European
Commission

Ocean Energy

In brief

Oceans represent a huge, predictable resource for renewable energy. The main forms of ocean energy are waves, tides, marine currents, salinity gradient and temperature gradient. Wave and tidal energy are currently the most mature technologies.

Tidal current energy is created by local regular diurnal (24-hour) or semi-diurnal (12+ hour) flows of ocean water caused by the tidal cycle. Kinetic energy can be harnessed, usually nearshore and particularly where there are constrictions, such as straits, islands and passes.

Wave energy is created as kinetic energy from the wind is transmitted to the upper surface of the ocean. At present there are several different wave energy technology designs and some are at the cutting edge of engineering design.

Ocean thermal energy conversion (OTEC) uses the temperature difference between surface and deep water in a heat cycle to produce electricity. Although tropical areas are most favourable for the exploitation of this source of energy, the potential resources are enormous.

Osmotic power generation exploits the energy available from differences in the salt concentration in seawater and is especially suited to countries with abundant fresh water resources flowing into the sea. There are two practical methods for this - reversed electro-dialysis (RED) and pressure retarded osmosis (PRO).

Ocean current technology is still at the embryonic stage and will not be discussed in any detail here.

The global tidal energy resource is estimated at 1 200 TWh/year (OES, 2012)

The potential of wave energy is estimated at 29 500 TWh/year (OES, 2012).

With an estimated 83 340 TWh/year (300 exajoules/year), or 90 % of the global ocean energy potential, OTEC has the largest potential of the different ocean energy technologies (IRENA, 2014a).

Ocean Energy Europe (2013) estimates that there is the potential to create 20 000 jobs throughout the supply chain of the marine energy sector by 2030.

The technology

Ocean thermal energy conversion (OTEC) harnesses the temperature difference between surface and deep water. It is most suited to equatorial and tropical waters of sufficient depth, where the temperature differential is at least 20 degrees Celsius all year round. OTEC has a low theoretical efficiency, (7-8 %), which could drop even further, to 2-3 % in practice (EC/JRC, 2014). On the other hand, OTEC farms can operate continuously and could reach capacity factors of up to 90 %.

Osmotic (salinity gradient) power generation exploits the energy available from differences in salt concentration between freshwater and seawater. In this technology, seawater and freshwater are channelled into different chambers, separated by a semi-permeable membrane. The saltwater molecules exert a pull on the freshwater molecules across the membrane and the resulting pressure is used to drive a turbine. This power generation technology can be used in countries with abundant freshwater resources flowing into the sea, such as the Netherlands and Norway. The total technical potential for salinity gradient power has been estimated at 657 GW, which is equivalent to 5 177 TWh of consumed electricity (IRENA, 2014b).

Wave and tidal energy

Currently, the main exploitable form of ocean energy is that found in waves and tides (W&T). Wave devices are currently lagging

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behind tidal in terms of technological development. However many wave devices and designs are currently being studied and/or developed.

As many as 170 types of wave energy converter have been designed, but fewer than 20 % are at the full-scale prototype stage. The main technologies used for wave energy extraction are:

- a terminator placed perpendicular to the main direction of the wave;
- an oscillating water column (OWC) which generates electricity by using the heave motion of waves to push air up a shaft and drive a turbine;
- a point-absorber which is a floating structure that absorbs energy from all directions through its movement at or near the water surface;
- an attenuator, oriented parallel to the direction of the waves;
- overtopping devices, a floating reservoir, partially submerged, in which a head of water is created and further used to run hydro turbines;
- bulge wave technology, whereby water forms a bulge in a rubber tube moored to the seabed, which gathers energy as it travels through the tube;
- submerged pressure differential devices, where wave motion causes the sea level to rise and fall above the device, inducing a pressure differential in the device.

Fact file

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Rated power capacity for a single system ranges from 70 kW to a few MWs. It is expected that several units will be assembled to create wave energy farms. Average load factors for wave power installations are expected to reach 3 500 to 4 000 full load hours per year (50 %).

In general, **wave devices** can be classified either by location, or by the way they react to wave motion:

Shoreline devices, either fixed to or embedded in the shoreline, do not require deep-water moorings or long underwater electricity cables and are easier to install and maintain. Their disadvantage is the less powerful wave resource available.

Near-shore devices are deployed at moderate water depths (20-25m), at distances of up to 500m from the shore. With many of the advantages of shoreline devices, they exploit higher power wave resources. They include several point absorber systems.

Offshore devices use the more powerful wave resources available in deep water (over 25m). More recent designs for offshore devices concentrate on small, modular devices, yielding high power output when deployed in arrays.

For **tidal technology** many converters are still in the R&D phase, but a small number of devices have undergone extensive sea testing using full-scale demonstration devices. The first array is expected to be deployed in 2016. There are several types of tidal system for wave energy:

- Horizontal axis turbines: These devices have two or three blades mounted horizontally to form a rotor; the kinetic motion of the water current creates lift on the blades causing the rotor to turn, driving an electrical generator.
- Vertical axis turbines: These devices generally have two or three blades mounted along a vertical shaft to form a rotor;
- Oscillating hydrofoil: This device operates like an aeroplane wing but in fluid; control systems alter the angle relative to the water current, producing lift and drag forces that create device oscillation; the physical motion from this oscillation feeds into a power conversion system.

> “The ocean is an enormous source of renewable energy with the potential to satisfy an important percentage of the European electricity supply. Conversion of the wave energy resource alone could supply a substantial part of the electricity demand of several European countries.”
>
> European Renewable Energy Council

- Venturi or Ducted tidal stream devices: In these devices the tidal stream is directed through a venturi to create an eddy of low pressure behind the turbine. This encourages the flow to be drawn across the turbine entrance. This technology is especially suited to tidal stream devices that are exposed to a rocky seabed. The venturi hood smooths out the undulant currents caused by the terrain.
- Gorlov helical turbines are cross-flow turbines with aerofoil-shaped blades. They generate mechanical power independently of the direction of flow of the tidal stream.

While individual devices are operating well and reliably, the next stage of the development process will involve the deployment of arrays of multiple devices.

Ongoing research

Medium-scale marine power demonstration facilities are currently being built or planned. European companies are active in shoreline, near-shore and offshore based devices.

Seatricity has recently installed its Oceanus 2 device to the Wave Hub test facility 16 km off the coast of Cornwall (UK). Another company, Carnegie, has also secured a berth at the Wave Hub and plans to deploy a 3 MW array of its next generation 1 MW CETO 6 technology in 2016, with the option to expand to 10 MW (Wave Hub, 2014).

Aquamarine Power has deployed and tested two full-scale Oyster devices at the European

Steps towards the full deployment of the wave and tidal energy sectors

		Energy yield optimisation for low resources
	Sub-systems consolidation	Reliability
	RDI&D for early-stage technology	Cost competiveness
Technology Development	Capacity factor >25% and availability >75–85%	Sub-systems optimisation
		Large arrays
		Demonstration for new technologies
	Pilot array deployment	Reduction of OPEX/CAPEX through innovation
	Identification of grid requirements	Survivability
Deployment and Risk Reduction	Standardisation of operations	Supply chain and manufacturing pooling (economies of scale)

Source: SI Ocean

Marine Energy Centre (EMEC): the 315kW Oyster 1 and the second-generation 800kW Oyster 800. Oyster 800 was grid-connected in June 2012 and is currently undergoing operational testing at EMEC's Billia Croo test site. Aquamarine Power has also been granted consent to install up to two further Oysters at EMEC alongside Oyster 800.

Meanwhile, with funding from the EU FP-7 and NER 300 scheme, WaveRoller is implementing the SURGE project in Peniche in Portugal, as part of which three 100 kW units were deployed in 2012. Furthermore, the Irish wave energy project WestWave is receiving EUR 19.8 million in funding under the NER300 programme, which is also funding SeaGeneration's Kyle Rhea tidal project and the Sound of Islay tidal array project (combined funding of almost EUR 40 million).

Regarding tidal energy, the Scottish government has about ten tidal energy projects at various phases of exploration and research (Scottish government, 2014). In March 2011 the Scottish government gave planning consent for a 10 MW tidal array for the Sound of Islay project. A 10 MW array is also being developed by Scottish Renewables Tidal Technology (SRTT) for Lashy Sound (Orkney Islands), with an estimated installation date of 2016-2019, with a possibility for a further 20 MW planned for 2020, subject to environmental impact assessments.

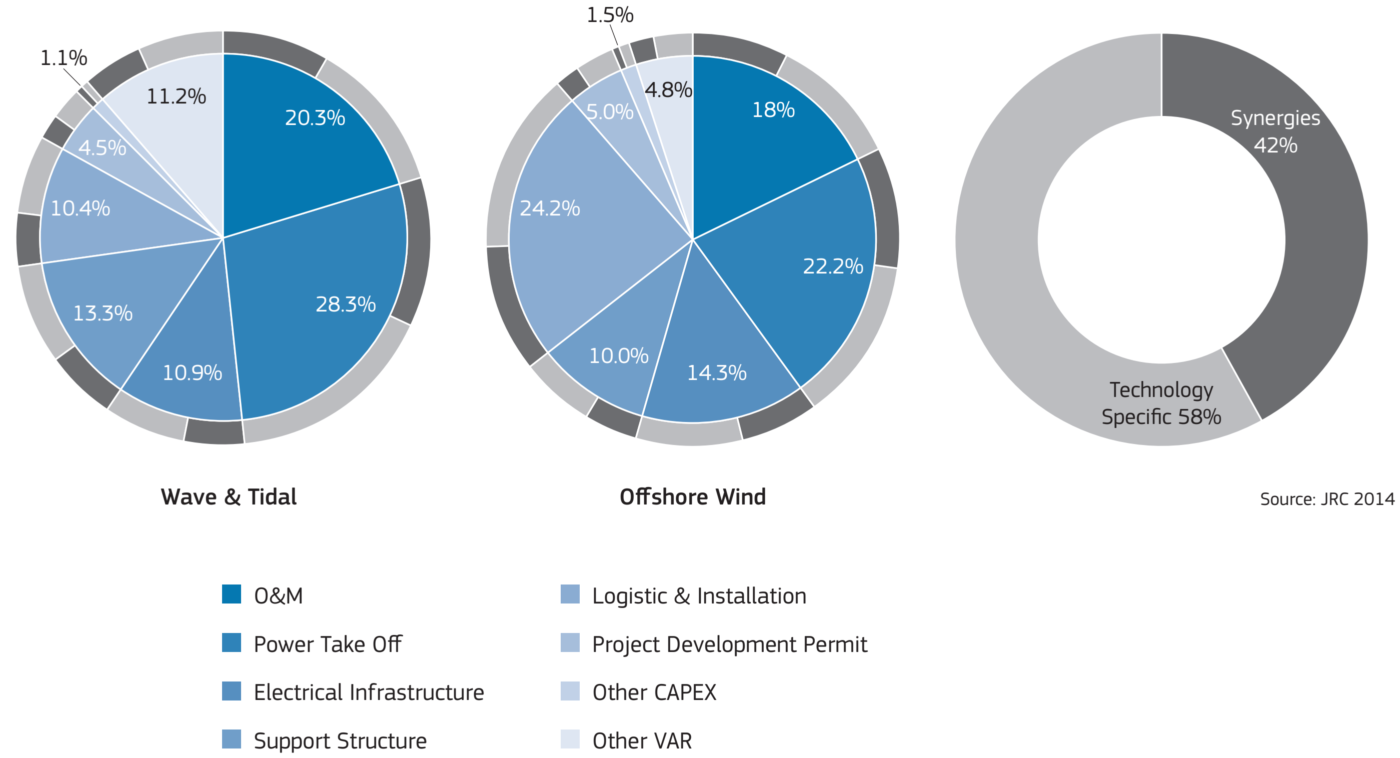
The Marine Energy Array Demonstrator (MEAD) scheme was launched in April 2012 to support a pre-commercial project to demonstrate the operation of wave and/or tidal devices in array formation over a period of time. The company Atlantis Resources Limited has secured financing for MeyGen, the world's largest planned tidal stream project, enabling the start of construction. When completed, the project will include up to 269 turbines submerged on the seabed, generating enough energy for 175,000 homes in Scotland.

For OTEC, research is currently being carried out on the environmental impacts of the technology. At the same time, technical challenges include developing the large-scale pipes needed, looking at bio-fouling of the pipes and the heat exchangers, the corrosive environment, and discharge of seawater (IRENA, 2014a).

The industry

Europe continues to be a global leader in wave and tidal technologies. European wave energy test centres are state-of-the art facilities, such as the European Marine Energy Centre (EMEC) in the Orkney Islands (Scotland), the Wave Hub off the north coast of Cornwall (UK), the Biscay Marine Energy Platform (BiMEP), at Lemoiz on the Basque Coast (Spain), the Danish Wave Energy Centre (Dan WEC) at Roshage in Hanstholm (Denmark) and others.

Synergies between wave and tidal energy and offshore wind



Source: JRC 2014

In the short term, wave and tidal energy technologies are still in the RD&D phase, with an estimated cumulative global capacity of 21 MW of wave power predicted for 2020, which is 20 % less than Bloomberg's 2013 forecast. Global capacity from tidal energy may reach 148 MW, about 21 % down on the previous estimate (BNEF, 2014). Recent analyses have estimated an installed capacity for wave and tidal energy combined of 15 GW by 2030 and 71 GW by 2050 depending on the success of this technology's development (2013 Technology Map, EC/JRC, 2014). As more devices are successfully deployed costs can be expected to come down and, in the longer term, a multi-GW annual market should evolve.

Barriers

According to a SI-Ocean (2013a), the major challenges and obstacles facing the sector include:

- **Enabling technology** – Some elements of core technology still have to be demonstrated over long periods of operation. Current installation practices and procedures are currently sub-optimal in terms of safety, practicality and cost, although this may be an unavoidable step in order to develop optimal deployment strategies and enabling technologies later on.

- **Risk management** – For the moment, utility scale projects may be deemed 'too risky' in the current economic and political climate. The current deployment pathway seems to be taking a technological jump that is larger than investors are able or wish to support.

- **Design consensus** – At present there is a lack of design consensus, particularly for wave energy technology, yet the wave and tidal sector does not have the significant market demand to support the generation of tailor-made solutions for each application or site. There is more scope for commonality in the tidal sector, where there is, for example, some convergence upon a horizontal axis turbine.

- **Grid access** – In some cases, particularly in Scotland, the lack of secured access to grid connection points is a significant barrier. Electrical connection to the grid makes up around 5 % of lifetime costs for both wave and tidal arrays, although this cost is highly variable between sites (SI-Ocean, 2013a). Grid connections to onshore grids can also be problematic, as in some cases the grid cannot absorb the electricity from wave energy production.

- **Economic perspective** – There is a need to bridge the gap between the expectations of investors and those of technology developers. Expectations need to be aligned with realistic deployment trajectories that are within the capabilities of technology developers and with appropriate funding, whether through public or private finance.

- **Environmental mitigation measures** – Some in the sector feel that legislators are over-cautious when formulating environmental legislation and call for greater flexibility. Also, when it comes to deployment, coastal management is key to regulating potential conflicts over the use of coastal space with other maritime activities (e.g. fishing, shipping lanes, etc.).

Fact file

- The levelised cost of electricity (LCOE) for early tidal arrays (10 MW) varies between EUR 0.24 and EUR 0.47/kWh, while the current cost range for similar wave energy arrays ranges between EUR 0.34 and EUR 0.63/kWh (SI Ocean, 2014).
- Installation makes up 18 % of lifetime costs for a wave array and 27 % of lifetime costs for a tidal array. Much of the cost for both wave and tidal devices is currently absorbed by the rental of suitable vessels for the installation work (SI Ocean, 2013).
- Operating and maintenance costs make up 17 % of lifetime costs for a wave array and 19 % of lifetime costs for a tidal array (SI Ocean, 2013).
- According to the UK's Carbon Trust, if the economically recoverable marine energy resource around the UK was fully exploited and displaced conventional fossil-fuel generation, the carbon dioxide output from the UK's energy system could be reduced by 42 million tonnes per year. This is based on the UK Department of Energy and Climate Change's conservative carbon saving of 0.43kg of CO_2 per kWh for wave and tidal electricity generating assets replacing combined cycle gas turbine (CCGT) power stations.

Other barriers include installation costs and maintenance. There is currently little experience in maintenance of offshore facilities. This work involves the use of infrastructure from the oil industry (e.g. ships and platform equipment), which is very costly and not always adapted to purpose.

Needs

There is a need for continued technology push support mechanisms as well as the large-scale deployment and market-pull support schemes that are currently in place. Large utility scale deployments may be an essential part of meeting EU marine energy deployment targets, but greater technology push support will help to facilitate technologies and sub-systems that may play a future role in bringing down costs and improving performance within ocean energy technologies (SI-Ocean, 2013a).

The marine energy community also needs to acquire a sufficient critical size. This requires information exchange and coordination efforts among the stakeholders.

With the expansion of marine energy, the requirements for grids will become acute. In many cases, there is no grid available in the nearby onshore areas for connections. On the Atlantic arc, significant investments will have to be made.

Installed capacity

According to the SI Ocean Wave and Tidal Energy Market Deployment Strategy for Europe, published in 2014, Europe could have up to 100 GW of wave and tidal energy installed capacity by 2050, delivering 260 terawatt hours (TWh) of electricity. According to other sources, the predicted cumulative wave and tidal capacity globally is expected to reach 169 MW by 2020 (BNEF, 2014). In terms of resources, in Europe the Atlantic arc from Scotland to Portugal is the most favourable area.

According to the International Renewable Energy Agency (IRENA), the largest OTEC project built to date is still the 1 MW plant located in Hawaii, which ran from 1993 to 1998. A number of 10 MW plants are in research and development and are planned for operation by 2015 (IRENA, 2014).

The world's first osmotic power plant with a capacity of 4 kW was inaugurated in 2009 in Tofte, Norway. Furthermore a 50 kW RED osmotic plant on the Afsluitdijk in the Netherlands began operation in 2014.

For further information:

SETIS section on marine energy
http://setis.ec.europa.eu/technologies/marine-energy

European Ocean Energy Association
http://www.eu-oea.com

EU Wave and Tidal Energy Strategic Technology Agenda 2014.
http://www.si-ocean.eu/en/upload/SI%20Ocean%20-%20WaveTidal%20Strategic%20Technology%20Agenda.pdf