

WAVE ENERGY

TECHNOLOGY BRIEF



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Highlights

- » **Process and Technology Status** – Wave energy converters capture the energy contained in ocean waves and use it to generate electricity. There are three main categories; oscillating water columns that use trapped air pockets in a water column to drive a turbine; oscillating body converters that are floating or submerged devices using the wave motion (up/down, forwards/backwards, side to side) to generate electricity; and overtopping converters that use reservoirs to create a head and subsequently drive turbines. On top of that, each category can be subdivided according to the technologies used to convert wave energy into pneumatic/mechanical energy (rotation/translation), their power systems (air turbines, hydraulic turbines, hydraulic engines), their structures (fixed, floating, submerged), and their positioning within the ocean (shoreline, near shore, off shore).

More than 100 pilot and demonstration projects exist throughout the world, but only a handful of technologies are close to commercialisation. The next step on the road to commercialisation is the demonstration of wave energy farms in the range of 10 megawatts (MW).

- » **Cost projections** – Due to the limited commercial experience, the estimates for levelised cost of electricity (LCOE) of wave energy technologies in 10 MW demonstration projects is in the range of EUR 330-630 per megawatt-hour (/MWh). However, there is considerable scope for economies of scale and learning, with the projected LCOE for wave energy in 2030 estimated to be between EUR 113-226/MWh if deployment levels of more than 2 gigawatt (GW) are achieved. Considerable research is going into improvements of the power take-off systems, which account for 22% of project life costs. In particular, efficiency improvements in air turbines (currently 50-60% efficient) and hydraulic systems to dampen the variability, are being explored. Furthermore, synergies with other offshore industries such as oil, gas and wind, are being pursued to reduce the costs of installation, operation and maintenance, and mooring (accounting for 41% of project life costs).
- » **Potential and Barriers** – With 2% of the world's 800 000 kilometre (km) of coastline exceeding a wave power density of 30 kilowatt per meter (kW/m), the estimated global technical potential is about 500 gigawatt electrical energy (GW_e) based on a conversion efficiency of 40%. Large wave energy resources can be found across the globe. At the same time, the wave regimes vary substantially across the different regions, resulting in a

wide variety of technologies. Consequently, there is a lack of industrial cohesion and limited supply chains for the variety of components required. For both planning and technology development purposes, synergies with other offshore industries would be advantageous to the wave energy industry. Similarly, there are opportunities to create more dedicated infrastructures – including ports and transmission grids – to support the installation and operation and maintenance of wave energy converters.

I. Process and Technology Status

Wave energy converters (WECs) capture the energy contained in ocean waves to generate electricity. Extracting energy from ocean waves is not a recent phenomenon, as researchers have been studying different concepts or solutions since the 1970s. Nowadays, the technology has evolved to a phase where different concepts are being tested at a full scale, pre-demonstration phase, and commercial demonstrations are being deployed. In 2013, there were more than a hundred projects at various stages of development, as estimated by some recent reviews (Falcao, 2010; Bahaj, 2011).

There is a wide range of wave energy technologies. Each technology uses different solutions to absorb energy from waves, and can be applied depending on the water depth and on the location (shoreline, near shore, off shore) (Cruz, 2008; Falcao, 2010). Although there is a wide range in technologies that signals that the sector has not yet reached convergence, it also shows the many different alternatives to harness wave power under different conditions and emplacements.

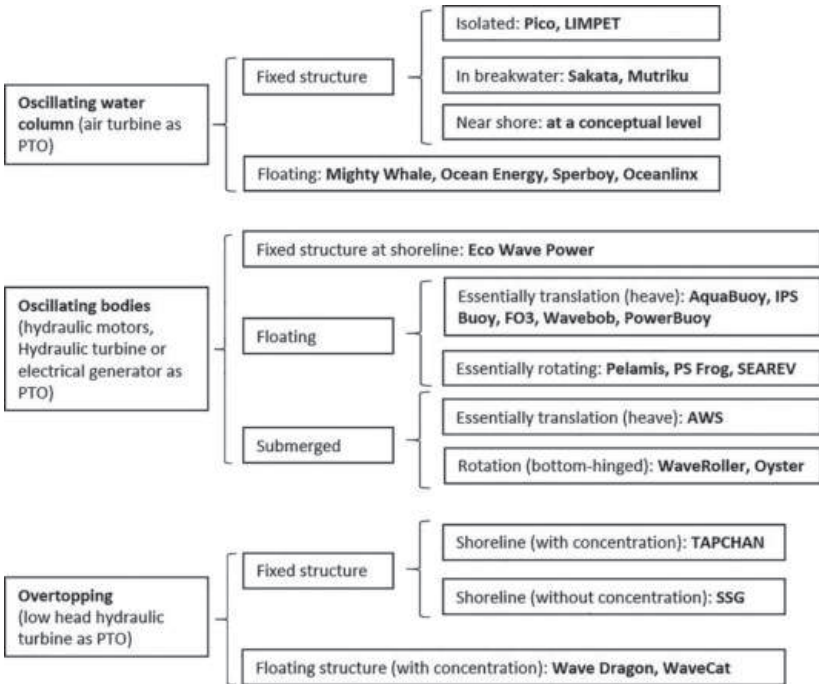
Future evolution of the sector will aim for an initial deployment of demonstrating WECs in small arrays of 10 MW, close to shore or on specific testing emplacements. Making the jump to the full commercial phase requires some research on the basic components to reduce costs and increase the performance. Also other solutions, such as hybrid or multiplatform concepts, could represent a solution that accelerates wave technology development. These platforms would combine wave energy technologies with offshore wind turbines or with aquaculture farms, which would result in a sharing of the foundation system costs, lower operation and management costs, and some environmental benefits as the impact of a combined emplacement will be smaller than that with different locations.

Wave energy technologies

Wave energy technologies consist of a number of components: 1) the structure and prime mover that captures the energy of the wave, 2) foundation or mooring keeping the structure and prime mover in place, 3) the power take-off (PTO) system by which mechanical energy is converted into electrical energy, and 4) the control systems to safeguard and optimise performance in operating conditions.

There are different ways in which wave energy technologies can be categorised,¹ e.g., by the way the wave energy is converted into mechanical energy or by the technology used. In this technology brief, we use a very broad categorisation for oscillating water columns (OWCs), oscillating body converters and overtopping converters, as shown in figure 1.

Figure 1: Wave energy technologies



Based on: Pérez and Iglesias, 2012

Oscillating Water Columns are conversion devices with a semi-submerged chamber, keeping a trapped air pocket above a column of water. Waves cause the column to act like a piston, moving up and down and thereby forcing the air out of the chamber and back into it. This continuous movement generates a reversing stream of high-velocity air, which is channelled through rotor-blades driving an air turbine-generator group to produce electricity.

¹ The European Marine Energy Centre (EMEC) distinguishes nine different categories (EMEC, 2014).

Extracting wave energy

Essentially all of the energy contained in a wave (95%) is located between the water surface and the top one fourth of the wave length. This energy can be extracted in different ways, which has given rise to the large variety of technologies available and deployed. Waves contain essentially three motions.

- A horizontal front/back motion (the “surge”) that can be extracted with technologies using a “roll rotation”;
- A horizontal side to side motion (the “sway”) that can be extracted with technologies using a “pitch rotation”;
- A vertical (up and down) motion (the “heave”) that can be extracted with technologies using a “yaw rotation” or “translation”.

One way to categorise wave energy technologies is by how the device extracts the surge, heave or sway motions of the wave (or a combination of each) (EMEC, 2014). In general, point absorbers convert the “heave” to drive a piston up and down, terminators and oscillating wave surge converters convert the “surge”, and attenuators convert the “pitch” of the wave to drive a rotor. Over half (53%) of WEC concepts developed are point absorbers, 33% terminators, and 14% attenuators (IRENA, 2014).

The main advantages of these systems are their simplicity (essentially there are no moving parts other than the air turbine) and the fact that they are usually reliable. Conversely, the performance level is not high, although there are new control strategies and turbine concepts under development, which are notably increasing the power performance. A new generation of floating OWC integrated on spar-buoys are substantially increasing the power performance. Some representative devices are: GreenWave (Scotland/UK); Mutriku (Basque Country/Spain); Ocean Energy Buoy (Ireland); Oceanix (Australia); Pico Plant (Azores/Portugal) and Wavegen Limpet (Scotland/UK) (Papaioannou, 2011; SI Ocean, 2012; International Renewable Energy Agency (IRENA), 2014). Figure 2, shows the Mutriku power plant as an example of an OWC technology.

Figure 2: OWC working scheme (left) and Mutriku's power plant (right).



Photo: Ente Vasco de la Energia; Source: Ente Vasco de la Energia (EVE)

Oscillating Body Converters are either floating (usually) or submerged (sometimes fixed to the bottom). They exploit the more powerful wave regimes that normally occur in deep waters where the depth is greater than 40 metres (m). In general, they are more complex than OWCs, particularly with regards to their PTO systems. In fact, the many different concepts and ways to transform the oscillating movement into electricity has given rise to various PTO systems, e.g., hydraulic generators with linear hydraulic actuators, linear electric generators, piston pumps, etc.

Figure 3: Oscillating body power converters: PowerBuoy (top left-tl), Plamis (top right-tr), Wave Star (bottom left -bl), and Oyster (bottom right-br).



Photo: tl -Ocean Power Technologies Inc.; tr – Pelamis Wave Power; br – Wave Star AS; bl – Aquamarine Power.

The advantages of oscillating body converters include their size and versatility since most of them are floating devices. A distinct technology has yet to emerge and more research, to increase the PTO performance and avoid certain issues with the mooring systems, needs to be undertaken. Figure 3, shows some representative devices of oscillating bodies: the PowerBuoy of Columbia Power Technologies, Oyster (Scotland), Seatricity (Cornwall), Pelamis (Scotland) and Wave Star (Denmark) (Papaioannou, 2011; SI Ocean, 2012; IRENA, 2014).

Overtopping converters (or terminators) consist of a floating or bottom fixed water reservoir structure, and also usually reflecting arms, which ensure that as waves arrive, they spill over the top of a ramp structure and are restrained in the reservoir of the device. The potential energy, due to the height of collected water above the sea surface, is transformed into electricity using conventional low head hydro turbines (similar to those used in mini-hydro plants).

The main advantage of this system is the simple concept – it stores water and when there is enough, lets it pass through a turbine. Key downsides include the low head (in the order of 1-2 m) and the vast dimensions of a full scale overtopping device. Some representative devices are shown in figure 4: WaveDragon (Denmark); Seawave Slot-Cone Generator (Norway); and WaveCat (Spain) (Iglesias, *et al.* 2011; Papaioannou, 2011; SI Ocean, 2012; IRENA, 2014).

Figure 4: Overtopping wave power technologies: WaveCat (left) and Wave Dragon (right).



Source: G. Iglesias, in Fernández, et al. (2012)(l); and Photo: Wave Dragon AS (r).

Power take-off (PTO) systems

There are a number of different PTO systems that can be used to convert the wave energy into electricity: turbines, hydraulic systems, electrical linear generators as well as full mechanical systems. OWCs use air turbines (pneumatic systems) to convert the wave motion into electricity, whilst oscillating bodies and overtopping converters predominantly use a variety of hydraulic PTO systems or turbines. PTO systems have to be adapted to be used in WECs, as the energy flow provided by wave energy is random and highly variable per wave, per day, and per season. As a consequence, air turbines can only reach efficiencies of 50-60%, while hydraulic turbines can reach efficiencies from 70-90%. Furthermore, high-pressure oil hydraulic motors are being explored that include gas accumulator systems capable of storing energy over a few wave periods, smoothing out the irregularities provided by wave energy. Other technological advances in PTO systems include multistage rotor turbines, and adjustable inlet guide vanes to increase the efficiency of the systems (Falcao, 2010). Of the current WECs concepts developed so far, 42% use hydraulic systems, 30% direct-drive systems (mostly linear generators), 11% hydraulic turbines, and 11% pneumatic systems (IRENA, 2014).

The current market for WECs

The first generation wave energy systems are based on the previously described technologies and placed at the shoreline or near-shore emplacements (to avoid higher grid connection costs). Although 67% of the current WEC concepts are floating, and only 19% are fixed (IRENA, 2014), experience so far has mostly been with:

- OWCs placed on the shoreline, on natural cliffs or breakwaters.
- Near-shore technologies based on bottom fixed solutions, often with terminal absorbers.
- Offshore technologies at specific testing or pilot emplacements.

Existing wave test facilities are available for testing up to 5 km offshore, and 50 m in depth (Joint Research Centre (JRC) 2013). The experience of piloting technologies at a real scale and then testing at sea, has led to substantial redesigns of some of the devices to make them more robust and durable. This has meant the initial expectations in cost reductions and power performance have not been achieved.

Europe is still the leading market for wave energy technologies, but other countries and regions are progressing fast. The first WECs that were deployed were the 750 kilowatt (kW) Pelamis prototype in the UK, and the 2 MW Archimedes Wave Swing² prototype in Portugal in 2004. In 2008, the first wave energy farm (2.25 MW) was tested based on three Pelamis prototypes in 2008 in Portugal. Aquamarine Power has its 315 kW Oyster in the Orkney Islands installed in 2009, and an 800 kW Oyster in 2011. The Danish company Dexawave is running projects in Denmark and Malta, and the Basque Energy Board (EVE) has opened the first commercially-operated wave power plant in Mutriku's breakwater, with 16 OWC wave turbines of 18.5 kW and a total installed capacity of 296 kW in 2011 (Papaioannou, 2011; SI Ocean, 2012). The Finnish company AW-Energy Ltd. has deployed three, 100 kW WaveRollers in Portugal, and is planning a 1.5 MW farm in France. Another Finnish company, Wello Ltd., is testing its Penguin design (using a rotating mass) in UK waters. The Norwegian company Langlee Wave power has moved its activities to the Canary Islands to start pilot projects in 2014. Seatricity is currently commissioning their 160 kW Oceanus 2 at the Wave Hub Facility in the UK, and is planning a 10 MW wave energy farm to be operational by 2015.

Globally, American, Australian, Canadian and Israeli technology developers include Ocean Power Technologies (with pilot projects in Australia, UK, US and expansion into Japan), Oceanlinx (with a 1 MW OWC launched in October 2013, in South Australia), Carnegie Wave Energy (with projects in Australia, Bermuda, Canada, Ireland and La Reunion), and Eco Wave Power (with projects in China, Cyprus, Mexico, and the UK). Additionally, China (Guangzhou Institute of Energy Conversion, National Ocean Technology Center, South China University of Technology, Sun Yat-sen University), Japan (Mitsui) and Korea (Maritime and Ocean Energy Engineering Research Institute (KORDI), Korea Maritime University) have recently shown a strong interest in wave energy. All the companies listed above have initiated and continued to support new research, development, pilot testing and demonstration projects (Papaioannou, 2011). For example, China has been running a 100 kW onshore OWC plant in Shangwei and a 100 kW onshore pendulum WEC in Dagan Island since 2000 (Whang, *et al.*, 2011).

Although the market is still dominated by start-up companies, large engineering firms and utilities have also entered the market. Lockheed Martin partners with Ocean Power Technologies, Alstom acquired a share in AWS in 2011, ABB

2 In 2013, Alstom announced that it would not be investing further in Archimedes Wave Swing.

has invested in Aquamarine Power, and DCNS is investing in AW-Energy's WaveRoller. During 2013, which was a mixed year, Voith Hydro and Alstom discontinuing investments in projects, whilst ABB, DCNS, Lockheed Martin, Mitsubishi Heavy Industries, Mitsui engineering and Shipbuilding Co. remain actively involved. From the utilities, E.ON has pulled out of Pelamis, but, Électricité de France (EDF), Fortum, Iberdrola (including subsidiary Scottish Power Renewables) and Vattenfall remain committed (IRENA, 2014).

Next generation

The next step for wave energy is to move from full-scale testing of individual technologies to the deployment of array and cost reduction measures. Furthermore, the next generation of WECs are expected to go further offshore, reaching larger depths and higher waves — test facilities with 100 m water depth and 15 km offshore are planned, as yet no devices have been installed further than 6 km from shore or in deeper waters than 50 m — (JRC, 2013). To ensure cost reductions of the existing technologies and the development of next generation WECs, improvement of basic subcomponents is a pre-requisite. Components and areas that require further research include (SI Ocean, 2012; The Low Carbon Innovation Co-ordination Group (LCICG), 2012; Energy Technologies Institute (ETI)/ UK Energy Research Centre (UKERC), 2014; Tzimas, 2014):

- New materials to reduce the device's weight and biofouling effects on the marine environment.
- Specific PTO systems e.g., hydraulic or electric generators to increase the overall efficiency of the converters and the electric performance.
- New mooring systems for floating devices adapted to the wave energy needs from the oil and gas industry for increased safety and or better interaction with the converter.
- Underwater power connectors that allow easy underwater operability and quick, easy and low cost maintenance interventions.
- Optimisation, operation, and control systems of arrays, including assessments of hydrodynamic interaction, and electrical connection issues (including grid and distribution codes).
- Collaboration and synergetic research with the offshore wind industry to reduce the cost of common offshore grid infrastructures, similar equipment and operation and maintenance (O&M) practices, and similar project development and permitting processes.

Furthermore, new concepts of multiplatform or hybrid devices, where wave energy technologies would be integrated or share the same infrastructure as other marine users, wind energy or aquaculture, are being investigated. Some of those synergies can be: an increase in the energy yield per unit of marine area, sharing a common grid infrastructure, sharing specialised marine equipment, lower O&M cost, sharing foundation systems, reducing the capital costs, and some environmental benefits as the impact of a combined emplacement will be smaller than that with different locations (Casale, *et al.*, 2011; Perez-Collazo, *et al.*, 2013). A clear example of these are three European Union (EU) funded projects which have been exploring such issues (Casale, *et al.*, 2011; Quevedo, *et al.*, 2012; MARINA Platform, 2014).

II. Potential

The best wave conditions for exploitation are in medium-high latitudes and deep waters (greater than 40 m deep), since wave energy is found to reach power densities of 60-70 kW/m in those locations (figure 5). For example, countries like Australia, Chile, Ireland, New Zealand, South Africa, the UK and the US have excellent wave resources with average power densities of 40-60 kW/m.

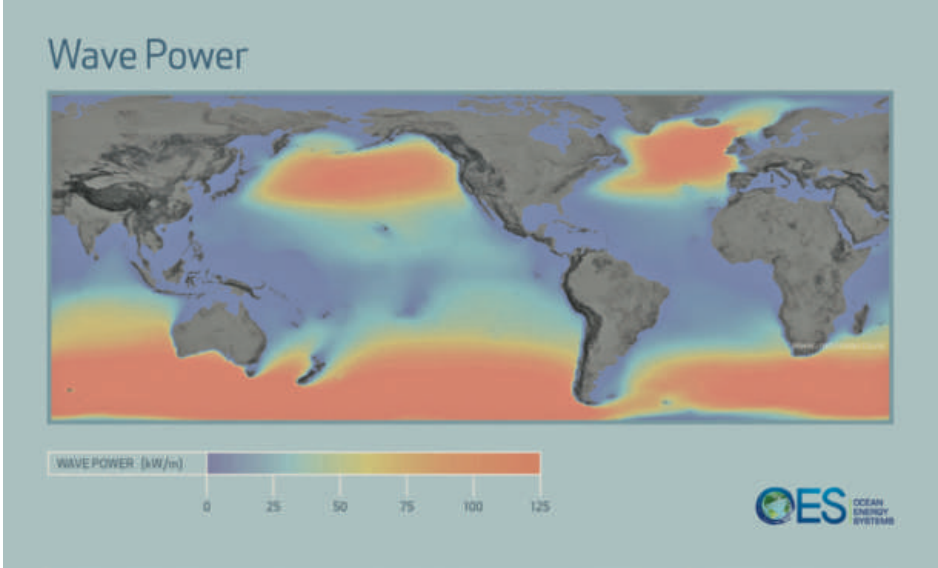
Global estimates for wave energy potential are still relatively uncertain. In 2012, the Intergovernmental Panel on Climate Change (IPCC) reported a theoretical potential of around 29,500 terawatt-hour per year (TWh/yr) considering all areas with wave energy densities higher than 5 kW/m (Lewis, *et al.*, 2011). On the other hand, the IPCC in its 2007 assessment estimated a technical potential of about 500 GW_e (or around 146 TWh/yr) assuming that wave energy technologies would only be deployed in the 2% of the world's 800 000 km of coastline that exceeds a power density of 30 kW/m (Sims, *et al.*, 2007). Other global estimates vary between 2 000-4 000 TWh/yr (Cruz, 2008; Falcao, 2010; Bahaj, 2011; Kadir, *et al.*, 2012). In contrast, the total European wave energy resource is estimated to be 1000 TWh/yr with available wave energy power resource for the North-Eastern Atlantic (including the North Sea) estimated to be around 290 GW, whilst for the Mediterranean it is 30 GW (European Ocean Energy Association³ (EU-OEA), 2010). Figure 5 shows wave energy resources across the world.

In 2013, wave energy converters were installed in Australia (1 MW), China (220 kW), Italy (150 kW), Norway (240 kW), Portugal (400 kW), Spain (296 kW), Sweden (230 kW), the UK (3.8 MW), and the US (30 kW) (IRENA, 2104; International Energy Agency implementing agreement on Ocean Energy Systems (IEA-OES), 2014a). Furthermore, there are plans for the first wave farms to be installed in Australia (21 MW), France (1.5 MW), New Zealand (22 MW), Sweden (10 MW), and the UK (10 MW) (Jeffrey and Sedgwick, 2011). Based on existing project pipelines and the European ocean energy industry roadmap around 100 MW may be expected by 2020 (EU-OEA, 2010; IRENA, 2014). A rapid build out of second generation systems is scheduled for the period between 2022 and 2040. Expectations are that deployment levels will reach the range of 2-10 GW (SI Ocean, 2014; ETI/UKERC, 2014), and the Euro-

3 The European Ocean Energy Association is also referred to as Ocean Energy Europe.

pean wave industry itself has set the ambition to provide 10% (or 188 GW) of European's electricity market by 2050 (EU-OEA, 2010).

Figure 5: Global annual mean wave power distribution. Source: IEA-OES, 2014b



III. Current Costs and Cost Projections

With the estimated levelised cost for wave energy farms (10 MW) between EUR 330-630/MWh (SI Ocean, 2013), these costs are considerably higher than other forms of renewables, including offshore wind and tidal current technologies. This is not surprising, given the early stage of technological development and where arrays of 10 MW of total installed capacity still need to be demonstrated. This directly affects the economies of scale, including the assumptions considered to estimate the current and projected costs. However, the potential for wave energy is significantly greater than the tidal resources across the same geographic area and is also less site specific, so the expectations are that wave energy costs will fall to levels similar to those of tidal current technologies (SI Ocean, 2014).

The latest estimates for European wave energy projects suggest that the PTO system accounts for 22%, installation 18%, O&M 17%, foundation and mooring 6%, and grid connection 5% of the total lifetime project costs (SI Ocean, 2013).

Table 1 shows the operational figures of the current estimated costs and cost projections for wave energy until 2050.

Table 1: Operational figures of Wave Energy

	Source	2010-2012	2020	2030	2050
Capital cost of farms [EUR/kW]	IEA	5 650	4 070	3 350	1 750
	UK	5 000-9 000	3 000-5 000		2 500-3 000
	ETI ^a / UKERC	4 840-9 680	2 723-4 235	2 118-2 723	1 513-2 118
Operation & Maintenance cost [EUR/kW/yr.]	IEA	86 (projected to decrease to 47)			
	ETI/ UKERC	48-97	30-73	18-30	12-24
Availability [%]	UK	75-85		90	90-95
	ETI/ UKERC	70-80	90	90-95	95-98
Array load factor [%]	ETI/ UKERC	25-35	32-40	35-42	37-45
Total electricity production cost [EUR/MWh]	IEA	286	207	172	
	UK	213-500		113-226	88-125
	ETI/ UKERC	242-605	121-242	85-121	61-97
Average levelised cost of energy per MWh	E&Y	505	268	148	108
	SI Ocean	330-630 ^b	280-350 ^c	150-180 ^d	
EU Market share, % of global electricity output	JRC	0	<<1	-1-2	> 10
Emissions (direct operation)	JRC	0			
Emissions indirect (as manufacturing, fabrication, installation, maintenance and commissioning)	JRC	25-50 gram/kWh (wave energy converters of 665 tonnes of steel and production 2.3 gigawatt-hour per year — GWh/yr.)			

^a The roadmap targets from ETI/UKERC apply to both tidal and wave energy.

Exchange rate used: 1.21 EUR/Gross Domestic Product (GDP).

^b Estimates for early arrays

^c Assuming deployment rate in the range of 100 MW

^d Assuming a deployment rate of around 5 GW

Table 1 shows that the costs are expected to fall by a net amount of approximately 70% by 2030 due to learning rates and economies of scale in the sector. This would mean for 2030 an average levelised cost of around EUR 150-180/MWh.

Globally, following the increase in efficiency and reduction of capital and maintenance costs through advances in the quality of materials, countries such as Australia, Canada, China, Japan, South Korea, and the USA are breaking into what was predominantly a European stronghold on technology competition. Consequently, not only has there been a promotion of various technologies, but also initiation of research and development programmes.

Furthermore, wave energy technologies will require supply chains similar to oil and gas, and offshore wind. The involvement of large and multi-disciplinary industries can be expected to promote synergies, which will generate economies of scale and cost reductions. Fortunately, utilities, large engineering firms and heavy industries, such as traditional shipbuilding, are now beginning to show interest in this emerging sector. This is creating the conditions necessary to install wave energy farms and continue to reduce costs.

IV. Drivers and Barriers

Important drivers for wave energy are its vast potential across multiple countries and regions around the globe, the relative benign environmental impacts even when compared to other renewable energy technologies, and its small visual impacts on the shoreline. This has led to support of both governments and private sector and has resulted in a large number of prototypes currently at a demonstration phase. Furthermore, a UK study has revealed broad public support (77%) for tidal and wave energy technologies (Department of Energy and Climate Change (DECC), 2014). However, the reality of deploying wave energy technologies at scale in the harsh ocean environment has tempered some of the initial expectations in terms of deployment levels.

From a technological readiness perspective, the sector is closely following the tidal current industry with a number of devices nearing commercialisation and a number of wave farms (in the range of 10 MW) announced. However, no clear dominant designs have appeared yet and consequently engagement from large engineering firms and utilities is still in a nascent stage.

Besides the technological challenge, wave energy faces similar barriers as the offshore wind and tidal energy industry: i) uncertainty on environmental regulation and impact; ii) the need for investments: considering current and projected costs, a market pull attracting private investment is necessary; iii) insufficient infrastructure: offshore grid connections, such as port facilities to perform O&M, are extremely expensive and non-existent; and iv) planning and licensing procedures: key to avoiding possible conflicts between different maritime users or to reduce potential costly administrative procedures.

1.) Environmental impacts

Based on preliminary studies or projects, wave energy seems to have a low environmental impact or disturbance, including benign landscape implications. The main side effect is a reduction of the wave climate and consequently, on the wave height, on the up flow to the coast. However, there are a number of areas – similar to other ocean energy technologies – where wave energy technologies have environmental impacts. Foundations and buoys do attract new marine life, but it is unclear whether this enhances or endangers existing marine life. Furthermore, little is known about the long-term effects of underwater noise from construction and operation. Similarly, it is unclear if the

electromagnetic fields produced from sea cables have impact on migratory fish and other marine organisms.

To better grasp the effects on the environment and streamlining the license process, the EU has funded the Streamlining of Ocean Wave Farms Impact Assessment (SOWFIA) project, which has recently delivered a set of guidance documents for assessment of environmental and other impacts of wave energy farms (Greaves, *et al.*, 2013). Additionally, the future Maritime Spatial Planning directive and the Integrated Coastal Management directives – developed by the European Commission – could become powerful tools to deal with possible positive or negative effects (reducing coastal erosion, avoiding carbon dioxide emissions, or reducing wave heights on surfing beaches).

II.) *The need for investments*

The market is still dominated by start-up companies and university spin-offs, which have been focusing on bringing technologies to pre-commercial status, promoting easy access to research facilities or supporting the creation of new demonstration sites at sea. Government funding through public research and development (R&D) investments has been key in this process. For example, the UK has provided around EUR 20 million on an annual basis between 2006 and 2011 (JRC, 2013).

The scale up of wave energy technologies to wave farms requires new and different kinds of investments and needs. In addition to the research development and demonstration (RD&D) requirements, funding and government grants, and policy support are needed to attract the private investment required for large scale deployment. Possible policy measures may include investment tax credits to attract investors, or feed-in tariffs, power purchase agreements, or production tax credits to attract end-users.

From a government perspective, public investments will remain important. Wave energy technologies should not only be seen as one of many renewable energy options, but also as a technology that could possibly develop or restructure the maritime economy and create a new manufacturing base for ocean energy systems (SI Ocean, 2014). In this way, the shipyard industry, some fishing communities, and the oil and gas auxiliary industries could benefit from wave energy development. An example of this potential could be the adaptation of shipyards into wave energy converter manufacturers, or recruiting and retraining fishermen to become O&M personnel.

III.) *Insufficient infrastructure*

Appropriate grid infrastructure and connections or port facilities are key for further development and to enable maintenance undertakings (SI Ocean, 2014). Wave energy farms deployed in deeper waters and further offshore will require specialised substation designs to connect the arrays, special underwater power, and cost-effective long-distance grid connections.

One approach to overcome this barrier is the development of integrated offshore grid infrastructures. For the offshore wind industry, the European Commission together with the industry and Member States is supporting an integrated offshore grid structure to deliver offshore wind to consumers, notably through the activities of the North Sea Countries Offshore Grid Initiative (NSCOGI). However, these activities are limited to the North Sea and the offshore wind industry.

Taking into account the needs of wave energy, as well as wind energy, developing joint projects can be more efficient than back-fitting afterwards. Costs can be shared and development of hybrid or multiplatform solutions encouraged. Furthermore, wind and wave can be complementary if high wind speeds shut down the turbines, but allow the wave energy technologies to continue. There are a number of projects and patents that address this issue (Aux Navalia, 2010).

Port facilities are also an important prerequisite for large-scale deployment. The O&M of marine systems are expensive and costs rise even further as these are performed under difficult marine conditions. The alternative is to unplug the wave energy converters from their offshore emplacement and perform the maintenance at a dedicated, safe and more accessible port facility. Such planning could be even more efficient if it also considered whether specialised marine expertise and servicing devices for wave energy could be shared with other coastal functions (e.g., offshore wind park servicing, or offshore operations).

IV.) *Planning and licensing procedures*

Due to the fact that wave energy, as well as other marine energies, are dependent upon specific geographical settings, a predefined zoning plan will help the sector to adapt in a much better way to overcome their local impediments.

At the same time, coastal communities and those engaged in more traditional marine activities, tend to be suspicious of the impact of new activities. Planning and licensing processes for ocean energy therefore needs to be open and comprehensive enough to take such concerns into account.⁴ The lack of processes for planning and licensing marine activities in areas where many different interests (transport, energy, tourism, fisheries, etc.) are concerned, tends to increase uncertainty and risks delays or failure of projects at sea.

4 For example, Pelamis Wave Power is holding a number of public consultation events ahead of their wave energy farm at EMEC. See: www.pelamiswave.com/news/news/159/Sutherland-and-Caithness-residents-to-be-consulted-on-wave-farm-plans.

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