AN INTERNATIONAL VISION FOR OCEAN ENERGY

2017

INDUSTRIAL GOAL

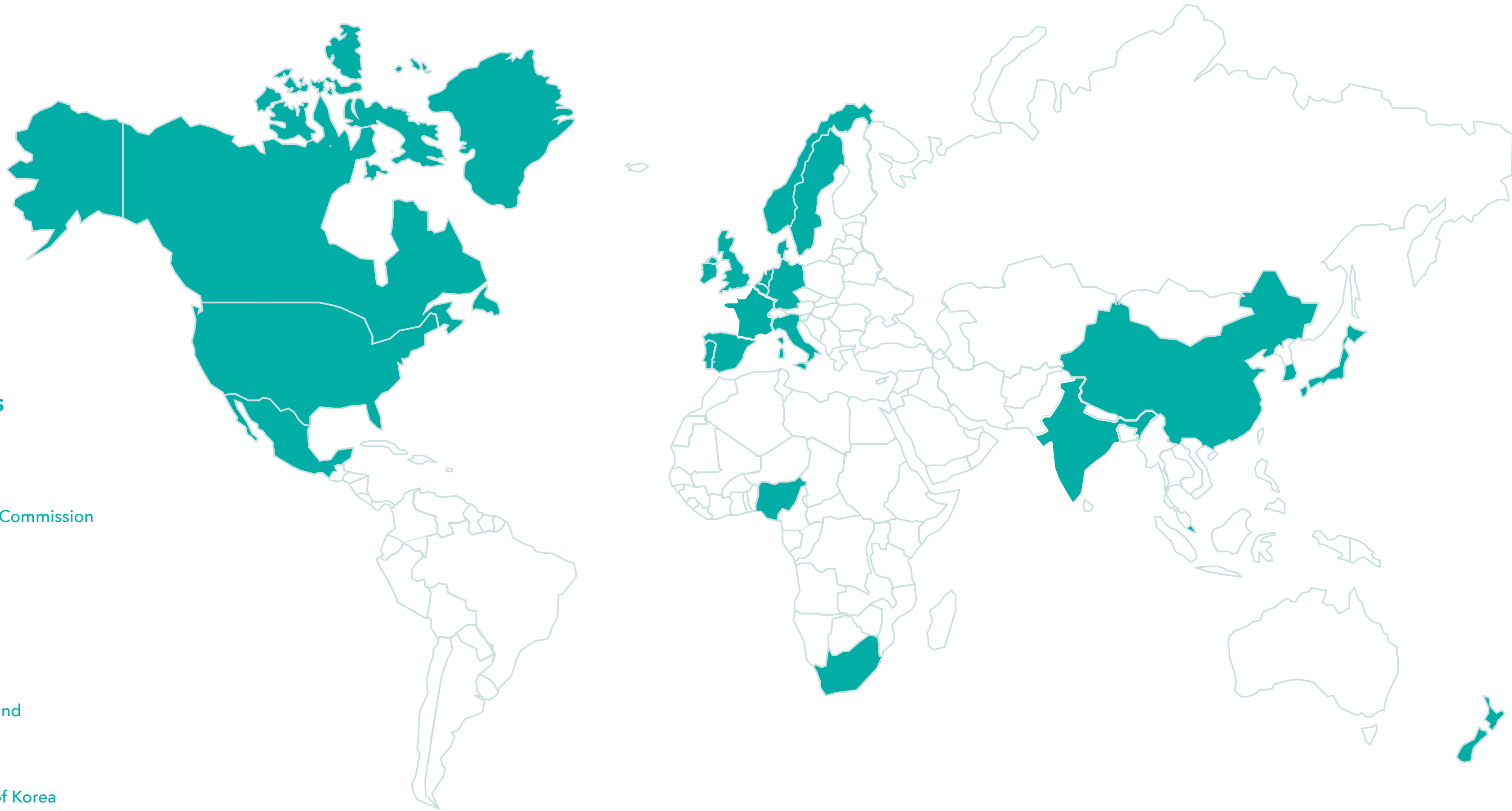
By 2050, ocean energy has the potential to have deployed over 300 GW of installed capacity.

SOCIETAL GOAL

By 2050, ocean energy has the potential to have created 680,000 direct jobs and saved 500 million tonnes of CO_2 emissions.

OCEAN ENERGY SYSTEMS

MEMBERSHIP



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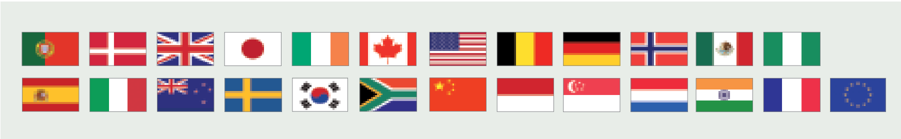
MEMBERSHIP IN DECEMBER 2016

Ocean Energy Systems (OES) was founded by Denmark, UK and Portugal in 2001 and has enjoyed steady growth to twenty-five members. The Executive is in discussions with fifteen other countries.

WHO IS OES?
AN AUTHORITATIVE INTERNATIONAL VOICE



The **Technology Collaboration Programme for Ocean Energy Systems (OES)** is an intergovernmental collaboration between countries, which operates under a framework established by the International Energy Agency in Paris. OES was founded by Denmark, UK and Portugal in 2001 and has grown to its present twenty-five members.

National governments appoint a Contracting Party to represent it on the Executive Committee (ExCo). The Contracting Party can be a government ministry or agency, a research institute or university, an industry association or even a private company. Membership is by invitation and payment of an annual subscription fee.

The representatives meet every 6 months to review the work of the ExCo.
The collaborative research work carried out by the OES is structured into specific tasks/projects to address issues of interest to the parties.

The strength of OES is that it is an intergovernmental and multi-national organization, which lends it an *Authoritative International Voice*. The diverse backgrounds of its ExCo ensure that all points of view can be represented at meetings – from central governments to ocean energy project developers. Working collaboratively, the ExCo achieve more through pooled capital, resources and efforts. There is a natural transfer of current experience and knowledge on ocean energy issues, whether it is R&D topics, policy initiatives or device developments.

WHY OCEAN ENERGY?

Utilization of ocean energy resources will contribute to the world's future sustainable energy supply. Ocean energy will supply electricity, drinking water and other products at competitive prices, creating jobs and reducing dependence on fossil fuels. It will also reduce the world energy sector's carbon emissions, whilst minimizing impacts on marine environments.

THE OES VISION FOR INTERNATIONAL DEPLOYMENT OF OCEAN ENERGY

Worldwide, there is the potential to develop 300 GW of wave and tidal current energy by 2050 and possibly as much again from Ocean Thermal Energy Conversion. Developments will be in locations with high resource availability (**Table 1**).
Deployment of ocean energy can provide significant benefits in terms of new jobs and additional investments. By 2050, the ocean energy deployment described in this Vision could create 680,000 direct jobs.
The global carbon savings achieved through the deployment of ocean energy could also be substantial. By 2050, this level of ocean energy deployment could save 500 million tonnes of CO_2.

OES GLOBAL OCEAN ENERGY DEPLOYMENT VISION	2050
Installed Capacity (GigaWatts) [1]	300
Direct Jobs [2]	680,000
Investment in 2050 year (US$) [3]	35 Billion
Carbon Savings (million tonnes of CO_2) [4]	500

Table 1: OES's Deployment Vision

1. IEA, 2016. Energy Technology Perspectives 2016. IEA, Paris, June 2016.
2. Source: Prorated from OES Vision Version II, 2012.
3. Source: As for 2 above.
4. Source: As for 2 above.

WORLD ENERGY
SUPPLY AND DEMAND

Global population is forecast to increase nearly 34% by 2050 to 9.47 billion[5]. This increase is likely to be in urban centres, whilst rural population may remain static or decline. Much of this new urban population will live close to the coast. Most of the growth will be in non-OECD countries, *i.e.*, presently under-developed but with opportunities to build new energy infrastructures.

This massive population growth will engender growing energy demand, so efforts to reduce greenhouse gas emissions, particularly CO_2, will continue to move towards a low-carbon global economy. These efforts are likely to centre on the energy sector, since this may be the easiest area to engage and enforce the required changes. Other areas, such as reducing transport emissions are more difficult, since the sources are more distributed, whilst investment in carbon capture and storage technologies has not yielded significant results to date. Renewable technologies will have to cope with their natural variabilities, so storage technologies may be an important partner in future.

By the end of 2014, total renewable energy power generation capacity had increased to 1,712 GW, an increase of 8.5% over 2013 (**Figure 1**)[6]. This increase came largely from non-hydro renewables – nearly 660 GW in total (an increase of 18% from 2013) – whilst hydro increased by only 3.6% to nearly 1,055 GW. Not surprisingly, increases in wind (51 GW, including 1.5 GW of offshore wind in Europe) and solar PV (40 GW) exceeded new hydro installations (22%) for the year 2014.

Investment is increasing in energy production from renewable energy sources and low-carbon technologies. Motivations for this shift include increasing oil prices (though this may be somewhat mitigated by the 2014-16 drop in price), national energy security, industrial competitiveness, local economic development and specific environmental impacts, such as urban air pollution.

The renewable energy market has seen 30 - 40% growth rates in recent years, due to market-creating policies and cost reductions. For the last 6 years, more money has been invested in renewable energy than conventional generation[7]. Whilst investment has been dominated by large utilities there has been a noticeable increase in community and residential ownership of small-scale generation.

Whilst the rate of growth of ocean energy has been slower than forecast over the last 15 years (with the exception of the commissioning of the Sihwa Lake Tidal Power Plant in South Korea in 2011), modelling undertaken for this report indicates that ocean energy may experience similar rates of rapid growth between 2030 and 2050 as offshore wind experienced in the last 20 years.

ESTIMATED RENEWABLE ENERGY SHARE OF GLOBAL ELECTRICITY, END-2015

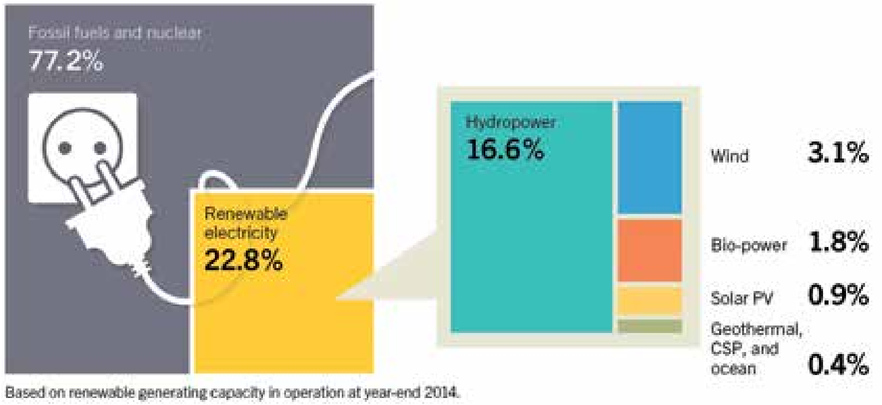


Figure 1: Renewable Energy Share of Electricity Consumption

5. IEA, 2016: Energy Technology Perspectives 2016. IEA, Paris. Figures from 6DS forecast.
6. REN21, 2015: Renewables 2015; Global Status Report. REN21, Paris.
7. Source: As for 6 above.

OCEAN ENERGY **RESOURCES**

The oceans contain 97% of the earth's water and 71% of the earth's surface is covered by seawater. Approximately 3 billion people live within 200 km of the coast and migration is likely to cause this number to double by 2025. So, ocean energy resources offer ready potential for delivery of power, heating and cooling, drinking water and other products to coastal markets.

There are at least six different potential energy resources, which derive from seawater:

- **Tidal currents**
- **Ocean currents**
- **Tidal range (rise & fall)**
- **Waves**
- **Ocean thermal energy**
- **Salinity gradient**

Offshore wind energy is not a form of ocean energy, since it relies on wind energy, albeit in a marine setting.

Overall ocean energy resources are vast, far exceeding human demand, although converting them to useful products can be difficult. Technologies to convert these resources into reserves (*i.e.*, useful products) are, by and large, still in development. Indeed, establishing commercial opportunities to develop these resources involves a complex, competitive balance between the sum of device & installation costs, operational and electricity export costs and the costs of other forms of energy generation or product supply.

Tidal Currents

The movement of ocean water volumes, caused by the changing tides, creates tidal current energy. Kinetic energy can be harnessed, usually nearshore and particularly where there are constrictions, such as straits, islands and passes.

Tidal current energy results from local regular diurnal (24 hours) or semi-diurnal (12+ hours) flows caused by the tidal cycle. Tides cause kinetic movements, i.e., current flows, which can be accelerated near coasts, where there is constraining topography, such as straits between islands.

Ocean Currents

Ocean currents flow in complex patterns around the world's oceans. They are driven by wind and solar heating of surface waters near the equator, whilst others result from density and salinity variations – the thermohaline convection system around the world.

Unlike nearshore currents, ocean currents are relatively shallow (<1,000 m), seasonal, slow-moving (~1 m/sec) and unidirectional.

Tidal Range

(Tidal Rise And Fall)

Tidal range energy is potential energy derived by height changes in sea level, caused by the gravitational attraction of the moon, the sun and other astronomical bodies on oceanic water bodies (**Figure 2**). The effects of these tides are complex and most major oceans and seas have internal tidal systems. Whilst the tidal range is not noticeable at sea, it becomes amplified close to shore. The rise and fall of the tide offers the opportunity to trap a high tide, delay its fall behind a barrage or impoundment, and then exhaust the potential energy before the next tidal cycle. Tidal ranges can reach as much as 17 m, where the principal lunar semidiurnal tide is amplified by local geography.

Tidal range is very predictable, although it can be modified by local weather conditions. The worldwide theoretical power of tidal energy, including tidal currents, has been estimated at around 1,200 TWh/year[8].

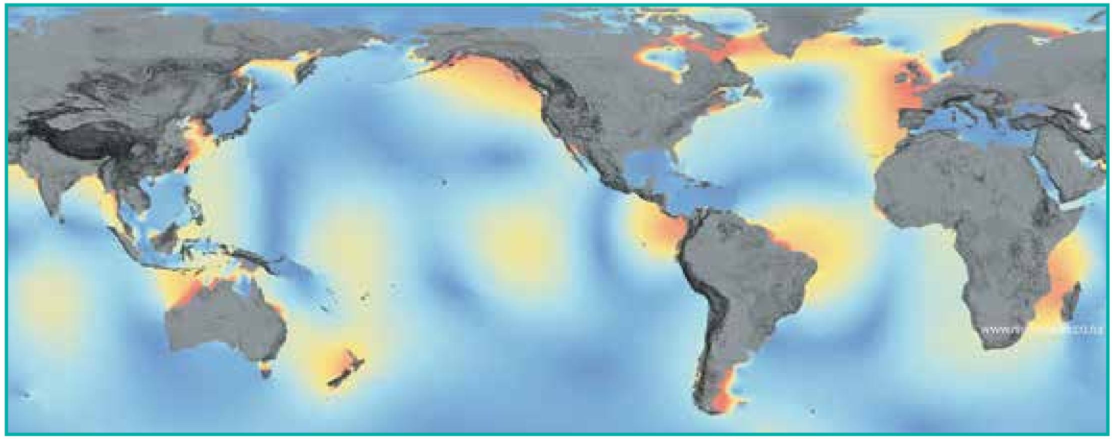


Figure 2: World Distribution Map of Tidal Range

Wave Power

Waves are created by the action of wind passing over the surface of the ocean. Wave heights and thus energy are greater at higher latitudes (greater than 40º from the Equator), where the trade winds blow across large stretches of open ocean and transfer power to waves and swells. West-facing coasts of continents tend to have better wave energy resources.

The map has been shaded to enhance the wave power flux between 15 - 75 KW/m, which is the likely operational range of wave energy converters (**Figure 3**). The worldwide theoretical potential of wave power has been calculated as 29,500 TWh/year[9].

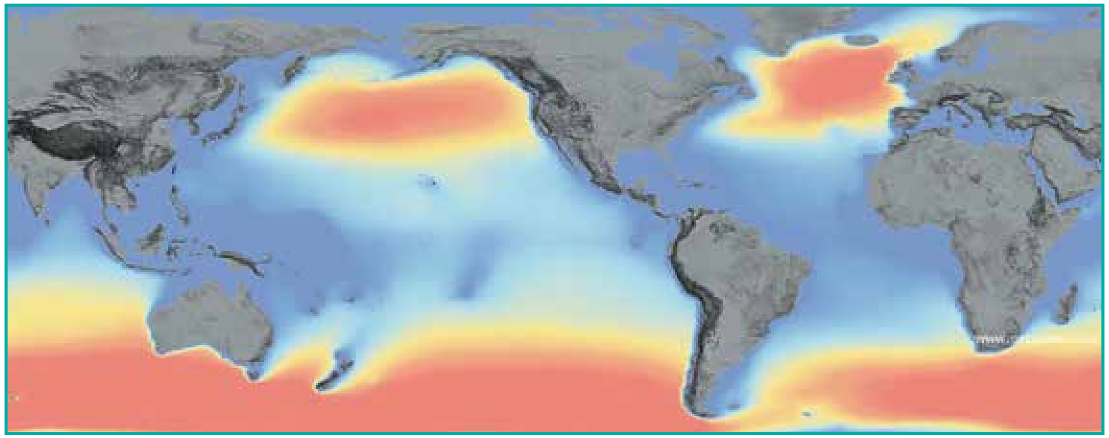


Figure 3: World Distribution Map of Wave Power

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8. World Energy Council, 2010
9. Mork, G., Barstow, S., Pontes, M.T. and Kabuth, A., 2010. Assessing the global wave energy potential. In: Proceedings of OMAE2010 (ASME), 29th International Conference on Ocean, Offshore Mechanics and Arctic Engineering, Shanghai, China, China, 6-10 June 2010.

Ocean Thermal Energy

The potential for ocean thermal energy arises from the temperature difference between near-tropical surface seawater, which may be more than 20° C hotter than the temperature of bathyal (>1,000 m) ocean water, which is relatively constant at about ~4° C. Bringing large quantities of this cold seawater to the surface enables a heat exchange process with the warmer surface waters, from which energy can be extracted.

The worldwide potential of ocean thermal power conversion has been conservatively estimated at 44,000 TWh/year. Note that this potential is concentrated around the Tropics in areas where ocean depths exceed about 1,000 m. Coincidentally ocean thermal energy has a complementary distribution with the distribution of wave energy[10].

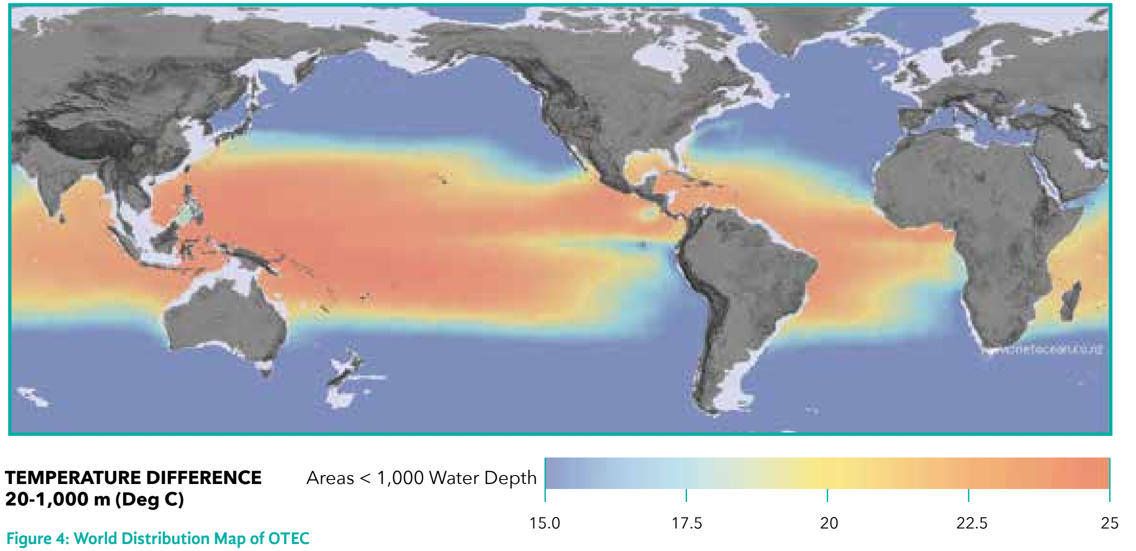


Figure 4: World Distribution Map of OTEC

Salinity Gradient Power

Seawater is approximately 200 times more saline than fresh river water, derived from rain water, snowmelt and ground water, which is delivered to the coast by major rivers. Seawater has salinity values around 30-50 ppt (parts per thousand), whereas fresh water has values of less than 0.5 ppt. Global salinity difference arises from submarine and surface current movements. The relatively high salinity of seawater establishes a chemical pressure potential with fresh river water, which can be used to generate electricity. Salinity gradient power thus achieves its greatest potential at the mouths of major rivers, where large volumes of fresh water flow out to sea.

The worldwide theoretical potential for salinity gradient power has been estimated at 1,650 TWh/year[11].

10. Nihous, G.C., 2007. A preliminary assessment of ocean thermal energy conversion resources. Journal of Energy Resources Technology, 129, pp. 10-17, March 2007.
11. Skråmestø, Ø.S., Skilhagen, S.-E. and Nielsen, W.K., 2009. Power production based upon osmotic pressure. In: Waterpower XVI, Spokane, WA, USA, 27-30 July 2009.

OCEAN ENERGY
TECHNOLOGIES

Over the last 10 years there has been an increased focus on development of technologies to utilize tidal currents and a slightly reduced focus on wave power. Tidal projects are also being developed, since the technology is already mature. Ocean currents, OTEC and salinity gradient technologies have been the subject of active R&D projects.

There is a wide array of technologies at different stages of development to harness the various ocean energy resources available. Some developments use existing and mature technologies (*e.g.*, hydro plant equipment in estuarine tidal barrages), whilst others require new technologies, which are only at the conceptual or R&D stage of development.

Presently, tidal range plants are mature technologies, which are being increasingly deployed in Korea and China. Tidal current technologies have begun to converge on a common design - horizontal axis tidal turbines – which are close to mature development and deployment. Overall these technologies are more advanced than the wide range of different wave devices being trialled. There are few specific ocean current technologies being tested.

Whilst tidal range technologies are usually utility-scale, tidal current and wave devices are generally smaller. They may eventually be deployed at utility-scale in multi-unit arrays or in smaller groups for off-grid applications. Most technologies have been deployed offshore but some, OTEC and salinity gradient, may work in coastal onshore locations, e.g., estuaries for salinity gradient projects. There are also a small number of research projects developing technologies to produce biofuels from seawater-derived algae or seaweed farming.

Tidal Currents

Tidal current devices convert the kinetic energy of a moving water current (usually reaching peak flows >2 m/sec). Several different device technology concepts have been proposed and tested in recent years (**Figure 5**). The main differences between the device types are related to the method of securing the turbine in place, the number of blades and how the pitch of the blades is controlled. Devices may be seabed mounted or floating. Tidal current devices are generally small (<1 MW), modular and intended for deployment in multi-unit arrays for utility-scale generation.

There is a wide variety of technology concepts but in the last 10 years there has been a convergence towards horizontal axis turbines, similar to wind turbine generators.

Current development themes for tidal current devices include cost reductions in installation, operations and maintenance. Specialized vessels may be more cost effective than using larger, more sophisticated and more expensive workboats borrowed from the oil and gas industry.

	Horizontal Axis Turbines	**Vertical Axis Turbines**	**Cross-flow Turbines**	**Other Concepts**
Description	Horizontal axis turbines have a 2- or 3-bladed rotor, which turns about a horizontally mounted axis. The kinetic motion of the water current creates lift on the blades, causing the rotor to turn, driving an electrical generator.	These devices have a 2- or 3-bladed rotor mounted around a vertical shaft. The kinetic motion of the water current causes the rotor to turn, driving an electrical generator. A number of these devices have been trialled, although none has been deployed at scale.	Cross-flow turbines have a multi-bladed rotor, which is usually horizontal with a central axis that is transverse to the current direction.	A number of other concepts, such as oscillating hydrofoil, helical screw devices, are currently being developed and tested.
Diagram				

Figure 5: Tidal Current technologies

Tidal Range

(Tidal Rise and Fall)

Tidal energy can be captured on the basis of the potential energy of the head difference between high and low tides, which creates a gravity flow. Tidal barrages are effectively conventional hydro dams, deployed in estuarine settings (**Figure 6**). Tidal impoundments are essentially offshore self-contained dams. Both tidal barrages and tidal impoundments require large capital investments and have been developed with multiple purposes to improve project economics, *e.g.*, providing roadways across estuaries and flushing for enclosed bays in addition to electricity generation.

	Estuaries and Enclosed Bays	Lagoons and Impoundments
Description	Tidal barrages across estuaries or enclosed bays utilize mature run-of-river hydro turbines to convert this energy to electricity. The 240 MW tidal barrage at La Rance in northern France has been operational since 1967. The 254 MW tidal barrage at Sihwa Lake near Seoul in the Republic of Korea has been operational since 2011. Other large and small scale tidal barrage plants have been proposed in Korea, China and Russia. Ireland, since 2008.	More recently, artificial tidal lagoons have been proposed, which use multi-chamber impoundments to extend electricity production beyond the diurnal tidal cycle. The impoundments are made from simple rock bunds, such as those currently used for breakwaters, to enclose a shallow offshore area. Again, these tidal lagoons will utilize existing run-of-river hydro turbines for electricity generation on both flood and ebb tides. A proof-of-concept proposal to develop a tidal lagoon in Swansea Bay, Wales, is currently under development.
Diagram		

Figure 6: Tidal Range technologies

Wave Power

Wave energy converters capture kinetic and potential energy from ocean waves and swells to deliver products, such as electricity. Wave energy converters are usually small (~1 MW) and are intended to be modular and deployed in multi-unit arrays (**Figure 7**). There is little design consensus for wave energy devices. Due to the diverse nature of the wave resource, it appears unlikely that one single device concept will dominate. Rather, a small number of device types will harness different regions of this vast resource, *e.g.*, heaving motion or wave rise and fall.

Most wave energy converters have to be able to operate in a wide range of conditions and to survive extreme conditions in storms. Consequently, the devices have to be tuned to local, ever changing conditions, whilst being robust enough to operate unattended.

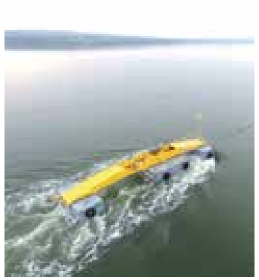
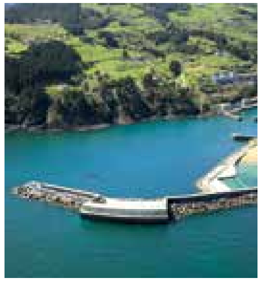
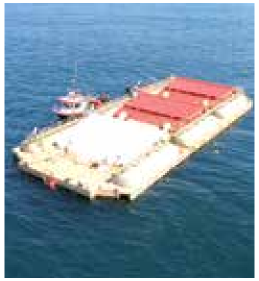
	Attenuators	Overtopping	Oscillating Water Column (OWC)	Oscillating Wave Surge Converters (OWSC)	Point Absorbers	Others
Description	Attenuator devices are generally long floating structures aligned parallel with the wave direction. The devices absorb some of the wave energy, being damped to selectively produce energy.	Overtopping devices, sometimes called terminators, are a wave surge/focussing system, which contain a ramp, over which waves travel into a raised storage reservoir.	In an OWC device a column of water moves up and down with passing waves, acting as a piston to compress and decompress an air column. This reciprocating air is then ducted through an air turbine to drive a generator.	An OWSC device extracts energy from the horizontal surge motion in waves. They are generally nearshore, seabed-mounted devices, though some are intended to operate from coastal locations.	A point absorber is a floating device, which absorbs wave energy from all directions. A wide range of different point absorber devices have been and still are under development, either as seabed-attached or fully floating devices.	A number of other wave energy converter types have been proposed. These range from devices, which utilize flexible membranes to absorb energy, converting wave power to pneumatic power through air compression, or gyroscopic motion to devices, which use unusual high-technology materials to generate electricity.
Diagram						

Figure 7: Wave energy technologies

Ocean Currents

Unlike nearshore currents, ocean currents are relatively shallow (<1,000 m), seasonal, slow-moving (~1 m/sec) and unidirectional **(Figure 8**).

This and other technologies are presently immature but may enable baseload electricity generation from slow-moving ocean currents.

Current issues for development of ocean currents technologies include the ability to generate electricity from slow-moving currents, distance from shore and seasonal movements of ocean currents.

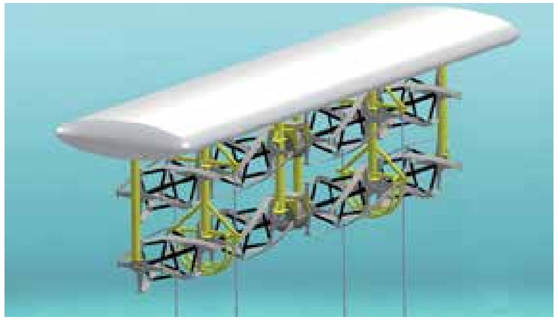


Figure 8: Ocean currents technology

Ocean Thermal Energy Conversion (OTEC)

OTEC is a technology to draw thermal energy from the deep ocean and to use it for heating, cooling or to convert it to electricity (**Figure 9**). The technology requires a year-round temperature difference of 20° C between warm surface water (>22° C) and the cold deep seawater (~4° C), so it is only possible in near-Equatorial seas.

There are also proposals to develop 'grazing' offshore OTEC plants, which could move around, producing energy carriers, such as hydrogen.

Spin-off benefits of OTEC plants include the production of potable water and the use of cold water for mariculture (e.g., salmon and lobster), refrigeration and seawater air conditioning.

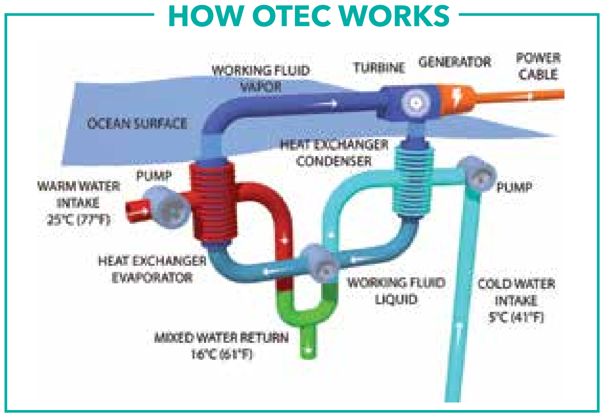


Figure 9: OTEC conversion principle and technology

Salinity Gradient Power

Salinity gradient harnesses the power that can be generated by the juxtaposition of fresh and saline water. There are a number of methods for generating power from salinity gradients, including Pressure Retarded Osmosis (PRO) and Reverse ElectroDialysis (RED), (Figure 10).

Other technologies, such as hydrocratic generators, solar ponds (vapour compression) and osmotic heat engines have been proposed. Whilst salinity gradient power has potential wherever a large body of fresh water, *e.g.*, a major river, enters a sea, technologies to date have not proceeded beyond R&D prototype plants.

Figure 10: Reverse Electrodialysis Plant

DEVELOPMENT THEMES

Development activities to improve ocean energy technologies follow two key themes:

1. Identifying best technologies from the current range under investigation, and
2. Reducing the cost of the best device designs (reducing CAPEX and OPEX), whilst enhancing reliability and performance of these devices (improving yields).

Reliability Improvement

Despite the relatively large number of wave and tidal current devices, which have undergone sea trials, future technical developments will address reliability, survivability, modularity and array deployments. Together, these will reduce downtime through redundancy and ease of maintenance.

Cost Reduction

Cost reduction is perhaps the most critical element to ensure that ocean energy technologies become competitive with other energy generation options. Cost reduction efforts integrate with efforts to improve both reliability and performance. More details on cost reduction is given in the next section.

Performance Improvement

Performance improvements are being affected by improving installation and recovery techniques, enhancing operability and access for servicing, thus reducing mean time to repair. Careful site selection and immediate and longer-term resource forecasting will also help to maximize energy recovery.

COST REDUCTION IN OCEAN ENERGY TECHNOLOGIES

OES believes that the first wave and tidal current device arrays and OTEC plants will be expensive by comparison with existing mature onshore electricity generation technologies (coal, gas, oil and nuclear) but the cost difference is typical for new energy technologies. Ocean energy technologies can be expected to follow the same cost reduction pathways of wind and solar energy. As the technologies become technically advanced and more efficient and their designs become mature and settled, they can be manufactured at scale. OES forecasts that the LCOE for the first commercial arrays should drop to US$ 120 - 280/MWh[12]. Salinity gradient and ocean current technologies are simply too immature to confirm long-term cost trends.

The challenges facing uptake of ocean energy are similar to those that faced offshore wind: costs competitive with existing generation forms, grid connection, engagement of a dedicated supply chain and new challenges of working and operating in hostile marine environments.

Reliable estimates for capital costs (CAPEX) and operating costs (OPEX) are presently difficult, since there is a plethora of diverse technologies – most still immature – few of which have had any significant operational service. Consequently, investors and technology developers have to utilize measures derived from other industries to extrapolate future cost trends, including Technology Readiness Levels and learning curves. More reliable cost information can be derived from studying the likely maturation pathways of currently immature technologies to commercial availability.

12. OES, 2015. International LCOE for Ocean Energy Technologies.

COST FORECASTING

Technology Readiness Levels

Over the last five years, government funding agencies, certification bodies and investors have begun to utilize Technology Readiness Levels (TRLs) to assess the maturity of technologies from initial concepts to commercially-ready hardware. TRLs are contributing to more targeted funding for devices or components.

At present, most ocean energy technologies are either conceptual or scaled prototypes. Few developers have been able to deploy full-scale prototypes in fully marine conditions. Despite claims to commerciality and first grid-connected electricity production, only a few developers have deployed a first array. Apart from tidal barrages, very few projects have achieved industrial scale (if not commercial success).

Learning Curves

Learning curves are used to forecast long-term cost reduction trends. For a doubling of deployed capacity, a percentage reduction in costs can be forecast. Wind turbine generators have demonstrated a learning rate of approximately 15% over the last 30 years, whilst photovoltaics have a rate closer to 20%.

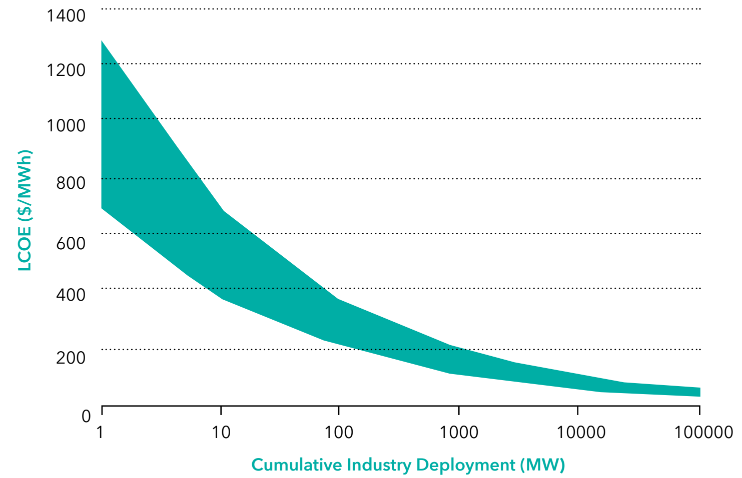


Figure 11: Learning Curve for Wave Energy Technologies

COST REDUCTIONS

Cost reduction is perhaps the most critical element to insure that ocean energy technologies become competitive with other energy generation options.

Cost reductions are likely to arise from:

- Manufacturing at scale
- Fundamental design modifications as technologies mature
- Standardization of components, e.g., PTOs, foundations, moorings
- Deployment in arrays, with concomitant benefits of modular development, maintenance scheduling and redundancy
- Operational efficiencies: installation, maintenance and recovery
- Performance data gathering for improved reliability and availability
- Integration with other technologies, such as platform- and other infrastructure-sharing with wind projects
- Recruiting related supply chains, such as oil and gas, offshore wind, shipping and aquaculture
- Resource analysis and forecasting
- Grid and network connections

Cost reduction efforts are a critical theme for the successful introduction of ocean energy into a very competitive energy supply market. OES has recently completed a study on the Levelized Cost of Energy (LCOE) for ocean energy technologies, available at the OES website.

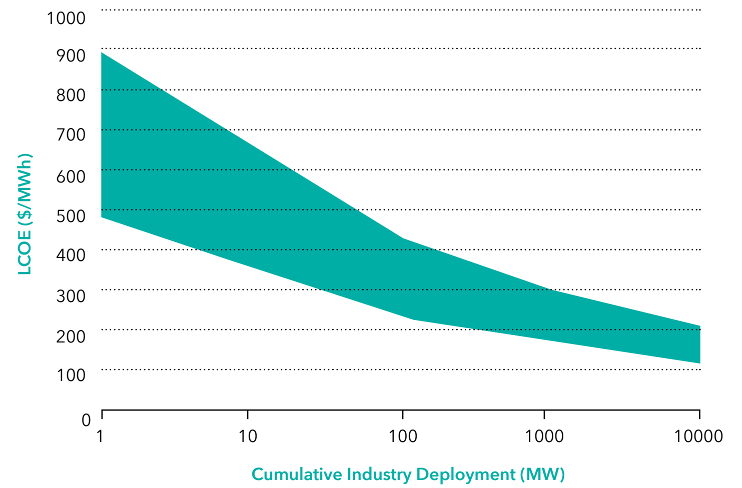


Figure 12: Learning Curve for Tidal Currents Technologies

TECHNOLOGY
DEVELOPMENT AREAS

Different devices require different development activities, though two encouraging developments are the spread of industry standards and collaboration between competing device developers to design common components, e.g., power take-offs.

Structures & Prime Movers

Being competitive, device developers devote most of their time and money to enhance the power conversion efficiency of their own devices. The lack of convergence of wave energy converter designs means that some of these efforts may eventually be wasted. Tidal energy devices are more convergent and key areas for development are blade design, material selection and fabrication. First generation devices may be over-designed, because developers deploy them in some of the most energetic resources areas and want to prevent failure due to unexpected conditions.

Foundations & Moorings

Foundations and moorings are critical to station-keeping for nearshore and offshore devices. Installing offshore foundations is very costly and, where seabed conditions permit, gravity bases are favoured. Floating devices do not require foundations.

Conventional moorings for ships are not analogous, since moorings for floating wave and tidal current devices must be able to address high loads, multiple movement directions and minimize energy reduction in the prime movers.

Power Take-Offs & Control Systems

Wave energy converter power take-off systems (PTOs) must convert irregular low frequency waves and swells to grid-compliant electricity. There are presently many different PTO arrangements, including turbines, hydraulic systems gearboxes and linear generators. Control systems, particularly for wave devices, will be important to 'tune' devices to local conditions and, in future, to individual incident waves. Pitch control systems for tidal current blades will increase yield and survivability.

Array Systems and Subsea Connections

The development of wave and tidal current device arrays require electrical systems and interconnections between devices and subsea hubs, subsea umbilicals, wetmate connectors and offshore conditioning of the electricity for export. To some extent, ocean energy technologies are benefitting from the widespread development of offshore wind farms, both in terms of technology developments but also, in future, in sharing offshore platforms and infrastructure and export cables.

Installation, Operational Maintenance and Recovery

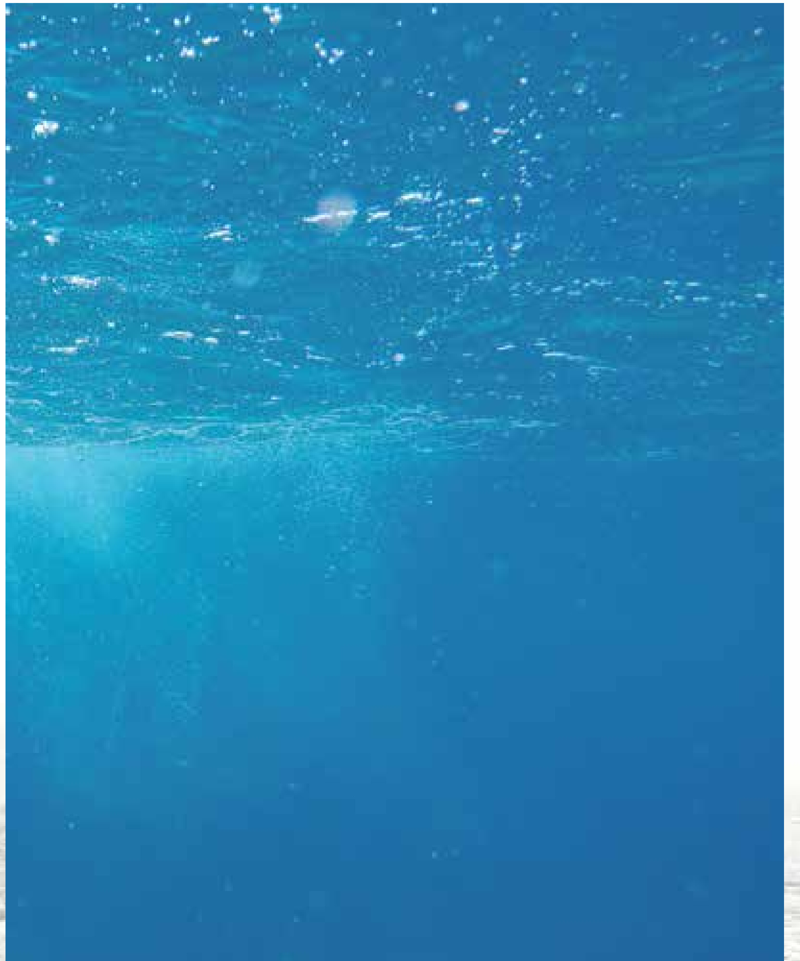
Generally, access to both wave and tidal current sites is limited by weather and tidal conditions. Offshore vessels are expensive to rent, so purpose-built vessels that can operate in a wide range of conditions will enable arrays to be more productive, whether they are installing or recovering devices or working on-site to maintain them. Modular construction of devices, so that generators can be removed and replaced on-site, for instance, offer opportunities to limit maintenance time on-site.

OTEC and salinity gradient technologies are presently immature with considerable R&D required to establish potential commercial technologies. Current areas for development of OTEC technologies include manufacturing and deploying the wide-diameter (4+ m) cold water pipe, improving heat exchanger efficiency and dealing with biofouling. Salinity gradient technologies are based around semi-permeable membranes. Enhancing the performance, reducing maintenance of and extending the life of membranes are current areas of active research. Pre-treatment of water and management of biofouling are also being investigated.

TECHNOLOGY DEVELOPMENT AREAS

- Structure & Prime Movers
- Foundations & Moorings
- Power Take-Offs & Control Systems
- Arrays systems and subsea connections
- Installation, operational maintenance & recovery

CHALLENGES FOR UPTAKE OF OCEAN ENERGY



The central challenges which are faced by the ocean energy sector can generally be classed under the headings of device & system deployment, sub-systems or components, design optimisation & tool development and commercial deployment.

Device and system deployment

Device and system deployment refers to a range of activities, which have a large influence on cost of energy. Improvements in this area would reduce capital expenditure (CAPEX) and operating expenditure (OPEX) costs by improving performance or optimising technology, enabling progress towards large scale deployment. Securing funding support for pre-commercial trials using economical installation and recovery methods will be required. This is an area well suited to cross-sector collaboration and presents many multi-sector opportunities.

Sub-systems or components

Sub-systems or components impact on the performance and reliability of a device. To improve capability, new solutions for these sub-systems are required. To a certain degree, optimisation will come through learning by doing, but slow progress has led to many original equipment manufacturers pulling out of the sector. The ocean energy sector will naturally converge on optimised solutions but collaboration and technologies transferred from mature industries will allow this to happen more rapidly.

Design optimisation and tool development

Design optimisation and tool development covers the tools and optimisation processes that could be used to aid future design, development and deployment. At this early stage of development, there is no clear consensus on the requirements for design tools in the ocean energy sector. Techno-economic and environmental impact assessment tools, providing metrics by which optimality can be measured, are hindered by high degrees of uncertainty.

Commercial deployment

The commercial deployment of ocean energy devices depends on addressing a number of additional issues, which arise when moving from single-device to multiple-device deployment. This requires a shift in focus, for instance, to commercial deployment reliability demonstrations, to ensure that devices are capable of long-term survival in the marine environment. Optimisation of subsea electrical systems and offshore grid design is fundamental but the step-up in scale is high-risk, high-cost and requires financial support and incentives. Computational modelling of commercial deployment is significantly more complex due to device interaction and collaboration between research and industry is required.

The ocean energy sector is now at a stage where numerous prototypes have been deployed. Despite this, there is still a need for many devices to prove long-term reliability and commercially viable energy production levels at a large scale. Much still needs to be done to build confidence in the sector and to overcome a number of challenges in the sector.

TECHNOLOGY CHALLENGES

Commercial Deployment

- Offshore Grid Design & Optimisation
- Multi-device Electrical System
- Sub-sea Electrical System
- Multi-device Interaction Analysis
- Offshore Umbilical / Wet MV Connectors
- Reliability Demonstration (Commercial deployment level)

Design Optimisation and Tool Development

- Device Modelling Tools
- Failure Modes & Conditioning Monitoring Techniques
- Environmental Impact Assessment Tools
- Site Characterisation Techniques
- Resource Analysis Tools
- Large Scale Design & Modelling Tools
- Techno-economic Analysis Tools

Device and Systems Deployment

- Performance Data Collection
- Knowledge Transfer & Dissemination
- Economic Installation Methods
- Economic Recovery Methods
- Connection / Disconnection Techniques
- Pre-commercial Device Sea Trial
- Pre-commercial Multi Device Sea Trial
- Vessels
- Reliability Demonstration (Device & Components)

Sub-systems or components

- Control Systems
- Intelligent Predictive Maintenance Systems
- Power Take-Off
- Power Electronics
- Device Structure
- Hydraulic Systems
- Cooling Systems
- Bearings
- Foundations & Moorings

BENEFITS & SYNERGIES
WITH OTHER SECTORS

Benefits of Ocean Energy

Ocean energy technologies must achieve a significant improvement in reliability and performance, whilst also reducing overall costs to be competitive with existing energy technologies. Identification of ways in which such technology improvements and cost reductions can take place are necessary and essential for ocean energy to reach full commercialisation and contribute to the global energy mix.

Although significant development has taken place within the ocean energy sector, primarily with wave and tidal energy, there are other sectors and mature industries which potentially offer an opportunity for knowledge or technology transfer into the ocean energy sector. Future development within the ocean energy sector could be catalysed by the potential transfer opportunities from other sectors and industries, however, it is important that this transfer and diversification of knowledge and expertise into the new market is effectively facilitated to include a range of areas, such as infrastructure, supply chain, sub-components, policy and regulation.

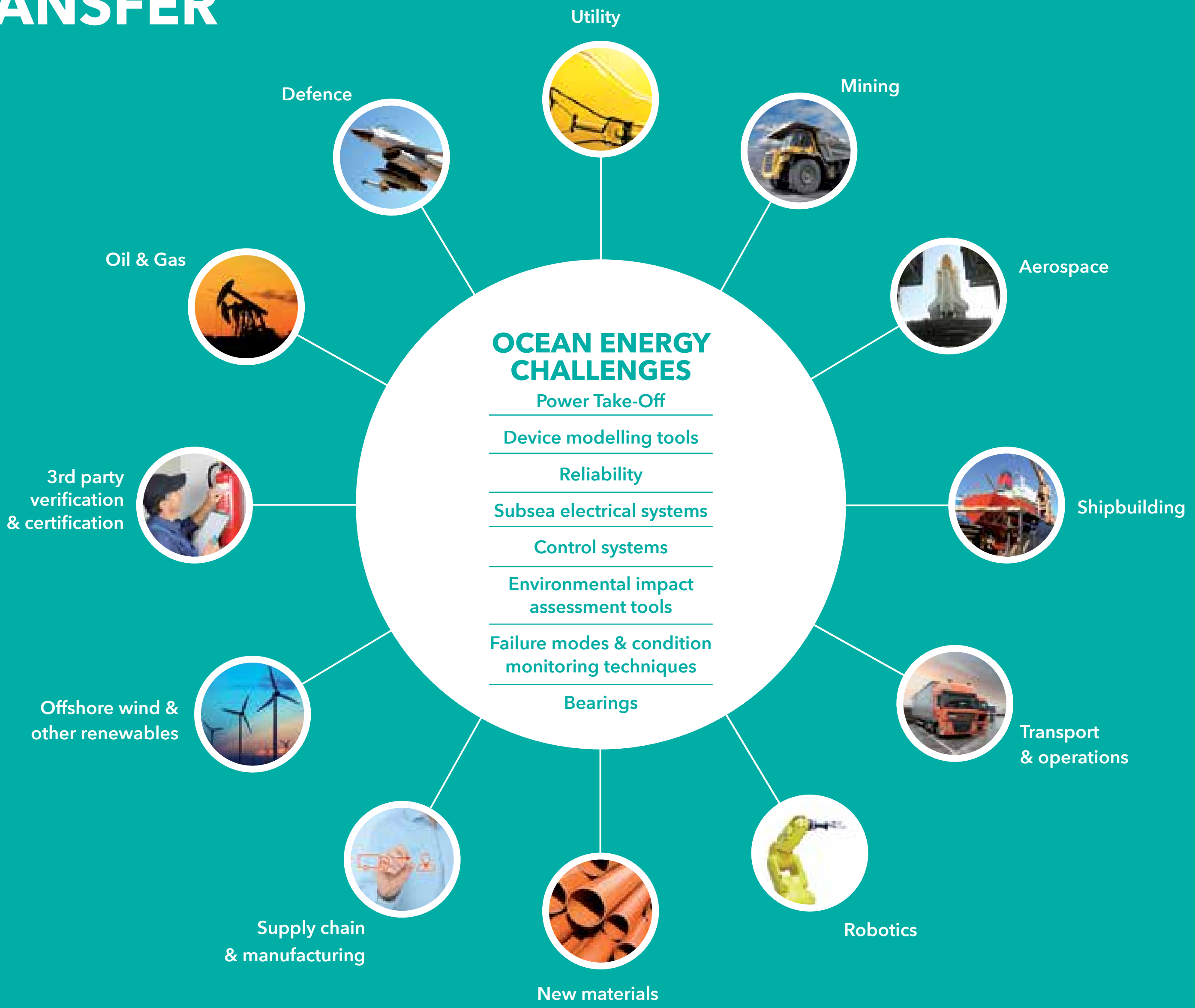
Synergies with Other Sectors

In addition to technology and knowledge transfer, there may be opportunities for co-location of technologies, for example the utilisation of common platforms, such as ocean energy and offshore wind, solar PV and aquaculture. Whether through colocation, knowledge or technology transfer, the opportunities for mutual learning and the shared innovations and infrastructure from a mutual supply chain are enormous for both the ocean energy sector and other industries and should not be underestimated.

Several sectors have been identified as potentially capable of knowledge sharing, either through technology and sub-components or skills and trained personnel. This opportunity can extend to organisations and countries which do not have direct offshore experience or resource to directly contribute to the ocean energy sector. These sectors include mature industries, such as oil and gas, defence, offshore wind & other renewable energies, utility, shipbuilding and aerospace.

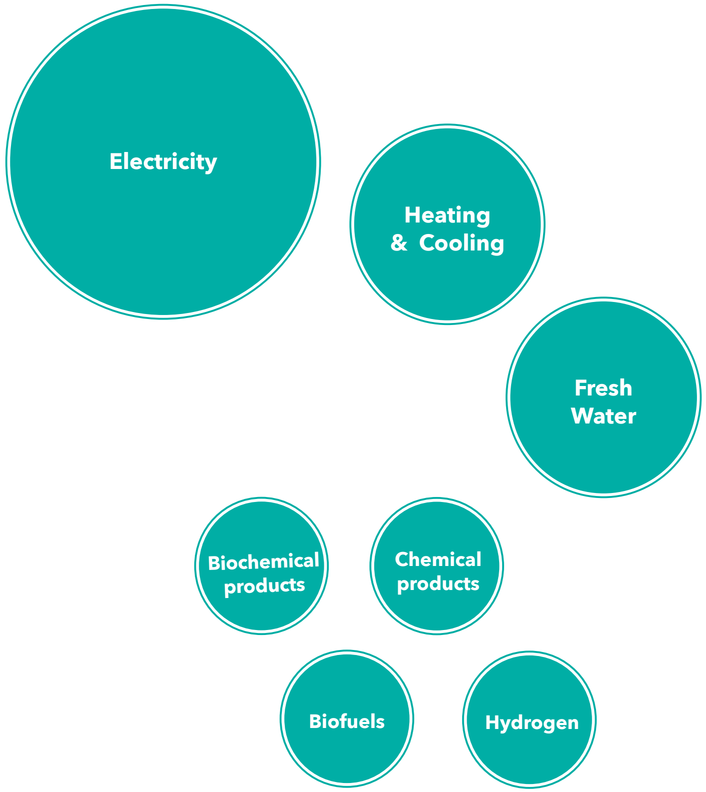
There are a number of ways in which specific synergies exist within varying industries, leading to a range of transfers from other industries into the ocean energy sector. In addition to those named above, these include mining, transport and operations, robotics, new materials, supply and manufacture and 3rd party certification.

TECHNOLOGY TRANSFER



PRODUCTS AND MARKETS
FOR OCEAN ENERGY

Most ocean energy technologies are being developed to produce electricity, although some of them are being developed to deliver other or multiple products, derived from the physical and chemical properties of seawater:



Utility-scale grid electricity generation

The dominant market for ocean power technologies will be grid-connected electricity generation, because of the size of the market opportunity.
The majority of technologies are being developed for utility-scale generation. Increasing demand for low-carbon renewable electricity supports through the growth of the ocean energy sector, through legal obligations to meet renewable energy and/or carbon reduction targets. Many countries expect to move to highly electrified energy systems, so this market will continue to grow. Tidal current energy is very predictable, often only affected by a weather overprint. Wave energy too is less variable and more forecastable than other intermittent renewables, whilst some future tidal range and OTEC plants may produce baseload electricity.

Islands electricity generation

Whilst the general theme of ocean energy development is towards utility-scale grid electricity generation, there are clear opportunities for development and deployment of ocean energy technologies at smaller scale.
Islands around the world are heavily reliant on costly oil imports for electricity generation. Because of the small size and isolated location of many islands, electricity costs in these locations are higher than on the mainland. This creates a competitive situation for ocean energy technologies and important job opportunities.

Off-Grid Applications

Where ocean energy resources are good, technologies can produce local, secure and low carbon electricity for off-grid communities. These communities traditionally depend on expensive imported fossil fuels, particularly diesel generation. This off-grid electricity is relatively expensive, so electricity from ocean energy could become competitive more quickly than in utility-scale settings.
This market also includes the potential for dedicated power production for remotely located demand applications, such as data centres. Data centres require high levels of both electricity supply and cooling capacity, both of which could be supplied by ocean energy technologies.

Other Uses – Heating, Cooling and Desalination

Heating and cooling, in the form of seawater air conditioning (SWAC) in tropical latitudes, are a likely future market. Some tropical island resorts have already begun to develop seawater air conditioning plants.
Some ocean energy technologies are being developed to produce potable drinking water in isolated locations as the primary product. Desalination facilities attached to OTEC plants may provide larger markets, such as western Mexico and the Caribbean Sea.

POLICIES
FOR OCEAN ENERGY

National governments use many policy instruments to ensure and enable investment in new technologies, including ocean energy technologies. These policies are intended to:

1. Accelerate the maturation of ocean energy technologies to commercial readiness
2. Make them cost-effective with regard to other renewable energy technologies

The selection of appropriate policies by national governments depends upon the maturity of the ocean energy sector, their national supply/demand balance, energy system resilience and willingness to invest in new technologies. National governments in the OES countries are utilizing a range of policy instruments to promote and accelerate ocean energy in their national waters (Table 3).

Most countries in which ocean energy technologies are currently being developed have renewable energy or renewable electricity generation targets, although a few have specific policies to promote ocean energy uptake. Similarly these countries use '*technology-push*' mechanisms through capital grants or financial incentives to create early-stage opportunities. Fewer countries use market, industry or supply chain initiatives (*i.e., 'technology-pull'*) specifically for ocean energy developments.

Most of the more advanced countries are developing ocean energy testing centres, of which the European Marine Energy Centre (EMEC) is the most well known. There is a growing network of wave and tidal energy testing centres, pilot zones and offshore hubs, where developers can use existing infrastructure to test technologies in controlled conditions.

Specific space/resource allocation regimes have been developed for ocean energy and competitive permitting is likely to become more common. Marine spatial planning is increasingly being used to map, control and coordinate ocean uses.

Government investment is critical to making ocean energy technologies viable but government commitments also encourage and support the larger contribution from public and private investors.

THEME	POLICIES	DESCRIPTION
Capacity or generation targets	Legislated Targets	National targets for total energy or electricity production
	Aspirational Targets and Forecasts	Non-legislated targets or forecasts for deployment of ocean energy technologies
Capital Grants and Financial Incentives	R&D Programmes/Capital Grants	Grants to encourage innovative research into ocean energy technologies
	Prototype Deployment Capital Grants	Grants to encourage deployment of prototype devices
	Project Deployment Capital Grants	Grants for deployment of projects (usually matching funds)
	Prizes	Prizes for achieving production targets from prototype devices
Market Incentives	Feed-In Tariffs	Guaranteed price (in $/kWh or equivalent) for ocean energy generated electricity
	Tradable Certificates and Renewables Obligations	Legislated requirements for electricity generators to invest in ocean energy-generated electricity
	Tendering Processes	Tendering for capped supply from ocean energy-generated power
Industry and Supply Chain Development	Industry & Regional Development Grants	Cluster developments
	Industry Association Support	Government financial support for establishment of industry associations
Research and Testing Facilities and Infrastructure	National Marine Energy Centres	R&D and deployment centres
	Marine Energy Testing Centres	Testing centres for prototype and pre-commercial device trials
	Offshore Hubs & Pilot Zones	Consented sites with connection infrastructure for devices
Resource Allocation and Industry Standards	Standards/Protocols	Development of international standards for wave, tidal and ocean currents
	Permitting Regimes	Crown Estate competitive tender for Pentland Firth licences
	Space/Resource Allocation Regimes	Department of Interior permitting regime in United States Outer Continental Shelf

Table 3: Policy Options for Ocean Energy

How does OES's vision for ocean energy translate into actions over the next 5 years?

The OES Executive Committee has developed a Vision for its own future, based upon new organisational and brand values. Successful delivery of its Vision will depend on four critical success factors (**Figure 13**):

1. High-Quality Information
2. Strong and Effective Communication
3. Effective Organization
4. Shared Capability Growth

THE VISION FOR OCEAN ENERGY

"Ocean Energy is recognised as being a respected and critical source of green energy. The diversity of devices available is fit for purpose and kind to the environment in which they operate. The capacity provided facilitates security of supply for nations and a commercial return for the supplier. As a green energy of choice, Ocean Energy is recognised for its contribution to economic growth."

THE VISION OF OES

"As the Authoritative International Voice for Ocean Energy we collaborate internationally to accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally acceptable manner."

OES BRAND VALUES

Trusted Independent Source
Substantiated knowledge
Inspiring Action
We care for society and the environment
Collaborative Sharing

OES ORGANISATIONAL VALUES

Integrity
Outcome Oriented
Knowledgeable
Inspirational
Collegial

CRITICAL SUCCESS FACTOR 1:
High Quality Information

CRITICAL SUCCESS FACTOR 2:
A Strong and Effective Communication Capability

CRITICAL SUCCESS FACTOR 3:
An Effective Organisation

CRITICAL SUCCESS FACTOR 4:
Shared Capability Growth

Figure 13: OES's vision and critical sucess factors

AN INTERNATIONAL VISION FOR OCEAN ENERGY

VERSION III: February 2017

Maps:
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Tidal Range› Richard Ray (NASA)
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