	1500-3000
				50-200MW farms	2000-3000
	Fingersh et al	2006	[13]	3MW	1500 ($2100)
	DETI	2002	[14]	Not quoted	1400-2000
	Horns Reef	2002		16MW	1700
	Barthelmie et al	2008	[15]	Not quoted	1650
	Luypert et al	2008	[16]	Not quoted	2500
		2010		5MW	3500-4500
WAVE ENERGY	Weiss	2007	[17]	90MW	1800 ($2600)
	Carbon Trust	2006	[18]	commercial	1400-3500
	Previsic (calculated from report)	2004	[19]	1MW	5350 ($7500)
				105MW farm	1900 ($2600)
	Dunnett	2009	[20]	Not quoted	2500 ($3500)
	Aquamarine	2010	[10]	1MW	9000[5]
	Dalton	2010	[9]	1MW	8000
				20MW	5800

TABLE 2: Cost per kW for various offshore wind and wave energy studies. (€1 =US$1.4, €1 =£0.82)

[5] €/MW quoted during question time after the paper presentation.

1.4.2 Cost of Electricity (COE)

Cost of electricity (COE) is measured in €/kWh or €/MWH. This metric is most useful for providing an economic relationship between the cost of the project and the electricity output. Levelised COE is location specific and does not factor in revenue. The metric can be confusing as some economists include revenue in the figure, which makes it difficult to compare with other published results which do not account for it.
There are two methods to calculate COE:
a. Simple COE: The total Initial cost of the project is divided by the total annual energy output of the device per MW (not recommended).
b. Levelised COE: The levelised annual average costs of the project including all annual OPEX costs are included in the estimate. This figure provides the most accurate metric for developers.

COE for wave energy is the highest amongst other renewable energy compared, as displayed in Figure 9, similar to trends discussed for Capex. However, caution must be exercised in using COE for the following reasons:

- COE can vary from technology to technology.
- COE will vary from report to report for each device. An example is displayed in Table 3 where COE obtained from different reports are quoted for the Pelamis. The COE quotes vary due to two main reasons:
    - Different locations for the device analysis provide different energy outputs.
    - Some reports include revenue support in the COE calculation, thus lowering the reported COE.

In conclusion, COE must be used with care when comparing technologies. Capex can be more reliable. In general, wave energy will involve high costs, which need to be supported by mechanisms, such as grants or feed-in tariffs. These latter requirements will need to be carefully investigated in conjunction with Capex/ COE analysis to gain the full picture of wave energy investment viability.

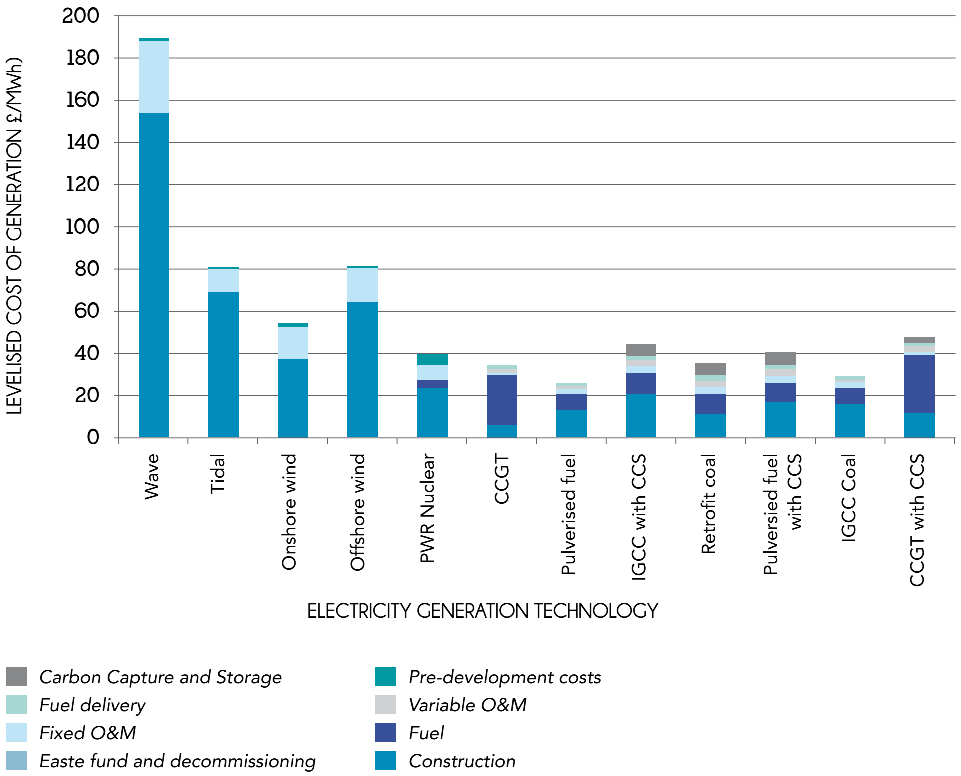


FIGURE 9: Cost of generating electricity (£pence per MWh). [21]

STUDY	REFERENCE	LOCATION	YEAR	NUMBER OF PELAMIS	COE €/KWH	SUBSIDY
EPRI (Previsic)	[19]	California	2005	213	0.08	0.06
ESBI	[22]	Ireland	2005	209	0.105	-
St Germain	[23]	Canada	2005	15	0.10-0.15	-
EPRI (Bedard)	[24]	California	2006	44	0.05-0.12	-
Carbon Trust	[18]	UK	2006	13,000 13	0.08-0.30	-
Allan et al	[25]	Scotland	2008	4000	0.10	0.05
Dunnet et al	[20]	Canada	2008	15-27	0.18-0.30	-
Pelamis	[26]	UK	2008	1	0.80-0.16	-

TABLE 3: Wave energy device studies reporting COE using the Pelamis power matrix.

1.5 Support Mechanisms

An essential ingredient for consideration by an investor intending to invest in renewable or wave energy technologies is the global support mechanisms promised by the government of the country under consideration. The currently available supports mechanisms (2010) for European countries are presented in Table 4.

Feed-in tariffs (FIT) schemes are the most prevalent support mechanisms for wave energy in Europe. The second most important mechanism is grant schemes provided. At present, the UK has the most comprehensive suite of grant support schemes.

The largest support fund promised will come from the EU, called NER300[6]. The NER300 is a common pot of 300 million EU ETS allowances, which could be worth as much as €4.5 billion if each allowance is sold for €15. Up to 50% of *"relevant costs"* are funded under the scheme. Each member state will have allocated at least one and a maximum of three projects[7]. A total of three ocean energy projects will be funded including wave tidal and ocean thermal. Wave energy devices of up to 5MW nominal power are eligible to apply[8].

In conclusion, there are many support mechanisms available throughout Europe, either via FIT or grants. Investors will need to balance costs versus supports, as well as the local wave energy resource, to come to a final decision on whether to invest.

2. WHY WAVE ENERGIES – FOR POLICY MAKERS IN EUROPE

Government renewable energy policies are the principal driver of the growth in renewable energy use. Renewable energy policies exist in 73 countries around the world and public policies to promote renewable energy have become more common in recent years. The criteria for policy making decisions are slightly different than those for investors, when considering the options of investing in wave energy.

Policy makers will be looking at the national perspective, taking into account a larger suite of factors, not all having direct financial returns in the short term, if ever.

The following is a directory of factors that will need to be considered from a policy making perspective.

[6] *http://www.ner300.com/*
[7] *http://ec.europa.eu/clima/funding/ner300/docs/faq_en.pdf*
[8] *http://ec.europa.eu/clima/funding/ner300/00031/index_en.htm*

	FEED-IN TARIFF (FIT)	RENEWABLE PORTFOLIO SCHEME (RPS)	GRANTS+ SUBSIDY	INVESTMENT/TAX CREDITS	PRODUCTION TAX CREDITS
Austria	√		√	√	
Belgium		√	√	√	
Czeck	√		√	√	
Denmark	√			√	
Estonia	√				
Finland			√		
France	√		√		√
Germany	√		√	√	
Greece	√		√	√	
Hungary	√			√	
Ireland	√		√	√	
Italy		√	√	√	
Latvia	√				
Lithuania	√		√	√	
Luxembourg	√		√	√	
Netherlands	√		√	√	√
Norway			√	√	
Poland		√	√		
Portugal	√		√	√	
Slovak	√			√	
Slovenia	√				
Spain	√		√	√	√
Sweden	√		√	√	
Switzerland	√			√	
UK			√	√	

TABLE 4: Global support mechanisms for renewable energy in general[9]

2.1 Climate Change and CO_2 Mitigation

The Organisation for Economic Co-operation and Development (OECD) states that technological innovation will play an important role in bringing down the costs of climate change mitigation over time [27]. It argues that a concerted research and development effort can be expected to yield important benefits, but not by itself. The International Energy Agency estimates that nearly 50% of global electricity supplies will need to come from renewable energy sources in order to halve carbon dioxide emissions by 2050 and minimize significant, irreversible climate change impacts [28]. With the adoption of the new "Energy from renewable sources" directive by the European Parliament and the European Council [29], the EU has committed to reducing its greenhouse gas emissions by 20% by 2020. It has been estimated that 300 kg of CO_2 could be avoided for each MWh generated by ocean energy [3]. Therefore, for 20 GW (49 TWh/year) of installed ocean energy, the CO_2 emissions avoided could be 14.5 Mt/year. These figures do not account for the baseload fossil fuel-produced power necessary to firm up ocean energy intermittency. The International Energy Agency (IEA) concludes, however, in the Energy Technology Perspectives Report [30] that 'it is unlikely that wave energy technology will play an important role in climate change mitigation 2030'. It points to the need to develop appropriate wave energy policies and effective measures essential to accelerate the development and deployment of wave energy technology and to address the barriers identified.

[9] *http://nextbigfuture.com/2008/02/feed-in-tariffs-support-for-renewable.html*

2.2 Security of Supply

The interdependence of EU Member States for energy, as for many other areas, is increasing – a power or gas pipe failure in one country has immediate effects in other countries [3]. A radical change is required in the way energy is produced, distributed and consumed. This means transforming Europe into a highly efficient, sustainable energy economy. Europe's dependence on imported energy has risen from 20% at the signing of the Treaty of Rome in 1957 to its present level of 50%, and the European Commission forecasts that imports will reach 70% by 2030 [3]. A second EU report forecasts import dependence reaching 67% in 2030, with import dependence from oil continuing to be the highest, reaching 95% in 2030 [31].

Some major European economies are already ahead of the general trend of dependency. The TG Trend report quotes that in 2007, Germany needed to import almost two thirds of its energy, while Spain and Italy's dependency rates rose to 81.4% and 86.8% respectively [32]. With regards gas supplies, most European countries are even more vulnerable. Spain, Portugal, Sweden and the UK in 2007 relied 100% on imported gas (Table 5) [32].

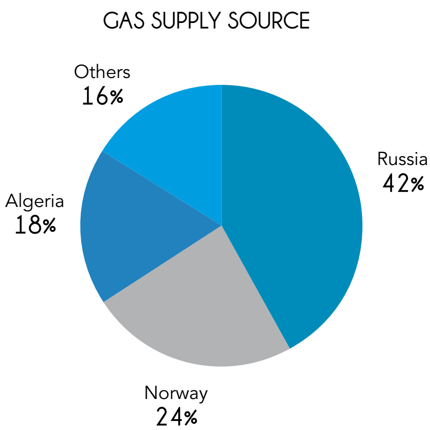
	% DEPENDANT
Spain	101.3
Portugal	100.0
Sweden	100.0
UK	100.0
Italy	91.2
Germany	83.6
France	80.0
Netherlands	61.6
Denmark	-101.3

TABLE 5: Dependence on imported gas for selected EU countries 2007 [32]

From a European perspective, the majority of supply sources are at present from areas in the world with least government stability, as is evidenced in Figure 10. The Russia-Ukraine gas dispute in January 2009 highlighted the impact that events far away can have on the transit of gas to the EU [33].

In conclusion, the use of renewable energy technologies increases the security of energy supply because they generally utilise indigenous resources [2].

In conclusion, Europe's increased dependence on a limited number of energy sources, as well as supply and transport routes, should stimulate investor confidence in the need for investment in alternate energy technologies.



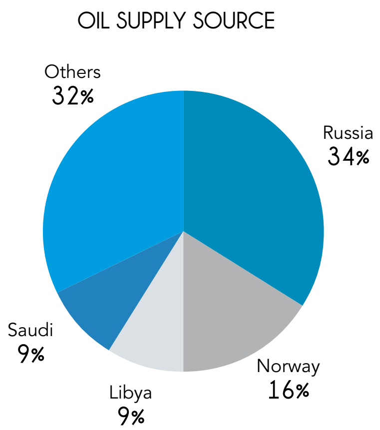


FIGURE 10: EU's gas and oil imports 2006 [32]

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2.3 A Diversified Energy Mix

A diversified energy mix, both geographically and technologically, can resolve the issue of variability. Ocean energy can bring added value to the European Union's energy mix. Indeed, it has been established that wind and ocean energy are complementary. Studies performed on wind energy show that diversification at a national (supranational) level improves intermittency [34]. A recent Renewable UK study concludes that diversifying the renewable energy mix by including a greater proportion of marine energy would reduce requirements for reserve capacity and lead to annual savings in relation to the annual wholesale cost of electricity [35]. An Irish study concludes that the integration of wind and waves in combined farms, allows the achievement of a more reliable, less variable and more predictable electrical power production. This is particularly clear in the case of a relatively small and quite isolated electrical system such as the Irish one [36]. A British study also concluded that reducing the variability of the renewable electricity supply with a wide mix of renewables reduces the additional balancing costs required [37]. Finally, a US study also states that co-located offshore wind and wave energy farms generate less variable power output than a wind or wave farm operating alone [38]. The reduction in variability resulted from the low temporal correlation of the resources and occurs on all time scales.

In conclusion, wave energy may become a crucial ingredient in Europe's energy portfolio - improving the quality of grid supply and reducing intermittency.

2.4 Job Creation

Ocean energy is well positioned to contribute to regional development in Europe, especially in remote and coastal areas. The manufacturing, transportation, installation, operation and maintenance of ocean energy facilities will generate revenue and employment. Studies suggest that ocean energy has a significant potential for positive economic impact and job creation. Parallels can also be drawn with the growth of the wind industry. Clean technology now account for €7.1 billion annually in Denmark, while in Germany, wind technology exports alone are worth over €5.1 billion. Based on the projections for installed capacity, by 2020, the ocean energy sector could generate over 26,000 direct and 13,000 indirect jobs [3]. By 2050 these numbers would increase to 314,000 and 157,000 jobs respectively.

In order to meet the Irish aspirational 500MW target, the Irish wave energy industry could produce 1,400 additional full time employment jobs and a net present value (NPV) of €0.25 billion, rising to 17,000-52,000 FTE jobs and an NPV of between €4-10 billion by 2030 [39].

Scotland has published several roadmaps for the development of marine energy [40]. The latest roadmap developed by the FREDS Marine Energy Group [41] estimates an overall expenditure of £2.4 billion to achieve 1,000MW installed in Scotland by 2020, generating 5,000 direct jobs.

In conclusion, the wave energy industry has tremendous potential in indigenous job creation.

CONCLUSION

'Why invest' in wave energy is a key question that must be answered before investors and policy makers make important decisions with regards investing both funds and time in the wave energy sector. This paper reviewed the key factors and data that need to be gathered and considered to help make a full analysis and decision.

Analysis of global supply of conventional fossil fuels, such as oil and gas, reveals that deposits are dwindling, and their prices are increasing. It is predicted that renewable energy sources, including wave, will fill the resultant vacuum. However, there are locations in the world which still have ample fossil fuel reserves and may be locations of less optimistic prospects for renewable energy interest and investment.

Demand side analysis shows positive indicators, both for global energy demand as well as global renewable energy demand. Forecast demands for wave energy, which are specified by targets, are also healthy.

The negatives that must be considered at present are very high Capex costs as well as the unit cost of electricity for existing wave energy devices. Capex has reduced for most renewables with time, due to learning curves, but experience from the offshore wind industry in recent years has shown that elevated demand and supply bottlenecks can increase Capex costs with time.

Although costs can be a considerable barrier, much effort has been made by national governments to provide support mechanisms for the young wave energy industry. Support mechanisms consist of feed-in tariffs, grants and national targets. The drivers for policy makers in government to provide these support mechanisms are many and encouraging for the wave energy investor. Climate change and CO_2 mitigation concerns must be addressed, as well as remedies for security of supply and reducing dependence on volatile supply sources. Renewable energy, especially wave energy, provides the obvious answer to these problems. Further benefits of adopting a diversified mix of renewables range from improving power output quality by reducing intermittency and variability to economic benefits due to green and indigenous jobs.

In conclusion, the investor can be encouraged that the majority of market drivers and indicators are positive toward wave energy at the present time, when macro-economic and socio-economic factors are considered. The wind and solar renewable energy industries are providing confident indicators of promising futures for wave energy. However, cost considerations are the most pressing concern for wave energy, requiring concerted government support and future innovation to remedy these issues.

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INTERNATIONAL NETWORK ON OFFSHORE RENEWABLE ENERGY (INORE): REALISING THE POTENTIAL OF YOUNG RESEARCHERS AND OFFSHORE RENEWABLE ENERGY

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INTRODUCTION

The International Network on Offshore Renewable Energy (INORE) is a fully autonomous organisation comprising over 500 members, 249 of which are full INOREans (Ph.D. students and early-stage industrial researchers from over 49 countries). This article outlines the need for an international network, a brief history of INORE, an overview of current activities and some future plans.

The need for an international network

The focus here is on offshore renewable energy, which is taken to mean offshore wind, tidal, and wave energy. When offshore renewable energy reaches its potential in the coming decades it will become a global industry. This will constitute an array of highly developed technologies and sub-industries, most of which already exist in a nascent form. As the industry grows, one of the many benefits will be the large number of jobs that will be created. Many of these jobs will be filled by experienced professionals from relevant industries, such as onshore wind, offshore oil and gas, etc. However, there will also be an outstanding need for a continuing supply of scientists, engineers, and other professionals who have advanced training specifically in offshore renewable energy.

As companies grow from small teams with a prototype device into larger manufacturing companies and service providers, huge amounts of research and development will be necessary. As these companies grow at a rate of 10s or even 100s of personnel per year, recruitment of quality staff could be a crucial bottleneck. Who are these people and where will they come from?

Many of them will be early stage researchers graduating with a PhD from one of hundreds of academic institutions around the world. The industry needs to engage with those people as early as possible; equally these people are hungry to engage with industry. The nature of academic institutions is that they are independent and no single thread ties them together. This means there is a need for a network to connect early stage researchers to each other, and to industry.

The purpose of the International Network on Offshore Renewable Energy (INORE) is to meet this need. The network is run by and for early stage researchers, and currently has over 500 individual members. Our focus is on knowledge sharing and collaboration.

Background of INORE

The idea of creating a network for young researchers who worked with offshore renewable energy evolved from the project "PhD Pool on Offshore Renewable Energy" which consisted of one Post Doc and three PhD students associated to the Norwegian Centre for Renewable Energy (NTNU) and financed by the Research Council of Norway. The intention of the PhD Pool was to let researchers from different fields work together in order to create solutions that are difficult to achieve without an element of interdisciplinary thinking. The PhD pool soon realised the need for a bigger community to enable the discussions needed to obtain this goal. Inspired by the blooming industry and lack of real academic co-operation across national borders, the work to establish an interdisciplinary and international network was started.

One of the key ideas was to establish a truly international network. To ensure the international spirit, an interim committee meeting with participants from four different countries was held near Trondheim in April 2007. The meeting was attended by the three initiators from Norway and three new committee members who were selected after applications. New committee members from three different countries, with different background and knowledge, were invited.

The network has since evolved and matured. The steering committee consists of elected volunteers, who serve no longer than 2 years, and the committee is partially renewed by election every year; membership is administered via the website (*www.inore.org*) and is growing year after year. There are currently 2 membership categories: web-member, open to anyone with an interest, and INOREan, open to early-stage/PhD researchers. INORE members represent 179 different bodies from industry, government agencies and universities.

INORE is an independent, non-profit organisation. Funding for the network's activities comes from sponsors, who have shown great support for the concept and therefore great commitment to the wider industry. Statkraft has been a main sponsor of INORE since 2007. Support in the past has also come from the Norwegian Centre for Renewable Energy (NTNU – SINTEF – IFE), Statoil (now StatoilHydro), the University of Edinburgh, Ghent University, and UKERC (UK Energy Research Centre). Specific sponsorship of the symposium in 2010 was provided by Vattenfall, MARIN, PML, PRIMaRE and RPS. Collaboration and in-kind support is also crucial to INORE's operation, and the industry as a whole has been very supportive, including collaboration with Wavetrain2, and organisational support from Renewable UK and OES-IA.

The INORE annual symposium

The most important INORE activity is the annual symposium. The annual symposium is a unique, five-day residential programme that brings together early-stage researchers for an intensive experience that provides an amazing catalyst for their research.

In April 2010, INORE hosted its fourth annual symposium, which included:

- Collaborative sessions set by industry experts; Garrad Hassan, Statkraft, Renewable UK, MARIN and RegenSW
- Presentations and posters from all 56 researchers attending
- Keynote talks from Vattenfall, MARIN, NREL and more
- Site visit to PRIMaRE at the University of Exeter in Cornwall, a key research institute for WaveHub
- Panel discussion with an array of experts.

FIGURE 1: attendees at the fourth annual INORE symposium, bringing together young researchers and industry for a week of knowledge sharing and collaboration.

The symposium took place in the bucolic surroundings of Dartmouth in Devon, UK. 56 early-stage researchers from around the globe – mostly Ph.D. students – attended the symposium, representing 31 institutions. This unique event, which was free of charge, brought together researchers to help achieve INORE's goal of stimulating knowledge sharing and collaboration in the offshore renewable energy research community. The symposium was fully funded by INORE - including travel costs - ensuring equal access for all researchers from around the world.

The feedback from the INORE symposium was overwhelmingly positive. The most common benefits cited by attendees were:

- The opportunity to meet collaborators
- Diversity of attendees and their subject areas, and how this opens their minds to the wider activities within the sector
- Contact with industry, to understand their needs and their perspective

The impact of this symposium on the 56 participants was profound. All the researchers returned to their institutions with new links to research in their field, and a strong understanding of the perspective of the major industrial players, such as utilities, device developers, and consultants. This has created a new generation of researchers who, as well as proving themselves as quality researchers through the traditional academic channels of peer review journals, PhD vivas, and conferences, are also in tune with the needs of industry. This is a crucial bridge to build if the offshore renewable energy sector is to grow into the industry that it could be.

The symposium also has an impact on the industrial partners. The collaborative sessions consist of real problems set by partners, and in 2010 included RenewableUK, Statkraft, Marine Research Institute Netherlands (MARIN) and consultants GL – Garrad Hassan. The participants work in teams to provide a solution within a few days, for example a technology review or a costing analysis, and these were well received by the industrial partners. A more detailed account is published in McCombes et al. (2010).

Other Activities

Collaborative research is a central part of INORE's vision and this is promoted through its International Collaboration Incentive Scheme (ICIS), which provides financial assistance to researchers at different institutions who would like to collaborate. Five awards were granted in 2010, leading to 3 collaborative technical publications so far, with more publications expected. The ICIS grants continue into 2011 with 5 grants awarded, and we look forward to seeing the outcome of these collaborative research ventures.

With members from over 50 countries, INORE is a truly international operation. This year, INORE has began its first activities in the Americas: an Americas representative was elected to the committee in April. This led to a very successful networking event for young researchers, which was held in Seattle in September - alongside the MTS/IEEE Oceans conference. This event consisted of brief research presentations and general networking and marks the beginning of further activities in that region.

Sharing the outputs of INORE activities is also important. At the 3rd International Conference on Offshore Energy (ICOE) in Bilbao, Spain, in October 2010, INORE members presented the outcome of the six collaborative sessions held at its symposium earlier in the year. INORE also held a networking event in Bilbao on the eve of the conference. Hosting a stand during the conference gave INORE excellent exposure to new members and new sponsors.

An exciting new development is our online WIKI, which is available on our website. The WIKI currently hosts posters and presentations from our symposium, plus some further work published by INOREans.

Currently, there is no central online resource for research in offshore renewable energy; publications are scattered across thousands of proceedings and journals. In the future, the INORE WIKI has the potential to be a one-stop shop for summaries of technical research in the field of offshore renewable energy, with references to publications and, where possible, direct access to those publications. This kind of extension to the WIKI is dependent upon further collaboration and funding.

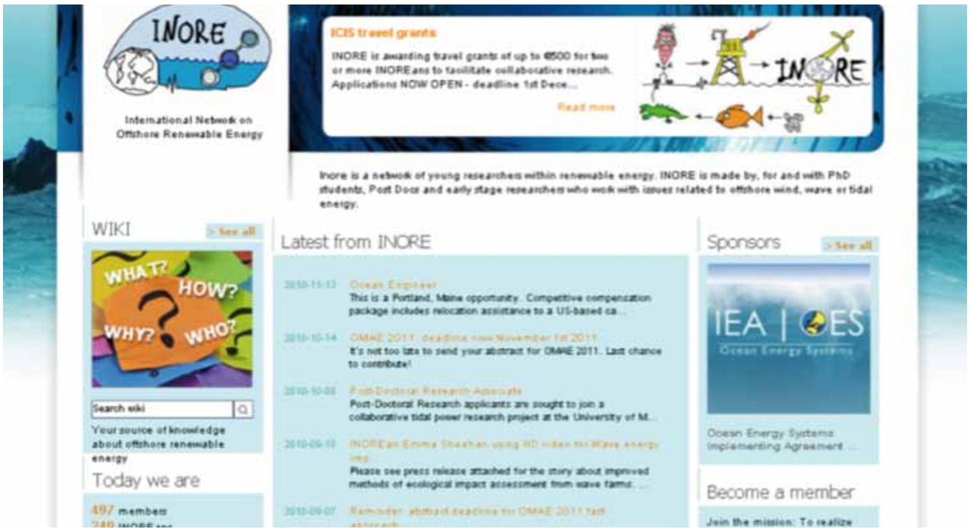

FIGURE 2: INORE's website which includes a new WIKI, member contact details, jobs adverts, INORE events management, and news from the industry

Future plans

After symposia in Trondheim, Edinburgh, Ghent and Dartmouth, the fifth annual symposium is moving south to Portugal (Alcoutim) from 8-13 May 2011. It will consist of the traditional intensive five-day meeting filled with presentations, collaboration, and discussion, for about 60 attendees, as well as local and international companies. The symposium is in the planning stages, so new members, sponsors and speakers are still welcome to become involved. This will be a unique opportunity for exposure to a select and normally diffuse community of offshore renewable energy researchers.

In 2011, we will be hosting a joint event with MARIN in Rotterdam. This new format of event will follow the OMAE conference in June 2011 and will consist of teams building a floating offshore wind turbine platform and testing the device in the wave tanks at MARIN.

Later in the year, INORE will be present at the European Wave and Tidal Energy Conference (EWTEC), in Southampton in 2011, where we hope that our ICIS travel grants will have facilitated several publications. We will also be hosting events in the Americas in 2011.

In the long term INORE's strategic goal is firstly to maintain its membership and reputation for being an excellent networking facility for researchers and industrial bodies relating to research. Secondly, we will be expanding our activities in the offshore wind sector. Thirdly, we will be adding a focus on developing countries, both on the research that takes place in developing countries, and also global research that is applied to developing countries, where the potential to have a positive impact is so great.

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ICOE 2010 – MOVING OCEAN ENERGY TO THE INDUSTRIAL SCALE

John Huckerby, AWATEA, New Zealand
António Sarmento, Wave Energy Centre, Portugal
Jochen Bard, Fraunhofer Institute, Germany
Chris Campbell, Ocean Renewable Energy group, Canada
Henry Jeffrey, UK Energy Research Centre (UKERC), Edinburgh University, United Kingdom
Eoin Sweeney, Sustainable Energy Authority of Ireland, Ireland
Jose Luis Villate, Tecnalia, Spain

Bilbao, Spain hosted the third International Conference and Exhibition on Ocean Energy (ICOE 2010) organised by EVE (the Basque Energy Board) and Tecnalia, with the partnership of OES-IA, the European Ocean Energy Association and the local energy industrial association. ICOE 2010 took place in October at the Bilbao Exhibition Centre and combined 3 days of conferences with an exhibition plus other parallel events. The event, with the support of Iberdrola as the main sponsor, attracted the top companies in the world from the ocean energy sector with more than 600 delegates and around 400 visitors to the exhibition and parallel events. These figures made ICOE2010 the world's largest ocean energy event to date.

The conference was officially opened on October 6th by representatives from the Basque Government, Tecnalia and Iberdrola with a clear message supporting the development of ocean energy as an important future renewable energy source.

After the formal opening session, the Vision panel was the first specific ocean energy session of the 2010 ICOE conference. The session encompassed full international representation for the ocean energy sector with speakers from the International Energy Agency, the European Ocean Energy Association, OREC (the main United States trade group) and with regional representation from the Basque country. This session provided a unique opportunity for each of these geographical regions to describe and debate their roadmaps, visions and forward strategies for ocean energy in a common forum. This discussion displayed not only how forward thinking each of these regions is regarding the planning for a rapid expansion of the ocean energy sector, but also the international commonality that exists between the strategies discussed. This commonality highlighted the potential for forming international synergies and collaborations to accelerate the progression of the ocean energy sector.

After the opening session, the conference ran 86 oral presentations divided into several parallel sessions grouped under three themes: Key Research Topics, Ocean Renewable Energy Development and Moving to the Industrial Scale.

Six sessions were organized under the track "Key Research Topics" to present 24 papers on different R&D aspects, namely: resource assessment and tools; array performance; tidal energy modelling, concepts and challenges; wave power concepts, components and characterization; environmental issues and performance assessment. A much larger number of papers were presented as poster. As a whole we may say that ICOE showed clearly that R&D activity on ocean energy is very much alive and covered not only the topics referred above in the oral presentations, but also site selection, numerical and experimental models, control and, to a less extent, operation and maintenance strategies and economics and marketing of ocean energy. As compared to the previous ICOE conferences, there have been a larger number of papers on tidal energy. Papers on ocean thermal energy conversion (OTEC) and salinity gradient were not present significantly, as well as papers on materials and offshore deployment issues. The weaker point in the oral and poster papers has been the much reduced impact of full-size or scale prototype tests in the sea in the presented R&D work. Indeed, and as far as the authors could find, only one paper on the airborne and underwater noise assessment at Pico plant reported work based on real data from sea trials of an existing prototype. This is a matter of relevance and worth further analysis as it shows that not sufficient information on the success and failures of ocean energy prototype deployment and tests is being passed to the wider community with the consequence that the resulting learning is insufficient. As a conclusion from the conference, the future R&D priorities must include collation and analysis of data, and verification of device performance (e.g. power production, environmental impact, resource interaction, survivability, reliability, etc) based on sea trials of full-scale grid-connected and partial-scale non-grid connected prototypes. R&D should also focus more on cost-effective installation and deployment tools, including dedicated support vessels, operations and maintenance techniques, new materials and new concepts.

"Ocean Renewable Energy Development" had 30 presentations divided into 6 sessions with the participation of technology developers covering wave and tidal energy converters, osmotic power and OTEC. A specific session was also organised to deal with a new trend, the combination of ocean energy devices with offshore wind turbines, which could benefit cost reduction due to synergies on common infrastructures. Grid integration and an update on the development of test facilities in Europe completed the review of ocean energy technologies.

"Moving to Industrial Scale" ran for three days and incorporated sessions on a range of topics, including presentations by 36 authors in seven sessions. The following is a necessarily brief review of the key points to emerge from the presentations in each session. Note that the listing of authors here is the actual order of presentations, which differed slightly from the original programme.

Economics and Cost Reduction

Gordon Dalton (HMRC) gave an interesting paper, one of only a few that tried to look at the economics of ocean energy, based upon what little public domain data is available. His conclusions were salutary: mid-life replacement, operations and maintenance costs and insurance can kill a project! Alex Raventos (Wave Energy Centre) described how fast marine energy could grow and tried to assess the saturation limit. His conclusion was that wave and tidal energy will become cost-comparative with other technologies between 2020 and 2030. Jochem Weber described Wavebob's three-pronged approach to viability – conceptual, technical and economic, insisting that all three were required. He demonstrated Wavebob's approach to optimizing values for levelised cost of energy, net present value and internal rate of return.
Cameron Johnstone's (University of Strathclyde) presentation focused on Nautricity's small contra-rotating horizontal axis tidal turbine. He showed that capital costs needed to fall from their current levels of GBP 8 million/MW to GBP 1.7 million/MW. Finally, Alan Mortimer described Iberdrola's involvement with the Hammerfest Strøm tidal turbine projects in Norway and Scotland.

The key conclusion from this session was that there is still insufficient data in the public domain and research work being undertaken on costs for marine energy and cost reduction strategies.

Planning, Permitting and Public Acceptability

Frank Neumann (IMI) described the OKEANOS modelling initiative and discussed legislative and regulatory requirements for ocean energy. Laura Zubiate (TECNALIA) discussed the need for Marine Spatial Planning (MSP) to secure and promote the role of marine energy amongst competing uses for marine space and resources. Julia Fernandez-Chozas (Spok) described a comparative study of public consultation and engagement for three marine energy projects, using examples from Kvitsoy in Norway, Wave Dragon in Wales and the Northwest National Marine Renewable Energy Center (NNMREC) in Oregon. Frédéric Villiers demonstrated an online GIS tool for MSP mapping developed by CETMEF.

The conclusions from this session were that it is unclear whether MSP will be a benefit or a threat to future marine energy projects. With respect to public consultation, the research by Fernandez-Chozas showed that there is no substitute for early engagement and communications.

Standardization

Melanie Nadeau, Chair of Technical Committee 114, gave a comprehensive presentation on the committee's current work on standards and technical specifications. Brian Holmes described his work on the five-stage development of marine energy devices (particularly wave and tidal current devices), before integrating these development stages with Technological Readiness Levels (TRLs), which are increasingly being used to

classify technologies in terms of the development state. Neil Rondorf, who chairs the US national committee of TC114, described the work being undertaken by US experts on development of standards and proposed some additional international collaborative research. Finally Andrew Cornett (Canadian Hydraulics Centre) talked about the guide on tidal resource assessment he had prepared for the Ocean Energy Systems Implementing Agreement (OES-IA), using examples from Minas Passage and the St. Lawrence River.
The conclusion of this session was that standards, guidelines and protocols will enable the marine energy industry to remain truly global by promulgating common practices and language about marine energy.

Removing Barriers and Building Competencies

Eoin Sweeney (SEAI) presented the recent publication Marine Renewable Energy – Research Challenges and Opportunities for a new Energy Era in Europe by the European Science Foundation. One of the interesting conclusions of this study was that marine energy could turn its low environmental impact into a competitive advantage, even with other renewable generation technologies. Juan Lopez described the €45 million Ocean Lider project, which brings together a number of Spanish companies and research centres with the aim of reducing costs for wave, tidal and wind energy projects. Marianne Boust gave details of an IHS high-level review of renewable electricity generation, showing forecast growth of 44% (over 2,000 MW) by 2025 with marine energy generation capacity forecast to grow to 1 GW by 2020 and to 10 GW by 2030. Lastly, Sarah Caraher reviewed the work of the postgraduate group, INORE, which now has 460 members, most undertaking postgraduate research on marine energy in collaboration with industry.

The conclusion is that marine energy has many international collaborative activities and these are providing direction and leadership to the development of the marine energy industry. The early involvement of postgraduate students is attractive, as it will be important to see turnover of industry participants.

Accelerating Progress

Daniela Dalton gave an interesting presentation on behalf of the Royal Bank of Scotland. She forecast a technology learning rate of 15% and said that the Bank expects marine energy to be cost-competitive with other technologies by 2020 (i.e., US$ 80-120/MWh). She said equity investment was preferred and that banks are unlikely to show interest in projects with less than 8,000 hours in the water. Pierre Brun reviewed Electricite de France's Paimpol-Brehat tidal project, which will use Open Hydro's 12 m diameter turbines. David Langston described the long history of the Wavegen technology – now with over 60,000 generating hours (and availability improved from 64% to 96% since 2005). Lastly, Tim Ramsey of the US Department o Energy detailed the use of TRLs to determine the maturity of marine energy projects, particularly with regard to their 2010 solicitation (which led to US$ 37 million being awarded to 27 projects).

The conclusion from this session was that there is no faster alternative route to commercialization than that provided by 'time in the water' for operating power plants.

Lessons Learnt from other Sectors

Neil Rondorf chaired a very interesting series of nine brief presentations by suppliers to other industries, offering equipment or services, ranging from grout or wind turbines to anti-fouling coatings for submerged devices. It was clear that there is a ready supply chain that can supply significant services to device and project developers.

Policies and National Initiatives

The final session chaired by Nathalie Rousseau (EU-OEA) was a very useful set of presentations of the policies and initiatives being used to promote and accelerate marine energy in Spain, the United Kingdom, France, Portugal and Canada. It was clear that there are many policy instruments available and many governments are developing approaches with specific expectation that marine energy can be a significant part of their clean energy strategies.

Round Table with Key Industrial Players

At the conclusion of the ICOE 2008 event in Brest, the wrap up panel of ocean energy sector leaders concluded that the emerging interest by utilities and by a few integrator/manufacturers was a good sign that ocean energy could move ahead. Fast forward to Bilbao in October 2010 and the sector has seen numerous investments by utilities and by a growing list of potential manufacturers, more full-scale trials of technology and the sector-focusing announcements of the potential 1.2GW in the 10 leases in Pentland Firth. So, a clear picture of the essential pathway for the sector emerged when Sue Barr, technology developer (Open Hydro), Jochen Weillep (Voith) and Philippe Gilson (Alstom) as integrator/maufacturers, Joe Hulm (International Power) and Luis Gomez Chavarria (Iberdrola Renovables) as power project developers, all engaged in a concluding panel, chaired by Chris Campbell (OREG).

The panel noted that the 2020 aspirations of 2-4GW installed that had come from a number of presentations was achievable if the experience with wind power manufacturing and development is to be repeated. However, they expressed an urgency to achieve a transition from research at the demonstrations scale to the accelerated learning from piloting power plants.

The message was one of focusing on demonstrating MWh of electricity produced by ocean energy. It was clear that even as only a few generators have achieved that target, work must focus on demonstrating pilot power plants as soon as possible. All agreed that planning for the permitting, financing, installation, operations and maintenance of array-scale pilots has to begin even as the individual generator trials are underway. Panellists reinforced the concept offered up by Iberdrola earlier in the conference that an effective development plan has to be working on 1 MW, 10 MW and commercial scale initiatives at the same time, aiming to incorporate the lessons learnt from one scale into the next. This recognises the challenge and time required to permit marine projects and to finance any move to larger scale, and fits with the conviction that technical and operational challenges will be solved at each of these phases. It also recognises that the interest of governments, utilities, manufacturers, investors and the supply chain can only be mobilised if they are working toward a target that is representative of an industrialised approach.

Addressing the need to accelerate this development, the panellists highlighted the need to focus assets on the path forward, and to avoid duplication. Testing in any jurisdiction should facilitate technology advance anywhere. The issue of the growing commitment to demonstration centres over the last two years led to a discussion of how these could take on unique roles rather than simply replicate the European Marine Energy Centre (EMEC). The discussion advanced the concept that these common infrastructure facilities could be better focused as development centres or incubators since they have the potential to solve the major impediments to moving forward, those of access to permitted ocean, and access to grid. The importance of coordination between all of them and dissemination of key outcomes can avoid duplication and accelerate overall progress since many advances are potentially widely applicable. Also their work should be focused on the needs of utilities in addition to technology developers, recognizing the fact that market-pull is critical to the 10MW+ generations of projects. Their early participation is essential so that they can become comfortable ahead of these major investments.

It was perhaps this discussion that set the closing challenge at ICOE 2010. Can the creation of the development centres in Ireland, France, Spain, Canada and the US be used to create some forms of Marine Energy Parks or incubators? Should these share the burden of permitting, grid access, environmental monitoring and marine operations and create an open pathway ahead of the power project and technology development plans? If the panel set a challenge to be reported on at ICOE 2012, it would be to show how these incubators are catalysing a phased development of power development projects as the prototype "power plants" for this sector.

ROUND TABLE:
Chris Cambpell (OREG),
Jochen Weillep (Voith),
Philippe Gilson (Alstom),
Sue Barr (Open Hydro),
Luis Gomez-Chavarria (Iberdrola Renovables)
and Joe Hulm (International Power).

PARTICIPANTS IN THE CLOSING SESSION:
Antonio Sarmento (Wave Energy Centre),
Oscar Zabala (Basque Government),
Jose Luis Villate (Tecnalia),
Thierry D'Estaintot (European Commission),
Jochen Bard (Fraunhofer IWES),
John Huckerby (OES)

ICOE2012

Eoin Sweeney thanked the Committee for the invitation to Ireland to host ICOE 2012. In accepting the invitation, he acknowledged the challenge of organising an event that will maintain the quality and enthusiasm that was evident at ICOE 2010. He congratulated EVE and Tecnalia and welcomed their continued involvement through the organising Committee for 2012. He stressed the commitment that the Irish authorities have shown to the development of ocean energy and the wholehearted support that exists across many agencies, to ensure that ICOE 2012 will be a success and welcomed all the participants to Dublin in October 2012.

ICOE 2010 attracted the top companies in the world from the ocean energy sector with more than 600 delegates and around 400 visitors to the exhibition and parallel events. These figures made ICOE 2010 the world's largest ocean energy event to date.

Future Research and Development priorities must include collation and analysis of data, and verification of device performance based on sea trials of full-scale grid-connected and partial-scale non-grid connected prototypes.

There is still insufficient data in the public domain and research work being undertaken on costs for marine energy and cost reduction strategies.

Test facilities should be better focused as development centres or incubators where technology developers and utilities are catalysing a phased development of power development projects as the prototype "power plants" for this sector.

2011

MARINE SPATIAL PLANNING AND OCEAN ENERGY

2011
MARINE SPATIAL PLANNING AND OCEAN ENERGY

MARINE SPATIAL PLANNING: AN IDEA WHOSE TIME HAS COME

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Before the last century, the oceans were used mainly for two purposes: marine transportation and fishing. Conflicts between uses were few and far between, except around some ports. Fisheries were managed separately from oil and gas development, which in turn was managed separately from marine navigation, despite real conflicts between and among these uses.

Single-sector management has often failed to resolve conflicts among users of marine space, rarely dealing explicitly with trade-offs among uses, and even more rarely dealing with conflicts between the cumulative effects of multiple uses and the marine environment. New uses of marine areas, including wind energy, ocean energy, offshore aquaculture, and marine tourism, as well as the demand for new marine protected areas, have only exacerbated the situation. Single-sector management has also tended to reduce and dissipate the effect of enforcement at sea because of the scope and geographic coverage involved and the environmental conditions, in which monitoring and enforcement have to operate. In sharp contrast to the land, little "public policing" of human activities takes place at sea.

As a consequence, marine ecosystems around the world are in trouble. Both the severity and scale of impact on marine ecosystems from overfishing, habitat loss and fragmentation, pollution, invasive species and climate change are increasing, with virtually no corner of the world left untouched.

Awareness is growing that the ongoing degradation in marine ecosystems is, in large part, a failure of governance. Many scientists and policy analysts have advocated reforms centred on the idea of "ecosystem-based management" (EBM). To date, however, a practical method for translating this concept into operational management practice has not emerged. One step in that direction is the increasing worldwide interest in "marine spatial planning".

What Is Marine Spatial Planning?

Marine spatial planning (known as maritime spatial planning, in Europe), or MSP, is a practical way to create and establish a more rational organization of the use of marine space and the interactions between its uses, to balance demands for development with the need to protect marine ecosystems, and to achieve social and economic objectives for marine regions in an open and planned way.

MSP is a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social goals and objectives that are usually specified through a political process.

Its characteristics include:

- **integrated** across economic sectors and governmental agencies, and among levels of government;
- **strategic** and **future-oriented**, focused on the long-term;
- **participatory**, including stakeholders actively in the entire process;
- **adaptive**, capable of learning by doing;
- **ecosystem-based**, balancing ecological, economic, social, and cultural goals and objectives toward sustainable development and the maintenance of ecosystem services; and
- **place-based or area-based**, i.e., integrated management of all human activities within a spatially defined area identified through ecological, socio-economic, and jurisdictional considerations.

It is important to remember that we can only plan and manage human activities in marine areas, not marine ecosystems or components of ecosystems. We can allocate human activities to specific marine areas by objective, e.g., development or preservation areas, or by specific uses, e.g., offshore energy, offshore aquaculture, or sand and gravel mining.

Why Is Marine Spatial Planning Needed?

Most countries already designate or zone marine space for a number of human activities, such as maritime transportation, oil and gas development, offshore energy, offshore aquaculture and waste disposal. However, the problem is that usually this is done on a sector-by-sector, case-by-case basis without much consideration of effects either on other human activities or the marine environment. Consequently, this situation has led to two major types of conflict:

- Conflicts among human uses (user-user conflicts); and
- Conflicts between human uses and the marine environment (user-nature conflicts).

These conflicts weaken the ability of the ocean to provide the necessary ecosystem services upon which humans and all other life on Earth depend. Furthermore, decision makers in this situation usually end up only being able to react to events, often when it is already too late, rather than having the choice to plan and shape actions that could lead to a more desirable future of the marine environment.

By contrast, marine spatial planning is a future-oriented process. It offers a way to address both these types of conflict and select appropriate management measures to maintain and safeguard necessary ecosystem services. MSP focuses on the human use of marine spaces and places. It is the missing piece that can lead to truly integrated planning from coastal watersheds to marine ecosystems.

When effectively put into practice, MSP can be used to:

- Set priorities - to enable significant inroads to be made into meeting the development objectives of marine areas in an equitable way, it is necessary to provide a rational basis for setting priorities, and to manage and direct resources to where and when they are most needed;
- Create and stimulate opportunities for new users of marine areas, including ocean energy;
- Co-ordinate actions and investments in space and time to ensure positive returns from those investments, both public and private, and to facilitate complementarity among jurisdictions and institutions;
- Provide a vision and consistent direction, not only of what is desirable, but what is possible in marine areas;
- Protect nature, which has its own requirements that should be respected if long-term sustainable development is to be achieved and if large-scale environmental degradation is to be avoided or minimized;
- Reduce fragmentation of marine habitats, i.e., when ecosystems are split up due to human activities and therefore prevented from functioning properly;
- Avoid duplication of effort by different public agencies and levels of government in MSP-related activities, including planning, monitoring and permitting; and
- Achieve higher quality of service at all levels of government, e.g., by ensuring that permitting of human activities is streamlined when proposed development is consistent with a comprehensive spatial plan for the marine area.

Why Is Space and Time Important?

Some areas of the ocean are more important than others - both ecologically and economically. Species, habitats, populations of animals, oil and gas deposits, sand and gravel deposits, and sustained winds or waves — are all distributed in various places and at various times. Successful marine management needs planners and managers that understand how to work with the spatial and temporal diversity of the sea. Understanding these spatial and temporal distributions and mapping them is an important aspect of MSP. Managing human activities to enhance compatible uses and reduce conflicts among uses, as well as to reduce conflicts between human activities and nature, are important outcomes of MSP. Examining how these distributions might change due to climate change and other long-term pressures, e.g., overfishing, on marine systems is another important step of MSP.

What Have Been the Principal "Drivers" of MSP?

Pressures from human activities have often led to initiatives to better manage marine areas. For example, in the 1970s, the threat of offshore oil and gas development and phosphate mining led to efforts to protect the Great Barrier Reef. More recently, particularly in Western Europe, MSP has been driven by national policies to develop offshore wind energy in Belgium, the Netherlands, and Germany (all of whom have developed and implemented marine plans), and the United Kingdom (England has only just begun development of marine spatial plans for two sub-regions of its marine area). There is also a requirement to designate more marine protected areas under directives of the European Commission. These "new" uses have had to compete with traditional users for scarce ocean space. Offshore wind energy has also been a driver for MSP in the states of Massachusetts and Rhode Island in the United States of America (USA), both of which have completed plans for their state waters that identify "appropriate" areas for wind energy development.

Since ocean energy remains in the R&D stage today, it has not been a principal driver of MSP in any country, to date. While interests in the development of an ocean energy sector are high, large-scale commercial development and economic viability appear to still lie in the future. In 2009, Marine Scotland published a consultation document on a framework for MSP and a guidance document for marine renewable energy for the Pentland Firth and Orkney waters (0-12 nm) - an area long recognized for its ocean energy potential.

In the USA, the State of Oregon is completing a plan for its marine waters that is considering the potential of ocean energy. Oregon has an ideal combination of high-energy waves and available infrastructure that has led many companies to try to stake a claim to the State's potentially lucrative waters. The Oregon State government reached an agreement in 2008 with the federal agency responsible for issuing ocean energy permits to suspend issuing wave energy permits while the State updated its Territorial Sea Plan to deal with the new use of the ocean. The Federal Government has to work with the State in permitting sites inside state waters (0 - 3 nm) and as far out as the outer continental shelf. Oregon's Ocean Policy Advisory Committee has been gathering data to identify possible wave energy sites, including key fishing grounds, important wildlife areas, and to other competing uses. The plan should be completed in 2012.

What Are the Key Elements of Marine Spatial Planning?

The development and implementation of MSP involves a number of steps, including:

1. Identifying need and establishing authority;
2. Obtaining financial support;
3. Organizing the process through pre-planning;
4. Organizing stakeholder participation;
5. Defining and analyzing existing conditions;
6. Defining and analyzing future conditions;
7. Preparing and approving the spatial management plan;
8. Implementing and enforcing the spatial management plan;
9. Monitoring and evaluating performance; and
10. Adapting the marine spatial management process.

These 10 steps are not simply a linear process that moves sequentially from step to step. Many feedback loops should be built into the process. For example, goals and objectives identified early in the planning process are likely to be modified as costs and benefits of different management measures are identified later in the planning process. Analyses of existing and future conditions will change as new information is identified and incorporated in the planning process. Stakeholder participation will change the planning process, as it develops over time. Planning is a dynamic process and planners and stakeholders have to be open to accommodating changes as the process evolves over time.

Comprehensive MSP provides an integrated framework for management that provides a guide for, but does not replace, single- sector management. For example, MSP can provide important contextual information for guiding marine protected area management or for fisheries management, but does not replace it.
MSP answers four simple questions:

- **Where are we today?** What are the baseline conditions?
- **Where do we want to be?** What are the alternative spatial scenarios of the future? What is the desired vision?
- **How do we get there?** What spatial management measures move us toward the desired future?
- **What have we accomplished?** Have the spatial management measures moved us in the direction of the desired vision? If not, how should they be adapted in the next round of planning?

What Are the Outputs of Marine Spatial Planning?

The principal output of MSP is a comprehensive spatial management plan for a marine area or ecosystem. The plan moves the whole system toward a "vision for the future". It sets out priorities for the area and - more importantly - defines what these priorities mean in time and space. Typically, a comprehensive spatial management plan has a 10- to 20-year horizon and reflects political and social priorities for the area. The comprehensive marine spatial plan is usually implemented through a zoning map, zoning regulations, and/or a permit system similar to a comprehensive regional plan on land. Individual permit decisions made within individual sectors (for example, the fisheries, or oil and gas, or tourism sectors) should then be based on the zoning maps and regulations.

MSP does not replace single-sector planning and decision making. Instead, it aims to provide guidance for a range of decision makers responsible for particular sectors, activities, or concerns, so that they have the means to make decisions confidently in a more comprehensive, integrated and complementary way.

Why Is Stakeholder Participation Critical to Marine Spatial Planning?

Involving key stakeholders, including those in the ocean energy sector, in the development of MSP is essential for a number of reasons. Of these, the most important is that MSP aims to achieve multiple objectives (social, economic and ecological) and should therefore reflect as many expectations, opportunities or conflicts that are occurring in the MSP area, as possible. The scope and extent of stakeholder involvement differs greatly from country to country and is often culturally influenced. The level of stakeholder involvement will largely depend on the legal or cultural requirements for participation that often exist in each country.

Generally speaking, all individuals, groups and organizations, which are, in one way or another affected, involved or interested in MSP, can be considered stakeholders. However, involving too many stakeholders at the wrong moment or in the wrong form can be very time consuming and can distract resources from the expected or anticipated result. To involve stakeholders effectively (e.g., leading toward expected results) and efficiently (e.g., producing expected results at least-cost), three questions should be asked:

- Who should be involved?
- When should stakeholders be involved?
- How should stakeholders be involved?

Where no legal obligations exist, it is important to define what type of stakeholder participation will be most suitable for a successful result. For instance, involving indigenous people in MSP efforts may not be a legal requirement, but they could however be greatly affected (positively or negatively) by MSP management measures, and should therefore participate.

Wide-ranging and innovative approaches to stakeholder participation and proactive empowerment should be used in the MSP process. Stakeholder participation and involvement in the process should be early, often, and sustained throughout the process. Stakeholder participation and involvement encourages "ownership" of the plan and can engender trust among the various stakeholders. Different types of stakeholder participation should be encouraged at various stages of the MSP process. The key stages at which stakeholders should be involved in the process include:

- **The planning phase:** Stakeholders need to be involved and contribute to the setting of goals and objectives of MSP. They also need to be involved in the evaluation and choice of specific management measure options and the consequences of these choices on their areas of interest;
- **The implementation phase:** Stakeholders should be involved in the actual implementation of MSP and its management measures. For example, an approach to enforcement may be identified and that would involve local communities in the regulatory and enforcement process. When the local communities understand the problems and benefits of taking action—and agree upon the management measures to be taken—they will be part of the enforcement process, at least to the extent of encouraging compliance; and
- **The monitoring and evaluation (post-implementation) phase:** Stakeholders should be involved in the evaluation of the overall effectiveness of MSP in achieving goals and objectives. The post-evaluation effort should involve all stakeholders in a discussion to identify plan results, evaluate results against objectives, and prepare the next round of planning.

CONCLUSION

While ocean energy has not been a principal driver of MSP so far, the situation is likely to change over the next two decades. Since ocean energy projects may take up significant areas of local ocean space, it is likely to compete with other purposes for the same space, including other human uses and areas reserved for nature conservation. The possible impacts of ocean energy on other uses, such as marine transport, offshore aquaculture, fishing, and recreation, will depend on the location of ocean energy infrastructure. Certainly over the next decade, MSP will be up and running in the marine areas of most countries. Early and continuing engagement with these emergent MSP processes will certainly benefit the ocean energy sector.

MARINE SPATIAL PLANNING (MSP) IN THE EUROPEAN UNION AND ITS APPLICATION TO MARINE RENEWABLE ENERGY

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INTRODUCTION

Maritime Spatial Planning (MSP) is an essential tool for the sustainable development of maritime regions. It is intended to promote rational use of the sea by providing a stable and transparent planning system for maritime activities and users. Numerous definitions of MSP exist: in the European Union (EU) it is defined as a process that relates to planning and regulation of all human uses of the sea while protecting marine ecosystems. It is accepted in the EU that MSP focuses on marine waters under national jurisdiction. However, the geographic coverage of any MSP system will vary according to regional conditions. In principle, from an EU perspective, the MSP process does not include coastal management or planning of the land-sea interface, which is to be addressed through the implementation of Integrated Coastal Zone Management (ICZM). Different terms tend to be used synonymously in current practice, for example, marine planning, ocean planning, and marine spatial planning. In the EU 'Maritime' Spatial Planning is preferred, as it is thought to capture the holistic, cross-sectoral approach of the process (COM(2008) 791 final). For this reason, the term Maritime Spatial Planning is used throughout this article.

This article initially outlines the policy basis for MSP in the EU, the principles for a common European approach and the status of MSP in individual Member States. The status is reviewed according to extant legislation, coordination of MSP and existing programmes, plans and projects that endeavour to implement MSP. While it is impossible to include a review of all national initiatives in this article, the approaches adopted by a selection of EU Member States are discussed and examples from key projects that focus on MSP, or aspects of it, are highlighted. To reflect the importance of MSP for marine renewable energy development, the article focuses on the application of MSP to marine renewable energy across Europe and, more specifically, how industry requirements are incorporated (or not) in existing MSP systems. The ocean energy sector is still developing and, as such, may have differing requirements to other sectors. The final section of the article considers other policy developments that are likely to influence the future development and functioning of MSP. As MSP is inextricably linked to Integrated Coastal Zone Management, the position of this in EU Member States is included.

Principles of Maritime Spatial Planning in the European Union

An Integrated Maritime Policy (IMP) for the European Union was published by the European Commission in 2007 (COM(2007) 575 final). This acknowledged that there was increasing competition for marine space and that this was leading to both conflicts between existing users and deterioration of the marine environment. The IMP clearly recognised that everything relating to Europe's oceans and seas is interlinked and, consequently, there is a need for an integrated approach to maritime governance and new tools to deliver this type of approach. Traditionally, management of marine resources and associated uses occurs on a sectoral basis with the existence of a management authority for almost every maritime activity. From previous experiences in resource management, it is known and accepted that such fragmented decision-making invariably results in conflicts of use, inconsistencies between sectors and inefficiencies. The Commission, through the IMP, therefore, sought to address this by applying the integrated management approach at every level, through the utilisation of both horizontal and cross-cutting policy tools. In this context, the IMP put forward maritime surveillance, Maritime Spatial Planning and [additional] data and information as three essential tools for integrated management.

Given the strong advocacy of MSP as the desired planning tool to be used for sustainable decision-making, the Commission felt it necessary to put forward a set of common principles to "facilitate the process in a flexible manner and to ensure that regional marine ecosystems that transcend national maritime boundaries are respected" (COM(2007) 575 final, p.6). A common approach was deemed necessary to ensure consistency. Competency for the design and implementation of MSP resides with individual Member States and not with the EU per se. This also explains why progress varies between Member States (see below). The Commission published their common principles in 2008 in a Communication entitled "Roadmap for Maritime Spatial Planning: Achieving Common Principles in the EU" (COM(2008) 791 final). In this Communication, the Commission put forward their rationale for the benefits of a European approach stating that, ultimately, the use and implementation of MSP will "enhance the competitiveness of the EU's maritime economy, promoting growth and jobs in line with the Lisbon agenda… in line with ecosystem requirements" (p.3). The over-arching principle for MSP is the ecosystem approach, whereby human activities affecting the marine environment are managed in an integrated manner promoting conservation and sustainable use, in an equitable way, of oceans and seas (COM(2005) 504 final, p.5). This is complemented by ten supporting principles, presented in Box 1.

- Using MSP according to area and type of activity;
- Defining objectives to guide MSP;
- Developing MSP in a transparent manner;
- Stakeholder participation;
- Coordination within Member States - Simplifying decision processes;
- Ensuring the legal effect of national MSP;
- Cross-border cooperation and consultation;
- Incorporating monitoring and evaluation in the planning process;
- Achieving coherence between terrestrial and maritime spatial planning; and
- A strong data and knowledge base.

BOX 1: European Union Principles for MSP (COM(2008) 791 final)

These principles were derived from existing approaches to MSP in Member States and other international examples that included research projects. Other legal instruments informed the creation of these principles. These include the United Nations (UN) Law of the Sea Convention, Regional Seas Conventions (e.g. OSPAR, HELCOM) and numerous EU legal instruments (e.g. Common Fisheries Policy, Water Framework Directive, Marine Strategy Framework Directive etc.). The Roadmap containing these principles is seen as "the first steps towards a common approach on MSP" (COM(2008) 791 final, p.11).

Status of MSP in EU Member States

Notwithstanding the strong policy base for MSP, implementation is taking place on a predominantly ad hoc basis. The EU member nations of the Ocean Energy Systems Implementing Agreement have implemented MSP differently (Table 1). Whilst few Member States have dedicated MSP legislation or an over-arching coordination authority, most have some form of programme or plan on MSP, a necessary first step in the MSP process. While such programmes and plans take a sectoral perspective, they have enabled initial debate on coexistence of maritime uses, conflicts between uses and problems with existing spatial management tools. This can inform the development of an appropriate MSP system, in line with the common principles above. Each Member State faces different challenges in developing an MSP system and it should be recognised at the outset that there is no single, correct approach to MSP. The approach taken will vary according to the size and nature of the maritime space, the types of activity and uses going on there, as well as the pertinent legal and institutional arrangements (MRAG/European Commission, 2008). As a result, a variety of mechanisms can be used to implement MSP, including specific regulations and zoning of sea areas. It is also important to stress that MSP is just one element of broader ocean management and should be viewed as a 'strategic vision' for a maritime area that is supported by a range of other policies, including sector specific policies (Ehler and Douvere, 2009).

MEMBER STATE	LEGISLATION	PROGRAMMES	COORDINATION	ICZM
Belgium	[red]	[blue]	[grey]	Equivalent measures
Denmark	[red]	[green]	[grey]	Sectoral tools
Germany	[green]	[green]	[green]	National strategy
Ireland	[red]	[green]	[red]	Sectoral tools
Italy	[red]	[red]	[red]	Strategy in preparation
Portugal	[blue]	[green]	[red]	National strategy
Spain	[red]	[red]	[red]	Strategy in preparation
Sweden	[green]	[red]	[red]	Equivalent measures
United Kingdom	[blue]	[green]	[green]	National strategy

TABLE 1: Status of MSP in EU Member States that are Members of the OES

Note: With respect to legislation for, programmes on, and coordination of MSP dark green indicates that the Member State has sectoral elements in place. Blue indicates that fully integrated elements are in place. Grey indicates that the status is unknown and red indicates that the element is not yet in place. The information presented in this table is adapted from Thetis, 2011.

Many States across Europe are just beginning to formulate an appropriate legal framework for MSP. This is complicated by competencies across governance levels in many EU Member States. In the case of **Germany**, for example, responsibility for MSP in the Territorial Sea (i.e. to the 12 nm limit) rests with the federal states (Länder) as part of their regional planning functions. Beyond the Territorial Sea, in the Exclusive Economic Zone (EEZ) (to 200 nm), MSP is the responsibility of the German Federal government. Specific legislation was enacted for spatial planning in the German EEZs of both the North Sea and the Baltic Sea in 2009. In **Sweden**, a Marine Environment Inquiry was appointed by the Government, in 2006, to explore ways in which their marine management could be improved. The report of the inquiry was released in June 2008 and found that it was time for a "third-generation environmental policy" that "must entail a holistic approach and full integration of environmental issues into all policy areas, stronger political leadership and, to a much greater extent, an international focus" (Ministry of the Environment, 2008). Despite this, no formal and integrated legal framework for MSP exists. Legislation for spatial planning of land, however, extends to the limit of the Territorial Sea. **Belgium** was among the first EU Member States to start implementing an operational, multiple-use planning system in its Territorial Sea and EEZ, through associated legislation, namely the EEZ Act of 1999 and the Marine Protection Act of 1999. In practice, these effectively provide for a zoning approach to regulate activities at sea rather than for a broader MSP process.

In contrast, the UK has adopted a new policy to deliver the provisions of the Marine Strategy Framework Directive (MSFD) in the **United Kingdom**[12] through the enactment of the Marine and Coastal Access Act 2009.[13] This Act also establishes an integrated planning system for managing seas, coasts and estuaries, a new legal framework for decision-making as well as streamlined regulation and enforcement. The new marine planning system has three components: the Marine Policy Statement, Marine Plans and Marine Licensing. The Marine Policy Statement sets the general environmental, social and economic considerations that need to be taken into account in marine planning (Part 3, Chapter 1, sections 44 - 48). This Statement applies to all UK waters. Marine Plans must be consistent with the Marine Policy Statement and, ultimately, will indicate to developers the locations where (1) they can conduct their activities; (2) they can conduct their activities under certain restrictions or (3) their activities are unlikely to be considered appropriate (Part 3, Chapter 2, sections 49 - 54). Following the adoption of a marine plan, public authorities taking consenting or enforcement decisions must do so in accordance with those Marine Plans and the over-arching Marine Policy Statement unless they can provide justification for doing otherwise (Part 3, Chapter 4, sections 58 - 60).

[12] The UK, in this context, refers only to England and Wales. The Marine (Scotland) Act 2010 and proposed legislation in Northern Ireland will introduce new marine planning systems in those jurisdictions.
[13] Formerly known as the Marine Bill.

Portugal has also been relatively progressive in implementing a legal framework for MSP. This stems from the publication of a National Ocean Strategy in 2006, which sought to integrate sectoral policies and define principles for both MSP and ICZM (Government of Portugal, 2006). As a response to this, work on the Plano de Ordenamento do Espaço Marítimo (POEM), a Portuguese maritime spatial plan, began in 2008. The development of this plan consists of four stages, (1) characterisation studies and assessment; (2) provisional maritime spatial plan; (3) zoning plan and implementation programme; and (4) public consultation. The public consultation stage has recently ended and the final version of the plan is due for publication in the near future. In Denmark, Ireland, Italy and Spain work on the development of an appropriate MSP system is just beginning. In **Denmark**, for example, this has involved the creation of a working group, consisting of the relevant Danish authorities, which is tasked with presenting proposals for future practice in terms of MSP in Denmark (Danish Government, 2010). A number of pilot projects on MSP in Denmark also exist. **Ireland** is in the process of reforming its foreshore management regime and it is hoped that this will reflect the EU's MSP principles (O'Hagan and Lewis, 2011). In **Italy** and **Spain** there is no integrated approach to MSP as yet, though there are some active projects which seek to apply MSP in specific locations.

Coordination of MSP systems also varies according to Member State. In some countries, there is a dedicated single management entity responsible for implementation of MSP. In the **UK**, for example, Part 1 of the Marine and Coastal Access Act 2009 provided for the establishment of the Marine Management Organisation, which is tasked with implementing the new MSP system, the associated licensing regime, management of fishing fleet capacity and designation of Marine Protected Areas. In **Portugal**, any amendments to the POEM will require approval by a multi-disciplinary team, consisting of representatives from the relevant government ministries, Instituto Nacional da Água (INAG; Portuguese Water Institute) and four external consultants, including some university representatives (Calado et al., 2010). Generally, the constitutional system in each Member State will dictate their governance structure. Consequently, in States with complex governance structures, such as **Belgium**, **Germany** and the **UK**, the constitutional system will determine both the entity that has legislative capacity for elements of MSP and the level of government that has primary competency over internal waters, the Territorial Sea, EEZ etc. (MRAG/European Commission, 2008). Despite the governance model that exists, what is essential is that there is a framework to support MSP and facilitate integration amongst sectors. As a tool for improved decision-making, MSP must ensure that all stakeholders are included and can get involved in the process.

Plans, Programmes and Projects on MSP

From the brief outline above, it is clear that progress on MSP across the European Union varies significantly with few fully integrated and developed MSP systems. One way in which this is being addressed, both at EU and individual Member State level, is to begin the MSP process with a dedicated MSP programme, or pilot demonstration, at specific locations, often where a range of maritime uses exist. Such initiatives can be instigated solely at national level but more commonly take a regional or pan-European approach, reflective of the approach suggested in the IMP, and as such can be funded under various EU research programmes such as FP7, Intelligent Energy Europe and INTERREG. Table 2 presents a selected sample of such projects, paying particular attention to those that have a marine renewable energy focus.

NAME	AIMS AND OBJECTIVES	WEBSITE
INTERREG III BALANCE: Baltic Sea Management: Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning	The project aims to develop transnational MSP tools and an agreed template for marine management planning and decision-making. It is based on 4 transnational pilot areas demonstrating the economic and environmental value of habitat maps and MSP (through 2 zoning plans). The tools and zoning plans integrate biological, geological and oceanographic data with local stakeholder knowledge	*http://www.balance-eu.org/*
INTERREG IV BaltSeaPlan: Towards a Spatial Structure Plan for Sustainable Management of the Sea	With a learning-by-doing approach, BaltSeaPlan will attempt to overcome the lack of relevant legislation in most Baltic Sea Region countries for MSP. The project developed pilot plans for 8 demonstration areas around the Baltic Sea and has also advanced methods, instruments and tools and data exchange necessary for effective maritime spatial planning.	*http://www.baltseaplan.eu/*
FP7 COEXIST: Interaction in Coastal Waters: A Roadmap to Sustainable Integration of Aquaculture and Fisheries	COEXIST is a broad, multidisciplinary project which will evaluate competing activities and interactions in European coastal areas. The ultimate goal is to provide a roadmap to better integration, sustainability and synergies among different activities in the coastal zone. Six case study areas are included in the project.	*http://www.coexistproject.eu/*
INTERREG III GAUFRE: Towards a Spatial Structure Plan for Sustainable Management of the Sea	The main aim of the project is the delivery and the synthesis of scientific knowledge on the use and possible impacts of use functions. Consequently, a first proposal of possible optimal allocations of all relevant use functions in the Belgian part of the North Sea (BPNS) will be formulated.	*http://www.vliz.be/projects/gaufre/index.php*
FP7 KnowSeas: Knowledge-based Sustainable Management for Europe's Seas	The overall objective of the project is to provide a comprehensive scientific knowledge base and practical guidance for the application of the Ecosystem Approach to the sustainable development of Europe's regional seas. It will be delivered through a series of specific sub-objectives that lead to a scientifically-based suite of tools to assist policy makers and regulators with the practical application of the Ecosystem Approach to various sectors.	*http://www.knowseas.com/*
EU Preparatory Action (IMP) MASPNOSE	The project will explore the possibilities for cross-border collaboration in maritime spatial planning in the North Sea and will build on other projects and initiatives that are already looking at integrating spatial information and planning.	*https://www.surfgroepen.nl/sites/CMP/maspnose/default.aspx*
FP7 MESMA: Monitoring and Evaluation of Spatially Managed Areas	This project aims to produce integrated management tools (concepts, models and guidelines) for monitoring, evaluation and implementation of Spatially Managed Areas (SMAs). The project results will support integrated management plans for designated or proposed sites with assessment methods based on European collaboration.	*http://www.mesma.org/*
FP7 ODEMM: Options for Delivering Ecosystem-Based Marine Management	The aim is to develop a set of fully-costed ecosystem management options that would deliver the objectives of the MSFD, the Habitats Directive and the IMP. The key objective is to produce scientifically-based operational procedures that allow for a step by step transition from the current fragmented system to fully integrated management.	*http://www.liv.ac.uk/odemm/*
EU Preparatory Action (IMP) PlanBothnia	The project, coordinated by the HELCOM Secretariat, will test MSP in the Bothnian Sea area as a transboundary case between Sweden and Finland. Partners provide background material on relevant human activities and natural features as well as draft material for plans for the Bothnian Sea region. This material will be considered in five dedicated transboundary planning meetings.	*http://planbothnia.org/*
INTERREG III PLANCOAST	The aim is to develop the tools and capacities for effective integrated planning in coastal zones and maritime areas in the Baltic, Adriatic and Black Sea regions. PlanCoast pilot projects formed the basis for recommendations at local and national level on how to implement, adapt and further develop the ICZM and MSP in each partner country.	*http://www.plancoast.eu/*
INTERREG III POWER: Pushing Offshore Wind Energy Regions	The central aim of POWER is to unify North Sea regions, to learn from each other, to set up common strategies overcoming economic changes, to respond to new educational needs and thereby give a positive impetus to continuing sustainable development of the region.	*http://www.offshore-power.net/*
EACI/IEE SEAENERGY 2020	The project will formulate concrete policy recommendations on how best to deal with MSP and remove MSP obstacles that hinder the deployment of offshore renewable energy. It will provide policy recommendations for a more coordinated approach to MSP and larger deployment of marine renewables (wind, wave, tidal).	*http://www.seanergy2020.eu/*
EACI/IEE WINDSPEED: Spatial Deployment of Offshore Wind Energy in Europe	Windspeed aims to assist in overcoming existing obstacles to deployment by developing a roadmap defining a realistic target and development pathway up to 2030 for offshore wind energy in the Central and Southern North Sea. This includes delivering a decision support system (DSS) tool using geographical information system (GIS) software. This will also facilitate the quantification of trade-offs between electricity generation costs from offshore wind and constraints due to non-wind sea functions and nature conservation, thereby assisting policy makers in terms of allocating space for the development of offshore wind the Central and Southern North Sea.	*http://www.windspeed.eu/*

▲
TABLE 2: Current and Completed MSP Projects of Relevance to Marine Renewable Energy Projects

The deliverables from many of the above mentioned projects will assist in the development of more effective national and regional MSP systems. This is particularly true of projects that have a specific sectoral or industry focus, such as renewable energy, or projects that consider the potential for conflict between actors, for example, fisheries and offshore wind energy.

Application of MSP to Marine Renewable Energy

Inclusion of marine renewable energy requirements in MSP systems varies not only according to location but also according to the status of the industry in that country. In **Germany**, for example, dedicated work on MSP was triggered by the economic interest in developing offshore wind energy, which was necessary to achieve the Government's emission targets (MRAG/European Commission, 2008). To secure the scale of investment needed for such large scale projects, a stable and predictable planning framework was required. MSP was viewed as the process which could help identify and allocate areas to certain activities and thus contribute to expediting the decision making process. Priority areas for offshore wind energy development in the German EEZs of both the North Sea and the Baltic Sea were subsequently zoned (Figure 1). **Belgium** has taken a similar 'zoning' approach and legally designated a 270 km² area for offshore wind projects (total capacity of 2,000 MW).[14] Whilst **Denmark** does not have an established MSP system in place, 23 sites were pre-selected for offshore wind energy development as far back as 2007 (Danish Energy Authority, 2007).

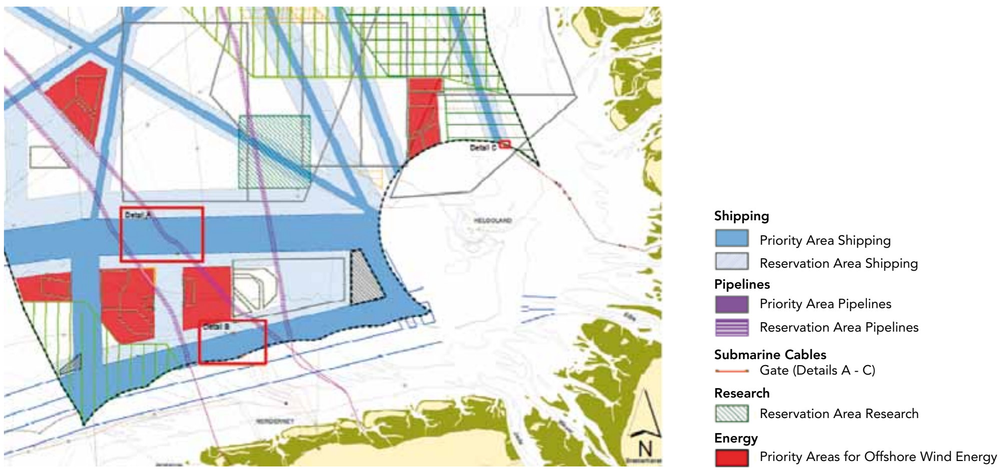

FIGURE 1: Extract from Spatial Plan Map for the German EEZ of the North Sea (BMVBS, 2009)

It should be emphasised here that zoning of activities/areas is one of a number of management mechanisms which may be introduced in a Marine Spatial Plan to help achieve the overall objectives of the MSP system. Technically, zoning can be described as a management tool for spatial control of activities with defined activities, permitted or prohibited from specified geographic locations (Gubbay, 2005). Zoning can separate conflicting activities or indeed give a particular sectoral interest exclusive use of an area of sea, as is the case in the above mentioned examples for offshore wind energy development. Generally, if an area is zoned for a particular use, that use will require the granting of a consent or licence[15] so that a dedicated space can be allocated. A consent or licence, therefore, is the mechanism by which the overall objectives of MSP are translated into the rights and responsibilities of individual users. Obviously, it is also essential that an MSP system is sufficiently flexible to take new information and, in the context of ocean energy, new technology types into account. An overly-prescriptive MSP system, for example, could restrict future developments and innovation. For this reason, an adaptive management approach is inherent in

[14] Royal Decree of 17 May 2004

[15] Different jurisdictions use different terms for this, e.g., consent, permission, licence, lease, permit etc. The term to be used will be defined by the applicable legislation. In Ireland, for example, under foreshore legislation, a licence is granted for short-term, non-exclusive use/occupation, whereas a lease is granted for long-term, sole use/occupation.

many MSP systems and any supporting Plan will set an explicit timeframe for review. The incorporation of adaptive management principles into MSP also allows the potential for coexistence of industries to be explored. It may be possible for certain fishing activities to co-exist with marine renewables developments, for example, fishing involving potting techniques.

Given the current status of ocean energy development in the European Union, very few existing maritime spatial plans currently include a dedicated area for ocean energy development. One exception to this is in **Scotland** and relates to the Pentland Firth and Orkney Waters and the MSP approach taken by Marine Scotland. This area has significant ocean energy resources and is also of high environmental quality. The area is host to a range of other uses and sectors such as fishing and shipping. Consequently, there was a need to examine how future ocean energy development could progress in a manner that avoided conflict with those users. MSP was the obvious solution of choice, but the legislative framework setting out the requirements and content of regional marine plans was not yet in place. A de facto Marine Spatial Plan Framework (MSPF) was put in place, which sets out a process for the development of future plans, covering the areas from the mean high water mark out to the limit of the Territorial Sea (12 nm) (Scottish Government/Marine Scotland, 2010). This Framework consists of a document that contains information on different uses of the seas, how these uses may impact on each other and ultimately aims to set out the process for developing the future, over-arching MSP System. The Framework document is complemented by a Regional Locational Guidance document, which provides guidance and advice to marine renewable energy developers and other stakeholders on the siting of wave and tidal developments in the Pentland Firth and Orkney Waters (Scottish Government/Marine Scotland, 2010).

Elsewhere, test sites and pilot demonstration zones are usually close to shore in the coastal zone, which is often outside the geographic scope of any existing MSP system. As yet, the latter applies primarily to territorial seas and EEZs, with nearshore coastal planning being the responsibility of the adjoining local authority or regional government. This boundary varies according to jurisdiction. In Britain and Ireland, for example, planning powers end at the low water mark and high water mark, respectively. In the Scandinavian countries, local governments have planning powers extending up to three miles offshore. This is of relevance to ocean energy development, as developments have the potential to straddle a number of maritime jurisdictional zones. A probable implication of this is that a number of regulatory bodies will be involved in the consenting process. MSP should, therefore, address this issue by providing an integrated planning framework.

More established maritime sectors and uses are subject to more mature management regimes and, as their needs are well known and documented, it is arguably easier to reflect their needs in a MSP system. Newer industries, such as ocean energy, have not reached this stage yet but still require the predictable and transparent planning system that MSP seeks to deliver. For this reason, it is essential that the needs of the industry are made known to those tasked with developing MSP in their region.

Key considerations include:

- Strategic development zones so as to ensure room for growth. Such zones also need to take existing support infrastructure into account (e.g. proximity to grid connections, ports, suppliers);
- Strategic development zones need to be tailored to device type/depth. MSP should operate on three dimensions (on the sea bed; in the water column; and on the surface) as it is probable that other maritime activities will therefore be able to co-exist with ocean energy developments;
- While still developing, the ocean energy sector should be considered in parallel with other, more established, maritime activities;
- The MSP system should be adaptive and flexible so as to include a range of possible deployment areas and enable new technological developments and scientific knowledge to be taken into account;
- From a practical perspective, 'zoned' rectangles are not wholly appropriate to ocean energy development and also present difficulties from an enforcement and compliance point of view;

- Ocean energy developments will straddle a number of maritime jurisdictional zones such as internal waters, the Territorial Sea and potentially the EEZ. Land based elements of such developments, for example, electrical sub-stations, must be considered as part of the total project. For this reason, there is a requirement for coherence and coordination between maritime and terrestrial planning systems;
- The terminology used in Maritime Spatial Planning needs to be clear and consistent. Terms like pilot, demonstration, temporary, and commercial can mean different things to different people and lead to conflict at a later stage.

Other Policy Developments with Implications for MSP Implementation

The Marine Strategy Framework Directive (2008/56/EC) was adopted by the European Commission in June 2008. This aims to achieve 'Good Environmental Status' (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. This Directive therefore enshrines the ecosystem approach in a legislative instrument. Accordingly, the MSFD will deliver the environmental pillar of the IMP. Under the Directive, Member States must develop a strategy for their marine waters. This strategy must contain a detailed assessment of the state of the environment, a definition of 'GES' at regional seas level and the establishment of clear environmental targets and monitoring programmes. Member States must determine a set of characteristics for GES on the basis of eleven qualitative descriptors listed in Annex I of the Directive. These descriptors are presented in Box 2.

- Descriptor 1: Biological diversity;
- Descriptor 2: Non-indigenous species;
- Descriptor 3: Population of commercial fish/shell fish;
- Descriptor 4: Elements of marine food webs;
- Descriptor 5: Eutrophication;
- Descriptor 6: Sea floor integrity;
- Descriptor 7: Alteration of hydrographical conditions;
- Descriptor 8: Contaminants;
- Descriptor 9: Contaminants in fish and seafood for human consumption;
- Descriptor 10: Marine litter; and
- Descriptor 11: Introduction of energy, including underwater noise.

BOX 2: Qualitative Descriptors for Determining 'Good Environmental Status' (Annex I, MSFD)

A number of these descriptors could have significant implications for future marine renewable energy developments. Following an initial characterisation, Member States are required to identify the measures which need to be taken in order to achieve or maintain GES in their marine waters. According to Annex VI of the Directive, programmes of measures can include, amongst others, spatial and temporal distribution controls: management measures that influence where and when an activity is allowed to occur. Theoretically, therefore, the MSFD could contribute to the implementation of MSP at Member State level.

To a certain extent, this has been the experience in Spain, for example, where the legislation transposing the requirements of the MSFD into national law specifically lists MSP as one of the measures that can be adopted to achieve or maintain GES (Suárez de Vivero and Rodríguez Mateos, 2012).

MSP is inextricably linked to Integrated Coastal Zone Management (ICZM). A review of the need for a new or revised instrument on ICZM in the EU is currently underway. Given these linkages, the review is being carried out in conjunction with an assessment of possible future action on MSP. The Commission will put forward a range of proposals as a follow-up to the EU ICZM Recommendation, in conjunction with an assessment of possible future action on Maritime Spatial Planning, as appropriate, by the end of 2011.

While it is not certain at this time what format the proposals will take, a new Directive on MSP may be one of the proposals. This would provide a common framework for MSP in Member States of the EU, making MSP mandatory, while simultaneously leaving Member States free to decide on how to implement the process. If there is a Directive on MSP, there may also be a separate, but related, Directive on ICZM.

CONCLUSION

Maritime Spatial Planning will have significant implications for the development of marine renewables generally and the ocean energy sector in particular. Economic development and marine environmental protection have an equal weighting in the EU's Integrated Maritime Policy and both elements are either already specifically addressed in legislation or will be in the near future. This means that it is essential for the ocean energy industry to engage fully in the Maritime Spatial Planning process to ensure that conflicts are minimised and that the industry can progress in a sustainable manner. From an industry perspective, it is essential that research is undertaken to understand the extent to which ocean energy developments can be deployed and co-located with other users of the sea. This could help lessen the need for 'exclusion zones' within MSP systems.

As a key player in the advancement of ocean energy, the Ocean Energy Systems Implementing Agreement (OES) is in a unique position to encourage device and project developers to involve themselves in the debates and processes surrounding development of Maritime Spatial Planning systems in different jurisdictions. The European Commission recognized that stakeholder participation will significantly raise the quality of MSP (COM(2008) 791 final). Developers already have a wealth of tacit knowledge from their experiences of deploying devices. They know what has worked well and where. This type of knowledge will help inform the creation of an MSP system that is both fully reflective of the needs of the industry and will also enlighten other industries as to the specific requirements of the ocean energy sector. The OES should promote this active involvement of the sector, as it is an essential criterion for progress and acceptance of MSP.

Acknowledgements

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SITING WAVE ENERGY ON THE OREGON COAST: THE OREGON TERRITORIAL SEA PLAN AND SITING ANALYSIS TOOLS

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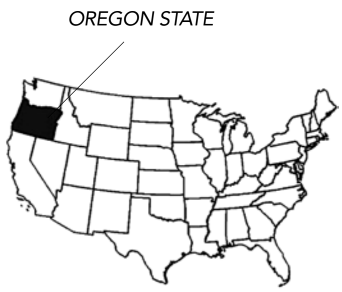
SUMMARY

Oregon's powerful waves, steady winds and strong renewable energy policies make the state a natural place for wave energy business. Healthy marine ecosystems, commercial and recreational fishing, marine transportation, tourism and the scenic beauty of the ocean are also important values to coastal communities. Encouraging development of a sustainable wave energy industry, while protecting existing coastal values presents a management challenge for the State of Oregon. It also presents an opportunity for a science-based discussion around how the ocean is currently used and how it can be used in the future to maximize public benefit. Over the last four years, the State of Oregon, led by the Department of Land Conservation and Development (DLCD), has worked to address this management challenge by updating its existing Territorial Sea Plan (TSP) to include wave energy siting considerations. The process has provided an important opportunity for a full accounting of existing uses within the territorial sea (state marine waters from 0-3 miles offshore). However, due to planning constraints of the TSP and Oregon's existing Statewide Planning Goal 19 (which serves to protect existing ocean uses and resources), the update process has not provided an opportunity for a full discussion of present and future marine renewable energy values, opportunities and industry needs. Through interviews with Oregon's planning and wave energy leadership, this article describes the Oregon TSP update process and discusses how that process has considered marine renewable energy (primarily wave energy), a new use of space in an already crowded sea. It also describes information products being used to map Oregon's coastal resources, as well as other tools under development in Oregon to support siting decisions.



The Oregon Wave Energy Opportunity and Energy Policy

With more than 300 miles of coastline and a wave climate well suited to power production, Oregon has long been considered a prime U.S. location for wave energy development. The presence of deepwater ports, manufacturing industries and diffuse coastal electricity demand offer developers excellent siting opportunities.

Recognizing the opportunity to be a leader in an emerging international industry focusing on marine renewable energy, Oregon has adopted policies to encourage wave energy developers to test, construct and locate devices in Oregon waters. In 2007, the Oregon Innovation Council began to fund the Oregon Wave Energy Trust (OWET), a public-private partnership that connects stakeholders and carries out research in support of wave energy development. In the same year, the state enacted a Renewable Portfolio

[16] Oregon Revised Statutes 469A.210, as amended by HB 3633 (2010). "The Legislative Assembly finds that community-based renewable energy projects, including but not limited to marine renewable energy resources that are either developed in accordance with the Territorial Sea Plan adopted pursuant to ORS 196.471 or located on structures adjacent to the coastal shorelands, are an essential element of Oregon's energy future, and declares that it is the goal of the State of Oregon that by 2025 at least eight percent of Oregon's retail electrical load comes from small-scale renewable energy projects with a generating capacity of 20 megawatts or less."

Standard that required 25% of power consumed in Oregon to be sourced from renewable resources and identified a preference for marine renewable energy development including wave energy.[16] In 2008, Oregon State University established the wave energy division of the Northwest National Marine Renewable Energy Centre, one of three US Department of Energy-sponsored research institutions that helps facilitate commercialization of wave energy devices.

The Oregon Territorial Sea Plan Part 5 and Statewide Planning Goal 19

The state's policy actions encouraging marine renewable energy created early enthusiasm for development on the part of the wave energy industry. As developers began to explore sites and engage in permitting processes, concern started to grow in coastal communities about the size of wave energy installations and how fast development could occur. In response, Oregon signed a Memorandum of Understanding (MoU) with the Federal Energy Regulatory Commission (FERC) - the federal agency that licenses grid-connected pilot and commercial wave energy projects - in March 2008, to agree that all proposed wave energy projects are responsive to State environmental, economic and cultural concerns.[17] The Governor then directed that Oregon's existing TSP should be amended to guide the siting of ocean renewable energy facilities.[18]

The Oregon TSP, created in 199419, guides ocean policy in state marine waters and provides important context and constraints for Oregon's current marine renewable energy planning activities. In 2009, a new Part 5 of the TSP was approved to establish state governance of marine renewable energy projects.[20] Part 5 describes the policies, standards and procedures that state agencies will use to approve new alternative energy developments within the territorial sea. These processes and procedures are additional to the existing FERC licensing process.[21]

A second and final phase of Part 5 is ongoing and expected to be completed by mid-2012. The second phase provides an inventory of existing resources, which are then used to create a master map of the Territorial Sea. The State hopes that the map will identify where development of ocean energy may occur without interfering with existing marine resources and other uses. Until both phases are complete, no new commercial-scale wave energy permits will be issued in Oregon waters.

The development of Part 5 of the Territorial Sea Plan is framed by Oregon Statewide Planning Goal 19,[22] (referred to as Goal 19), which guides all planning activities that could affect ocean resources. Paul Klarin is Oregon's Department of Land Conservation and Development's (DLCD) Marine Affairs Coordinator and staff lead for the TSP update process. According to Klarin, Goal 19 "provides three planning pillars that need to be addressed during the TSP update; broadly speaking, these are to protect 1) marine ecosystems, 2) areas important to fisheries, and 3) existing uses of the territorial sea."

Mapping the Oregon Coast

The DLCD is using Goal 19 to drive the TSP mapping process, setting out to identify Goal 19 resources in the territorial sea and creating a map layer for each of the three planning pillars described above. "Those three sets of maps are combined to give us an understanding of the total areas that need to be protected from new development," said Klarin.

Goal 19 does not provide specific guidance on measures necessary to "maintain and protect" ecosystems, fisheries and existing uses. The DLCD has indicated that it will take a conservative planning approach to identify Goal 19 resources first and then buffer them against marine renewable energy installations. At this point, planning options exclude marine renewable energy from Goal 19 protection areas.

[17] *http://www.ferc.gov/legal/maj-ord-reg/mou/mou-or-final.pdf*

[18] *Executive Order 08-07: Directing State Agencies to Protect Coastal Communities in Siting Marine Reserves and Wave Energy Projects. http://www.oregon.gov/Gov/docs/executive_orders/eo0807.pdf*

[19] *By the Ocean Policy Advisory Council (OPAC) http://www.oregon.gov/LCD/OPAC/*

[20] *http://www.oregon.gov/LCD/OCMP/docs/Ocean/otsp_5.pdf*

[21] *The Bureau of Ocean Energy Management (BOEM) has jurisdiction for siting in federal waters greater than 3 miles offshore. BOEM and FERC coordinate on the project licensing process in federal waters; though the state also has a say in these projects through Coastal Zone Management Act consistency review.*

[22] *http://www.oregon.gov/LCD/docs/goals/goal19.pdf*

The DLCD is using a web-based interactive mapping tool called MarineMap[23] to assemble spatial data, show the location of existing Goal 19 resources and to inform stakeholder dialog around planning options. MarineMap does not describe potential compatibility of new uses with those that currently exist, or tradeoffs, if uses were co-located.

The Goal 19 data layers within MarineMap portray one side of the energy siting story: potential constraints to wave energy development. Energy opportunities, to date, have not been incorporated into the spatial analysis. The assumption of the DLCD is that once Goal 19 resources are identified, the space that remains could be considered for marine renewable energy development. In this way, the planning process will "back into" energy opportunities.

Marine renewable energy experts are concerned by this approach. According to Jason Busch, Executive Director of OWET: "The fact is wave energy can't just go anywhere. Minimizing distance from deepwater ports, nearby transmission infrastructure, suitable bathymetry, an adequate wave climate and other factors make the difference between a viable site and one that is not feasible."

The concern is that the space remaining after Goal 19 resources are identified and buffered will be minimal and may not be suitable for marine renewable energy. And while it is possible for some developers to move further offshore into federal waters, siting in the Territorial Sea to keep costs low is likely to be desirable for the first generation of projects. Furthermore, some wave devices are designed exclusively for nearshore and shallow depths; these devices do not have the option of moving offshore.

So, the question is: how does the State meet its obligation to protect Goal 19 resources, while ensuring adequate space in the right places to support marine renewable energy?

Consideration of Energy in the Planning Process

All parties acknowledge that it is difficult to plan for an industry that is brand new. Without considering a specific device in a specific location, the Oregon Wave Energy Trust has attempted to define compatibilities and what the industry needs most. "OWET has already mapped high priority areas and vetted the parameters with industry," said Busch. He believes that planning for marine renewable energy should "begin with these high priority areas with a thought toward commercial development and try to find sites that strike a balance."

While broadly supportive of wave energy development, the State's existing directives are not explicit about how to strike that balance between uses. "What we lack," said Klarin, "is any kind of decisive policy on the part of the State and Federal Government about how to site renewable energy in the ocean specifically and how to weigh it against other uses."

Most energy facilities in Oregon are sited on a project-by-project basis, typically at the local (county) level. Very large wind generators, gas facilities, transmission lines and other major energy infrastructure trigger jurisdiction under the State's Energy Facility Siting Council. This body issues a site certificate for an energy facility, if it can meet a series of standards that protect natural resources and public health and safety. If the facility does not meet one or more of the standards, the Council cannot issue a site certificate, unless the applicant can show that the overall public benefits of the facility outweigh potential damage to resources. This type of balancing requires an understanding of the benefits of all uses involved. Fishing, marine ecosystems and tourism provide benefits to the State and citizens of Oregon. Marine renewable energy has benefits in high technology job creation and new carbon free power that could displace other more polluting forms of energy. But current planning goals in Oregon do not provide the ability to consider carbon mitigation, economic development and other benefits of a marine renewable energy installation and weigh those against protection of existing uses and Goal 19 planning goals.

"A good MHK [marine hydrokinetic] test site is tremendously valuable for the State and it's frustrating that we're not able to weigh that value in the planning process and fully consider how it compares to other existing uses," said Busch.

[23] *http://marinemap.org/*

Other states and countries have also wrestled with the uncertain benefits and impacts of marine renewable energy in their own coastal and marine spatial planning processes. On the U.S. East Coast in Massachusetts, Rhode Island and Maine, state plans have recognized that uncertainty requires some level of flexibility. For example, preserving ample space for multiple uses, where energy project applications could be considered on a site-by-site basis under existing law. Klarin and Busch both recognize this need for flexibility in the Oregon plan.

Busch would like to see consideration of the appropriate level of protection for Goal 19 resources, so that in some cases co-location with energy facilities could be an option. "What does it mean to protect Goal 19 resources?" he asks. "There are obvious no-go zones -MPAs [marine protected areas], previously permitted sites and cables, for example - but are there other Goal 19 areas that are a little more flexible where multiple uses might work and existing uses could be maintained? No one has actually analyzed what the impacts of renewable energy might be in some of these areas. The question is: are you willing to make a decision today about categorical exclusion of those sites?"

Klarin argues that multiple use zones where energy could be allowed make sense where Goal 19 resources are not as significant, but concedes that a "very large percentage of the territorial sea is going to be off-limits for marine renewable energy for one or more reasons." And according to Klarin, many of the areas with overlapping Goal 19 resources are likely to be around deepwater port facilities that the marine renewable industry sees as prime locations for the first generation of projects. Recognizing the impact this could have on early industry adopters, Klarin sees "temporary use areas" as a potential option in certain Goal 19 areas. He explained that "temporary use areas could allow testing or deployment for sites with a small footprint, limited duration and an understanding that, after testing, equipment would be removed and commercial development would occur outside of the Goal 19 area."

According to Busch, "temporary use areas might work but the details are important. If we could work out an arrangement where after demonstration, the developer could keep some critical infrastructure in place, like cables, and then move beyond the three mile line or to a site nearby for a larger build out, it could be acceptable."

The TSP process is moving into a public phase in the beginning of 2012, with increased opportunity for discussion and participation from the renewable energy industry as well as other interested stakeholders. Workable solutions that meet both Goal 19 and state renewable energy targets will require the transparency of public process, as well as a better understanding of both the potential impacts and benefits of renewable energy technologies. As planning details are worked out over the next 10 months of public process and in the period following adoption of the updated TSP, the State and stakeholders will have a growing data set and tools available to support transparent decision making.

Decision Support Tools to Guide Planning and Siting in Oregon

In addition to providing spatial representation of uses and resources in the Territorial Sea to inform the planning process, the DLCD has selected MarineMap as its decision support tool for considering new energy permits. MarineMap contains dozens of spatial layers for Goal 19-eligible resources and uses. A one-square mile grid is applied to the Territorial Sea so that those varied spatial data layers are combined to provide a coarse filter representing the presence of all relevant Goal 19 resources and uses.

Virtually all spatial planning analyses today are built around the power of existing geographic information systems (GIS) applications. This is popular because these systems already exist and adapting them for planning tasks is straightforward. They are widely available and there is a large user base familiar with GIS systems. However, most available GIS systems do not handle multi-dimensional or incompatible data well; they do not account for uncertainties in the data; they do not handle temporal data well or at all and they do not help the user make value-balancing decisions.

Therefore, the scientific focus of marine renewable energy siting tools currently under development is to add to the spatial power of GIS with a processing engine that can handle the three missing components: complexity, uncertainty and time. In addition, the tools should support decision making once the scientific analysis is complete.

To address these issues, three federal agencies, U.S. Department of Energy, National Oceanic and Atmospheric Administration and the Bureau of Ocean Energy Management are providing funding to a team comprised of Parametrix, Oregon State University,[24] Robust Decisions and The Nature Conservancy to develop a tool using Bayesian logic, called a Bayesian Analysis of Spatial Siting, or BASS. BASS can integrate disparate data in a manner where the uncertainty of that data is known and the user can see risks associated with making decisions. The BASS tool is building on a previous OWET effort involving many of the same partners to assess cumulative effects, potential impacts and benefits of various marine renewable energy scenarios.

Klarin sees these analytical tools as particularly valuable post planning, to "zoom in on particular sites, do tradeoff analysis and inform adaptive management." Busch had envisioned the tools as useful in the broader planning context.

Parametrix acknowledges that the BASS project is in early development and will not be ready to apply to the Territorial Sea Planning process in the next few months. Because of the intensity of data inputs and complexity of the results, this tool is most applicable in small-scale or project-specific siting work, instead of territorial sea-wide planning.

NEXT STEPS AND CONCLUSIONS

After nearly four years of policy work, data collection, mapping and stakeholder meetings, Klarin sees the TSP update process as "in the home stretch." He predicts that the mapping process will take up most of the first half of 2012, culminating in a series of recommendations25, which will eventually reach the Oregon Land Conservation and Development Commission. The Commission will then consider those recommendations, as well as additional stakeholder input, before making a final decision to adopt a plan, likely in third quarter of 2012.

Planning is a public process and Klarin and Busch both see a great deal of value in that process. "The TSP update invokes a public discourse that engages a wide range of stakeholders and members of the general public in an informed discussion they've never had before about a particular use," says Klarin. Busch agrees: "What's most important to me is at some level we have a rational, legitimate, scientifically based conversation about whether and how we move this industry forward in Oregon."

As an emergent coastal interest, Klarin sees benefits to the marine renewable energy industry for having participated in the TSP update: "Having gone through the planning process, we've built the bridge between developers and stakeholders and encouraged discussions before they walk through the regulatory door. If you clear impediments in advance, the regulatory process is accelerated. What makes the regulatory process slower is conflict."

Busch is cautiously optimistic about the outcome of the TSP process. The marine renewable energy industry, as the most recent industry in an already crowded sea, "will be held to the highest level of environmental scrutiny, as all user groups should be." He sees value in a planning process that allows full consideration of all current and future uses of the territorial sea. "If that process works, it means that we brought everyone to the table, we sorted through all of the available information and we made decisions to the benefit of the State. If we can do that, I think that ocean energy has a fighting chance."

[24] *http://nnmrec.oregonstate.edu/*

[25] *To the Ocean Policy Advisory Council (OPAC) and the Territorial Sea Plan Advisory Committee (TSPAC)*

MOUNTAINS OF "BLUETAPE" BARRIERS TO UNITED STATES AND NEW ZEALAND MARINE RENEWABLE ENERGY PROJECTS

Ian Boisvert

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Part One: Introducing the Mountains of "Blue Tape"

New Zealand and the United States share many characteristics. They each have Anglo-derived common law systems, English is the lingua franca, and both support liberalized, capital markets. For all these commonalities and more, they could not have more dissimilar regulatory regimes for permitting offshore renewable devices such as wave energy converters, tidal turbines and wind turbines.

To put a device in the ocean without being connected to the grid a developer in the United States may have to deal with three different governments (federal, state, and native sovereignty) each with multiple agencies who enforce a dizzying web of laws and regulations on different timeframes. A developer in New Zealand, on the other hand, has to deal with one central government, one authorizing body at the local level, and, for the most part, one statute.

The difference in the amount of "blue tape" standing between the developer in United States and the one in New Zealand can be measured in years and millions of dollars. And that is just for pilot project development. When a proposed development increases to a commercial scale that difference dissipates: both the New Zealand and United States developer faces the possibility of spending millions of dollars over years just to obtain permission to build. Still, for all the well-intentioned policies and Memoranda of Understanding (MOU) that United States agencies and states create to make pilot permitting more streamlined, the United States developer faces a longer, harder, more complex process than its New Zealand equivalent.

Part Two of this article explains the three United States permits suited to deploying pilot-scale ocean renewable devices. Part Three explains the New Zealand consent process for a similarly scaled project and contrasts that with the United States approach. Part Four examines, with two brief case studies, why neither the United States' nor New Zealand's permitting processes are equipped to handle commercial-scale ocean renewable development. Part Five concludes with lessons for regulators in both countries.

Part Two: United States's Mountain Chains of Blue Tape

Ocean renewable power developers in the United States intent on deploying a pilot-scale device must deal with federal and state agencies and laws. The Federal Energy Regulatory Commission (FERC) is arguably the most important of the federal agencies because under the Federal Power Act it has authority to regulate and license hydroelectric projects on navigable waters.[26] A developer must get FERC approval to operate the device, whether a pilot project will lie within an adjoining state's jurisdiction of three nautical miles from shore (ten miles for Texas and parts of Florida) or back into federal jurisdiction beyond the Outer Continental Shelf (OCS).

Over the decade since FERC first asserted jurisdiction over an ocean energy project in Makah Bay, Washington, three types of permits have emerged for pilot-scale projects.[27]
The three types are: preliminary permits, "Verdant Orders", and pilot project license policy.

[26] 16 USC sec. 817(1).

[27] Prof. Rachael Salcido, Siting Offshore Hydrokinetic Energy Projects: A Comparative Look at Wave Energy Regulation in the Pacific Northwest, 5 Golden Gate University Environmental Law Journal 109, at 125 (2011).

A preliminary permit allows a potential developer to explore and investigate a site for up to three years.[28] The applicant applies through submitting a plan to conduct baseline studies for the preferred site.[29] In reaction to public comments FERC now reviews these applications on a "strict scrutiny" basis to avoid potential "site banking."30 FERC will take at minimum 60 days to process the application, but that could extend to years under certain conditions.[31] That is, whether the myriad other federal, state, or tribal agencies intervene.

The value of the preliminary permit for the prospective developer is to secure a site, study the site's viability for the proposed device(s), and to engage the site's other stakeholders in voluntary, early consultation. The obvious drawback is that the developer may not deploy or operate any device in the site with only the preliminary permit.

If the developer is prepared to move beyond mere site investigation and has an experimental device it would like to test, the Verdant Order is the appropriate permit to apply for. A Verdant Order arose from a FERC interpretation of the Federal Power Act as it applied to Verdant Power LLC's efforts to site its experimental tidal turbines in New York's East River.[32] To secure a Verdant Order the applicant must be seeking to conduct studies on an experimental technology only for a short time (undefined) and, critical to a successful application, any power generated does not displace and is not trasmitted to the national grid.[33] Importantly, under a Verdant Order the applicant-developer might still have to obtain all other necessary approvals such as the Clean Water Act Section 404 and 401 permits, Endangered Species Act Section 7 permit, as well as state, municipal, and, where applicable, tribal approvals.[34]

The value of the Verdant Order permit is that it allows the developer to avoid full-blown FERC commercial license procedures, which can be quite daunting, to test a few experimental devices for a short period of time. However, one drawback is the developer may still have to adhere to multiple other environmental permits that could, as in the case of Verdant, lead to years of permit hearings and studies. The other drawback is that the developer can only test the device for its operation in the water and not truly its ability to generate electricity because of the limitation against displacing power in the national grid.

If a device developer is interested in both testing pilot-scale devices and generating electricity that enters the grid then FERC's pilot project license is the relevant permit. The pilot project license is only a policy that flows from FERC's interpretation of 18 CFR § 5.18.[35] Because it is not law, FERC is not legally bound to follow it. The requirements for an application to be considered for the pilot project license are: (1) small scale (e.g., 5 MW or less); (2) must avoid "potentially" sensitive areas as described by the applicant, commented on by stakeholders, and determined by FERC; (3) devices can be shut down or removed on "short notice" if "unacceptable risks" arise—FERC defines neither term more explicitly; (4) applicant must seek either a multi-decade license or completely decommission site at end of pilot project license duration; and (5) the applicant initiates the permit through a draft application that offers sufficient information for environmental analysis.[36] The last point means the applicant must still get all other environmental approvals from other federal, state, and, where applicable, tribal agencies. These include Army Corps of Engineers-issued Clean Water Act Section 404 and 401 permits, National Marine Fisheries Service approvals for devices in "Essential Fish Habitat," as well as National Oceanic and Atmospheric Administration Marine Mammal Protection Act approvals.

[28] *16 USC sec. 797(f).*
[29] *18 CFR 4.81*
[30] *Prof. Rachael Salcido, Siting Offshore Hydrokinetic Energy Projects: A Comparative Look at Wave Energy Regulation in the Pacific Northwest, 5 Golden Gate University Environmental Law Journal at 131 (2011).*
[31] *Pacific Energy Ventures, Siting Methodologies for Hydrokinetics: Navigating the Regulatory Framework, p. 14 (December 2009).*
[32] *Verdant Power, LLC, 111 FERC 61,024 (2005), on reh'g, 112 FERC 61,143 (2005).*
[33] *Pacific Energy Ventures, Siting Methodologies for Hydrokinetics: Navigating the Regulatory Framework, p. 14 (December 2009).*
[34] *Stoel Rives LLP, The Law Of Marine And Hydrokinetic Energy, ch. 3, at 4 (4th ed. 2011).*
[35] *Federal Energy Regulatory Commission, Licensing Hydrokinetic Pilot Projects White Paper (Apr. 14, 2008), available at www.ferc.gov/industries/hydropower/indusact/hydrokinetics/pdf/white_paper.pdf*
[36] *Id.*

If an applicant succeeds in securing all necessary approvals, the pilot project license permits the developer to test its technology and transmit electricity into the national power grid, as well as pursue a standard license application following the pilot project license.[37] However, an application for a standard license must be initiated 5 years prior to generation. Paradoxically, the applicant must simultaneously apply for the pilot project license and standard license even though the applicant will not have yet collected the data to support the standard license.

Moreover, a wide array of stakeholders can comment on and make recommendations about the applicant's proposed plans, overall draft application and request for waivers, which further complicates and adds time to the application process. Even after FERC accepts the application, parties can still file interventions and comment on the application and monitoring and safeguard plan proposals. Any of these delays in processing time eats into the five-year timeframe for which the applicant has to test its devices.

The value of the pilot project license is, according to FERC, a streamlined permit process offering device developers an opportunity to test devices, collect *in situ* data, and build the case for commercial development. The drawbacks, though, are significant. The application approval process is likely to take over 12 months because of the additional authorizations and opportunity for public comment and intervention. That delay reduces possible operations within the 5 years the pilot project license runs. Moreover, if a developer wanted to pursue a commercial-length FERC lease, the pilot project license would be of little value, because the developer would need five years to complete the commercial lease process. The developer will not have that data until after the pilot project license ends. Consequently, no ocean renewable developer in the United States has secured a pilot project license in the three years since FERC made it available.

	UNITED STATES	NEW ZEALAND
Agencies Potentially Involved	FERC; BOEM; Army Corps; USWFS; NMFS; EPA; USCG…; State & Municipal Agencies	Regional Council; Dept. of Conservation
Laws Potentially Involved	FPA; NEPA; ESA; CWA; CZMA; MMPA; MSA; NHPA; CFRs…140 possible federal laws; State laws, too	Resource Managem't Act; Local Gov't Act
Jurisdictions Potentially Involved	Federal; State; Municipal; Native Sovereignties	Regional; National
Minimum Estimated Processing Time	2 months	4 weeks

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Comparing United States and New Zealand Regulatory Regimes

Part Three: New Zealand's Hills of Blue Tape

New Zealand ocean renewable developers face a wholly different consenting regime than their United States counterparts. The New Zealand regime is governed by the Resource Management Act 1991 (RMA), which is the prevailing statute for any project that uses natural resources. Its overarching purpose is to guide "sustainable development" through an "effects-based" testing model that addresses the extent to which a proposed project affects the environment.[38]

The RMA's relevance to prospective ocean renewable energy developers is that it lays out the consent process by which regional government bodies approve developments. The RMA offers three tracks the developer can pursue: (1) limited- or non-notification; (2) public notification; and (3) call-in process. For a pilot or small-scale

[37] *Id.*

[38] *Resource Management Act (1991), Section 5, Paragraph 1.*

project, the most relevant and useful track is the limited/non-notified consent process. Although developers can request a particular track, regional government bodies ultimately make that decision.

Part 6 of the RMA lays out the process for securing resource consents. One of the first steps is that the consent authority determines whether the applied-for project should be publically notified or not. If the authority determines the proposal only needs limited notification then the consent authority must decide if there are any affected persons, customary rights group or customary marine title group in relation to the activity.[39] Under the RMA an "affected person" must have some nexus with a project such that the "activity's adverse effects on the person are minor or more than minor (but are not less than minor)" and determination made by consent authority.[40] Whether "adverse effects [are] likely to be more than minor" is determined by the consent authority.[41] However, a project applicant can limit the number of "affected persons" by getting written pre-approval from persons to undertake the proposed project.[42]

For limited- or non-notification consultation requirements only those people served with notification of the application have the right to make a submission (comment) on the application.[43] Moreover, they must also prove their submission shows they are likely to be directly affected by an adverse effect that the proposed project will have on environment.[44]

The value of proceeding with a non- or limited-notification resource consent hearing means the scope of input the developer needs to actively solicit, and therefore respond to, is much less than with a public notification hearing. Consequently, the developer can expect a relatively rapid hearing process as compared to if the developer were pursuing a US permit for a similarly scaled project. A regional council would be very unlikely to accept a non- or limited-notification resource consent for a large- or commercial-scale project. For example, Crest Energy Ltd. sought to deploy 200 x 1 MW tidal turbines in the narrow mouth of the Kaipara Harbour and had to follow a public notification process, which took over 6 years. In comparison, Chatham Islands Marine Energy Ltd. secured a non-notified resource consent in under 6 months for a single 220 kW oscillating water column device to be installed near Point Durham, Chatham Island, for up to 35 years.

In short, limited notification gives an applicant a much higher chance of gaining approval within a few months and reduces the chance of litigation. It is thus like FERC's Pilot Project Policy License without the regulatory and concomitant temporal uncertainty.

COMPANY	PROJECT DESCRIPTION	PUBLICLY NOTIFIED	LT'D/ NON-NOTIFIED	CONSENT PROCESSING	LOCATION
Crest Energy	200 x 1 MW tidal turbines; 35 years	YES		+6 years	Kaipara Harbour
Tangaroa Energy	1 x 20 kW device for 35 years	YES		Ongoing	Stewart Island
WET-NZ/PPL	3 devices (up to 20 kW each); up to 5 years		YES	<3 months	Various
Neptune Power	1 x 1 MW device; up to 10 years		YES	<6 months	Cook Strait
CHIME	1 x 220 kW device; 35 years		YES	<6 months	Chatham Island

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New Zealand Limited/Non-Notification Vs. Public Notification

[39] *Resource Management Act (1991), Section 95E-F.*
[40] *Resource Management Act (1991), Section 95E(1).*
[41] *Resource Management Act (1991), Section 95D.*
[42] *Resource Management Act (1991), Section 95E(3).*
[43] *Resource Management Act (1991), Secs. 95(B) & 96(3).*
[44] *Resource Management Act (1991), Sec. 308B.*

Part Four: Commercial Scaling - The Impassible Mountain of Blue Tape

The New Zealand and United States governments proclaim supporting innovative, clean technology that mitigates climate change and promotes job creation. But marine renewable device innovators and project developers are experiencing respective regulatory regimes, which are not in synch with that broader message. As noted above, Crest Energy proposed a 200 tidal turbine array in 2006. Because of the scale of their project, Crest Energy had to follow the public notification process. Over the next 5 years the company faced public opposition, opposition from the Department of Conservation, and risk aversion from the resource consent authority, the Northland Regional Council, who was uncertain of what environmental effects the development might have. Accordingly, the first commercial-scale marine renewable project in New Zealand has so far cost Crest Energy hundreds of thousands of dollars and upwards of 5 years just to secure consent to develop. After Crest Energy achieved final consent approval, the conditions Northland Regional Council imposed on their development add further doubt as to whether Crest Energy will be able to fully develop their project before 2022.

In the United States, Energy Management Inc. (EMI) has been entangled in a similar experience over the development of Cape Wind. In the early 2000s EMI proposed an offshore wind farm of 130 wind turbine off the Massachusetts coast. The regulatory landscape alone has been daunting: seventeen Federal and State agencies are involved with overlapping jurisdictions, inconsistent timelines, and each enforcing numerous and different statutes and regulations. Additionally, EMI has had to face opposition - allowed because of the notion of "public attorneys general" written into many environmental laws - from local landowners, Indian Tribes, fishing interests, and environmental groups. The multi-dimensional scale of the regulatory hurdles makes commercial-scale marine renewable energy development in the United States a lawyer's dream but a developer's nightmare.

PERMIT TYPE	UNITED STATES	NEW ZEALAND	TARGET ACTIVITY	EST. PERMIT PROCESS TIME	PERMIT TERM
Preliminary Permit	√		Site selection and study	60 days min.	3 years
Verdant Order	√		Testing devices	Depends if EIS is required?	Short-term
Pilot Project Lic.	√		Proving devices	6 mo. min	5 years
Publicly Notified Resource Consent		√	Commercial-scale development	Months to years	Up to 35 years
Lt'd/Non-Notified Resource Consent		√	Testing, proving, small-scale	Weeks to months	Up to 35 years

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New Zealand Limited/Non-Notification Vs. Public Notification

Part Five: A Suggestion to Regulators: Scale Back the Blue Tape

New Zealand and the United States have both nationally proclaimed interest in promoting marine renewable energy development. Nonetheless, developers in both countries have faced, and continue to face, complex regulatory frameworks with multi-year timeframes for commercial-scale development. As such, it appears both countries have room to make meaningful changes to their regulatory regimes that could reduce a major obstacle to marine renewable energy development. Part of the change could be a shift in what appears to be institutional risk aversion, which marine renewable energy developers face, due to bureaucratic unfamiliarity with marine energy projects and their environmental effects. Whereas offshore oil development in the United States can secure permits in less than one year, marine renewable developers experience much longer timeframes although the greatest risk renewable development represents pales in comparison to that of offshore oil drilling platforms. In light of this, regulators could consider reducing institutional risk aversion to marine renewable energy development, streamline and coordinate their permit requirements and process schedules, and align regulatory regimes with national proclamations of support by designing one-stop permit processs for commercial-scale marine renewable energy development. Without reducing the amount of "blue tape," marine renewable energy developers may have a difficult time scaling their pilot projects to commercial scale developments.

2012

DEVELOPMENT OF THE INTERNATIONAL OCEAN ENERGY INDUSTRY: PERFORMANCE IMPROVEMENTS AND COST REDUCTIONS

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Cost Reduction Pathways for Wave Energy

Mirko Previsic,
Re Vision Consulting

ESB Ocean Energy Projects – A Utility Perspective on Cost and Performance Requirements

John Fitzgerald and Fergus Sharkey,
ESB Ocean Energy

UK wave and tidal projects – Update and look ahead

John Callaghan,
The Crown Estate

From turbine prototype to prototyping an industry: a critical change in perspective

Chris M Campbell and Elisa Obermann,
Marine Renewables Canada
Tracey Kutney,
CanmetENERGY, Natural Resources Canada

COST-REDUCTION PATHWAYS FOR WAVE ENERGY

Mirko Previsic[1]
Re Vision Consulting / Sacramento, California

INTRODUCTION

Marine renewable energy, including wave energy, has made continuous progress towards commercialization over the last five years. The impetus behind this evolution in recent years has been the knowledge gained from the deployment of pilot devices, and a focus, more recently, on the deployment of small arrays in Europe. This evolution not only has advanced the commercialization of wave energy technology, it has also provided data that enhance our understanding of the cost drivers and the economics of these projects – data that point to higher commercial opening costs than previously anticipated.

This paper discusses important considerations for evaluating technologies in the wave energy sector, including:

- The projected cost as a function of technology maturity
- Uncertainty ranges in the cost assessment process
- Economies of scale with regard to plant size
- Learning curves
- Technology innovations that can make a significant contribution to long-term cost reductions

Cost Predictions at Different Technology Maturity Levels

The trend of increasing cost predictions observed over the last decade in marine energy is very common in the development of new technologies and new industry sectors. It is typical that during the early phases of product development designers both are optimistic about device performance and have a limited understanding of all the factors that will eventually contribute to lifecycle cost and performance. As a design matures, a more-complete understanding of all aspects of the technology emerges, and cost predictions tend to move higher, as shown in Figure 1. With the deployment of the first commercial machine, the various components of a system's economic viability become fully quantified and understood. This baseline understanding can then be used to develop second-generation technologies, which can be used to reduce cost.

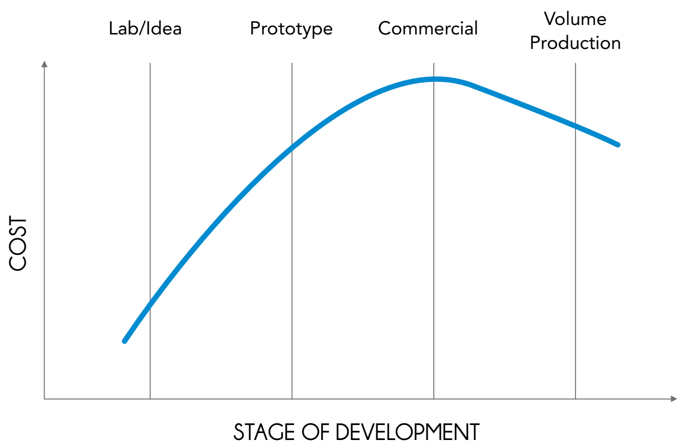

FIGURE 1 : Project cost as a function of development stage.

[1] *Mirko Previsic is the principal at Re Vision Consulting (re-vision.net). Over the past decade, he has focused on accelerating innovation cycles in the marine renewable sector, with a clear focus on economic viability. Contact him at mirko@re-vision.net.*

The key challenge in predicting commercial opening costs in the wave energy sector is acquiring meaningful data. Very few data points are available from actual deployments, and all existing data points come from pilot demonstration projects, not larger-scale farms.

The following section discusses uncertainties inherent in the cost assessment process.

Uncertainties in Cost and Economic Assessments

It is important to understand that most cost assessments carried out to date were based on projected costs and were not derived from direct project experience. The reliance on projected costs leads to uncertainties in the cost assessment process that can be substantial and also that depend on the stage of development of the technology and the assessment detail. Table 1 -- which was developed by the Electric Power Research Institute (EPRI) and adapted by Re Vision Consulting from our experience working with cost estimates from a wide range of power generation technologies -- shows the percent uncertainty as a function of the amount of effort going into the cost assessment and the development status of the technology.

COST ESTIMATE RATING	A MATURE	B COMMERCIAL	C DEMONSTRATION	D PILOT	E CONCEPTUAL (IDEA OR LAB)
A. Actual	0	-	-	-	-
B. Detailed	-5 to +5	-10 to +10	-15 to +20	-	-
C. Preliminary	-10 to +10	-15 to +15	-20 to +20	-25 to +30	-30 to +50
D. Simplified	-15 to +15	-20 to +20	-25 to +30	-30 to +30	-30 to +80
E. Goal	-	-30 to +70	-30 to +80	-30 to +100	-30 to +200

TABLE 1: EPRI cost estimate rating table showing cost uncertainty (%).

The best cost and economic assessment datasets come from demonstration or pilot plants and hence significant uncertainties remain, even if costs are predicted with great care. As shown in Table 1, the range of cost uncertainty for a demonstrated technology is on the order of -15 percent to +20 percent, while the cost uncertainty for a conceptual design has a -30 percent to +200 percent range.

Effects of Plant Size on Cost of Electricity

Wave energy technologies have been deployed in relatively small-scale plants as prototypes or small farms of devices of a few units. The cost of electricity (CoE) from these deployed devices is driven by a combination of factors, including:

- Lack of economies of scale in the manufacturing process
- Need to rely on expensive installation and maintenance methods devised for the offshore industry
- High borrowing cost of capital required to finance these early projects
- Need to overdesign early commercial machines to insure their survival in the harsh marine environment

Most of the above factors driving these high initial costs can be attributed to the lack of any significant deployment scale. Establishing detailed cost breakdowns at different deployment sizes can help to identify the cost-drivers and their importance as technology moves towards commercial scale[2]. (See Figure 2.)

[2] A detailed assessment of the economies of scale in wave energy was carried out under a recently completed independent cost and economic study for the US Department of Energy using inputs from a wide range of device developers. The study, "The Future Potential of Wave Power in the United States," can be downloaded from www.re-vision.net.

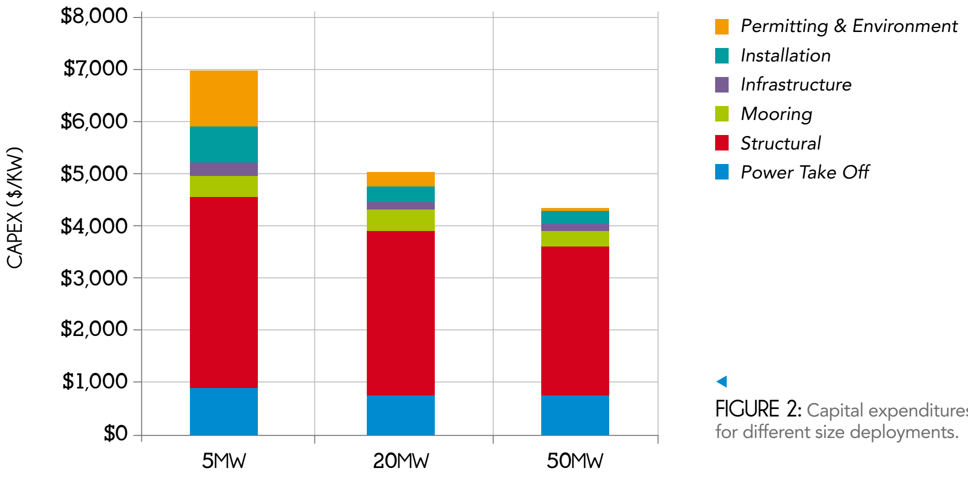

FIGURE 2: Capital expenditures (CAPEXs) for different size deployments.

Significant cost reductions can be observed in the costs that are shared between devices, including permitting and environmental assessment and Infrastructure costs. Cost reductions in these areas are fostered by the ability to share these costs between more devices in a project at a larger deployment scale.

Device-related costs tend to be dominated by steel costs. While cost reductions for manufactured steel are anticipated at large-deployment scale due to the ability to leverage economies of scale in the manufacturing process, these cost reductions are finite. Therefore, further cost-reductions required to make these technologies cost competitive with other sources of energy will require technological innovations and changes, such as:

- Different materials
- Improvements in device performance
- Minimizing load conditions and reducing the structural strength required by load-carrying elements

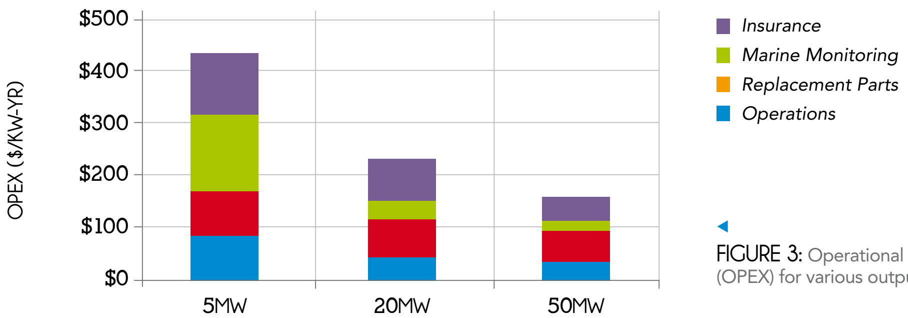

FIGURE 3: Operational expenditures (OPEX) for various output levels.

Even more significant are the cost reductions expected in the operation and maintenance (O&M) of wave energy devices. (See Figure 3) Replacement part costs stay about constant at increasing deployment sizes (no decrease in failure rates is considered), but the other cost centers reduce O&M costs significantly:

- **Insurance costs** - Insuring one-off devices in the offshore industry can be quite costly, on the order of 2 percent of CAPEX per annum. As technology matures and technology-related risks are reduced, insurance costs are expected to drop to a level similar to those for wind energy today.
- **Marine monitoring** - Many early adopter projects are expected to require ongoing monitoring of environmental effects from the plant to satisfy regulatory agencies. This includes active and passive acoustic monitoring, fish studies, and sediment transport studies. These costs do not increase much with increasing project sizes, and hence a net cost-reduction is anticipated.
- **Operational cost** - Cost reductions in this area come largely from being able to switch from carrying out maintenance activities from vessels of opportunity to relying on dedicated vessels that are optimized to carry out the operational tasks of the farm more effectively.

The cumulative effects of moving to larger-scale farms reduce the CoE by approximately 50 percent, without considering any technology innovations, as illustrated in Table 2. CoE in this case was calculated using a fixed charge rate (FCR) of 12.4 percent and a project life of 20 years. This is typical for commercial, mature, utility-scale power projects in the United States. The power-density at the reference deployment location to compute device performance is 34 kW/m.

	PLANT CAPACITY		
	5 MW	20 MW	50 MW
CAPEX	$6,912	$5,035	$4,347
OPEX	$438	$239	$162
O&M percent of CAPEX	6.3%	4.7%	3.7%
PERFORMANCE	5 MW	20 MW	50 MW
Capacity factor	30%	30%	30%
Availability	95%	95%	95%
COE (¢/KWH)	5 MW	20 MW	50 MW
CAPEX Contribution	30	22	19
O&M Contribution	22	12	8
Total	52	34	27

TABLE 2: Reference cost and economic profile from aggregated data and techno-economic modeling

It is important to point out that the CoE in this study was computed using a utility generator CoE model, with returns on capital seen typically in utility-scale power plants, hence the study does not consider the impact on higher capital borrowing costs that are typical for immature technologies. In reality, there would be a risk premium paid by the developer at smaller-scale plants.

Learning Curves

While predicted commercial costs for larger-scale farms are well below present pilot and demonstration cost levels, significant cost reductions will need to be achieved by the industry if the technology is to be deployed at a large deployment scale in competitive utility-industry marketplaces.

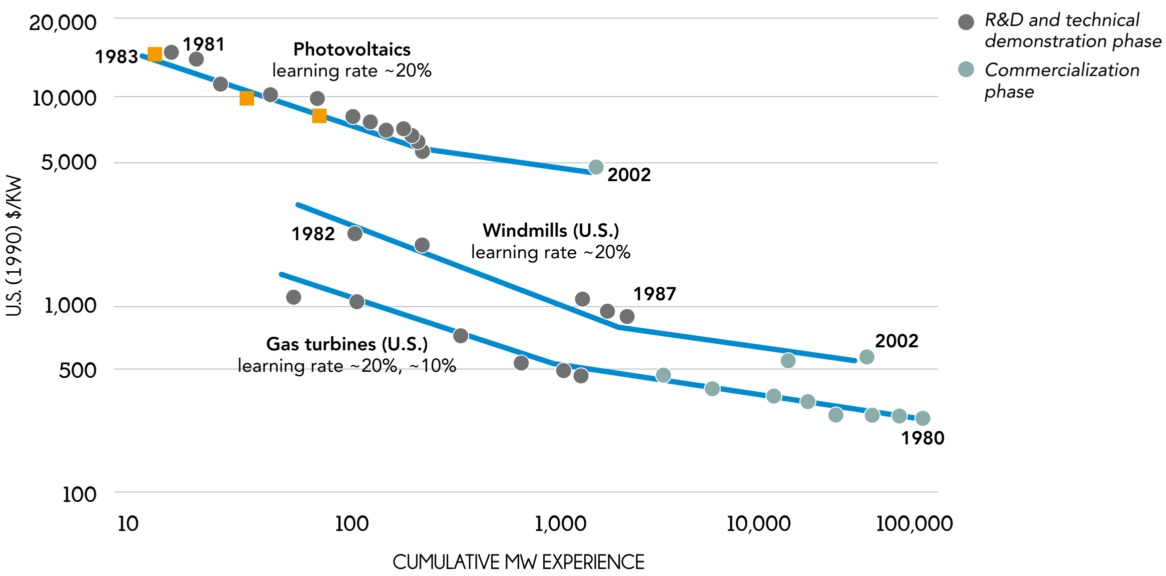

FIGURE 4: Historical learning curves. (Source: "Learning Curves," *Project Finance*, July 2008.)

Learning curves are typically used when predicting longer-term cost reductions for an industry. For each doubling of the deployed capacity, a certain percentage cost reduction is attained. Similar renewable energy technologies have historically attained learning rates on the order of 70–90 percent. Wind technology, for example, which is the most closely related analog, has demonstrated progress ratios on the order of 85 percent. It is important to understand that these cumulative cost reductions are tied to a wide range of factors that can drive cost down, including manufacturing scale, operational efficiencies, improved reliability and availability, and fundamental design changes. (See Figure 4.)

Globally only a limited number of wave energy devices have been deployed, with a cumulative installed capacity of less than 10MW. Furthermore, the wave technology space is characterized by a wide range of different technical approaches, typical for an emerging technology with limited deployments and very similar to wind about 20 years ago. The limited global deployment also means that no technology lock-in has occurred, which is typical for more-established technology sectors. Technology lock-in occurs as a particular technology approach is perfected, manufacturing capacity is built up, and it becomes increasingly more difficult for an alternate technology-topology to enter the market place and compete effectively. A typical example is wind technology, where the 3-bladed, upwind, variable-pitch turbine technology has become the dominant technology. The lack of a technology lock-in makes transformational technology shifts easier to accommodate in the marketplace and opens up the possibility for rapid cost-reduction pathways.

Technology Areas Contributing to CoE Reduction

Within the following set of cost-reduction categories, we used in-house techno-economic models to evaluate how much the CoE from wave energy could be reduced within the near-term, based on the improvement potential of technologies now under development:

Development of efficient operation and maintenance strategies -- Although O&M strategies used in the offshore industry are often adapted for wave energy, they are frequently inefficient and costly. Developing and optimizing O&M strategies and relying on custom vessels specifically built to carry out wave energy operations could allow for a significant reduction in the O&M costs of these devices. Furthermore, recent advances in unmanned vehicle technology (for both surface and underwater vehicles) could allow the use of these vehicles to perform routine inspection and maintenance tasks, a significant opportunity for cost reduction. Early adopter commercial arrays could be used as test-beds for such intervention technologies.

Improving device power capture --The total costs of most wave power machines today are dominated by structural costs. Specifically, these devices show a poor ratio of power output to the structural cost of the absorber. Most of the wave energy devices deployed today are tuned by adjusting the damping on the power takeoff slowly from sea state to sea state. Many of the device concepts studied to date show significant potential to improve power capture if optimal tuning strategies can be applied. To accomplish this improvement, three different areas of technology innovation are needed --

- The ability to accurately predict waves in the open ocean on a time horizon of 30 seconds
- Development of control strategies
- Development of power-conversion systems that allow the implementation of rapid-tuning techniques

Reducing structural overdesign through improved load-prediction tools -- Most design standards used in the offshore industry are very conservative, leading to a tendency of overdesigning the structure. This overdesign is a direct result of the uncertainties in predicting the driving-load cases for which the structures must be designed. An improved understanding of these loads could significantly reduce required safety factors and hence the total material (and cost) of these devices.

Use of alternate materials -- Prototype devices are mostly built from steel today. While steel is a great material choice for building one-off devices and can easily be repaired and modified if needed, it is labor intensive to manufacture and hence expensive. In many cases, composites and concrete could be used instead, providing significant opportunities to reduce labor and material costs in the manufacturing process.

Improve reliability - The system reliability drives O&M costs because it dictates intervention cycles and also replacement part cost. It is expected that with deployment experience, these system will become more reliable and robust over time.

If the above improvements are applied to the baseline CoE profile of 27 cents/kWh at commercial scale, it would allow a cost reduction on the order of almost 50 percent over present cost to a CoE of about 15.5 cents/kWh, as illustrated in Figure 5. Given the uncertainties in the prediction of the baseline cost of +/- 30 percent, the range of CoE values that could be achieved is on the order of 10 – 20 cents/kWh.

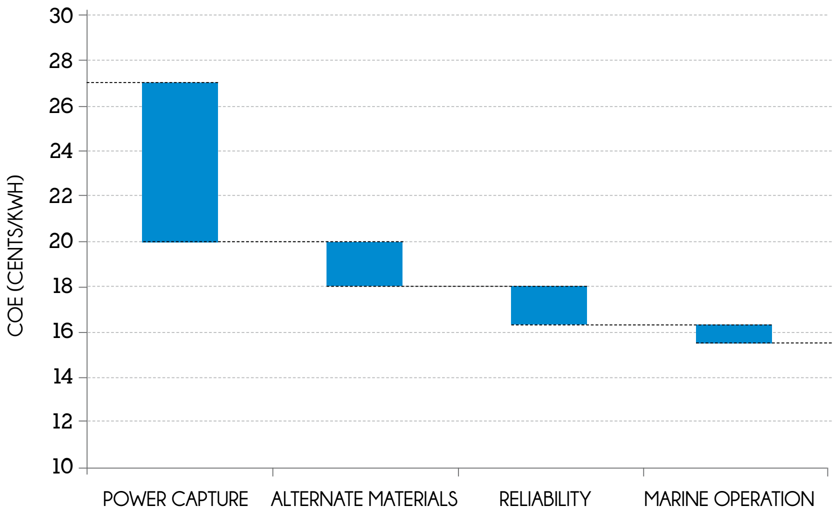

FIGURE 5: Contribution to cost reduction of different cost centers.

Cost Reductions in the US Context

Two scenarios were developed to illustrate how the cost reduction could be established in the US marketplace. The first scenario (the blue lines in Figure 6) shows how the cost would decline from today's levels to the commercial opening cost level predicted by this study if the technologies stayed the same. Cost reductions in this case are largely based on economies of scale (going from 5 MW plants to 50 MW plants) and improvements in device reliability (eliminating the high failure rates typical in pilot and demonstration projects). From the projected opening cost, an 85 percent learning curve indicates predicted cost reductions as the cumulative installed capacity base grows beyond 100 MW. Figure 6 shows that the breakeven target for the lower 48 states, at which no subsidies would be required, occurs at about 50,000 MW cumulative global installed capacity. This point is very similar to the deployed capacity levels at which land-based wind started to become very competitive.

The second scenario (the red line in Figure 6) shows what would happen if an accelerated research, development, and deployment (RD&D) strategy were pursued. Such an accelerated program could potentially reduce the CoE to a level of about 15 ¢/kWh within the first 100 MW of cumulative installed capacity. Cost projections extending out from the 100 MW point were assumed to follow a more traditional learning curve with an 85 percent progress ratio. Figure 6 shows that the CoE would become competitive in Hawaii at a cumulative deployed capacity of less than 200 MW. The learning in this early adopter market would allow costs to be further reduced without any required subsidies, and therefore would minimize the public investment into the technology space. At a cumulative installed capacity of about 3,000 MW, wave power would then reach grid parity with the US mainland (lower 48 states and Alaska).

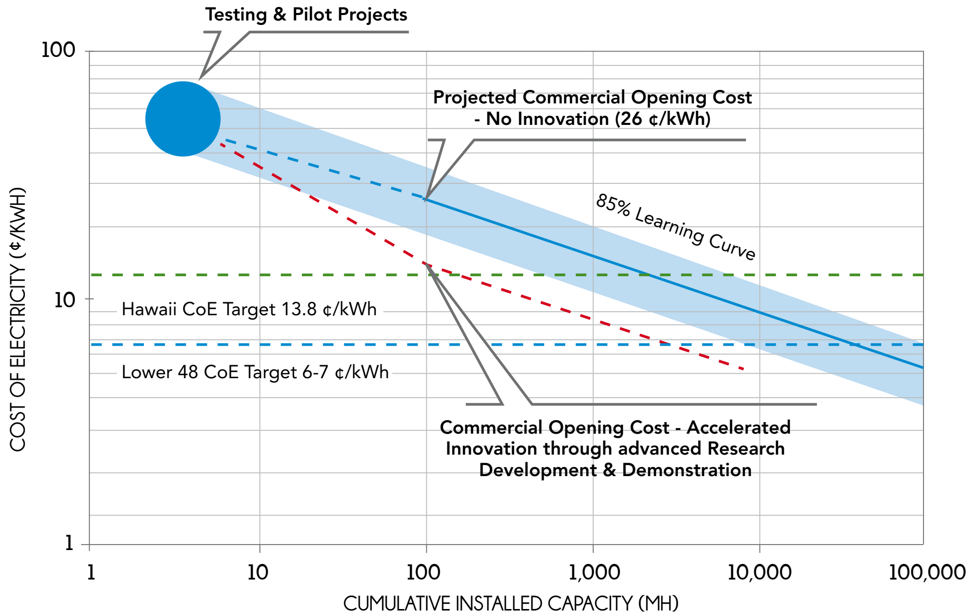

FIGURE 6: Potential cost-reduction pathways

Programmatic R&D Needs

The above areas for innovation can only be attained if strong RD&D programs are in place that nurture this early industry. Although there are no programmatic silver bullets, these guiding principles should be pursued to ensure success:

- **Clear focus on cost-reduction pathways** -- Continued benchmarking of technology innovations with respect to their contributions to reducing the CoE is an important factor in identifying solid cost-reduction pathways and measuring program success. It is important that such benchmarking occurs by modeling commercial-scale arrays from a performance, cost, and economic point of view. Cost drivers at commercial scale are different from the cost drivers at pilot scale, and it is important to engage in the design and optimization process with the end goal in mind.

- **Demonstration and validation** -- Demonstration projects allow the design community to develop a comprehensive understanding of all the elements contributing to the CoE of a particular technology. It is important to transfer the knowledge gained from these demonstrations to the development community so novel design concepts can incorporate those lessons without having to repeat their mistakes. An independent test and validation program can go a long way toward achieving that goal. While this has proven to be difficult to implement, given the commercially sensitive nature of this type of activity, it is a critical ingredient to accelerating technology innovation. Such independent validation work can then be fed back as lessons learned into computational codes and design standards.

- **Development of strong theoretical modeling capabilities** -- The key difference between engineering capabilities existing 30 years ago and today is that modern computing capabilities allow rapid simulation and trade-off studies to be performed on devices that would have required extensive physical testing in the past. Moore's law, which predicted that computational capabilities double every 18 months, has largely held true over the last 30 years (back to when wind power was in its infancy). Over this 30-year period, this yields a millionfold improvement in computational capabilities. By far the most fundamental technological difference today, theoretical modeling allows innovation cycles to be accelerated, enabling rapid progress and reducing cost, by reducing the need for validation and testing. Where traditionally such code development was the domain of national laboratories and universities with supercomputing capabilities, today desktop computers are often sufficient for these problems, enabling small companies to contribute to this code development more rapidly and at much lower cost.

- **Nurturing technological breakthroughs** -- Systematic studies of novel design concepts should be carried out to keep feeding the innovation pipeline. At this stage of wave energy industry development, major breakthroughs are likely to come from radically different design approaches and concepts. Too much focus on established technology could lock out potential breakthroughs that are needed to reduce the CoE in this sector.

CONCLUSIONS

The CoE from wave energy devices deployed today is high, primarily because of the lack of any large-scale deployments. However, careful analysis shows that the commercial opening cost of wave energy is just slightly higher than offshore wind, which is at about 22 cents/kWh today in the US. The detailed study of innovation pathways that can lead to a reduction in CoE furthermore shows that significant cost-reduction potential exists, which could reduce the CoE from commercial-scale wave power plants to about 15 cents/kWh in the near future. Nurturing this innovation potential and carefully benchmarking novel concepts and technologies will be critically important over the coming years if substantial cost reductions are to be attained.

ESB OCEAN ENERGY PROJECTS – A UTILITY PERSPECTIVE ON COST AND PERFORMANCE REQUIREMENTS

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INTRODUCTION

ESB believes Ocean Energy projects can ultimately compete with other forms of renewable energy and that offshore wind economics is a suitable benchmark to inform ocean energy targets. Current offshore wind costs are in the region of €4m/MW installed. ESB sees Ocean Energy cost reducing and performance improving in progressive phases as projects are rolled out by ESB and others. This paper sets out the cost, performance, and revenue requirements for these project phases. While there are areas of significant cost and performance risk in the medium term, technical fundamentals suggest that forms of ocean energy have the potential to meet this cost trajectory and contribute to meeting ESB's renewable energy targets.

The Offshore Renewable Energy Market

In terms of large scale electricity generation market, offshore renewable energy projects must compete with other forms of renewable energy. However, competitiveness must be considered within the context of:
a) Increasing demand for secure and low carbon forms of electricity to meet government targets.
b) Terrestrial constraints to the widespread deployment of onshore wind, hydro and other renewables that are already close to competing with conventional generation.

This has resulted in the introduction of market incentives favouring the importing of renewable electricity from increasingly remote locations back to more densely populated load centres that require it. These incentives are required to overcome the increased costs as well as transmission of electricity over longer distances. Offshore wind is currently the vanguard in this trend and is commercially viable in a number of jurisdictions, including the UK under current incentives of 1.9 Renewable Obligation Certificates (ROCs). Over 2GW of offshore wind is now operational in the UK alone. There is potential for over 50GW of offshore wind to be further developed under recent seabed leasing rounds in the UK and it is expected to make a strong contribution to meeting UK renewable energy targets, where there are constraints to onshore developments in densely populated areas of southern Britain. As EU energy markets integrate and renewable targets evolve, such offshore wind opportunities offer the potential to meet the demands of more densely populated regions across Northern Europe.

In the medium term, there are no obvious constraints to offshore wind's expansion though there are risks to accessing the deeper water sites identified to meet future requirements. Renewable UK [1] expects investment costs of offshore wind to remain at circa £3m/MW (~€4m/MW)[1] up to 2022 with levelised cost of energy (LCOE) reducing to £130/MWh (€160/MWh) during that period. Given the potential scale of the offshore wind expansion, in order for other forms of offshore renewable energy to gain significant penetration in the market, they will need to achieve similar or lower cost levels. Furthermore, given that ocean energy is operating in a similar or more severe environment than offshore wind and shares similar marine foundation and transmission costs, it is likely that ocean energy will also require economies of scale similar to offshore wind for long term viability. Whereas offshore wind was able to benefit from onshore wind technology to build up such economies of scale, ocean energy technologies must find a similar bridging market to develop a supply chain, while also benefiting from the lessons of offshore wind in terms of electrical infrastructure and marine operations.

[1] An exchange rate of £1 = €1.25 is assumed

ESB and Ocean Energy

ESB (Electricity Supply Board) is the largest utility in Ireland comprising of 6GW of generation capacity in Ireland and Great Britain as well as the transmission and distribution system on the island of Ireland. ESB has ambitious decarbonisation targets requiring significant investment in renewable generation such as wind energy and ocean energy. As such, ESB's interest in ocean energy relates to its considerable potential to contribute to ambitious renewable generation targets.

ESB has a dedicated Ocean Energy team, which is responsible for the strategic approach to developing wave and tidal stream energy generation assets. ESB has had an involvement in Ocean Energy for a number of decades including technology partnership with numerous device developers such as MCT, Wavebob and Wave Dragon. ESB is currently developing their own wave energy project called WestWave (*www.westwave.ie*) and this has been developed with partners such as Pelamis Wave Power, Aquamarine Wave Power, Ocean Energy Ltd. and Wavebob Ltd. There has been significant progress in technology verification in recent years. However, given that technology is still being proven based on single device testing, ESB envisages that it could still be some time before large commercial ocean energy generation projects of the scale seen in offshore wind energy will become viable investment propositions.

ESB envisages that the bridging market for ocean energy projects will require enhanced public support until economies of scale can be realised. ESB define three broad phases of Ocean Energy projects in this regard. These phases are as follows:

- **Phase 1: Pre-Commercial Arrays (5-10MW)**

This would follow on from successful single prototype device verification. Phase 1 projects would be the first step in establishing the potential reliability and operational costs of ocean energy arrays. As described later, ESB believe that this phase will require significant grant and tariff support. ESB's WestWave project is an example of a Phase 1 project.

- **Phase 2: Small Commercial Arrays (25MW+)**

This Phase would involve the first projects of significant scale using technologies proven with the benefit of Phase 1 projects and expanding manufacturing capability. It is likely that tariff support over and above what would be sustainable in the long term for large scale electricity generation projects may be required to develop projects at this phase.

- **Phase 3: Large Commercial Arrays (50MW+)**

This Phase would involve large deployment of technologies in 50MW+ scale arrays. A sustainable tariff must be sufficient to develop projects at this phase, similar to the case of offshore wind. The future availability of a sufficient tariff will depend on the future electricity market and in particular the future supply and demand for low carbon and secure forms of energy.

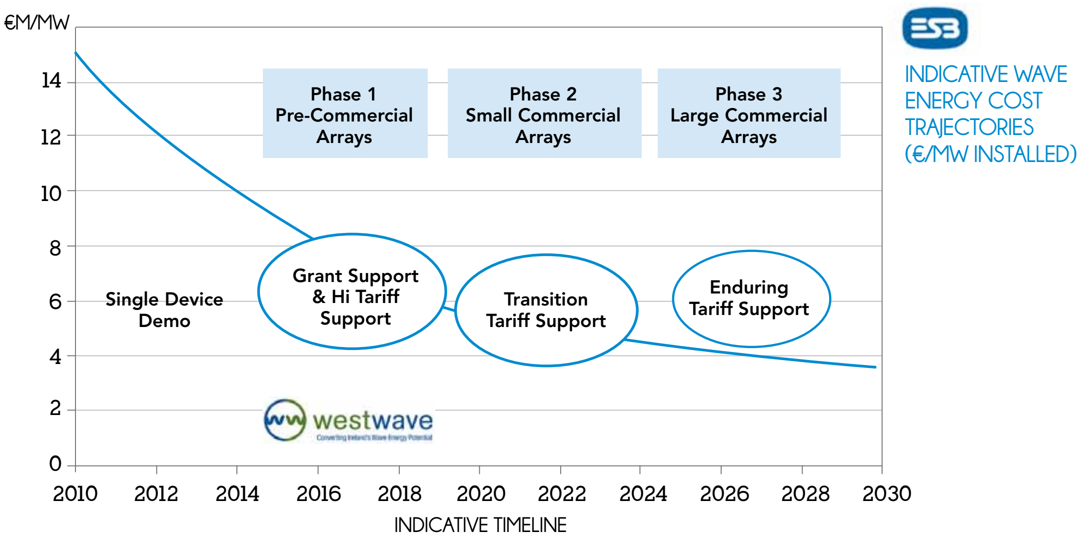

FIGURE 1: An ESB cost projection for projects based on an indicative wave energy technology, showing the role of the WestWave project in putting technology on a commercial cost trajectory

- The WestWave phase 1 project is a 5MW pre-commercial project in Irish waters. Site selection, resource monitoring, grid connection and consenting works are progressing. As part of the first steps in a procurement process for WestWave, ESB has been undertaking detailed technical dialogue with technology developers to support this activity. In undertaking such work, ESB has established Readiness, Cost and Performance criteria to guide suppliers of ocean energy technology towards that required for viable early project investment propositions. ESB present these criteria in terms of:
- Cost & Performance Envelopes
- Technology Readiness Levels (TRLs)

Cost & Performance Envelopes provide clarity on what combination of cost and performance is likely to be affordable from a project investor's perspective. These envelopes will correspond to a particular market. Technology Readiness Levels (TRLs) are used by ESB and others to describe the criteria that technologies must meet for projects at different phases.

Cost and Performance Envelopes

Figure 1 gives an indicative cost trajectory for a typical wave energy technology based on matching offshore wind costs in the future and ESB's estimates of current wave energy cost and performance. However, acceptable capital expenditure (Capex) for such projects will in reality depend on other characteristics of the project, in particular:

- The amount of energy actually produced by the project. This is usually given in terms of capacity factor: the average output as a percentage of the rated capacity installed. This is influenced by reliability and plant uptime as well as variability in the input resource.
- The ongoing annual operational expenditure per MW (Opex), required to operate and maintain the project. This must also include insurance costs.

As such Figure 1 is only an indicative cost trajectory based on particular assumptions of capacity factor and Opex expected for a wave energy technology. To describe acceptable cost constraints more generally, ESB has devised cost and performance envelopes.

Phase 1 Cost & Performance Envelopes:

Phase 1 projects will be required to establish the reliability and predictability of plant cost and performance in advance of larger project investments upon which economies of scale can be built. In order to understand the investment case in such activity, one must consider:

1. The internal rate of return (IRR) demanded by a commercial investor: For such early projects, investors may be willing to accept a reduced IRR where there is strategic value to being involved in an early project, especially where it would provide access to subsequent investment opportunities. An IRR of 7% is selected for this analysis to determine realistic phase 1 project financing costs, though this will vary depending on the project and the investor appetite. An IRR of 7% is probably optimistic as it is not risk-adjusted to the uncertainty involved in the deployment of hardware in the marine environment without a proven track record of reliability. However, it is assumed that all safety critical risks can be managed satisfactorily at this stage.

2. The revenue stream for the project: ESB considers that tariffs of circa €300/MWh are expected to be available in some jurisdictions (e.g. 5 ROCs in the UK market) to undertake these early projects of limited scale.

3. The lifetime of the project: ESB considers that a reduced project economic life of 10-12 years is appropriate for Phase 1 projects as early technology is likely to become obsolete and be replaced at a date earlier than the design life.

Based on the above, an affordable Capex per MW can be established. In order to represent technology variability, the affordable investment cost is presented in Table 1(a) and is calculated for varying capacity factor and annual Opex (as a percentage of Capex). Table 1(a) is the case where it is assumed that no additional grant aid is available for the project. This table provides an "affordable cost envelope" for private project financing of early stage projects.

The influence of capacity factor and Opex on these affordable costs is considerable. For example, for a tidal stream generation plant rated at 1MW, a Capex in excess of €7m is affordable where capacity factors of 45% can be achieved but this reduces to only €4.75m where capacity factors are limited to 30% (for the case of Opex is 4% of Capex). Similar variation is apparent for wave energy technology, where there is ambiguity about how such converters are rated and consequently about what capacity factors can be expected. This highlights the need for caution in how developers rate energy conversion machines and for how investors compare the cost of technology using the crude metric of €/MW installed. There will also be variability in terms of Opex depending on reliability, accessibility and the cost of maintenance operations, such that the affordable investment costs can also vary considerably depending on these attributes. This highlights the need for project investors to undertake detailed technical due diligence to establish realistic expectations of energy production, reliability, availability and operational costs.

Affordable Capex falls within the range of €3-8m for the range of capacity factors and Opex considered in Table 1(a). ESB anticipates that such early projects are more likely to fall in the range of €6-10m per MW. As such, it is likely there will be a shortfall between the required €6-10m and what can be justified as a commercial investment alone, especially where Opex is likely to be high and reliability low for phase 1 projects. As such, these projects are termed "pre-commercial" by ESB and require additional sources of funding.

Additional Phase 1 project funding:
Grant aid is likely to be essential to establishing this vital bridging market of phase 1 ocean energy projects. Funding supports are already available through schemes such as the EU's NER300 and the UK's Marine Energy Array Demonstration Fund (MEAD). Table 1(b) below repeats the calculation for phase 1 projects, but considers the case where a €3m/MW grant is made available to the project. Note that this grant aid is further limited to half of the total investment cost up to a maximum of €3m (as in many cases it is difficult to grant fund projects by over 50%). The resulting project costs that can be funded in this way then fall into the Capex range of €6-10m and ESB consider these as acceptable project costs for phase 1. As such, the cost and performance envelope described in Table 1(b) represents a useful target to maximise the chance of successfully financing a phase 1 project.

Phase 2 Cost and Performance Envelopes:
Once phase 1 projects are performing reliably and operational costs and associated risks are understood with some confidence, it should be possible to build a business case for larger projects and take advantage of economies of scale. Grants will be difficult to justify at this scale and so such projects will need to be commercial based on a bridging tariff alone (such as the 5 ROC market in the UK or equivalent feed in tariffs). Phase 2 affordable costs are calculated here based on:

1. The internal rate of return (IRR) demanded by an investor: Projects at this scale will need to pay for themselves using normal commercial finance. An IRR of 10% is selected for this analysis, though this will depend on the project and the investor. However, offshore projects will carry risk, and some contingency must be included to attract such finance.

2. The revenue stream for the project: ESB considers that tariffs of between €220/MWh (proposed Renewable Energy Feed in Tariff (REFiT) for Ireland) and €300/MWh (approx equivalent to 5 ROCs in the UK market) will be available to undertake these early projects of limited scale. There may also be niche applications for technology (e.g. island communities or in applications for offshore oil and gas activities) where higher tariffs are payable for small projects. €300/MWh is used in this analysis.

3. The lifetime of the project: A project life of 20 years (approaching expected design life of hardware) is appropriate for Phase 2 projects.

Table 2 shows the resulting affordable cost and performance envelope for phase 2 projects. An enhanced tariff of €300/MWh is likely to be unsustainable at scale and therefore there will be a limited market for such projects.

Phase 3 Cost and Performance Envelopes:
Economies of scale, incremental technology improvements as well as improvements in performance and reliability will have a significant impact on the economic case. In order to achieve economic parity with offshore wind, ESB considers the following case:

1. The internal rate of return (IRR) demanded by an investor: As for Phase 2 projects, an IRR of 10% is selected for this analysis. Offshore projects of large scale will still carry risk, and some contingency must be included to attract such finance.

2. The revenue stream for the project: Based on Renewable UK [1] projections for offshore wind levelised costs; ESB considers that tariffs of £130/MWh (~€160/MWh) may be available for offshore renewable generation projects beyond 2020.

3. The lifetime of the project: A project life of 25 years is considered appropriate for Phase 3 projects.

Table 3 represents the resultant cost and performance envelope. Note that the current investment cost of offshore wind projects in the UK are circa €4m/MW and such projects can now achieve a capacity factor of 35-40% with operational costs of €80-90k/MW/year (see Renewable UK [1]). These costs are within the envelope described in Table 3 (highlighted). As such, Table 3 represents the cost and performance currently required for a significant market to develop, as for offshore wind.

a)

PHASE 1: AFFORDABLE INVESTMENT COSTS FOR GENERATION PROJECTS						
OPEX €m/MW/annum CAPEX €m/MW			ANNUAL OPEX AS % OF CAPEX			
			2.0%	4.0%	6.0%	8.0%
CAPACITY FACTOR	20%	*OPEX*	*0.07*	*0.13*	*0.17*	*0.20*
		CAPEX	3.60	3.17	2.83	2.55
	25%	*OPEX*	*0.09*	*0.16*	*0.21*	*0.26*
		CAPEX	4.50	3.96	3.53	3.19
	30%	*OPEX*	*0.11*	*0.19*	*0.25*	*0.31*
		CAPEX	5.40	4.75	4.24	3.83
	35%	*OPEX*	*0.13*	*0.22*	*0.30*	*0.36*
		CAPEX	6.30	5.54	4.95	4.47
	40%	*OPEX*	*0.14*	*0.25*	*0.34*	*0.41*
		CAPEX	7.21	6.34	5.65	5.11
	45%	*OPEX*	*0.16*	*0.29*	*0.38*	*0.46*
		CAPEX	8.11	7.13	6.36	5.74
to yield a 7% IRR for a 12 year project life where a tariff of €300.00/MWh is payable						

b)

used in table 7

PHASE 1: AFFORDABLE INVESTMENT COSTS INCLUDING A GRANT FACILITY						
OPEX €m/MW/annum CAPEX €m/MW			ANNUAL OPEX AS % OF CAPEX			
			2.0%	4.0%	6.0%	8.0%
CAPACITY FACTOR	20%	*OPEX*	*0.12*	*0.20*	*0.26*	*0.29*
		CAPEX	6.19	5.11	4.27	3.68
	25%	*OPEX*	*0.14*	*0.25*	*0.32*	*0.37*
		CAPEX	7.09	6.24	5.34	4.60
	30%	*OPEX*	*0.16*	*0.28*	*0.38*	*0.44*
		CAPEX	7.99	7.03	6.27	5.52
	35%	*OPEX*	*0.18*	*0.31*	*0.42*	*0.50*
		CAPEX	8.89	7.82	6.98	6.30
	40%	*OPEX*	*0.20*	*0.34*	*0.46*	*0.56*
		CAPEX	9.79	8.61	7.69	6.94
	45%	*OPEX*	*0.21*	*0.38*	*0.50*	*0.61*
		CAPEX	10.69	9.41	8.39	7.58
to yield a 7% IRR for a 12 year project life where a tariff of €300.00/MWh is payable **and a grant of €3m/MW is available up to matched funding level**						

TABLE 1: Phase 1 project affordable investment costs without grant (a) and with matched funding grant up to a maximum of €3m/MW (b)

PHASE 2: AFFORDABLE INVESTMENT COSTS FOR GENERATION PROJECTS						
OPEX €m/MW/annum CAPEX €m/MW			ANNUAL OPEX AS % OF CAPEX			
			2.0%	4.0%	6.0%	8.0%
CAPACITY FACTOR	20%	*OPEX*	*0.08*	*0.13*	*0.18*	*0.21*
		CAPEX	3.82	3.34	2.96	2.66
	25%	*OPEX*	*0.10*	*0.17*	*0.22*	*0.27*
		CAPEX	4.78	4.17	3.70	3.33
	30%	*OPEX*	*0.11*	*0.20*	*0.27*	*0.32*
		CAPEX	5.74	5.01	4.44	3.99
	35%	*OPEX*	*0.13*	*0.23*	*0.31*	*0.37*
		CAPEX	6.69	5.84	5.18	4.66
	40%	*OPEX*	*0.15*	*0.27*	*0.36*	*0.43*
		CAPEX	7.65	6.68	5.92	5.32
	45%	*OPEX*	*0.17*	*0.30*	*0.40*	*0.48*
		CAPEX	8.60	7.51	6.66	5.99
to yield a 10% IRR for a 20 year project life where a tariff of €300.00/MWh is payable						

used in table 7

TABLE 2: Phase 2 Affordable capital investment for commercial projects >25MW

PHASE 3: AFFORDABLE INVESTMENT COSTS FOR GENERATION PROJECTS						
OPEX €m/MW/annum CAPEX €m/MW			ANNUAL OPEX AS % OF CAPEX			
			2.0%	4.0%	6.0%	8.0%
CAPACITY FACTOR	20%	*OPEX*	*0.04*	*0.07*	*0.10*	*0.12*
		CAPEX	2.15	1.87	1.65	1.47
	25%	*OPEX*	*0.05*	*0.09*	*0.12*	*0.15*
		CAPEX	2.69	2.33	2.06	1.84
	30%	*OPEX*	*0.06*	*0.11*	*0.15*	*0.16*
		CAPEX	3.23	2.80	2.47	2.21
	35%	*OPEX*	*0.08*	*0.13*	*0.17*	*0.21*
		CAPEX	3.77	3.27	2.88	2.58
	40%	*OPEX*	*0.09*	*0.15*	*0.20*	*0.24*
		CAPEX	4.31	3.73	3.29	2.95
	45%	*OPEX*	*0.10*	*0.17*	*0.22*	*0.27*
		CAPEX	4.85	4.20	3.71	3.32
to yield a 10% IRR for a 25 year project life where a tariff of €160.00/MWh is payable						

used in table 7

current offshore wind (approx)

TABLE 3: Phase 3 Affordable capital investment for commercial projects >50MW to be competitive with offshore wind.

Technology Readiness Levels (TRL)

In order for a project to demonstrate that it can fall within an acceptable cost envelope, technology developers must complete a test and validation programme that demonstrates this to the satisfaction of investors. ESB has developed technology readiness level (TRL) definitions [2], adapted from those developed for aerospace technology by NASA. The ESB wave energy TRL definitions have gained some broader acceptance as a means to evaluate the maturity of ocean energy conversion technology and to communicate validation requirements for future projects. ESB's TRL levels range from TRL1 to TRL9 with TRL9 being a fully developed 'commercial', certified product with significant in-service experience (similar in maturity to offshore wind converters such as the ubiquitous Siemens SWT 3.6-120 turbine). Under the ESB definition, the TRL level of a technology is evaluated based on it meeting certain criteria in both functional readiness and lifecycle readiness.

- *Functional readiness* describes how it has been verified that a technology performs its specified major functions including energy production performance and maintaining station.
- *Lifecycle readiness* describes how well it has been verified that the lifecycle of a project based on the technology is viable, considering aspects such as manufacturability, deployability, operability, reliability, maintainability and overall commercial viability.

The TRL levels are summarised in Table 4 below.

TRL	FUNCTIONAL READINESS	LIFECYCLE READINESS
1	Basic principles observed and reported	Potential uses of technology identified
2	Technology concept formulated.	Market and purpose of technology identified
3	Analytical and experimental critical function and/or characteristic proof-of-concept.	Initial capital cost and power production estimates / targets established
4	Technology component and/or basic technology subsystem validation in a **laboratory environment**. (>1:25 Froude)	Preliminary Lifecycle design: targets for manufacturable, deployable, operable and maintainable technology
5	Technology component and/or basic technology subsystem validation in a **relevant environment**. (>1:15 Froude)	Supply-chain Mobilisation: Procurement of subsystem design, installation feasibility studies, cost estimations, etc.
6	Technology **system** prototype demonstration in a **relevant environment**. (>1:4 Froude)	Customer interaction: consider customer requirements to inform type design. Inform customer of likely project site constraints.
7	Technology **system** prototype demonstration in an **operational environment**. (>1:2 Froude)	Ocean Operational Readiness: management of ocean scale risks, marine operations, etc.
8	Actual Product (first of type) completed and qualified through test and demonstration. (1:1 Froude)	Actual Marine Operations completed and qualified through test and demonstration.
9	Operational performance and reliability demonstrated for an array of type machines.	Fully de-risked business plan for utility scale deployment of arrays

TABLE 4: TRL summary definition. Full definition in [2]

Although the ESB TRLs also make reference to the cost and performance of a technology within the lifecycle readiness criteria, this is in an absolute sense relative to a particular project business case. Using the cost and performance envelopes outlined above, it is possible to consider economic viability in terms of target costs. These define the maturity of a technology in terms of economic competitiveness in more detail. Table 5 proposes economic competitiveness levels for offshore renewable technology.

LEVEL	ECONOMIC COMPETITIVENESS	RELEVANT ESB COST TARGETS
1	Potential for incremental changes to meet key performance requirements to enable commercial projects	Table 1(b)
2	Economic viability under distinctive and favourable market and operational conditions. **Limited market**	Table 2
3	Sufficiently competitive to be a "new entrant" renewable energy of scale in general electricity generation market (e.g. offshore wind). Tariff Supports Required. **Significant market**	Table 3
4	Sufficiently competitive to be best cost renewable (e.g. onshore wind). Supports may still be required. **Very large market potential**	N/A
5	Competitive in general electricity market without special support mechanisms. **Market constrained by resource only**	N/A

TABLE 5: Economic Competitive Level summary definition.

Weber [3] also recently published similar Technology Performance Levels (TPLs) as well as the concept of using both TRLs and TPLs to plan and describe the progression of technology development. Such definitions of economic competitiveness permit technology developers to consider aspects such as:

- Although a technology may be very well advanced in terms of prototype testing, even to full scale, it may have poor performance and high costs. While it may be viable for pre-commercial projects under particular financial incentives, it may not be on a trajectory towards overall competitiveness in the renewable energy market.
- Experimental iterations to increase economic performance at a high readiness level may be cost prohibitive as any design changes require repetition of large scale prototype testing. However, achieving high economic performance at a low readiness level may also be difficult due to the limitations of laboratory and numerical analysis and in such cases important deficiencies in technology may not be detected until it is tested at larger scale in the ocean. By considering a combination of TRLs and economic targets, Weber [3] describes how one can capture an optimal "trajectory" in terms of developing technology towards the performance and readiness required by utility project developers.

In the economic competitiveness levels described in Table 5, Level 3 is a realistic ambition for offshore renewables as it defines generation technology that is cost competitive with "best new entrant" forms of renewable energy, required to meet government targets (currently offshore wind in the GB market). However, there is inherent uncertainty on the future value of renewable electricity and this relates to the demand derived from government targets as well as the potential future availability of newer, more competitive forms of renewable energy. For now, ESB considers offshore wind to be the appropriate "new entrant" renewable energy that ocean energy must match economically in order to access a market of scale in Great Britain and Ireland electricity markets. As such, the cost and performance envelope defined in Table 3 is indicative of an ESB Phase 3 project cost requirements.

Project Requirements

ESB have set required TRL and economic hurdles for each of the three project phases outlined previously, as shown below in Table 6. This shows the developing combined technical maturity (TRL) and economic viability which must be demonstrated before each phase of projects can be developed.

ESB OCEAN PROJECT	INDICATIVE PROJECT	REQUIRED TRL LEVEL	REQUIRED COST ENVELOPE
Phase 1 Project	Pre-Commercial Array (5-10MW)	TRL 8	Table 1(b)
Phase 2 Project	Small Commercial Array (25MW+)	TRL 9	Table 2
Phase 3 Project	Large Scale Array (50MW+)	TRL 9	Table 3

TABLE 6: TRL and Economic Requirements for ESB Ocean Energy Projects

Ocean Energy Cost Trajectories

Based on the cost envelopes in Tables 1 to 3, it is possible to extract realistic cost trajectories that ocean energy must achieve for commercial acceptability. For example, consider a wave energy technology that has been verified to TRL8 and is assessed to have a potential capacity factor of 25% (based on the application of specifications such as IEC 62600-100 and 62600-101 as well a realistic allowance for availability). Assuming that investors are happy that annual operational expenditure (Opex) can be kept at or below €250k per MW per year then the affordable capital expenditure (Capex) according to table 1(b) is €6.24m/MW. If this is sufficient to fund a phase 1 project, then as the industry grows for subsequent projects there is potential for overall project Capex and Opex to fall while energy yields increase. Table 7 below sets out a realistic trajectory for wave energy technology costs through the three phases. In this case, ultimate project Capex is projected to be €3.3m/MW, a little less than offshore wind, though Opex is a little higher, perhaps owing to accessibility to high wave energy sites. Figure 1 is based on this same logic, though it should be considered that different technologies will have varying expectations of capacity factor and Opex so many such Capex curves could be produced. It is only important that Capex, Opex and capacity factor are collectively within acceptable envelopes (Tables 1 to 3) at each stage.

PROJECT PHASE	PROJECTED CAPACITY FACTOR	PROJECTED OPEX	TARGET CAPEX
1 5-10MW	**25%** based on TRL8 testing and application of IEC standards and allowance for poor reliability initially.	**€250k/MW/year** based on allowance for poor reliability, increased need for intervention and lack of dedicated supply chain / vessels	**€6.2m/MW** (from table 1b)
2 25MW+	**30%** based on phase 1 project performance and demonstrated reliability (TRL9)	**€200k/MW/yr** based on improved reliability and supply chain experience	**€5.0m/MW** (from table 2)
3 50MW+	**35%** based on improved reliability, design and access to more energetic sites.	**€130k/MW/yr** based on bespoke supply chain facilities, vessels and much reduced need for repair intervention.	**€3.3m/MW** (from table 3)

TABLE 7: Realistic Cost Projections for Wave Energy Conversion Projects

Project Cost Breakdown

The costs given above are total project costs and it is useful to consider what cost breakdown is expected for wave and tidal energy projects. These costs can be broken down in various ways [4], [5] but will be broken down here under the below headings. Offshore wind is a useful guide [6] to understand the typical breakdown that is targeted. Opex is not considered here, so this is a breakdown of Capex only.

- **Development** – This is typically 4% of total Capex for offshore wind, it is expected that this will be similar for wave and tidal farms with similar consenting requirements.
- **Converters** – WECs / TECs – In offshore wind, turbines are typically 40% of the total Capex, uninstalled. It is expected that this will be closer to 45-50% for both wave and tidal farms due to the potential for savings in other Capex components.

- **Foundations / Moorings** – In offshore wind, foundations make up approximately 20% of the total Capex, uninstalled. This is likely to be similar for tidal farms, with fixed foundation requirements, but potentially less for wave farms, with mooring system requirements.
- **Electrical Connection** – In offshore wind, electrical components make up 15% of the total Capex, uninstalled. This is expected to be similar for wave farms, due to similar distances from shore, but perhaps less for tidal farms, which can be close to shore.
- **Installation** – In offshore wind, the installation of foundations, electrical cables and turbines makes up approximately 20-25% of the total Capex. This is expected to be similar for tidal farms but perhaps less for wave farms depending on WEC installation strategy.

There is still a large variety of wave and tidal energy converter concepts, more so in wave energy. It is therefore difficult to put a fixed breakdown of Capex for both that will be universally accurate. A prospective breakdown of costs for wave and tidal energy arrays is Shown in Figure 2. These cost breakdowns are for Phase 3 projects only. Phase 1 and 2 projects are expected to have a different cost breakdown.

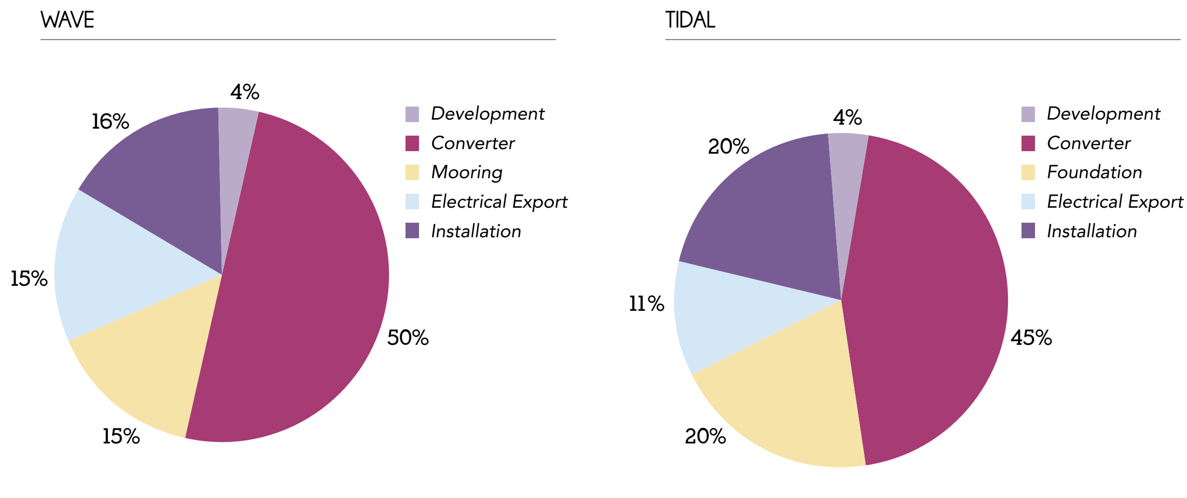

FIGURE 2: Prospective Capex Breakdown for Phase 3 Wave and Tidal farms

Although the target costs for Ocean energy projects are circa €4m/MW to be comparable to offshore wind (Table 3), this would equate to a target costs of circa €2m/MW for the wave energy converters and €1.8m/MW for tidal energy converters themselves. This is the 'dry' cost to deliver the hardware to the quayside before installation. It is possible to assess metrics, such as structural tonnes/MW of particular solutions to see if the material costs are likely to be consistent with these long-term requirements. Cost requirements are similar to the current cost/MW of offshore wind energy converters. Given that the input energy resource for both wave and tidal energy can be denser than for wind energy (see Table 8), ESB see no fundamental reason why these alternative offshore energy converters cannot achieve competitive structural costs. However, in order to realise this, technology developers must ensure that their solutions have the potential to be as structurally efficient as offshore wind energy converters in order to meet the longer term phase 3 cost requirements.

Cost Indicators and Risks

Presently, evaluating the economic potential for technology can prove difficult as only a small number of wave and tidal technology developers have progressed past TRL7, at which stage there is credible visibility of final commercial costs. In terms of performance there are only a small number of technology developers that have completed meaningful levels of generation and running hours and can therefore give credible capacity factor projections. As such, the evaluation of economic competitiveness at this stage is, for the most part, more subjective than that of TRLs. ESB believe that technology developers will have a firmer understanding of costs and performance once TRL8 is achieved. In the meantime, there are other cost indicators which may be used to inform economic competitiveness. These 'cost indicators' at a pre TRL7 phase include:

RENEWABLE POWER SOURCE	POWER DENSITY
Wind Power per m^2 of input wind at 12m/s (typical rated velocity of an offshore wind turbine)	1,100 W
Tidal Power per m^2 of input water current at 2.4m/s (typical rated velocity of a tidal turbine to achieve >30% capacity factors)	7,000 W
Wave Energy flux per m^2 of seastate Hs = 6m, T_z = 8s sea state (typical rated sea state for wave energy converters to achieve >30% capacity factors)	9,400 W (average in upper 10m of sea)

TABLE 8: Power Flux from different renewable sources of power through a vertical $1m^2$ reference area. Reference wind velocity, current velocity and sea state are chosen as typical rated values that would be sufficient to achieve capacity factors of >30% at suitable sites.

- Tons of steel per MW
- Wetted surface area and working surface area (e.g. blade area, rotor swept area, and float size)
- Foundation or mooring concept
- Mechanical complexity of overall system and PTO
- MW rating for single unit
- Type of WEC and PTO
- Construction, installation, and maintenance concepts

Other than the basic costs of the converter hardware itself there are other cost risks to projects which are outlined briefly below. If the focus is solely on reducing the cost of wave or tidal energy converters, design changes could introduce other non-core cost risks to a project. These risks include;

- **Device rating** – Most wave and tidal energy converters are currently rated at around 1MW. By increasing the MW rating of devices, there can be a significant reduction in other parts of the Capex such as electrical infrastructure, installation and foundations/moorings, consistent with the experience of offshore wind. Also increasing the unit rating may reduce the Capex per MW of the converter itself, although this has remained relatively constant for offshore wind.
- **Capacity factor** – The capacity factor has a direct impact on the productivity per MW installed and this is reflected clearly in acceptable cost and performance envelopes (Tables 1-3). However, the electrical system must also be rated for the maximum output power and a lower capacity factor means a low utilisation of this expensive infrastructure. Low capacity factors can result in significantly increased downstream per MW infrastructure costs. In wind energy, optimal capacity factors are higher than for onshore wind as a result of the cost of offshore electrical balance of plant (35-40% offshore as opposed to 25-30% onshore).
- **Insurance** – Insurance is a critical part of the viability of a project and it is likely that in early stage wave and tidal farms this will contribute significantly to Opex. In-service data, certification, and warrantees will go some way towards reducing the insurance costs and managing the safety critical risks to the satisfaction of utility investors.

CONCLUSIONS AND PERSPECTIVE

The above assessment shows a challenging but realistic view of the market for ocean energy. In some jurisdictions the market conditions exist to allow investment in pre-commercial Phase 1 small array projects. These projects will begin the process along the cost reduction trajectory presented. Supplementing offshore wind with wave or tidal stream energy as large scale sources of renewable generation will only occur when costs are competitive. ESB believe that ocean energy can develop towards sustainable and competitive projects. This trajectory is achievable, based on economies of scale and learning rates, but consistent supports and long term policy are required to deliver a bridging market to cost competitive ocean energy. Technology developers that focus on delivering technology within realistic economic constraints are likely to be successful in the long term.

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"FROM TURBINE PROTOTYPE TO PROTOTYPING AN INDUSTRY: A CRITICAL CHANGE IN PERSPECTIVE"

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Tracey Kutney – *CanmetENERGY, Natural Resources Canada*

Over the course of 2012, there have been signals that the global marine renewable energy industry focus has evolved from a technology commercialization paradigm to a focus on demonstrating a clean power industry option. This shift has been recognized by both Canada and the UK, as the immediate goal sought by both countries has become demonstration of multiple devices – "arrays" - to create utility-scale power plants.

Prototyping an Industry

The focus on array-scale development is evident in many of the recent Canadian and UK initiatives. With both countries viewed as global leaders in this industry, it is very telling of where the sector is going and what is needed to achieve a sustainable industry.

Canada's strategy to date has been focused on the end-game and the steps to demonstrate a marine power industry solution, with an assumption that technology would advance to meet its needs. The 2011 Canadian Marine Renewable Energy Technology Roadmap[1] focused primarily on solving the challenges of transitioning from the technology development phase to the array or power plant phase—and highlighted the technical and business opportunities this transition would present. A central tenet of the roadmap strategy was that a broader suite of innovation must be launched urgently, effectively and efficiently. The roadmap identifies pioneer prototype power plants as the incubators for this critical transition.

Even as the first single device deployments were still only planning initiatives, Nova Scotia's Fundy Ocean Research Center for Energy (FORCE) made a commitment to develop the offshore interconnectors for four pilot tidal power plants – arrays of devices with capacity outputs of 16 MW each, totaling 64 MW. This action was based on the idea that the demonstration needed to convince the power industry and its financiers was not simply that a tidal generator can produce significant amounts of electricity, but the critical step was going to be showing the availability and reliability of electricity generated from a marine power plant.

That same perspective is seen in the UK's most recent strategic support initiatives. The Marine Energy Array Demonstrator scheme overtly targets two such pilots – at least three devices and preferably in the 5-10MW capacity range[2]. The Marine Renewables Commercialization fund is focused on levering two or more such projects ahead in Scotland, to prove:
"That wave and tidal devices can be installed in various real-sea locations.
That installation vessels and teams can install and commission multiple devices in close proximity.
That the supply-chain for marine energy devices and balance of plant can be mobilized to manufacture and assemble multiple components, beginning to deliver economies of scale.
That power from such devices can be combined and delivered to shore.
That devices can generate continuously to the grid, and that projects can be funded based on the sale of that electricity."[3]

The focus on driving these developments with market-pull mechanisms has become increasingly critical, with a number of mechanisms advancing in several countries. In the UK, the Renewable Obligation Certificate (ROC) banding sets a premium on the value of wave or tidal energy and after a number of reviews, the UK Department of Energy and Climate Change has decided to offer 5 ROCs per MWh.[4] This premium of about $300 over the clean electricity price is designed to support projects up to 30 MW - a scale proposed to encourage commercial-scale pilots. In the United States, the first tidal power purchase agreement for Ocean Renewable Power Corporation (ORPC) was created by an obligation to purchase tidal power.

[1] *http://www.marinerenewables.ca/technology-roadmap/*

Similarly, Canada has also recognized the need for this market support. In Nova Scotia, the Community Feed-In-Tariff (COMFIT) of $652/MWh has attracted five community-scale project proposals from Fundy Tidal Inc. which have received approval by provincial government. Nova Scotia is also in the process of setting an array-scale FIT which is expected to be established in spring 2013.

Accelerating the innovation

The focus on array-scale development partly stems from the need to accelerate innovation around some of the leading generator systems. For example, the Canadian roadmap recognized this relationship between larger projects and innovation stating: *"Canada's marine renewable energy sector must continue to develop in this direction to accelerate innovation and collaboration, and drive the development of commercial- scale wave, in-stream tidal, and river-current demonstrations."*

The roadmap proposed that the development of technology incubators to share experience and accelerate innovation is fundamental to the progress along these pathways. It suggested that aggregating early activity will create the scale and momentum needed to incent the development of technologies and the transfer of skills from other sectors (such as oil and gas, fisheries, marine and salvage operations). The early achievement of full-scale demonstration would showcase Canada's engineering, procurement and construction capabilities as a demonstration of expertise by solving the needs of these projects.

Likewise, the pursuit of full-scale demonstration is evident in UK thinking. The 2012 Technology Innovation Needs Assessment by UK's Low Carbon Innovation Coordination Group identified initial deployment of first arrays and R&D to address the challenges identified in the first arrays[5] as two priority actions. The 2010 UK UKERC/ETI roadmap also focused on crosscutting enablers for cost reduction to accelerate progress on the first arrays[6]. Similarly the UK Technology Strategy Board and Scottish Government recently committed funding to seven projects focused on array development enabling technologies addressing the range from designs for installation and service vessels to a standard foundation connection.[7]

Building a supply chain, which assembles the best component supply, manufacturing and operational approaches, is a problem for one-off assemblies and demonstrations. Array-scale development catalyzes this industrial-scale activity because they create needs that demonstrations of single devices can avoid... The multi-device systems will require an integration of technology, technical approaches and operating practices, which may not have been needed for single-device testing. The requirements of these prototype power plants are already driving the focus of strategic and collaborative innovation initiatives (Figure 1).

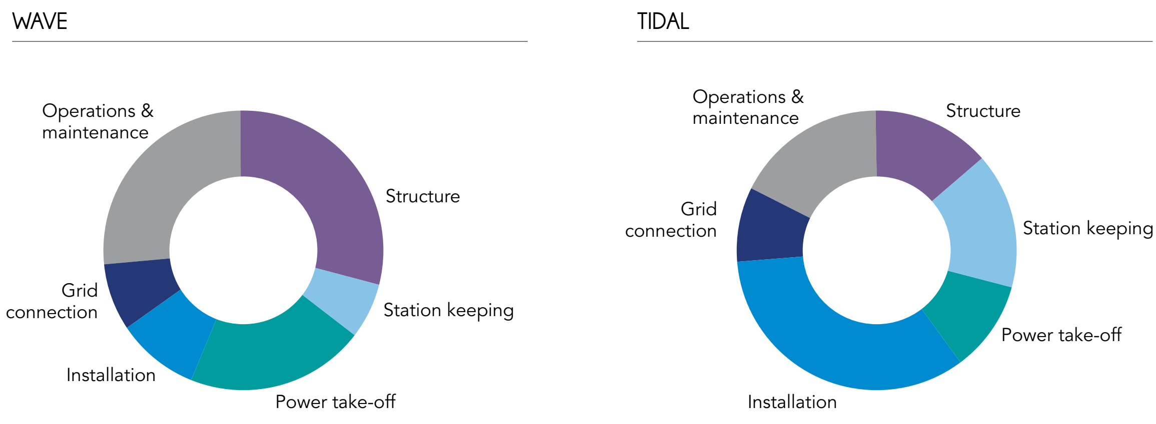

FIGURE 1: Cost Components for Wave and Tidal Energy Projects (source: Carbon Trust)

[2] *http://www.decc.gov.uk/en/content/cms/meeting_energy/wave_tidal/funding/mead/mead.aspx*
[3] *http://www.carbontrust.com/client-services/technology/innovation/marine-renewables-commercialisation-fund*
[4] *http://www.decc.gov.uk/assets/decc/11/consultation/ro-banding/5936-renewables-obligation-consultation-the-government.pdf*
[5] *www.lowcarboninnovation.co.uk/document.php?*
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[7] *https://connect.innovateuk.org/web/marine-energy-supporting-array-technologies/articles/-/blogs/trackback/presentations-available-from-marine-energy-supporting-array-technologies-event*

Refining real costs, avoiding delays caused by not being a favoured-customer and having to make one-off decisions on installation and operations can mean that the learning from device trials may not actually contribute to an understanding of the necessary industrial approaches. The breakdown of the cost components indicate that generator structures are only part of the total cost of the power plant.

Team building for industrial scale delivery

Multi-device projects will require the human and financial resources that will resemble those required in the 'developed' industry. Financing and delivering the first array projects present challenges that are beyond the capacity of the device developers who out of necessity have been playing project development roles for their early device testing and demonstration. The need to engage in site characterization, permitting and all of the other "project" development activities has meant that device developers have had to incorporate skills that draw on financial resources, yet may not be part of the long-term business plan. In some cases and at some stages the "burn rate" associated with this non-core business has exceeded that for the core device development.

Delivery of these projects is a new challenge and the 2012 launch of Nautimus (Vattenfall, Abengoa and Babcock) is a significant development triggered by the needs of the first projects.
This evolution will push technology developers to move into the business of manufacturing series of devices for these projects – the engagement of major integrator/manufacturers (Alstom, Andritz, DCNS, Lockheed Martin, Siemens, Voith Hydro and others) over the last year or two are bringing that transition into focus.
These array projects will enable electricity companies like Emera, EDF, E.ON, RWE, Scottish Power, SSE, Vattenfall and others to understand the scope and opportunity that future development presents. The electricity industry is accustomed to power projects in the hundreds of MW or even gigawatt scale and typically sees high transaction costs, interconnection challenges and attrition rates when dealing with large numbers of smaller projects. Reliability and availability risks are perceived to be higher when managing small projects. Against this background it is not surprising that utilities want to see arrays of devices in order to build confidence in the generation method and to have operations that at least are indicative of a small operating power plant.

Finance is a continuing challenge as projects require the amount of capital normally addressed by project finance, but without the experience expected by the project finance players. Narec Capital is advancing an effort to manage risk and mobilize finance[8]. Morgan Stanley has been attracted to the sector through the UK's Meygen array project. Strategic financiers like the European Investment Bank are seeing the opportunity to make these early industrial-scale projects the learning experience that financiers need.

After A Decade Of Technology Push

Many lessons that can be applied to these future projects have been learned from what has essentially been a push to commercialize marine renewable energy generation devices. The multi-year operation of Siemens/MCT SeaGen in Strangford Lough, Northern Ireland, has not only demonstrated technical feasibility but, more generally, the concept of a megawatt-scale marine renewable energy generator that can be installed and operated for long periods. As 2012 closes, at least two wave technologies, and three other tidal generator companies have accumulated experience with these large–scale generators.

The scale of prototype trials, the time to iterate technological developments and demands for accessing marine sites have been challenges addressed by the creation of permitted test centres with shared infrastructure. Despite this support, development rates have been slower than anticipated, in large measure due to financing difficulties which has also made supply chain development challenging.

Potential tidal and wave converter customers or investors, now familiar with the "accepted" design of wind turbines, express concern that the wide range of device designs demonstrate an immaturity in the marine renewable energy industry. This raises concerns about how to pick a winner. Most customers need to see the integrated system that makes the device into a power plant they could use. These customers want to know: does it reliably supply electricity? Are the project risks understood? Is the electricity affordable? Is this a viable hedge against long-term cost-of-fuel increases?

[8] *www.nareccapital.com*

The interests of the integrator/manufacturers

Some of the early device demonstration successes have attracted strategic partners with a background in manufacturing, system integration and sales in the power market. In a few cases, these early device demonstrations have led to partnerships with utilities. These relationships extend from access to components, access to design, testing or development experience, all the way to outright ownership by the manufacturers or utilities.

In most cases manufacturers have had a real interest in moving to a stage where orders for series-production units can be expected. In some cases manufacturers are deciding to focus on the core of the devices, as closest to their existing industry experience, believing that other parts of the single device "system" needs to be significantly developed by others with better experience and capacity.

Emergence of a market pull

Climate change action agendas have resulted in progressive targets for renewables development. In some countries a drive for energy security has added to this an imperative for resource diversity. In others it has been a focus on new marine industrial and economic opportunity that drove initial investment in technology development and more recently the transition to create economic value out of the delivery of complete clean marine electricity solutions.

These market-pull initiatives have resulted in ratepayers investing in the success of pilot projects – the rate is only paid for what the project delivers. As experience drives down cost, these market support mechanisms are expected to adjust so that ratepayer support for later projects can be decreased ultimately to the point where marine renewable energy promotes will compete equally with other renewables. With the energy densities of marine resources and ongoing reductions of lifecycle costs, these projects may ultimately be competitive with traditional forms of energy generation.

Market pull is likely to stimulate formation of supply chains that will work together through all stages, eventually delivering the scale at which marine renewable energy is that competitive choice.

The issue is now one of demonstrating integrated systems: how projects are sited and permitted; how they are designed and installed, how they are operated and maintained, what their availability as a "plant" is and how the power output meets power interconnection requirements.

For marine electricity

The focus is shifting toward demonstration of reliable and scalable projects that can deliver marine electricity of value to the consumer. It must be demonstrated, even through these initial trials, that it will be practical for a significant part of the power portfolio to come from marine renewable energy. More importantly, the potential for improvements in operations and costs must be demonstrated to make the case for marine renewable energy as a reliable and competitive electricity resource.

What must marine renewable energy demonstrate?

It was suggested earlier that there are significant parts of an industrial-scale project that may not be addressed in device–level demonstrations. This includes some of the following aspects:

Technical solutions:

Balance of Plant

The functionality of devices may have been demonstrated, but plans for utility-scale installations and their servicing can be expected to drive the development of new approaches to: foundations, installation and service vessels, cable interconnection and a host of other technical and operational interfaces that integrate those generation systems into a commercial plant.

Generation systems

For marine renewable energy plants to be accepted market solutions, they must demonstrate that they can meet utility interconnection requirements. While a system may be blind to a small demonstration, experience with pilots large enough to attract system administrator interest is critical. System control and data delivery needs to meet utility industry standards. Resource forecasting, plant availability and energy forecasts have to be suitable as planning and operating tools.

Balance of Project
The scale change from device trials to prototype arrays will require new responses from regulators, supply chain, manufacturers and financiers. It is critical that this prototype value chain be demonstrated if the scalability of marine energy is to be pursued.

CAPEX acceptability
System capital costs have to reduce by almost 2/3 to compete wind.[9] This reduction in CAPEX has to be achieved by incorporation of new innovations in project design and development, learnings from doing that eliminate costs, and economies of scale that come from series production of components and from maximizing deployments from project infrastructure. This trend will only be driven by a focus on the needs of multi-device projects.

OPEX viability
Operations and maintenance expenditures also have to be reduced by almost 2/3. Significant improvements will come through integrations of operations and maintenance planning into equipment selection or design, availability of service infrastructure that matches project needs for planned and emergency service and through development of operating experience and the efficiencies that that will bring. Only with larger-scale deployments will the necessity to refine operations and maintenance come to a head.

CONCLUSION

While there is certainly a lot of room for proving and improving of marine renewable energy technologies, it is clear that focusing on prototyping an industrial approach will drive those improvements and the emergence of a host of enabling technologies and operational approaches. The necessary technology transfer, supply chain development, customer engagement, access to the financial sector and political support depends on that demonstration of what this industry will look like and what it can offer.

[9] *www.lowcarboninnovation.co.uk/document.php?*

UK WAVE AND TIDAL PROJECTS – UPDATE AND LOOK AHEAD

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INTRODUCTION

During the last decade, commercial interest in wave energy and tidal energy grew significantly in the UK, supported by government policy measures which encouraged research, development, testing and demonstration of generation technologies. In the current decade, interest is continuing to grow, particularly towards making the transition from proving the viability of technologies, currently deployed as single prototypes, to constructing and operating initial projects involving multiple machines deployed in arrays.
The Crown Estate is pleased to be playing a key role in this, primarily by providing leases for seabed sites.
As owner of the offshore seabed around the UK within territorial waters (up to 12 nautical miles from the coast) and with rights to provide licences in the Renewable Energy Zone (further offshore, in some places up to 200 nautical miles), we are landlord to the majority of UK wave and tidal projects. But our work in wave and tidal energy extends beyond this. We have a strategic long-term interest in growth of the industry, which means we are interested not just in leasing sites today but actively supporting their development as projects over years to come, including such steps as obtaining statutory consents and securing grid connections. We are also now considering investing in first array projects in order to help catalyse investments by others.

This article gives an overview of recent developments in the UK, considering government policies which support project development and the industry's progress in developing projects; summarises The Crown Estate's activities over the last few years; and briefly looks ahead to the future, including opportunities for international engagement and collaboration.

Policy and regulatory context

Government bodies across the UK, including the central government and devolved administrations of Scotland, Wales and Northern Ireland, support the development of wave and tidal energy. The 2010 Coalition Agreement indicated that the UK Government would "introduce measures to encourage marine energy" and the devolved administrations have made similar commitments.

Waters around the UK are now subject to Strategic Environmental Assessments (SEAs) for wave and tidal energy development. In connection with a European Commission Directive concerning the 'assessment of the effects of certain plans and programmes on the environment', SEAs provide recommendations for plan implementation and are used to inform guidance for developers. The first country of the UK to complete a SEA for wave and tidal energy was Scotland, with the assessment covering waters to the north and west of the country (2007)[1]. Subsequently, wave and tidal development in waters around England and Wales was covered in an offshore energy SEA by the UK Department of Energy and Climate Change, DECC (2011)[2]; and a SEA for offshore wind, wave and tidal development in multiple zones off Northern Ireland was completed by the Northern Ireland Department of Enterprise, Trade and Investment (also 2011)[3].

There will soon be a consistent level of revenue support for wave and tidal stream projects across the UK. This is under the Renewables Obligation, a supplier obligation system involving green certificates known as Renewables Obligation Certificates (ROCs). Various renewable electricity technologies are eligible for different numbers of ROCs per unit of generation. Wave and tidal stream generating stations are becoming eligible for 5 ROCs per MWh for projects up to 30 MW capacity. The ROC price varies, but at the current level of approximately £40/MWh[4], this support is worth £200/MWh[5] (about US $320/MWh[6]) on top of the

[1] See http://www.scotland.gov.uk/Topics/marine/marineenergy/wave/WaveTidalSEA
[2] See http://www.offshore-sea.org.uk/consultations/Offshore_Energy_SEA_2/index.php
[3] See http://www.offshorenergyni.co.uk/

wholesale price of electricity. The move to 5 ROCs/MWh follows the 2011 Renewables Obligation Banding Review and the level is set to take effect from April 2013.

DECC is currently developing a new revenue support system as part of a package of measures called Electricity Market Reform (EMR). The new system will be based on Contracts for Difference Feed-in Tariffs, which work by reference to a fixed 'strike price' for each technology and a variable 'reference price' reflective of the wholesale electricity price. At times when the reference price is below the strike price, the generating company will receive a subsidy equal to the difference between the prices, and vice versa (the company will have to pay the difference when the reference price is above the strike price). This arrangement is intended to ensure that the generating company always receives the strike price but not more than this. Initially, strike prices will be set by an administrative process, but over time, the Government intends to move to an auction system. Contracts for Difference will be available from 2014 (except in Northern Ireland, where they will be offered from 2016) and the Renewables Obligation is planned to be phased out in 2017. In the transition period, generating companies will be able to choose between revenue support under the Renewables Obligation or Contracts for Difference[7].

In addition to revenue support, DECC and the Scottish Government are offering capital grants for first array projects in two parallel initiatives called the Marine Energy Array Demonstrator scheme (MEAD, £20m, US $31.7m) and the Marine Renewables Commercialisation Fund (MRCF, £18m, US $28.6m). The Scottish Government is also offering to invest in first arrays through its Renewable Energy Investment Fund (REIF, £103m, US $163.4).

UK projects may also benefit from European support. In December 2012, it was announced that two UK tidal projects had been offered funding through the European Commission NER 300 programme. These are ScottishPower Renewables' Sound of Islay project (€20.7m, US $27.5) and Siemens Marine Current Turbines' Kyle Rhea scheme (€18.4m, US $24.4m)[8].

Progress in project development

As of January 2013, there are 41 wave and tidal projects under development or operation in UK waters on The Crown Estate, with a total potential installed capacity of over 2.0 GW. The projects are of four main types:

- Managed test and demonstration facilities, which provide infrastructure and/or services for several single prototypes and small arrays of devices;
- Test projects up to 3 MW, which typically involve a single prototype technology;
- Test and demonstration projects between 3 MW and 50 MW, which are generally for arrays of devices; and
- Commercial array projects of 50 MW or greater capacity.

Table 1 gives the number and total potential capacity of each type and Figure 2 shows the geographic locations of the projects.

TYPE OF SITE	NUMBER OF SITES	TOTAL POTENTIAL INSTALLED CAPACITY [MW]
Managed test and demonstration facilities	7	See note*
Test projects up to 3 MW capacity	9	< 10
Test and demonstration projects, 3 MW to 50 MW capacity	12	> 190
Commercial projects, 50 MW+ capacity	13	1,800
Total	41	Over 2,000

TABLE 1: Types of UK wave and tidal site on The Crown Estate, January 2013. *Some test and demonstration facilities are not grid-connected. Of those that are, the project capacity is variable depending on the technologies installed.

[4] *Source: Non-Fossil Purchasing Agency, www.e-roc.co.uk*

[5] *Not including the recycling benefit. For further information about the Renewables Obligation, see the Department of Energy and Climate Change website: http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/renew_obs/renew_obs.aspx*

[6] *Exchange rates correct as of January 2013.*

[7] *For further details on EMR, see the Department of Energy and Climate Change website, http://www.decc.gov.uk/en/content/cms/meeting_energy/markets/electricity/electricity.aspx*

[8] *Source: European Commission; see http://ec.europa.eu/clima/news/articles/news_2012121801_en.htm*

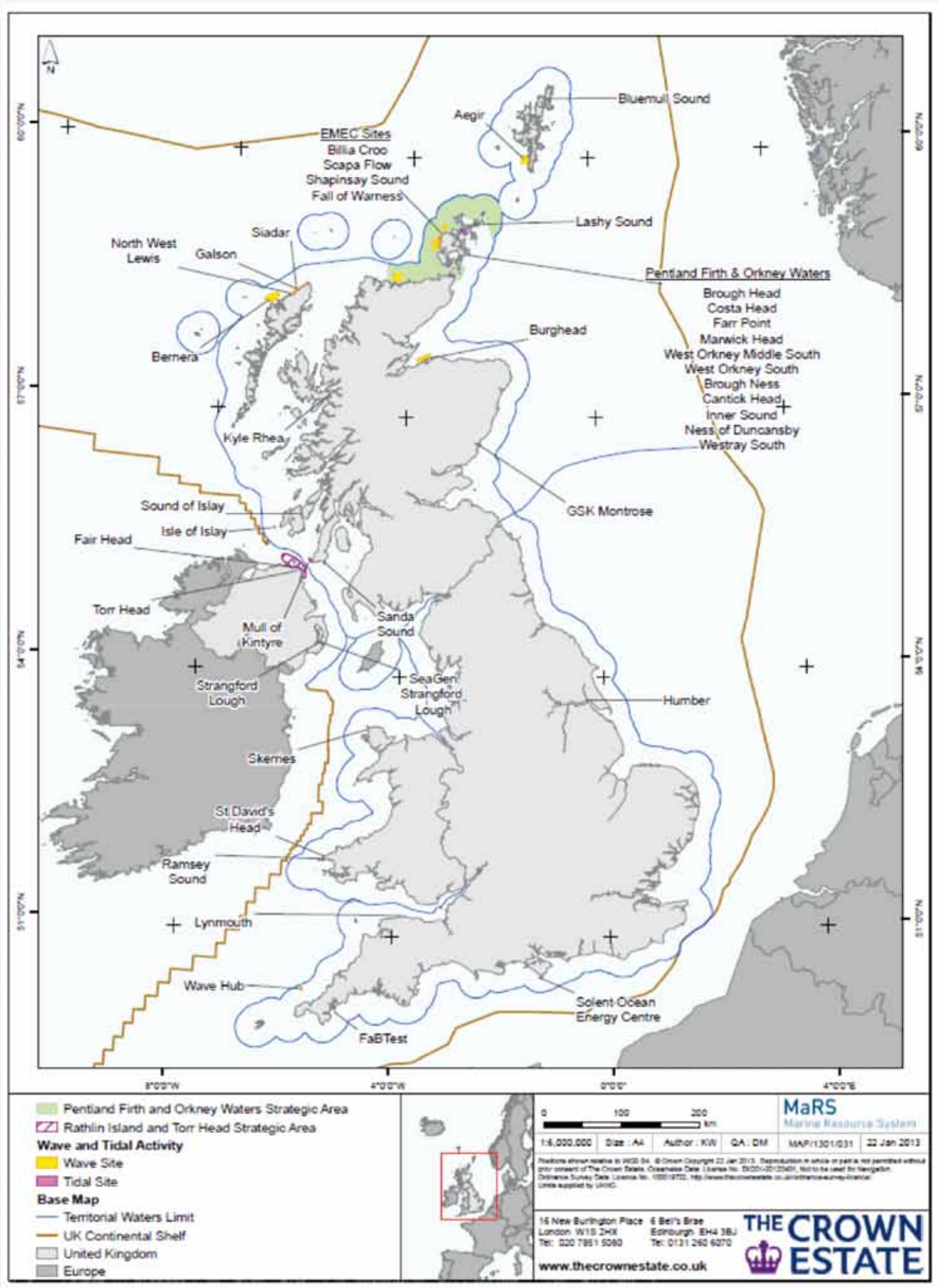

FIGURE 1: Locations of UK wave and tidal site on The Crown Estate, January 2013

The managed test facilities include three sites for sea trials, where devices may be tested but not grid-connected. These are the European Marine Energy Centre (EMEC) Fall of Warness site; the EMEC Shapinsay Sound site (Orkney); and Fabtest, a facility operated by Falmouth Harbour Commissioners in Falmouth Bay (Cornwall). The other four sites are either already grid-connected or planned to be connected and include the EMEC Billia Croo and Scapa Flow test areas (Orkney); Wave Hub near Hayle (Cornwall); and the Solent Ocean Energy Centre (SOEC) off the Isle of Wight. EMEC has been operational since 2004 and seen a number of technologies deployed at its sites, including, for instance, the Pelamis Wave Power wave energy converter, two of which were deployed during 2012[9]. Wave Hub was installed during 2010 and Fabtest opened in 2012. The SOEC is currently under development.

[9] *Source: EMEC. For further details about EMEC's recent activity, see http://www.emec.org.uk/blog-another-record-year-for-emec/*

Of the test projects up to 3 MW, which are in various places around the UK, one is currently operating: Siemens Marine Current Turbine's Seagen machine at Strangford Lough (County Down). The other projects are currently under development, including scoping and preparation of environmental impact assessments (EIAs) to support consents applications. The same is generally true of the test and demonstration projects between 3 MW and 50 MW, except ScottishPower's 10 MW Sound of Islay tidal project, which received consents from the Scottish Government (Marine Scotland) in March 2011. Several other projects are awaiting consents decisions from either the Scottish Government (including Aquamarine Power's 10 MW Galson and 30 MW North West Lewis projects) or Welsh Government (including Siemens Marine Current Turbines' 10 MW Anglesey Skerries scheme).

The commercial projects of 50 MW+ are in two main areas: the Pentland Firth and Orkney waters strategic area around the north of Scotland and the Rathlin Island and Torr Head strategic area off Northern Ireland. In total they comprise approximately 90% (1,800 MW) of the total potential installed capacity of current UK wave and tidal projects. The Pentland Firth and Orkney waters projects have been under development since 2010, including environmental scoping and EIA preparation. In July 2012, Meygen submitted a consents application for its Inner Sound project to the Scottish Government. Following connection applications from several of the Pentland Firth and Orkney waters developers, new grid infrastructure to enable wave and tidal projects to be connected to the west of Orkney Mainland, and the power to be transmitted back to the Scottish mainland, is being designed by transmission company Scottish Hydro Electrical Transmission (SHE Transmission, part of SSE). Development of the Rathlin Island and Torr Head projects is getting underway, following The Crown Estate awarding agreements for lease in October 2012.

The Crown Estate's work to date

The Crown Estate's strategic objective in wave and tidal energy is to support growth of the emerging industry, attract significant investment to the sector and encourage major players to commit to development. We are also helping government bodies to define policies that support development of the industry.

We have been providing seabed rights for wave and tidal projects for over ten years, starting with initial prototype projects such as the IT Power (later to become Marine Current Turbines) Seaflow installation off Lynmouth, Devon. However, the wave and tidal portfolio has shown particular growth since 2008, due to the Pentland Firth and Orkney waters leasing round between 2008 and 2010, the Rathlin Island and Torr Head leasing round from 2011 to 2012, and leasing of demonstration and small commercial projects over the encompassing period – including via four six-month applications windows between autumn 2010 and autumn 2012. During 2012, we ran an industry engagement exercise to invite views on where, when and how we should lease further wave and tidal sites. We are currently reviewing the responses and updating our leasing approach, with a further announcement planned in due course.

In 2009, we announced plans to support development of the Pentland Firth and Orkney waters projects and subsequently established an enabling actions fund of £5.7m (US $9.0m). This is covering a range of research, data gathering and other activities to de-risk development of the projects, across various topics including environmental impact assessment, physical characterisation of sites and supply chain development. Examples to date include a study to identify cumulative environmental impacts, near-shore bathymetry surveys and a report on the products and services necessary to build the projects. The work is selected and monitored by The Crown Estate and a Developers Forum, which comprises representatives of the Pentland Firth and Orkney waters developers. Some of the work is done in partnership with other organisations, including the Scottish Government and agencies (e.g. Marine Scotland and Highlands and Islands Enterprise). A number of reports are free to download from our website[10].

Looking ahead

The range of sites we have leased in UK waters reflects the diversity of activities underway here. Technology developers and manufacturers are continuing to focus on testing devices to make them ready for commercial deployment, while project developers are preparing sites to receive the devices in future years. It is appropriate these activities are happening in parallel given that the project development process can take several years to receipt of consents and new grid infrastructure is sometimes needed.

[10] *See http://www.thecrownestate.co.uk/energy/wave-and-tidal/pentland-firth-and-orkney-waters/enabling-actions/*

The next key milestone for the industry is installation and operation of first array projects. In the next few years, it is possible that several first wave and tidal arrays could be constructed and installed around the UK, by technology manufacturers and project developers working together. Such projects will improve technical understanding about how multiple devices can best be installed in particular site conditions and clarify operational performance characteristics (e.g. wake effects) and costs.

There are opportunities for international engagement in reaching this next milestone. While wishing the UK to maintain its international lead, The Crown Estate is highly supportive of such engagement. In the last year we have been pleased to respond to information requests from organisations in a number of countries, including the USA and Canada. We are also developing a data and information sharing system for the wave and tidal industry, known as the Knowledge Network, which will have international reach.

For more about The Crown Estate's work in wave and tidal energy, please contact us as follows:
waveandtidal@thecrownestate.co.uk
www.thecrownestate.co.uk/energy/wave-and-tidal/

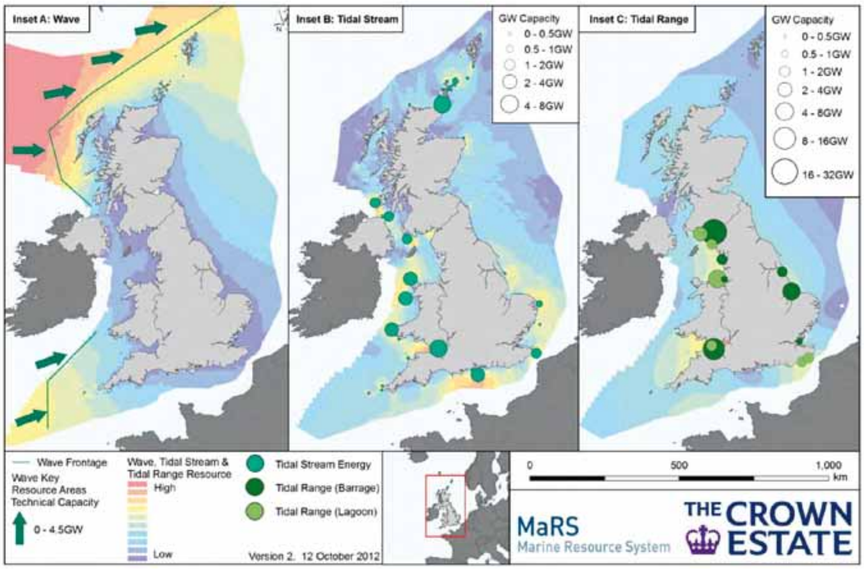

FIGURE 2: Distribution of UK wave and tidal energy resources

UK wave and tidal energy resources

In October 2012 The Crown Estate published new findings about the theoretical size and distribution of wave, tidal stream and tidal range energy resources around the UK. The resources are estimated to be follows:

- Wave: 69 TWh/year (27 GW)
- Tidal stream: 95 TWh/year (32 GW)
- Tidal range (barrage schemes): 96 TWh/year (45 GW)
- Tidal range (lagoon schemes): 25 TWh/year (14 GW)

For further details, see the UK Wave and Tidal Key Resource Areas Project - Summary Report, available to download from The Crown Estate website[11].

[11] *See http://www.thecrownestate.co.uk/news-media/news/2012/new-report-shows-extent-of-uk-wave-and-tidal-resources/*

First array investments

In January 2013, The Crown Estate announced that we are interested in investing in first array wave and/or tidal stream projects. We are considering investing up to £20m (US $31.7m) in total in two projects, alongside other companies and in parallel with government grant support. To be eligible, projects must involve an array of devices with a total installed capacity of 3 MW or greater, already have a Crown Estate agreement for lease, have or soon obtain statutory consents and grid connection agreements and realistically be expected to reach final decisions for capital investment by March 2014.

Our intentions in investing are:

- To make an acceptable commercial return, in line with our vires (powers); and
- To catalyse investments in first array projects by others, by virtue of sharing risk exposure and reducing the amount of capital others have to invest.

A guidance document which provides further information is available on our website[12].

[12] *See http://www.thecrownestate.co.uk/news-media/news/2013/looking-to-invest-in-wave-and-tidal-energy-arrays/*

OCEAN ENERGY SYSTEMS

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