European Commission

# LOW CARBON ENERGY OBSERVATORY

# OCEAN ENERGY
## Technology development report



Joint Research Centre

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# Acronyms and abbreviations

| | |
|---|---|
| ARENA | Australia Renewable Energy Agency |
| ADEME | French Environment & Energy Management Agency |
| CAP | Long-term decarbonisation scenario |
| CAPEX | Capital Expenditure |
| CF | Capacity Factor |
| COP | Coefficient of Performance |
| COST | Cooperation in Science and Technology |
| CPI | Current Policy Initiative |
| DOE | US Department of Energy |
| DOI | Declaration of Intent |
| EC | European Commission |
| EMEC | European Marine Energy Centre |
| EIB | European Investment Bank |
| ETIP | Energy Technology Innovation Platform |
| ETRI | Energy Technology Reference Indicators |
| EU | European Union |
| FP6 | $6^{th}$ Framework Programme |
| FP7 | $7^{th}$ Framework Programme |
| HAT | Horizontal Axis Turbine |
| H2020 | Horizon 2020 Programme |
| IA | Innovation Actions |
| IEE | Intelligent Energy Europe |
| IEA-OES | International Energy Agency Ocean Energy Systems |
| LCoE | Levelised Cost of Energy |
| MRL | Manufacturing Readiness Level |
| MS | Member State |
| MSCA | Marie Skłodowska-Curie Actions |
| NER300 | New Entrants' Reserve |
| NREAP | National Renewable Energy Action Plan |
| PA | Point Absorber |
| PRO | Pressurised Reverse Osmosis |
| PTO | Power Take Off |
| OFGEM | Office of Gas and Electricity Markets |
| OPEX | Operating Expenditure |
| OTEC | Ocean Thermal Energy Conversion |

| | |
|---|---|
| OWC | Oscillating Water Column |
| OWSC | Oscillating Wave Surge Converter |
| RED | Reverse Electro-Dialysis |
| RIA | Research Innovation Actions |
| SET-Plan | Strategic Energy Technology Plan |
| SME | Small-medium Enterprise |
| TEC | Tidal Energy Converter |
| TRL | Technology Readiness Level |
| VAT | Vertical Axis Turbine |
| WEC | Wave Energy Converter |

Units

Throughout the report we use mEUR as an abbreviation of millions of EURO and bEUR for billions of EURO.

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# FOREWORD ON THE LOW CARBON ENERGY OBSERVATORY

The LCEO is an internal European Commission Administrative Arrangement being executed by the Joint Research Centre for Directorate General Research and Innovation. It aims to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

## *Which technologies are covered?*

- Wind energy
- Photovoltaics
- Solar thermal electricity
- Solar thermal heating and cooling
- Ocean energy
- Geothermal energy
- Hydropower
- Heat and power from biomass
- Carbon capture, utilisation and storage
- Sustainable advanced biofuels
- Battery storage
- Advanced alternative fuels

## *How is the analysis done?*

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

## *What are the main outputs?*

The project produces the following report series:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Future and Emerging Technology Reports (as well as the FET Database).

## *How to access the reports*

Commission staff can access all the internal LCEO reports on the Connected LCEO page. Public reports are available from the Publications Office, the EU Science Hub and the SETIS website.

# 1 INTRODUCTION

The purpose of this report is to provide an assessment of the state of the art of ocean energy technology, to identify their development need and barriers and to define areas for further R&D in order to meet announced deployment targets and EU policy goals. The analysis focuses primarily on tidal and wave energy technology, considering their potential to provide a significant contribution to the European energy mix in the coming years.

In order to undertake the different tasks set out for this report, different approaches have been employed, based primarily on in-depth literature reviews, expert judgements, existing KPIs identified by the sector, employment of technology specific database, collection of techno-economic information and analysis of the information collected to provide an unbiased assessment of the ocean energy sector.

## 1.1 Literature review and analysis

An in-depth literature review was carried out to assess the state of the art of the ocean energy sector. This review stemmed from the 2014 JRC Ocean Energy Status Report [Magagna & Uihlein 2015a] and recent high level reports [SI Ocean 2013, IRENA 2014a, Kempener & Neumann 2014, IRENA 2014b], complemented by an assessment of ongoing development in the sector, and by the availability of an extensive and validated ocean energy database developed by the JRC [JRC 2014] and updated in 2016 [Anonymous 2016]. Information has been update with a review of literature as shown in section 2

From the analysis of the sector's state of the art, sub-technologies were categorised and prioritised, based on their technological advancement (TRL and MRL) and their potential to provide a significant contribution in the short-term period. The definition of TRL employed for the analysis is the one provided by the European Commission Horizon 2020 framework. This analysis was complemented by extended TRL definition provide by the European Commission guidelines in 2017 [A. De Rose, M. buna, C. Strazza, N. Olivieri, T. Stevens, L. Peeters 2017]; which offer a more details assessment of checkmarks for each TRL.

Technology gaps have been identified during the first two steps of this analysis, and coupled with techno-economic data to analyse particular areas (components and sub-components) of the technology that could provide a significant cost-reduction to ocean energy technologies and therefore should become areas for focussed research in the upcoming calls.

## 1.2 Data sources

Table 1 presents the data source employed for the current analysis. The main sources of data were CORDIS[1] and the JRC Ocean Energy Database, IEA-OES studies. Techno-economic infor-

[1] The Community Research and Development Information Service (CORDIS) is the European Commission's primary source of results from the projects funded by the EU's framework programmes for research and innovation (FP1 to Horizon 2020) – see https://cordis.europa.eu/en

mation was gathered according to the ETRI [Carlsson et al. 2014] methodology, and complemented with updated data [Tsiropoulos et al. 2018].

*Table 1 Data sources for the analysis.*

| **Data sources** | **SOA*** | **DT**** | **TE⁺** | **BAR⁺⁺** | **Trends** |
|---|---|---|---|---|---|
| Most relevant EU-funded projects ( H2020, NER300, ERA-NET) | ✓ | ✓ | ✓ | ✓ | ✓ |
| SETIS | ✓ | ✓ | ✓ | | ✓ |
| CORDA/Compass database | | | | ✓ | |
| EU Member State or regionally co-funded projects | ✓ | ✓ | ✓ | | ✓ |
| Major international projects (IRENA, OES) | ✓ | ✓ | | | ✓ |
| National projects from major non-EU countries | ✓ | ✓ | ✓ | | ✓ |

* State of the Art, **Development trends,⁺, Techno-economic projections, ⁺⁺Technology Barriers

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# 2 TECHNOLOGY STATE OF THE ART

Energy present in oceans and seas can occur in many different forms including waves, tidal range, tidal currents, ocean currents, temperature differences and salinity gradients [Lewis et al. 2011, Magagna, MacGillivray et al. 2014, Magagna & Uihlein 2015b].

All forms of ocean energy can be used generate electricity, Salinity gradient and OTEC technologies will be able to produce base-load electricity. Other forms of ocean energy show variable generation, with different predictability [Lewis et al. 2011].

In the EU, the highest resource potential for ocean energy exists along the Atlantic coast, with further localised exploitable potential in the Baltic and Mediterranean seas and in overseas regions (e.g. Reunion, Curacao). The theoretical potential of wave energy in Europe is about 2800 TWh annually, and the potential for tidal current was estimated to be about 50 TWh per year [Lewis et al. 2011, EC 2014a]. OTEC offers potential only for the EU overseas islands since its deployment is basically only possible in tropical seas [Magagna & Uihlein 2015b].

Given the resources available in the EU, and the advancement of the technologies, it is expected that in the short-to-medium term (up to 2030), ocean energy development in the EU will be largely dependent on the deployment of tidal and wave energy converters. The deployment of OTEC in continental waters is limited, whilst it is not clear how salinity gradient technologies could develop both in terms of technology and market.

Eight EU Member States have included ocean energy in their 2009 National Renewable Energy Action Plans (NREAP). The plan for 2020 was to reach a combined tidal and wave energy capacity of 2 250 MW. However, ocean energy deployments are taking place at a slower pace than expected, with only 12 MW of operative tidal energy capacity and 5 MW of wave in 2018. Additionally, it shall be noted that part of the current installed capacity is deployed for demonstration projects, and may be removed once projects end.

In March 2018, the SET-Plan Ocean Energy Implementation Plan was endorsed [European Commission 2018]. The Plan sets out actions to support the development and deployment of ocean energy, based on the cost-targets outlined in the SET-Plan Declaration of intent [European Commission 2016].

Taking into account the current rate of development for the sector, JRC-EU-TIMES[2] forecasts indicate that the total capacity that could expected by the sector for 2050 is 28-46 GW. Tidal energy is expected to be cost-competitive by 2030 and accounting for most of the share of ocean energy installed capacity (28 GW). According to the JRC-EU-TIMES model, wave energy could reach 18 GW of installed capacity by 2050, only under the assumption of the SET-Plan scenario. This indicates the need for steep cost-reductions and for technology breakthroughs. The development and commercial uptake of ocean energy in Europe relies on the ability of developers to identify innovative solutions that could stimulate significant cost-reductions and on R&D activities addressing the key-issue currently undermining technology development.

## 2.1 Technology Status

The state of the art of ocean energy technologies varies according to the conversion type (wave, tidal, OTEC and salinity gradient) and the different technologies under development.

[2] No support mechanisms are considered within the model.

A wide array of ocean energy technologies has been developed, some with significant differences in terms of principle of operation. For example, according to EMEC, the European Marine Energy Centre, there are 8 different classes of wave energy converters and 7 different classes of tidal energy converters [EMEC 2014a, EMEC 2014b].

Similarly, salinity gradient comprises three different conversion technologies, Pressurised Reverse Osmosis (PRO), Reverse Electro-Dialysis (RED) and hydrocratic ocean energy.

In order to provide a relevant overview of the progress made by the ocean energy technologies over the past two years, the state of the art review of this report will be prioritised to reflect the key advances in the sector.

Table 2 presents an overview of the technologies that will be addressed in the Ocean Energy Technology Development Report, because these are considered the most promising device types at the moment.

Over the past two years, technology progression of wave and tidal energy technologies has included innovative development of key components such as the Power Take-off (PTO) and moorings (Table 3).

Further information on key ocean energy technologies, innovations needs and challenges has been developed as part of the Future Emerging Technology Work-Package, which is complimentary to the work presented in this report. It is therefore recommended to consult the report "Workshop on Identification of Future Emerging Technologies in the Ocean Energy Sector" for detailed analysis of innovation possibilities for ocean energy technologies and components.

*Table 2 Sub-technologies and priorities*

| Sub-technology | Priority |
|---|---|
| **WP2** | |
| Tidal energy | |
| Horizontal axis turbines, ducted turbines, tidal kites | High |
| Floating technologies | High |
| Vertical axis turbine | Medium |
| Wave energy | |
| Point absorber | High |
| Oscillating water column | High |
| Surge converters | High |
| Others WECs | Low |
| Ocean thermal energy conversion | Low |
| Salinity gradient | Low |

*Table 3 Components priority*

| Area | Priority |
|---|---|
| **WP2** | |
| Power take-off (PTO) optimisation and improvement | High |
| Moorings and foundations | High |
| Array dynamics and interactions | High |
| Environmental impacts and monitoring | Medium |

## 2.2 Deployment Status and Outlook

The ocean energy sector is a promising sector, which has significant potential to contribute to the decarbonisation of the EU energy system as well as establishing a new EU-lead industry. The challenges for ocean energy technologies, as identified by the SI Ocean project [Magagna, Tzimas et al. 2014], include providing reliability, survivability and viability.

In the past two years (2016 to 2018), considerable progress has been achieved in the proving different kind of tidal energy concepts. Turbines developed by Nova Innovation, Atlantis, Andritz Hydro-Hammerfest, Openhydro, Scotrenewables (now Orbital), Schottel, and Tocardo have been operational in demonstration and pre-commercial projects in Europe and Canada. These are the first examples of technology reaching higher TRL, but they are still considered as demonstration projects, as the technology is still being tested for prolonged times and, and operational strategies are being implemented and improved before commercial roll-out can take place.

On the other hand, wave energy technologies are lagging behind tidal energy in terms of performance, especially in terms of electricity generation.

Single device demonstration have been deployed, or are expected to be deployed in the second part of 2018, by different technology developers including Wello Penguin at EMEC and Seabased as demonstration projects, Oceantec Marmok, Corpower C3, Wedge W1, Demowave, SinnPower, Nemos and Ecowavepower at lower TRL. WaveRoller, OceanEnergy, Laminaria and Hace are among the technology developers that are expected to deploy their technology in the second half of 2018.

The current outlook indicates that the ocean energy sector is fertile, and compared to two years ago with a higher than ever number of ocean energy technologies deployed. Yet, tidal energy and wave energy technologies are far from being commercially viable. Technology improvements and steep-cost reductions are needed for both wave and tidal energy to become cost-competitive.

The SET-Plan declaration of intent for ocean energy [European Commission 2016] has set ambitious targets for wave and tidal energy technologies (Table 4). Tidal technologies are expected to reach a levelised cost of energy (LCOE) of 15 cEUR/kWh by 2025 and of 10 cEUR/kWh by 2030. Wave energy technologies are expected to reach the same targets with a five-year delay, 15 cEUR/kWh in 2030, and 10 cEUR/kWh by 2035. In order to meet these targets, technology costs need to be reduced by about 75 % from 2016 values [JRC 2016].

Cost-reduction is expected to go in hand with increased technology deployment and further technology validation gained by the operation of first-of-a-kind farms. These processes are expected to unlock cost-reduction through economies of scale (large industrial production, optimised O&M) as well as through learning by research (improvement of technology through R&D).

*Table 4 LCoE targets for wave and tidal energy technologies. Source: (European Commission 2016)*

| **Technology** | **Year** | **Target** |
|---|---|---|
| Tidal energy | 2025 | 15 cEUR/kWh |
| Tidal energy | 2030 | 10 cEUR/kWh |
| Wave energy | 2025 | 20 cEUR/kWh |
| Wave energy | 2030 | 15 cEUR/kWh |
| Wave energy | 2035 | 10 cEUR/kWh |

In particular, in order for the ocean energy sector to reach their targets, by 2025 tidal energy technology should have an average capacity factor of about 37.5%, Wave energy technology is required to reach a minimum capacity factor of 30% to meet the 20cEUR/kWh target. It shall be noted that indication of capacity factors targets for 2025 are determined by the JRC using an LCOE model, assuming 12% learning rate. Lower capacity factors could still allow reaching LCOE targets, provided that CAPEX and OPEX are reduced further.

This is a considerable increase in requirements compared to key performance indicators presented in the SET-Plan integrated roadmap [EC 2014b] where a minimum capacity factor of 25 % by 2020 was required, along with an availability target of 85 %. In terms of capacity factors, some tidal energy technologies have already demonstrated that it is possible to reach 37% or higher. The ongoing demonstration projects have also shown that it is possible to generate electricity continuously with at times capacity factors above the set target. Lowering the cost of the technology through economy of scale, improved O&M, and innovation in terms of CAPEX would continue driving tidal technologies towards commercialisation.

Wave energy technologies, despite a number of demonstration units at TRL7, still have to achieve significant operational hours coupled with a reasonable level of electricity generation. The devices currently deployed are showing increased survivability, operating throughout the year and surviving storms; however the total electricity produced is small, indicating that most devices are still at pre-commercial phase.. The proposed targets for LCOE, availability and capacity factor appear to require further improvement in the conversion technologies themselves in order to be met.

In terms of manufacturing, the industry has made significant steps forwards. Multiple tidal energy turbines have been manufactured for different projects (Nova Innovation, Andritz Hydro-Hammerfest, Tocardo, Schottel and Openhydro), the first manufacturing plant has been opened in France [Marine Energy.biz 2018] and other developers (SIMEC Atlantis, Scotrenewables) are currently building new devices. Seabased has a fully functional manufacturing facility located in Sweden, Wello are currently building the second of their Penguin devices for deployment in 2019r [Renews 2018a]. Most of ocean energy technology is ranked at manufacturing readiness level (MRL) of 5-6. . The increase of manufacturing capabilities and the improvement of manufacturing efficiencies are areas expected to lead to CAPEX reduction on top of technology R&D. Nevertheless, the leap between MRL6 to MRL7 requires that the current project pipeline, comprising demonstration farms of 4-5 units as well as larger projects announced for 2020 and later, reach final investment decision.

## 2.3 Tidal energy

The tidal sector has reached a critical phase of development, with a, thus with a clear focus on deploying demonstration farms and developed systems and strategies for the optimisation of operations and power output.

The increasing number of deployment projects signals that tidal energy has reached a high level of technological maturity. Horizontal axis turbines have reached a technology readiness level (TRL) of 8, with leading technologies on the verge of completing the TRL path.[3] This include both bottom-fixed and floating concepts, with power rating ranging between 100 kW to 2 MW per device. Other technologies that have made considerable progress are enclosed tips turbines and tidal kite devices.. Tidal kite technology has reached TRL 6, with a 10 MW demonstration plant being prepared. Compared to two years ago, a number of companies are

[3] TRL scale can be found here https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

now working on vertical axis turbines, which offer the advantage of being developed also in river streams opening a new market segment for the tidal energy sector.

Horizontal axis turbine represents the most advanced category of tidal energy converters. Many of the proposed designs have reached TRL8, with most demonstration projects located in the UK, France, the Netherlands and Canada.

In the UK which is one of the key players in ocean energy development and from 2008 to 2018 over 23 GWh of electricity generated by ocean energy have been fed to the grid (see Figure 1), mostly generated by horizontal-axis tidal devices [Ofgem 2018]. The 2018 data shows a total of 9.5 GWh were fed into the grid. Of this, Meygen delivered almost 7.4 GWh, and the Scotrenewables (now Orbital) project 1.9 GWh.

This is a follow up from the single device demonstrations that took place between 2008 and 2013, when the durability and long-term reliability of the Andritz Hydro Hammerfest turbine HS300 (operated for more than 5 years, generating > 1.3 GWh), the SeaGen turbine originally developed by Marine Current Turbines/Siemens (MCT), and the Alstom/TGL Deep Gen 1 MW turbine (since 2013, generated > 1.2 GWh) were tested. In average, these devices have logged capacity factors in the range of 20-30 %. Capacity factor reached 45 % [Ofgem 2018] in specific months, mainly related to limited maintenance, good conditions that did not required shut-off of the device, and implementation of good control measures.

Currently, a number of major tidal deployment projects are ongoing that are mainly at the stage of pre-commercial array demonstration (Table 6). Most of them employ HAT devices, demonstrating the higher level of design consensus achieved in tidal energy, yet a number of alternative solutions employing ducted turbines, tidal kites and vertical axis turbines are currently being developed.

Enclosed tips tidal energy converters, such as the one developed by Naval Energies/Openhydro are the class of device that have reached comparable level of technology development to HAT devices.

Two open centre turbines have been deployed in Nova Scotia in July 2018; a further deployment is expected in Japan. The Normandie Hydro array, a 14 MW array to be deployed in France, will make use of the performance results of the Openhydro turbines in Canada and Japan to optimise power output.

Another class of device making significant step forwards towards commercialisation is the tidal kite. Currently a 0.5 MW device is being deployed in Wales, for the first phase of the 10 MW Holyhead Deep project. The technology, developed by Minesto, is being tested at TRL6. A similar project developed by SeaQurrent in the Netherlands is still rated at TRL4-5.

Hydroquest in France, GKinetic and DesignPro in Ireland, are developing vertical axis concepts. Hydroquest is expected to test a 1MW device in the second half of 2018 in France, and the device is currently being manufactured in Cherbourg. Verticle Axis turbines are operational in China, installed in a multi-structure. The possibility for employing vertical axis turbines in river streams has opened up the market for these concepts. In terms of technology development, vertical axis turbines are behind HAT devices, with TRL ranging between 4-7.

Table 5 summarises the TRL of the different classes of tidal energy devices

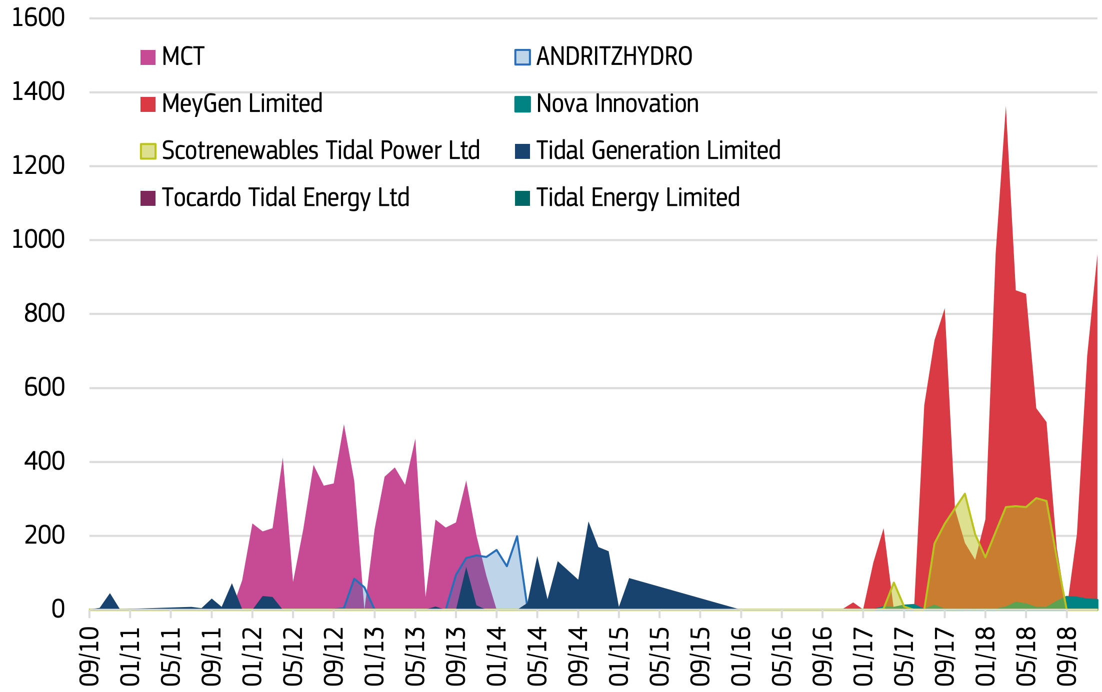


*Figure 1 Tidal energy generation in the UK 2010 -2018. Source:* [Ofgem 2018].

*Table 5 TRL levels of tidal energy devices*

| Device class | Highest TRL achieved | Highest TRL attempted |
|---|---|---|
| Horizontal axis turbine | 8 | 9 |
| Vertical axis turbine | 5 | 7 |
| Oscillating hydrofoil | 5 | 5 |
| Enclosed tips | 7 | 9 |
| Tidal kite | 6 | 7 |
| Archimedes screw | - | - |
| Other | - | 5 |

*Table 6 Major tidal current pre-commercial and first-of-a-kind demonstration projects. Source project websites and NER300 update reports (confidential).*

| Project | Country | Location | Capacity | Class | Turbines | Status |
|---|---|---|---|---|---|---|
| MeyGen Phase 1A | UK | Pentland Firth | 6 MW | HAT | 4 x 1.5 MW (3 Andritz HS1000, 1x Atlantis) | Operational since 2016. Currently 2 devices removed for maintenance |
| Cape Sharp | Canada | Bay of Fundy | 4 MW | Enclosed tips | 2 x Openhydro (2 MW) | Devices deployed July 2018 |
| Orbital | UK | EMEC | 2 MW | HAT | SR1-2000 | Operational since 2016 |
| Sabella D10 Demonstrator | FR | Ushant | 2 MW | HAT | D10 | Operational (currently under maintenance) |

| Project | Country | Location | Capacity | Class | Turbines | Status |
|---|---|---|---|---|---|---|
| Shetland Array | UK | Shetland | 300 kW | HAT | 3 x Nova 100 kw tidal turbine | Operational December 2015. Extension to 600 kW |
| Plat-I | UK / Canada | Canada | 280 kW | HAT | 4 Schottel Instream turbine (62 kW each) | Deployed 2017 in UK, Awaiting deployment in Canada |
| Eastern Scheldt | NL | Eastern Scheldt | 1.25 MW | HAT | 5 Torcardo turbines (250 kW each) | Deployed on storm structure in 2015. |
| Afsluitdijk | NL | Afsluitdijk | 300 kW | HAT | 3 Tocardo T1 turbines | Deployed on storm structure in 2015 |
| Texel | NL | Texel | 250 kW | HAT | 1 Tocardo T2 turbine | Deployed on floating structure in 2016 |
| InToTidal | UK | EMEC | 1.2 MW | HAT | 4 Tocardo T2 turbines | Deployment on semi-submerged structure. On hold |
| Ocean2G | UK | EMEC | 2 MW | HAT | 1 Magallanes contrarotating turbine | To be deployed 2018 |
| Holyhead | UK | Holyhead | 500 kW | Tidal Kite | 1 Minesto Deepgreen | Deployment TRL7 |
| Hydrouqest | FR | N/A | 1 MW | VAT | 1 Hydroquest | Device being manufactured, installation expected 2018 |
| Normandie Hydro | FR | Raz Blanchard | 14 MW | Enclosed tips | ? | Planning. Deployment delayed until data from Canada are coming |
| Meygen 1B | UK | Pentland Firth | 8 MW | HAT | 4 SIMEC Atlantis devices (NER300) | Awaiting final investment decision |
| Holyhead deep | UK | Holyhead | 10 MW | Tidal Kite | 10 Minesto deep green | Planning |
| Sound of Islay | UK | Islay | 10 MW | HAT | 4 x: Andritz HS1000 (NER300) | Awaiting final investment decision |

### 2.3.1 Cost of tidal energy

One important aspect in assessing the progression of tidal energy technologies is the reduction of levelised cost of energy (LCOE). In order for tidal energy technology to become commercially viable, improvements in performance and electricity generation have to be match by a significant reduction in the costs. In 2015, the LCOE of tidal energy was estimated to range between 47 and 102 cEUR/kWh, with a reference value of 62 cEUR/kWh. Following the cost reduction curve, related to increased deployment of tidal technologies (12 MW in Europe) indicates that the reference LCOE should be around 40 cEUR/kWh. This trend would indicated that the 2025 SET-Plan target would be achieved when installed capacity ranging between 250 MW (positive case) and 5000 MW are deployed, as shown in Figure 2.

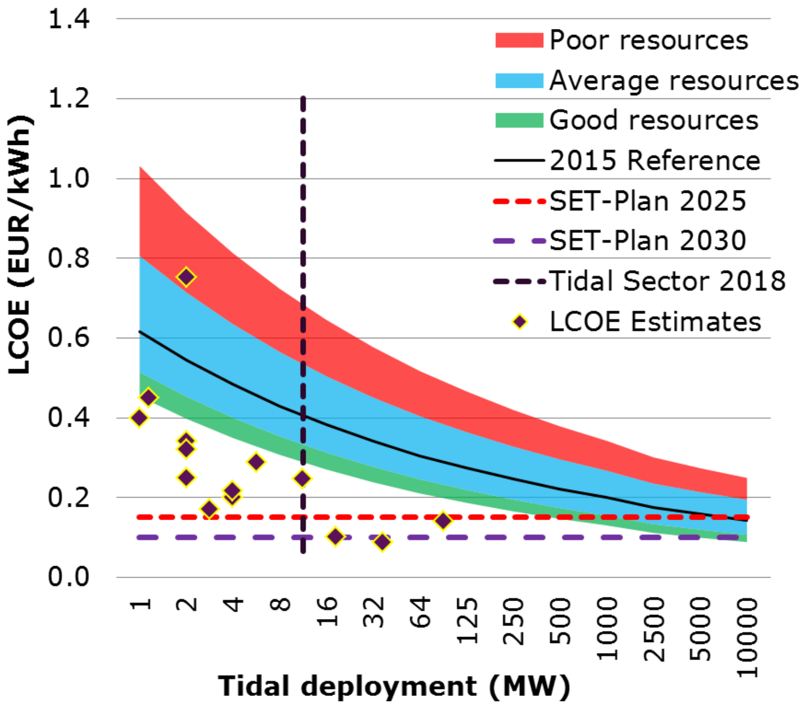


*Figure 2 LCOE predictions for tidal arrays. Sources:* [ETRI 2014, Tsiropoulos et al. 2018]*, updated; own analysis*

Nevertheless, the data available from developers (which will be discussed in more detail in the following chapters) indicate that the LCOE of tidal energy technology may already be lower than 40 cEUR/kWh and that the 2025 SET-Plan targets could be reached with lower capacity than previously expected. The expectation is that the ongoing demonstration projects, as well ongoing R&D could drive further reductions in the cost of energy and accelerate the rate at which the SET-Plan targets could be met.

### 2.3.2 Alternative applications

The development of tidal energy technology is taking place both through the development of commercial scale applications (Simec Atlantis, , Andritz Hydro Hammerfest) as well as through the development of smaller, localised projects such as Sabella in France, or Nova Innovation in Scotland.

The predictability of tidal energy coupled with the possibility of ensuring almost 20 hours of generation per day, has led to exploratory projects where electricity that cannot be used by the grid is directed towards the generation of hydrogen as an energy storage solution. EMEC in Scotland is already undertaking work in this area [EMEC], whilst Sabella are planning to implement a hydrogen system for their deployment on the island of Ushant. Excess electricity from the Nova Innovation turbines is used for the production of ice for the fishing industry.

## 2.4 Wave energy

Compared to tidal energy, wave energy shows greater design variance. In fact, while the horizontal axis turbine is the dominating design for tidal energy converters, there's currently no dominant design in wave energy. The most common types of devices are point absorbers, oscillating wave surge converters (OWSC) and oscillating water column (OWC). In addition, six other distinct device classes can be differentiated, all with specific design and characteristics [Magagna & Uihlein 2015c].

Even within a device class there are significant differences based on how devices are operated and on the conversion system (PTO) employed. For example, some point absorber converters employ a linear direct drive generator (Wedge, Seabased), others use mechanical systems (Corpower, Waves4Power), and some pneumatic systems such, as the Marmok device developed by OceanTEC. Similarly, some OWSC have been designed to employ hydraulic PTOs while others employ mechanical systems.

The lack of design convergence has already been highlighted as one of the drawbacks of wave energy development so far.

Since 2016, the number of wave energy devices deployed and operational as increased significantly. Seabased has deployed the first 3 MW wave energy array in Sweden [OES 2018], Wello has deployed the first of the three-Penguin device at EMEC as part of the CEFOW project, the Marmok device has been operational at Bimep, and so has the Wedge device at Plocan. Corpower deployed their C3 WEC at EMEC, whilst the Wave4Power WavEel buoy was retrieved in 2018 following damages to their mooring lines. The Wavepiston device and Weptos were deployed in Denmark, the SinnPower WEC is operative in Crete, and Nemos are ready to deploy their WEC in the North Sea. Outside of the EU, devices are being tested in Australia, in the US.

When the expected deployments planned for the second part of 2018 and in early 2019 are taken into account it is possible to see that a lot of R&D is directed closing the gap towards commercialisation for wave energy converters. Planned deployments include the Wave Roller full scale deployment in Peniche, the second Wello Penguin device – WEC2 at EMEC, Laminaria at EMEC and OceanEnergy buoy.  Yet the only wave energy plant that has been consistent in delivering power to the grid is the Mutriku Wave Power plant in Spain.

Devices currently deployed are showing the capability to survive wave loadings; however reliability is still to be fully proven. Information regarding the electricity generation from wave energy deployment is limited, even for UK deployments. Given the lack of electricity generation data, which would serve to validate the progress of wave energy technology, we consider most of the current wave energy deployment to be undergoing testing at TRL7, with only the OWC class of device having demonstrated TRL8.

Table 7 presents an overview of the TRL reached and attempted by wave energy converters. Classes highlighted in red indicate no significant progress or R&D activity in the past two years.

*Table 7    TRL levels of wave energy devices*

| Device class | Highest TRL achieved | Highest TRL attempted |
|---|---|---|
| **Attenuator** | 7 | 7 |
| Point Absorber | 7 | 7* |
| OWSC | 7 | 7* |
| OWC | 8 | 8 |
| **Overtopping** | 5 | - |
| Submerged pressure differential | - | 6 |
| Rotating Mass | 7 | 7* |
| Other | 3 | 5 |

* indicates expected deployment at higher TRL.

The lack of success of proving wave energy converters at higher TRL underlines the gap to commercialisation. The limited amount of electricity generated by wave energy converters suggests that designs still need to be optimised; and that conversion technologies, in particular reliable Power Take Offs (PTO) need still to be validated. As a matter of fact, since 2016, R&D support has been granted in Scotland, at EU level and in the US through projects aimed at developing low TRL technologies as well as innovative PTO systems. The JRC has identified 57 companies active in developing wave energy, 40 of which are still in the early phase of development.

Nevertheless, whilst many wave energy converters are still not ready yet for commercialisation, developers are intensifying their activities in terms of identifying suitable business plans to close the gap to the market. Finnish company Wello has made a number of agreements with suppliers for the manufacturing of their devices; Seabased is working in Ghana and as further expanded its manufacturing plant in Sweden.

Technology developers are looking to increase the power rating of their devices. The second Wello Penguins is expected to yield 50% more power than the first Wello Penguine device at EMEC. AW-Energy has announced plans to expand the WaveRoller from 350 kW to 1 MW, whilst the 350 kW has yet to be deployed in Peniche as part of the Wave Roller first-of-a-kind deployment.. Similarly, OceanEnergy working with Dresser Rand to develop a 1 MW turbine for their device (the same device will be equipped with a 0.5 MW device for its deployment in the US).
A number of wave demonstration projects are ongoing; with a few devices expect to be installed in farm layout. (Table 8). Many of them will be deploying point absorbers.

*Table 8 Wave energy demonstration projects*

| Project | Country | Location | Capacity | Class | Devices | Status |
|---|---|---|---|---|---|---|
| Mutriku | ES | Bay of Biscay | 300 kW | OWC | 16 Voith turbines. 1 Turbine chamber used for testing new concept | Operational since of 2011. First WEC to surpass 1 GWh generation to the grid. |
| Sotenäs | SE | Västra Götaland | 10 MW | Point absorber | Seabased | 3 MW already deployed and operational since 2015. |
| Ghana | GH | Ada | 14 MW | Point absorber | Seabased | First 6 converters (0.4 MW) assembled and grid connection installed since 2016. |
| Perth Project | AU | Perth | 0.72 | Point Abosber | 3 x CETO 5 device | Operational, Sustained hours at sea, technology to be upgraded to CET6 |
| Isle of Muck | UK | Isle of Muck | 22 kW | Attenuator | Albatern | 3 WaveNET unit installed |
| Marina di Pisa | IT | Pisa | 25 kW | OWSC | H24 from 40Southenergy | New transmission currently being installed on device. Upgraded and grid connected in 2018. |
| AzuraWave | US | WETS | 500 kW | Point Absorber | AzuraWave | Deployed in 2015, status uncertain |
| Sinn Power Heraklion | EL | Heraklion | 2 kW | Point Absorber | SinnPower | Deployed 2nd PA in 2018 |
| Pantelleria | IT | Pantelleria | 100 kW | Rotating Mass | Wave4Energy device | Installed in 2015. Currently testing new device in Aalborg. |
| Gibraltar | UK | Gibraltar | 500 kW | Attenuator | WaveClapper | EcoWavePower looking to expand project to 1 MW |
| Fred Olsen | US | WETS Hawaii | 60 kW | Point | FredOlsen Bolt | Second deployment (follow- |

| Project | Country | Location | Capacity | Class | Devices | Status |
|---|---|---|---|---|---|---|
| | | | | Absorber | Lifesaver | ing 2016) to assess ability of device to power autonomously |
| Runde | NO | Runde | 100 kW | Point Absorber | WavEel | Retrieved in March 2018 due to mooring failures |
| Marmok | ES | Bimep | 30 kW | OWC | Marmok A5 | Deployed as part of Opera project. Currently installing new turbine developed by Kymaner |
| Wedge Global | ES | Canary Island | N/A | Point absorber | Wedge Global | Operational since 2014. |
| CEFOW EMEC | UK | EMEC | 3 MW | Rotating mass | Penguin | 1st Penguin was deployed in 2017 as part of Cefow project. 2nd device is ready for deployment |
| C3 @ EMEC | UK | EMEC | N/A | Point Absorber | Corpower C3 ¼ scale | Device installed in benign waters for testing. |
| Laminaria | UK | EMEC | N/A | Other | LamWEC | Expected deployment 2nd half 2018, supported by Foresea |
| Hace | FR | Semrev | N/A | OWC | Hacewave | Supported by Foresea, status uncertain |
| Nemos | BE | North Sea | 200 kW | Point Absotrber | NEMOS WEC | Deployment expected for 2nd half 2018 |
| MPS Wales | UK | Prembokshire | N/A | Point Absorber | Marine Power Systems | TRl5/6 Deployment without grid |
| StringRay | US | WETS - Hawaii | 650 kW | Point Absorber | Columbia Power Technology | Expected deployment 2nd half 2018 |
| Life DemoWave | ES | Vigo | N/A | Point Absorber | DemoWave | Deployed in July 2018 |
| OceanEnergy | US | WETS - Hawaii | 500 KW | OWC | OceanEnergy Buoy | Manufacturing in US, deployment in US |
| FOAK WaveRoller | PT | Peniche | 350 kW | OSWC | AW Energy Wave Roller | Expected for 2nd half of 2018 |
| Cabo Verde | CV | Cabo Verde | N/A | OWSC | Resolute Marine Energy | Wave powered desalination |
| São Vicente wave farm | CV | Cabo Verde | 42 kW | Point Absorber | 21 WECS from SInnpower | Expected delivery 2019 |
| CETO6 | AUS | Garden Island | 4 MW | Point absorber | Carnegie CETO6 | 1 MW device, 3 MW demo array planned. Partnership with Enel Green Power announced in July 2018 and with Nemos for PTO |
| Swell | PT | Peniche | 5.6 MW | OWSC | WaveRoller | Funded by NER 300 (9.1 mEUR), planned for 2018, 16 devices |
| Westwave | IE | Killard, Ireland | 5 MW | t.b.d. | ESBI currently carrying out due-diligence for identification of suitable WECs | Project funder under NER 300 (34 mio. EUR), planned for 2018 A number of developers are carrying out due-diligence to deliver this project including Wello and AW-Energy |

### 2.4.1 Cost of wave energy

The cost of energy of wave energy technology provides a good indicator of the development and progression that is required for the technology to meet the SET-Plan targets and become competitive in the EU energy system. In 2015, the LCOE of wave energy ranged between 47 cEUR/kWh and 1.4 EUR/kWh and a reference value of 72 cEUR/kWh. In 2018, with 8 MW of capacity installed in 2018, wave energy LCOE is expect to have decreased to 56 cEUR/kWh, as shown in Figure 3. One of the reasons wave energy lags behind tidal energy is also related to the technology being more expensive. Nevertheless, as some of the LCOE estimates of Figure 3 indicate, some developers are indicating that cost of wave energy technology could drop below the 2025 SET-Plan targets at a faster rate than expected. Their forecasts, will be de discussed in detail later, are based on unlocking manufacturing potential (Wello and Sea-based) as well as improving the performance of their devices (Wello). These improvements could help make a stronger case for wave energy technologies; however, as mentioned earlier, wave energy converters need to show that they can generate electricity reliably to gain the trust of investor and manufacturers to unlock economies of scale cost-reduction.

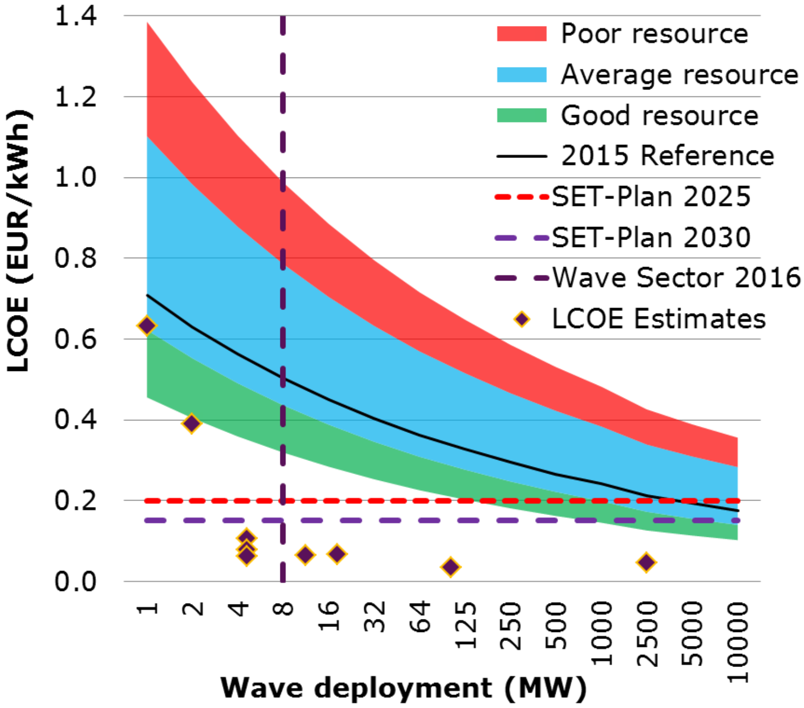


*Figure 3 LCOE predictions for tidal arrays. Sources:* [ETRI 2014, Tsiropoulos et al. 2018], *updated; own analysis*

### 2.4.2 Other applications

The key issues of wave energy being currently immature to compete with market-ready technologies, has lead the sector to investigate the use of this technologies for other sector rather than electricity market at utility scale. Possible markets investigated include the desalination market, powering of remote areas (diesel displacement) and powering of offshore oil and gas platforms. The US DOE has undertaken a detailed approach to understanding the possibility of alternative use for wave energy [DOE 2018].

Example of technology that fall in this category is the Resolute Marine Energy OWSC device (50 kW) developed for desalination (with ongoing project in Cape Verde), the Squid from

Albatern employed to power aquaculture farms and the Wedge1 device, which has been designed to operate in Island conditions, and replace diesel generators.

From an economic perspective, evaluating the use of ocean energy converters for alternative uses, offers a development path that is less risky compared to the utility market. The SET-Plan targets, for example, expects wave energy costs to be around 20 cEUR/kWh by 2025, whilst in some areas cost of electricity from diesel generators are above 35 cEUR/kWh. Nevertheless, even with favourable economic conditions, wave energy converters designed for alternative application are still required to show that they are value-for-money, or more specifically they would still be required to show that the technology could generate power reliably (or provide sufficient pressure to drive desalination membranes), and to survive storms. The risk for wave energy technology is still similar to the one of the utility market: that alternative technology (such as wind and solar PV) may prove that wind/solar-driven PV is more reliable and therefore preferable.

# 3 R&D OVERVIEW

A review of policy mechanisms supporting the development of ocean energy technologies is undertaken in order to understand the level of support received by the sector and to identify any gaps that may need to be addressed for the design of specific collaborative actions at European level.

The analysis takes into account EU funds made available through different R&D Framework programmes (FP6, FP7, Horizon 2020), national and regional programmes collected by the JRC and expected 2019 contributions for the period between 2007, year in which the SET-Plan started and 2019. As such, projects expected to begin in 2018 and 2019 such as NER300 and demonstration projects are accounted in the analysis

European, National, Regional and Ocean-ERA-NET programmes have contributed to fund ocean energy projects for 850 mEUR, for a total worth of the projects equal to 1.39 bEUR,.A breakdown of the funds and project cost is provided in

The US DOE has announced that for the financial year 2018, 70 m$ (60 mEUR) have been allocated for the development of marine hydrokinetic technologies (MHK), mainly focusing to wave energy.

Table 9, whilst Figure 4 presents the breakdown of funds given to wave and tidal energy technologies

From the analysis, it emerged that  270 mEUR of funds have been directed to Wave energy R&D, and 470 m EUR to tidal energy. The remaining 110 mEUR were directed to other areas of research such as resource modelling, and not to one specific technology. In contrast, in the period between 2008 and 2017, the United States Department of Energy has provided $327 million (circa 283 mEUR) in funds to ocean energy, of which 77% directed to wave energy R&D.

The US DOE has announced that for the financial year 2018, 70 m$ (60 mEUR) have been allocated for the development of marine hydrokinetic technologies (MHK), mainly focusing to wave energy.

*Table 9 Breakdown of funds for ocean energy through European National, Regional and OceanERA-NET support.*

| | Total Projects Cost | Funding Contribution |
|---|---|---|
| **OceanERA-NET** | €11,468,779 | €7,627,938 |
| **ERDF** | €264,941,103 | €209,509,646 |
| **EU** | €681,792,107 | €389,350,048 |
| **National** | €436,629,384 | €244,288,780 |
| **Total** | €1,394,831,373 | €850,776,412 |

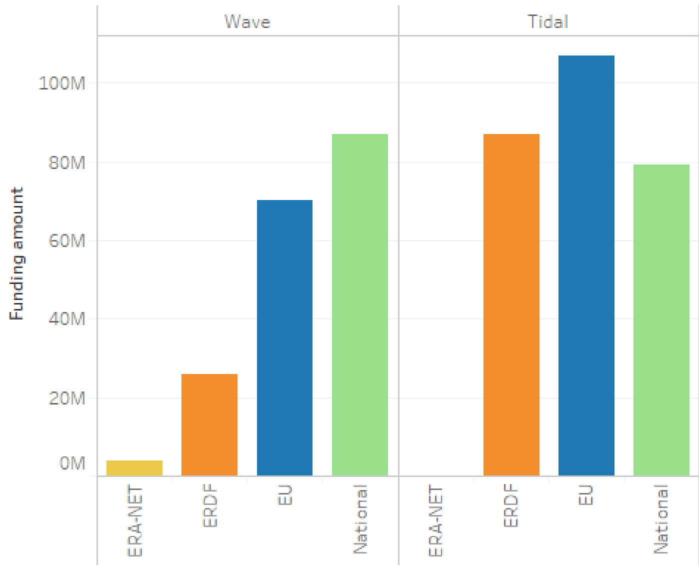


*Figure 4 Funding directed wave and tidal energy technology for the period 2007-2019. Projects or programmes direct to ocean energy in general are not taken into account in this graph.*

Each project has been assessed to evaluate the Technology Readiness Level (TRL) of the technology under investigation at the start of the research project. EU support for wave energy is predominant for mid-TRL projects (TRL 5,6); whilst support for tidal energy at EU level is mainly directed to single device demonstration (TRL7) and demonstration projects (TRL 8). In terms of national support, it can be seen that funds directed to wave energy are addressing low-medium TRL technology. National funds supporting the development of tidal energy technology play a key role for high TRL (demonstration), as shown in Figure 5.

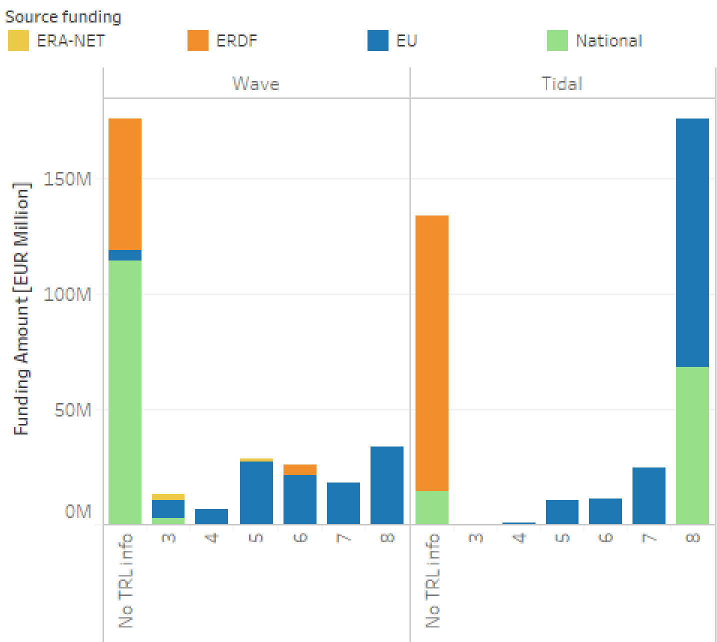


*Figure 5 Funding directed to ocean energy per TRL for the period 2004-2019. Project of programmes where no specific TRL information could be retrieved are categorised under no TRL info. Programmes directed to ocean energy R&D without further details are omitted from the analysis.*

For tidal energy in particular, the availability of different funding and financial instruments provided by the EU and Member States is facilitating the deployment of first-of-a-kind demonstration projects (TRL8). Historically, support for tidal stream technologies and wave energy has historically been very different (Figure 6). Wave energy has benefitted from EU funds from the early 2000s. Many mid-TRL projects have been supported with the FP6 Framework Programme. Most recently, however, projects supported through Horizon 2020 calls are mainly focussing on lower TRLs (TRL3-5) technologies. Only a limited amount of projects are supporting demonstration of single unit or arrays in real water. The distribution of public support reflects previous calls made to encourage work on fundamental research and developing phase-gate procedure to ensure that TRL progression is measured and that funding instruments are directed to technologies that have successfully met the requirement needed for each stage. If wave energy technology currently at TRL 4-5 was to progress to a higher TRL would have limited support mechanisms in place. This gap should be addressed later on in the implementation phase of this plan.

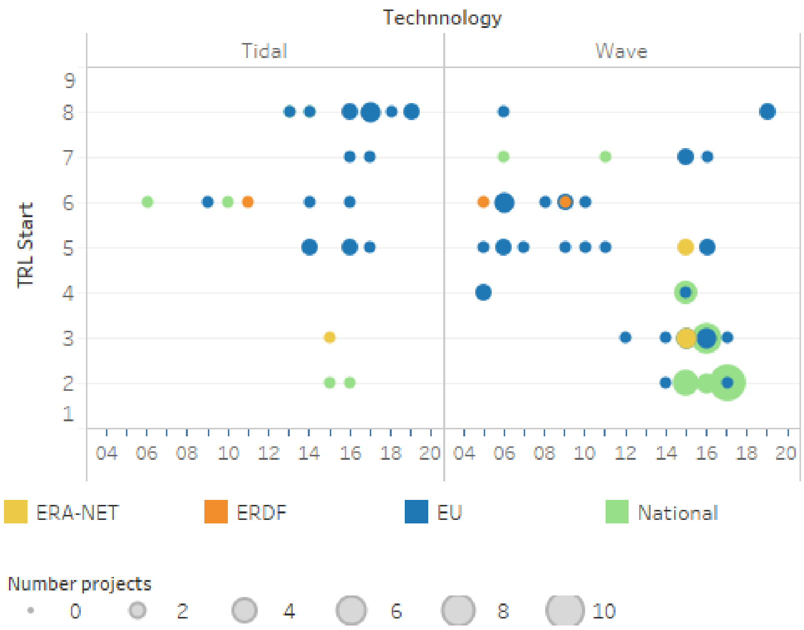


*Figure 6.Assessment of the phase of development (TRL) for each project/funding stream. The size of the bubble refers to the number of projects awarded*

Support for tidal energy technology was provided predominantly through national grants in the period between 2004-2010 funds directed to tidal stream technologies were. EU funds and loan support have been awarded from 2012 onwards, focusing on supporting single demonstration of devices and pre-commercial farms at high TRLs. Figure 7 shows the technology progression of some flagship tidal energy technologies[4] and highlights how the combination of national and EU support is driving the deployment of demonstration arrays. In many cases the availability of both national and EU funds is necessary for the developer to reach final investment decision. Better coordination among funding bodies and available

[4] EU and National funds show in Figure 7 are often directed to a consortium working on a given project and not to the technology developer alone. We refer to projects that are contributing to the development of the same technology family, identified by the name of the developer.

funds across Europe could play a key role in increasing the deployment rate of demonstration tidal energy farms.

The mix of contribution available in Europe from EU, national and regional funding could provide a significant boost to the development of wave and tidal energy technologies in achieving the targets set in the SET-Plan DOI.

The project analysis shows, for the case of wave energy in particular, low and mid-TRL programmes should be reinforced. Implementing stage-gate metrics in line with funds may ensure that progression from low-mid TRL to TRL takes place.

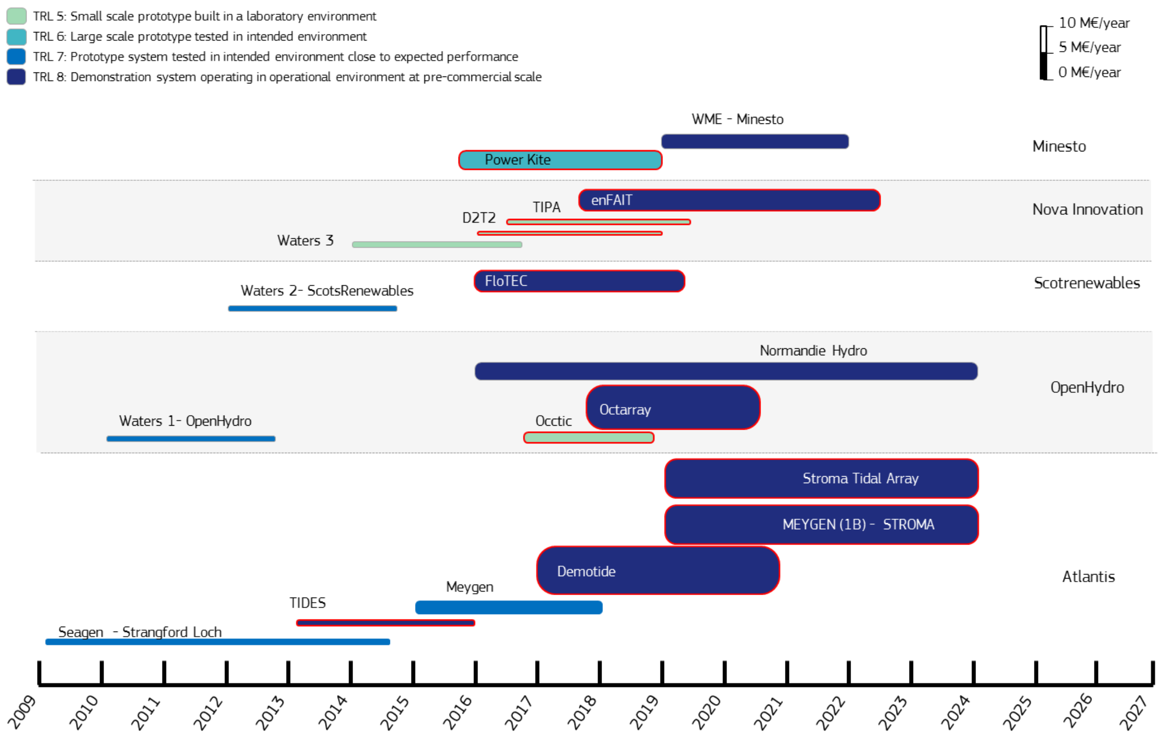


*Figure 7 2018 status of tidal energy R&D projects grouped by technology, TRL and public funding. Projects funded by the EU are outlined in red. Funds are considered are those for the project consortium and do not indicate support received by single developer.*

## 3.1 EU Co-funded Projects.

The European Commission supports different activities addressing the development of ocean energy technologies. In particular, since 2014, the year when the Horizon 2020 (H2020) Framework Programme was launched, the EC has supported 44 projects[5] addressing different technologies at various stages of the development. With the H2020 Framework Programme, the EC has funded 140 mEUR of ocean energy projects, a significant increased from the 60 mEUR directed to ocean energy during the 7th Framework Programme (Figure 8).

[5] Count updated in July 2018. It also accounts for projects launched and later suspended.

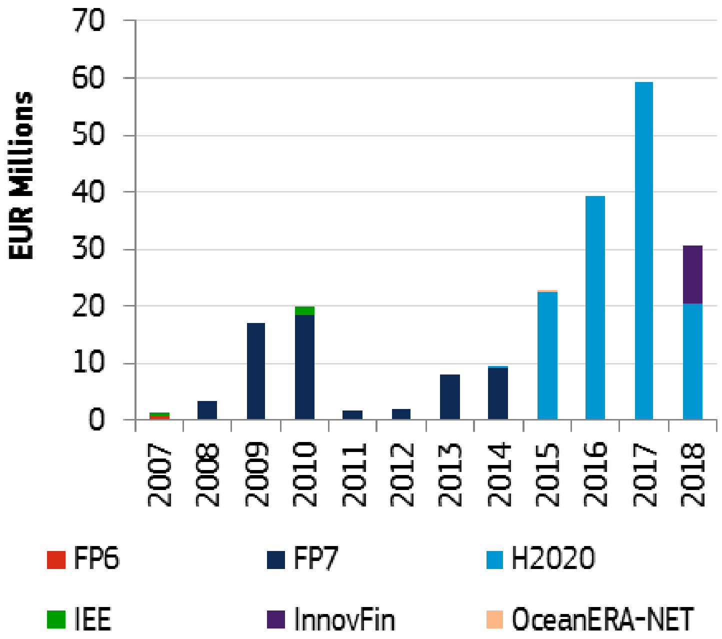


*Figure 8 Breakdown of EU support for ocean energy in the different framework programmes.*

In total the EU has supported projects for a total cost of 333 mEUR, funding directly 50 % of the funds 165 mEU, when projects funded under the Life programme are taken into consideration. (Table 10).

From Table 10 it is possible to see that Small-Medium Enterprises (SME) is supporting fourteen ocean energy developers, ten at stage one (feasibility) and four at stage two. SME projects aim at helping technology developers to further their business case in order to work on the viability of the company. Marie Skłodowska-Curie Actions (MSCA) support five ocean energy projects, mainly focus on low TRL technologies and explorative research. Coordination and Support Activities (CSA) projects ETIP Ocean and Muses focus on identifying research areas to fill technology gaps and barriers (ETIP Ocean) or to gather information on environmental monitoring and licensing (MUSE). The Era-Net Cofund supports the OceanERA-NET project which involves different National and Regional Agencies supporting ocean energy projects.

*Table 10 Breakdown of EU supported projects for funding categories. Categories in green identify projects were private contribution is expected.*

| | EU Financial Contribution | Total Project Cost | # Projects |
|---|---|---|---|
| **CSA** | 2,603,354. | 2,603,354 | 2 |
| **ERA-NET-Cofund** | 5,980,141 | 18,121,641 | 1 |
| **IA** | **90,585,209** | **242,908,214** | 9 |
| **MSCA** | 2,199,500. | 2,199,500 | 5 |
| **RIA** | 56,065,983 | 56,065,983 | 12 |
| **SME-1** | **500,000** | **714,290** | 10 |
| **SME-2** | **6,328,256** | **9,153,605** | 4 |
| **Climate** | **924,871** | **1,836,788** | 1 |
| **Grand Total** | 165,187,317 | 333,603,376 | 44 |

Research, development and deployment projects support by the EU fall mostly under the IA (Innovation Actions), RIA (Research Innovation Actions) and also under Climate actions. Climate actions are taken into account in this analysis since the Life programme is supporting the development of the Life DemoWave WEC in Spain. IA and RIA projects account for the majority of the funds provided by the EU to ocean energy, both in terms of funds (146 mEUR) and in terms of total project costs (299 mEUR). The EU contribution is 100% of project cost for RIA, while IA projects it accounts for about 37% of the total project costs.

In the context of this report, IA and RIA projects are considered more in detail, since they have strong relevance to technology development and to the action of the SET-Plan Implementation Plan [European Commission 2018].

## 3.2 Other EU Programmes

In this section projects and initiative that support the development of ocean energy technologies

### 3.2.1 Ocean-ERA-NET

Ocean-ERA-NET Cofund is a network of 8 European RTD agencies located in 6 different MS (France, Ireland, Portugal Spain, Sweden, United Kingdom), receiving support from the H2020 programme for the coordination of research projects. The Ocean-ERA-NET Cofund follows up the Ocean-ERA-NET project which consisted of European RTD agencies from 8 different MS (Belgium and Netherlands took part in the first Ocean-ERA-NET).

The Ocean-ERA-NET Cofund project aims to:

- Increase Cooperation between R&D programmes;
- Support industry-led projects;
- Strengthen the EU position in the ocean energy sector.

Under the first Ocean-ERA-NET project 13 R&D projects were support for a total of 11 mEUR of funds made available [OceanERANET 2014, OceanERA-NET 2018].

Are of research included:

- Moorings: LamWEC, Elasmoor;
- Numerical Modelling: MIDWEST;
- Resource Assessment: Moredata;
- Corrosion: Oceaninc;
- Reliability / Component failure: Recode, Riasor I, Riasor II;
- Novel devices: TupperWave, Se@ports;
- Offshore operations: Kraken;
- PTO Captow, MAT4OEC.

The first call of the Ocean-ERA-NET Cofund project, with a budget of 17 mEUR, aimed at supporting transnational, collaborative projects to demonstrate and validate innovative technologies for ocean energy. Topics included: Ocean energy devices, components and subsystem, grid connection and power systems, materials and structures, installation and O&M, and resource assessment.

10 projects have been selected for funding, for an estimated 10.4 mEUR support, out of 18 projects that met the required standards for the call.

The OceanERA-NET projects address a gap between the research priority of H2020 and other EU R&D framework programme, and national programmes which mainly address low TRL research projects. In some cases, such as LamWEC, the support from Ocean-ERA-NET has been fundamental for the technology developer (Laminaria) to obtain support in preparation of the first deployment at EMEC.

### 3.2.2 InnoEnergy

InnoEnergy was established in 2010 and is supported by the European Institute of Innovation and Technology (EIT) as one of a series Knowledge and Innovation Communities (KICs). The InnoEnergy network includes 24 shareholders, as well as more than 360+ associate and project partners. It invests in businesses and helps develop innovative products, services, and solutions. According to the information on its web site, it has invested in two ocean energy technology: Corpower [InnoEnergy 2018a] and Minesto .

InnoEnergy has joined Corpower for the HiWave project and Minesto for the DeepGreen 500 project with a 4.5 mEUR investment [InnoEnergy 2018b]. InnoEnegy supports technology developers via the provision of funds, equity investments and assist developers in developing their business case, like a specialised incubator for innovative energy technologies.

### 3.2.3 Interreg

Interreg projects aim at fostering transnational cooperation among neighbouring countries, encouraging collaboration to improve economic, social and territorial development of European regions. As of 2018, three Interreg projects addressed the development of ocean energy technology.

- Foresea: The Foresea project joins together test centres from UK (EMEC), Ireland (SmartBay), France (SEM-REV) and the Netherlands (DMEC). The projects help technology closing the gap to the market by providing free-access to the test centres facilities and has a budget of 10.75 mEUR. The project is helping wave and tidal energy developers such Tocardo, Corpower, Lamianria to test their technologies, by providing the necessary support for these technology to cover the costs of a first-of-a-kind deployment.
- ITEG (Integrated tidal power, grid and hydrogen) – is a 11 mEUR Interreg project with partners across France, UK, Belgium and the Netherlands. The project supports the development of hydrogen through a tidal energy-powered electrolyser. The aim is to investigate the feasibility of hydrogen production from excess tidal energy and its effects on grid balance.
- MET-Certified (met-certified.eu/). MET-Certified, like ITEG, comprises partners from France, UK, Belgium and the Netherlands, and it's been designed to help increased the adoption of insurable and bankable marine energy projects through the development of internationally recognised standards and certification schems. The project include certification bodies such as DNV-GL and Bureau Veritas and may play a key role in addressing the 6 action of the SET-Plan Implementation Plan on standardisation.

### 3.2.4 Infrastructures

One particular areas of research that is addressed by EU programme is the provision of infrastructure. Horizon 2020 supports the Marinet 2 and Marinerg-I projects, whilst Foresea is supported Interreg. Given the relevance of this topic, these proejcts are presented in a separate section.

The Foresea project offers project developers access to leading test centres in Europe to support deployment of wave and tidal energy technology at higher TRL. Marinet 2 and Marinerg-I are two projects that provide access to research and infrastructures across Europe.

Marinet 2 brings together 39 partners across Europe, offering access to test facilities ranging from small-scale wave tanks to test-centres (EMEC and Bimep), whilst offering trainings for early researchers and young professionals on thematic such as wave energy modelling, resource assessment and environmental modelling.

The Marinerg-I project bring together 14 EU research and test centres, and works on the implementation of best-practices, guidelines and standers to de-risk investments in ocean energy. The long term aim it to develop and integrated European Research Infrastructure designed to facilitate the growth and development of offshore renewable energies.

### 3.2.5 S3P Marine Renewable Energies

The S3P Smart Specialisation Platform is a project launched by DG ENER and DG REGIO to support regions in areas of excellence. The Interregional partnership on Marine Renewable Energies, which also include offshore wind, pools together regional resources and expertise with the aim to create new business opportunities and growth for the sector.

The S3P partnerships is led by the Basque Country (ES) and Scotland (UK) and comprises fifteen regions with expertise in marine renewables across eleven different countries.

The work of the partnership is focusing on advance manufacturing for energy application in harsh environment, with a key focus on large components manufacturing, corrosion, and monitoring. It is a result of a prioritisation exercises which assessed regionals strengths and possibilities of the new market (http://s3platform.jrc.ec.europa.eu/marine-renewable-energy).

### 3.2.6 European Cooperation in Science and Technology (COST)

COST Actions are bottom-up science and technology networks with duration of four years. There is no funding for research itself. Currently, one project addressing ocean energy is supported through COST:

- CA17105 – A pan-European Network for Marine Renewable Energy – which is addressing bottlenecks specific to wave energy to assist the development of wave energy arrays.

### 3.2.7 NER300

NER 300 is a demonstration programme for CCS and RES projects involving all Member States. The programme aimed to support a wide range of CCS technologies and RES technologies (bioenergy, concentrated solar power, photovoltaics, geothermal, wind, ocean, hydropower, and smart grids). For the period 2021-2030 the Commission has proposed a new programme called the ETS Innovation Fund.

Five Ocean Energy projects have been approved under NER300:

- NEMO – Development of 10 MW OTEC technologies in Martinique. The project is currently suspended due to technical consideration.
- Swell – Development of a 5.6 MW wave energy array in Portugal. The project is currently on track. FID is expected in second half of 208, whilst the First of a kind installation of the Wave Roller devices is expected in summer 2018. Installation of the 5.6 MW array expected between 2019-2020 with operations starting in 2020.
- WestWave – 5 MW wave energy array on the west coast of Ireland. Whilst the identification of viable wave energy technology cannot still be completed (a number of technologies are currently being evaluated including Wello and AW-Roller) the project has obtained planning permission and is undertaking stakeholder consultations
- Sound of Islay – 10 MW tidal farm. There are currently no updates available.

- Stroma – The Stroma NER300 project looks at the development of Meygen 1B (6 MW tidal array). The project is focusing on reaching final investment decision, however, as in the case of the H2020 Demotide, this is yet to be formalised.

### 3.2.8 InnovFIN Energy Demo Projects

Innovfin EDP is an instrument designed by the European Commission and the European Investment Bank (EIB) to support innovative energy demonstration projects. Support is given in the form of loans, loan guarantees and equity-type finance.

Projects should aim at demonstrating the commercial violability of pre-commercial technologies (TRL8) or enhance the competitiveness of the manufacturing process. In order to receive EIB support, projects need to show reasonable potential for a successful demonstration, and to show the potential to be bankable.

The SWELL project, which has received support also under NER300, has received support from EIB for 10 mEUR under the InnovFIN EDP programme (7 mEUR from Finland and 3 mEUR from Portugal). Project Stroma (also supported under NER300) is under appraisal for support since 2017[EC].

The requirement of EIB of showing sufficient prospects for bankability currently poses a hurdle for tidal deployment in the UK. Whilst capital supports is often offered, the lack of revenue schemes (feed-in-tariff or alternative) hinders the bankability of the projects given the higher cost of the electricity generated compared to market rates.

## 3.3 International programmes and developments

Support for the development of ocean energy technologies takes place in many countries at national level, in EU member states and other countries outside of the EU. A quick overview of the schemes in the countries participating in the International Energy Agency (IEA) Ocean Energy Systems (OES) is here presented.

### 3.3.1 Australia

Arena, Australia Renewable Energy Agency, supports the development of ocean energy technology, funding nine different projects from tidal energy resource assessment and the creation of Australia Wave Energy Atlas to supporting the development of ocean energy technologies. Carnegie and Bombora are two Australian developers that have received significant contribution from Arena.

Carnegie, which is developing the CETO6 1.5 MW converter in Australia, following the support to develop the CETO5 project with three converters installed [Ocean Energy Systems 2018][OES AU Delegation 2018].

Bombora is developing 1 .5 MW device. The company has received R&D support.

ARENA also provided 5.8 mAUS to carry out a detailed assessment of tidal energy resources to understand its feasibility and contribution to Australia's future energy mix. Many developers have been contacted in order to increase the accuracy of the study. The study is expected to provide a clear technological and economic feasibility assessment for tidal energy integration to Australia's electricity infrastructure, including consideration grid integration and competitiveness against existing and new sources of generation, intermittency and farm design.

Similarly, the Australian Wave Energy Atlas, has increased the level of details of the wave energy resources in Australia, overcoming the limitation in terms of spatial and temporal availability of data series.

### 3.3.2 Canada

Support for ocean energy technology in Canada take places mostly in the form of support scheme for demonstration projects in Nova Scotia, although low TRL research is also supported.
The Offshore Energy Research Association (OERA) has supported five projects in the areas of environmental effects monitoring, marine operations, and cost reduction technologies. The province of British Columbia has launched a wave and tidal resource modelling activity, for the creation of an ocean energy atlas for the region [Ocean Energy Systems 2018].
In terms of technology demonstration, the government of Nova Scotia has assisted the creation of the Force tidal energy centre, where a number of deployments are taking place. Canada, including the recent deployment (July 2018) of the Openhydro device[Renews 2018b]. Feed-in-tariffs are available for developers.

### 3.3.3 China

As part of the “13th Five-Year Plan for Marine Renewable Energy (2016-2020)" China has set-out targets for the development of four marine energy demonstration projects, with the aim of achieving 50MW of installed capacity by 2020. China has set aside 1.1 bRMB (circa 140 mEUR) supporting eleven projects in ocean energy. 50 % of the funds have supported demonstration projects, with only 10% going directly to R&D. R&D projects cover the development of wave energy, OTEC, salinity gradient systems, and towards the development of a 2-bladed horizontal axis turbine rated at 650 kW. This device is expected to be tested in late 2018.
In terms of demonstration funds have been directed towards the demonstration of the 100 kW Sharp Eagle WEC, and of a 60 kW point absorber installed on a platform employing magneto-hydrodynamic generatos. The platform is expected to be deployed in 2020.
In terms of tidal energy, the 3.4 MW LHD platform has been operational since 2016, and has generated 700 MWh until May 2018. The platform employs both vertical and horizontal axis turbines (2 x 300 kW) [OES CN Delegation 2018].

### 3.3.4 France

Public support for the development of the ocean energy technologies in France take places under the supervision of ADEME (Environment and Energy agency) and the ANR (National Research Agency).

In the period 2015-2017 10 mEUR have been directed by the ANR to 6 ocean energy projects [OES FR Delegation 2018].

ADEME has supported the development of wave and tidal energy converters, as well as river-in stream turbine. The scope of the support offered by ADEME is broader, with 21 projects converting also key components and subsystems such as subsea connectors or hubs, foundation concepts, specific dredging or installation tools.

Further support in France is provided by BPI France (Public bank of investment), which has invested 3.3 mEUR in the Eel tidal energy converter [Ocean Energy Systems 2018].

### 3.3.5 Ireland

The development of ocean energy technology has benefitted from two main government lead programmes: The SEAI prototype development fund, which since 2009 has supported over 100 projects with more than 14 mEUR funds, and the Pre-commercial technology fund. The latter aims to be a tool to help closing the funding gap for devices and sub-system at TRl>3 supported through the prototype development fund. The OceanEnergy OWC device has benefitted from the Pre-commercial technology fund and it's currently being manufactured for deployment. Other devices being supported are Seapower (wave) and Gkinetic (tidal) [Ocean Energy Systems 2018].

### 3.3.6 Republic of Korea

The republic of Korea in 2015 launched a “Mid-term and Long-term Clean Ocean Energy Development plan 2015-2025”. This has later been followed up by the "Action Plan for Renewable Energy Policy 3020” and by the “2030 Ocean Energy Development Plan”. The republic of Korea has the ambitions to build 1.5GW of ocean energy capacity by 2030, including wave energy systems of 220 MW, hybrid power generation systems of 300 MW, and tidal energy systems of 700 MW and to extend the Shiwa Lake tidal range power plant of 254 MW [Ocean Energy Systems 2018].

In order to achieve this target, the Korean government has invested 200 mUSD for ocean energy R&D and demonstration projects in the period 2000-2017. R&D projects focus on the development of wave energy converters, tidal turbines and OTEC.

Wave energy converters include a 300 kW floating pendulum and devices incorporated on breakwaters, tidal research focuses on ducted turbine to power a bridge (5 kW) as well on a 200 kW active-control horizontal axis turbine installed in Uldolmok in July 2018 [OES KR Delegation 2018].

### 3.3.7 United Kingdom

The United Kingdom is at the forefront of Ocean energy development, and has been particularly active in supporting all the stages from academic research through the demonstration of ocean energy arrays.

On top of participation in EU funded programmes, the UK has a number of key domestic programmes.

Wave Energy Scotland, established in 2014 to overcome the lack of progress in wave energy, has since support 61 different research projects for a total of 24 mGBP (28 mEUR). Research projects focus on wave energy addressing: novel device concepts, new materials, power take off and control system.

Wave Energy Scotland is also developing stage-gate metrics approach to ensure that device move to the next stage of funding when performance from testing reaches a required value.

Low TRL research in the UK is supported through the Supergen Offshore Programme, led by the University of Plymouth. Supergen joins together 10 UK universities specialising in ocean energy. Each year a 0.5 mGBP call for projects will be launched for the period 2018-2020.

### 3.3.8 United States of America

The United states have supported the development of ocean energy through the MHK (Marine HydroKinetic) programme and the water power programmes supported by the Water Power Technologies Office (WPTO). Since 2013, 291m USD have been supporting the development of ocean energy technologies, with a focus in early-stage innovative technologies [OES US Delegation 2018]. Support has been directed to four main areas:

- Foundation and Crosscutting R&D: supporting the design and development of ocean energy converters in laboratory and open-water.
- Technology-specific design and validation, aimed at the optimisation of ocean energy converters.
- Reducing barriers to demonstration, by building a network of infrastructure
- Data sharing

The most recent programmes focus on:

- Development of early-stage of wave and tidal device of systems with high potential. This call is supporting up to 10 different projects.
- Control and power take off. Funds support 6 projects (lasting max 3 years), with projects expected to build PTO in relevant scale and in parallel develop a control mechanism
- Dissemination of environmental data to facilitate the regulatory process, focussed on the development of tools and methodologies for understanding the environmental impacts of ocean energy converters.

Further activities carried out by the US DOE is the development of a wave energy classification system for wave energy converters, similar to the one already employed by wind energy. The US DOE has also developed tools for the simulation of wave energy converters.

### 3.3.9 IEA-OES Programmes

The Ocean Energy Systems Technology Collaboration Programme (TCP) brings together countries to advance research, development and demonstration of ocean energy technologies.

Currently, OES operates 13 tasks designed to advance the status of ocean energy, addressing different aspects of ocean energy from technology specific tasks on wave, tidal or OTEC technology, to consenting process and environmental monitoring.

- Task 1 – Dissemination;
- Task 2 – Guidelines;
- Task 3 - Grid Integration;
- Task 4 - Environmental Issues;
- Task 5 - Technology Development;
- Task 6 - GIS map;
- Task 7 - Cost of Energy;
- Task 8 - Consenting Processes;
- Task 9 - Technology Roadmap;
- Task 10 - Wave Energy Modelling;
- Task 11 – OTEC;
- Task 12 - Stage Gate Metrics;
- Task 13 - Tidal Energy Modelling;

In 2017, new tasks were launched, addressing in particular the development of a common methodology to monitor the evolution of the cost of ocean energy technologies (task 7) and one on the development of stage gate metrics.

The collaborative tasks run by the OES are often high-level tasks, nevertheless they allow for the comparison and homogenisation of best-practises at international level.

In particular, Task 12 on stage gate metrics offers the potential to reach consensus on targets for ocean energy development among different supporting agencies (US, UK and EC); while Task 7 on the Cost of Energy allows comparing how ocean energy technologies are becoming market competitive. Both tasks were approved in 2017, started in 2018; therefore results and recommendations are expected for 2019.

# 4 IMPACT ASSESSMENT OF H2020 PROJECTS

In this chapter the contribution of significant EU funded H2020 projects towards the advancement of ocean energy technologies is analysed. The projects are categorised according to the SET-Plan actions presented as outlined in the SET-Plan Implementation Plan approved in March 2018.

## 4.1 SET-Plan areas of interest

The SET-Plan Implementation Plan has presented 11 actions to help ocean energy achieve commercialisation [European Commission 2018]:

Technical Actions:

1. Tidal energy – assist technology development and knowledge building up to TRL6
2. Tidal energy – support system demonstration in operational environment and knowledge building in the TRL 7-9 categories.
3. Wave energy – support technology development, system demonstration and knowledge building up to TRL6
4. Wave Energy – encourage and support device and system demonstration at early demonstration array scale up to TRL 7- 9.
5. Collaborate in the areas of installation, logistics and infrastructure.
6. Co-ordinate the development of standards and guidelines for wave technology evaluation and LCoE analysis.

Financial Actions

7. Investigate the potential for creation of an Investment Support Fund for ocean energy farms: EU and National Authorities should collaborate in order to create a Fund providing flexible capital, and enabling further private capital to be leveraged
8. Progress the creation of an EU Insurance and Guarantee Fund to underwrite various project risks: This would be targeted at the first ocean energy projects to cover risks such as availability, performance, unforeseen events, failures, etc. Consider the provision of a common reserve fund available to multiple projects in the initial farm or plant roll-out, to spread the risk and reduce the cost of providing guarantees.
9. Support the development of a collaborative procurement model adaptation of the "Wave Energy Scotland" approach for wave energy development at EU Level using pre commercial procurement or similar.

Environmental Actions

10. Collaboration on the development of certification and safety standards for the development, testing, deployment of ocean energy devices,
11. •Continue the de-risking of environmental consenting through an integrated programme of measures and in particular through promoting open data sharing.

It is noted that the technical and financial actions are inter-dependant on each other, especially given the current phase of ocean energy technology development. As can be seen from Table 11 most of the H2020 projects address the SET Plan technology actions, with only CSA projects addressing (or partly addressing) the other actions.

ETIP Ocean Technological priorities

ETIP Ocean has developed a report highlighting the challenges for the ocean energy sector to develop commercially viable technology. 29 challenges have been identified, of which 14 are considered urgent and to be tackle in the short term, including six technological challenges, as shown in Table 12 [ETIPOcean 2017]. The full list of ETIP Ocean priorities is shown in Appendix C.

In order to provide further detail to the scope of H2020 funded projects, these are benchmarked against the ETIP Ocean technological challenges. Individual projects may address multiple challenges, especially those at higher TRL. This will be highlighted in the analysis. Information was gathered from CORDIS, Compass and project websites where available. A categorised summary of the projects supported under H2020 is shown in Appendix A. TRL assessment for H2020 project is available in Appendix B.

*Table 11 Classification of H2020 projects according to the SET-Plan Implementation Plan actions*

| | Action | IA | RIA | FTIPIlot | SME | CSA | MSCA |
|---|---|---|---|---|---|---|---|
| Technology Actions | **1 Tidal Energy TRL1-6** | | RealTide (*Sabella, EnerOcean*)<br>PowerKite (*Minesto*)<br>Taoide (*ORPC*)<br>TIPA (*Nova Innovation*) | | Direct Drive TT, D2T2 (*Nova Innovation*)<br>HydroKinetic-25, DP Renewables (*Design Pro*)<br>SEAMETEC (*EnerOCean*)<br>SUBPORT (*current2current*) | ETIPOcean<br>OCEANERA-NET COFUND | OpTICA |
| | **1 Tidal Energy TRL7-9** | ~~Demotide (*Atlantis*)~~<br>~~Octarray (*Openhydro*)~~<br>FloTEC (*ScotsRenewables*)<br>EnFAIT (*Nova Innovation*) | ~~Occtic (*Openhydro*)~~ | InToTidal (*Tocardo*)<br>OCEAN_2G (*Magallanes*) | | ETIPOcean<br>OCEANERA-NET COFUND | |
| | **3 Wave Energy TRL1-6** | | IMAGINE (*UmbraGroup SPA*)<br>WETFEET (*Simphony*)<br>Waveboost (*Corpower*)<br>Opera (*Oceantec*)<br>SEA-TITAN (*Wedge*) | | Butterlfy (*Rotary Waves*)<br>OHT(*Ocean Harvesting Technologies*)<br>Wavepiston (*Wavepiston*)<br>eForcis BeForcis (*eForcis*) | ETIPOcean<br>OCEANERA-NET COFUND | MoWE |
| | **4 Wave Energy TRL 7-9** | Cefow (*Wello*)<br>LIFE DEMOWAVE (*LIFE*) | MegaRoller (*WaveRoller*) | | | ETIPOcean<br>OCEANERA-NET COFUND | |
| | **5 Installation / Logistics** | | | InToTidal (*Tocardo*) | | ETIPOcean<br>OCEANERA-NET COFUND | |
| | **6 Standards and Guidelines** | DTOCeanPlus | | | | ETIPOcean | |
| Financial actions | **7 Investment Support Fund** | | | | | ETIPOcean | |
| | **8 EU Insurance Guarantee Fund** | | | | | ETIPOcean | |
| | **9 Wave Energy Europe** | | | | | ETIPOcean | |
| Environmental and consenting | **10 Certification and Standards** | | | | | ETIPOcean | |
| | **11 Environmental Consenting** | | | | | ETIPOcean<br>MUSES<br>RICORE | |

*Table 12 ETIPOcean priority challenges. Source:* [ETIPOcean 2017]

| Category | Challenge |
|---|---|
| Technology | Developing novel concepts for improved power take-offs (PTOs) |
| | Increasing device reliability and survivability |
| | Investigating alternative materials and manufacturing processes for device structures |
| | Investigating novel devices before moving towards convergence of design |
| | Defining and enforcing standards for stage progression through scale testing |
| | Developing and implementing optimisation tools |
| Financial | Providing warranties and performance guarantees |
| | Linking stage-gate development processes to funding decisions |
| | Maintaining grant funding for early TRL technologies |
| | Establishing long term revenue support |
| Environmental and socio-economics | Enhancing social impact and acceptance |
| | Minimising negative environmental impacts |
| | Facilitating knowledge transfer and collaboration |
| | Implementing adaptive management systems |

## 4.2 Tidal energy R&D

The EU supports the development of low TRL tidal energy technologies through four H2020-LCE projects and six H2020 SMEs projects (Table 13).

*Table 13 H2020 projects on low TRL tidal energy technologies and related ETIP Challenges*

| Main Technology | Device Class | Project | ETIP Challenge |
|---|---|---|---|
| M100 (Nova Innovation, UK) | Horizontal Axis turbine | TIPA | Power Take off, Device reliability Improving costs and efficiency |
| | | D2T2 (SME) | Direct drive PTO |
| | | Direct Drive TT (SME) | Direct drive PTO |
| ORPC (Ocean Renewable Power Company, US/IE) | Cross Flow Horizontal Axis Turbine | TAOIDE | Power Take off, Device reliability Improving costs and efficiency |
| Deep Green (Minesto, SE) | Tidal Kite | PowerKite | Power Take off, Device reliability Improving costs and efficiency |
| D10 (Sabella, FR) | Horizontal Axis Turbine | ReaTide | Implementing suitable condition monitoring systems |
| Design Pro/GKinetic (IE) | Vertical Axis Turbine | HydroKinetic-25 (SME) DP Renewables (SME) | Power Take off, Device reliability Investigating novel devices |
| Current2Current | Vertical Axis Turbine | Subport (SEM) | Investigating novel devices |

### 4.2.1 TiPA

TIPA is a project coordinated by Nova Innovation, 7 partners. The aim is to reduce the lifetime cost of NOVA turbines by 20% by developing an innovative drive train. The main goal of the project is to optimise the PTO and doing so by developing a direct-drive wet-gap generator.

#### 4.2.1.1 Expected impacts

- Improved performance of PTO expected to drive LCOE from 400 EUR/MWh to 320 EUR/MWh. Second generation PTO can provide cost reduction of 20-35% (low carbon innovation coordination group)

- Improved reliability, project aims to increase service interval. Reliability can achieve 35-55% cost reduction by 2050 (LCICG) – to be verified
- Demonstrate survivability of device to 20 years through testing.

#### 4.2.1.2 Innovations

The project, which has reached his half-term milestones, has finalised the design of the new PTO (Figure 9). The PTO is fully commissioned and will be tested at Aachen University in Germany, before deployment at sea in 2019.


*Figure 9 Fully assembled and commissioned TiPA PTO*

The PTO will be tested on 1 MW test rig, with a cooling system implemented to substitute the real operational environment. Prior to the test-rig experimental phase, the new PTO has undergone a number of mechanical system requirements checks, including stator and PTO leak tests. The new PTO weights 10 tonnes.

The delivery of the TiPA PTO has seen Nova Innovation working with key suppliers for the provision of subsystems such as:

- SKF Group - Schweinfurt, Germany Main Shaft Unit and Actuator
- SKF Group - Judenburg, Austria Debris Seal
- Siemens (via HMK Automation & Drives) Power Electronic and Control Components

#### 4.2.1.3 D2T2

As part of the D2T2 SME project, Nova Innovation has investigated accelerated cost-reduction for the commercialisation of the Nova Innovation PTO. The aim is a 30 % cost-reduction through 15 % increased reliability, 8 % increased availability and 7 % increased efficiency of the PTO. The focus is on the direct drive, and not on WET-gap PTO, with the project being complimentary to the TiPA project.

### 4.2.2 EnFait

NOVA innovation is also the coordinating partner of the EnFait projects which aims at scaling up the existing 300 kW tidal array located in Shetland in order to reduce cost and improving reliability of turbines. This project is at higher TRL, however, it is presented here to offer a complete overview of the projects in which Nova Innovation technology is involved.

The aim is to extend the Shetland array from 300 kW to 600 kW and then 700 kW by adding new 100 kW tidal turbines and test different layout for the optimisation of the power output.

#### 4.2.2.1 Project phases

- Operate existing turbines
- Upgrade turbines
- Manufacture 4th turbine and expand
- Move to array of 6 turbines
- Optimise performance by changing array design
- Use 7th turbine to create/generate improve O&M strategy

#### 4.2.2.2 Expected impacts

- Concept design review
- Technology update review
- 20% OPEX/CAPEX savings

#### 4.2.2.3 Status and updates

The project has just passed its first-year mark of the 5 year project lifetime. In the first year of the project the consortium has focussed on the collection of the required document for licensing the expansion of the array to 7 turbines.

In terms of technology, the consortium has already identified the list of upgrades that are necessary for the turbine, including new condition monitoring tools to be installed on the devices. The three turbines currently operational are expected to be retrieved and upgraded by the end of the year.

The consortium has also defined the designed and procurement process for the new turbines, with turbine 4 currently being manufactured and expected to be delivered between end of 2018 and first quarter of 2019.

In terms of market prospect, the consortium has undertaken an investor engagement report, where they highlighted the need of showing a credible LCOE cost-reduction programme to gain investors' confidence.

### 4.2.3 TAOIDE

The Taoide project, similarly to the TiPA projects, focuses on the development of wet-gap drive train for the cross-flow tidal device developed by ORPC. The ORPC device has been developed in the US and has been tested in river flows. SKF, which is involved in the Taoide and Tipa projects, is currently carrying out a trade analysis of seals and bearing for the project.

#### 4.2.3.1 Expected impacts

- Develop a ‘wet-gap’ electrical generator design capable of operating in a fully-seawater flooded condition
- Extended maintenance levels (5 years) – availability of 96%
- Develop bearings and seal designs for hydrokinetic machines
- Develop control system to optimise power output and quality.

### 4.2.3.2 Innovations

The Taoide project has reached half way. As part of the project, the consortium is developing a synchronous permanent magnet generator rated at 38 kW (max rating 56 kw). During the first part of the project, the design of the RivGen 2.0 generator has been finalised. The generator is designed with a split rotor design where the output shaft rotates, together with the permanent magnet rotor while the inner races of the bearings are supported by a stationary cantilever (Figure 10).

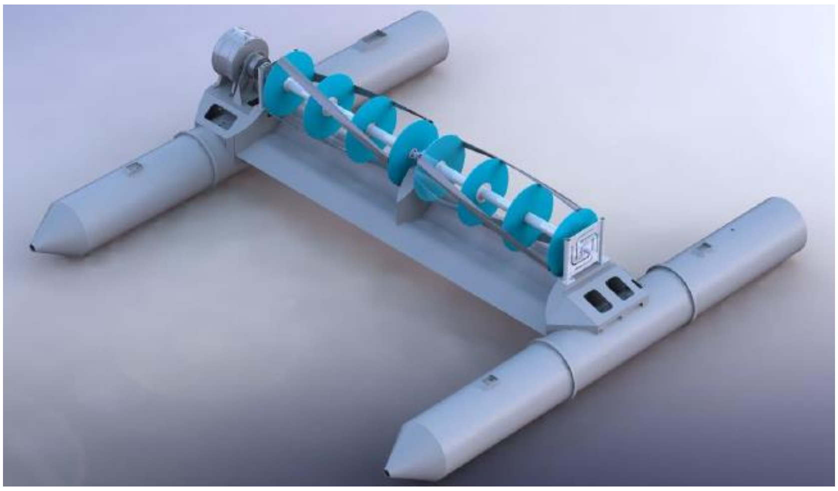

*Figure 10 RivGen 2.0*

IKM (Norwegian partner) and Sintef have been working on the wet-Gap permanent magnet and on the identification of protection solution for the stator and the generator as a whole. They considered the use of different types of epoxy resin to protect the stator, considering a gap of 5 mm. Design freeze for the generator was reached in April 2018, this will facilitate the identification of the bearings. SKF has been working on the selection of suitable seawater seal for the generator.

Subsystem testing is expected for late 2018, and wet-gap generator testing for 2019. No performance or cost data are available.

## 4.2.4 PowerKite

The PowerKite projects aims improving the reliability of the Minesto tidal energy converter. The device is not a horizontal axis turbine, but a tethered kite equipped with a turbine for power conversion. The project is currently in the last 6 months, and will terminate in December 2018. The first Minesto Deep Green500 was deployed in Holyhead in Setpmeber 2018, and started to deliver electricity to the grid in October 2018 [Renewables Now 2018].

### 4.2.4.1 Expected impacts

The overall objective of the project is to enhance the structural and power performance of the PTO. Core innovation of the project resides in the electro-mechanical design of the PTO.

### 4.2.4.2 Innovations

As part of the project, the consortium has focused on optimising the PTO through the identification of new turbines designed (5 turbine tested), the optimisation of tethers. The improvements have resulted in 23 % power output, achieved through the optimisation of tethers behaviour during motion/generation and of the bottom joint.

Minesto has highlighted the solution identified for the "bottom joint connection", "tether system" and "tether-kite connection" subsystems could be commercially attractive for other applications.

#### 4.2.4.3 Others

The focus of the SME projects is often directed at understanding the commercial viability of the projects, As indicated earlier in the D2T2 project Nova Innovation undertook a market study for their turbine, similarly DesignPRO developed a market study for their 25 and 60 kW vertical axis turbines designed for riverine applications. The expected cost of the 25 kW turbine is of 167 000 EUR, which could compete with off-grid wind and solar PV applications, in terms of projected LCOE. The company works closely with GKinetic an Irish developer working on floating tidal energy converters with similar design.

Current2Current involved in the Subport project, is developing a subsea unit converting tidal stream and ocean currents into electrical power of Oil and Gas and other remote subsea applications. Their long-term plan is to sell 26 units by 2023 with revenue of 20.8 mEUR. A feasibility study was undertaken to understand the need of the oil and gas sector to allow for market entry of the Current2Current turbines as a replacement of subsea umbilicals.

## 4.3 Tidal Energy Demonstration

The EU supports 7 tidal energy projects as for technology at TRL7-9 as shown in Table 14. Four projects are dedicated to the demonstration of tidal energy technology, one on optimisation tidal turbines, and two are funded through the FITPlot.

*Table 14 H2020 Tidal energy projects at TRL>7p and related ETIP Challenges*

| Main Technology | Device Class | Project | ETIP Challenge |
|---|---|---|---|
| AR1500 (Atlantis, UK) | Horizontal Axis turbine | Demotide | |
| Openhydro (IE/FR) | Ducted turbine | Octarray | |
| | | Occitc | |
| SR2-2000 (ScotsRenewable, UK) | Horizontal Axis Turbine (Floating) | FloTEC | |
| M100 (Nova Innovation, UK) | Horizontal Axis Turbine (small size) | Enfait | |
| S250 (Tocardo, NL) | Horizontal Axis Turbine | InToTidal | |
| Magallanes (ES) | Horizontal Axis Turbine (Floating) | Ocean_2g | |

### 4.3.1 Demotide

The Demotide project aims at deploying the Meygen 1B array (4 x 1.5 MW), which has been acquired by Atlantis following the purchase of MCT, and benefits from NER300 support (comparable to a feed-in tariff). The initial phase of the project, Meygen 1A (6 MW) is operative since November 2016, and has delivered over 22 GWh to the grid (data updated October 2019). The project aims to reduce cost of electricity from 450 EUR/MWh to 120 EUR/MWh. It is part of the overall Meygen project for up to 396 MW generation capacity in the Pentland Firth. It is not clear when the second phase will be actually deployed.

#### 4.3.1.1 Expected impacts

The aim of the project is to define the optimal array design (offshore) and allow for standardisation and replication of the performance.

Atlantis is responsible for the onshore activities, whilst MCT responsible for technology and offshore electrics

- Moving from gravity base to monopole (optimal solution)
- Increasing rotor diameter to reduce CAPEX
- Financial modelling (maximising revenue, working towards financial close, expected in 2018)
- Belief is that financial close is within reach.

#### 4.3.1.2 Status and updates

Currently Meygen 1Ais operational. The project has shown that capacity factors of 37% percent can be achieved, and has already fed about 22 GWh to the grid (data from Ofgem). Atlantis has shown interest in developing 3 GW of projects in France by 2027.

### 4.3.2 Occtic and Octarray

The Occtic project is focussed on the optimization of the open centre tidal turbine developed by Openhydro, whilst Octarray aims at scaling up Openhydro technology for array deployment as part of the 14MW Normandy Hydro– pilot array. The project is intended to focus on the techno-economic viability of the project (LCOE) and assess capabilities to scale up to 300 MW based on performances. However in mid-2018 Openhydro ceased to trade, and its activities are suspended [Renews 2018c].

### 4.3.3 FloTEC

FloTEC is a demonstration project of a 2MW floating tidal energy converter. The aim of the projects is to reduce the cost of the technology from 250 EUR/MWh to 200 EUR/MWh. Currently The SR1-2000 is operational at EMEC as part of the FLOTEC H2020 project. A second device SR2-2000 is under constructions, building on the experience of the current FloTEC learning.

#### 4.3.3.1 Expected impacts

- Significant improvements from current device – access to the device and to the nacelle –
- Ease of installation access.
- Legs are hinged to facilitate access
- Variable pitch in the turbine blades
- Increase rotor diameter from 16 to 20 m, increasing swept area and capacity facture
- Simplification of manufacturing – assembly at location
- Construction of the new device in 2018

#### 4.3.3.2 Innovations

- 20 m Rotor diameters – Increase energy capture and reduced LCOE. Possible Pitch control. Double swept areas increases energy capture of 50%.
- Design for manufacture – reduction of cost for automated steel fabrication (from 7000 EUR/ton to 5000 EUR/ton)
- Mooring dampers – reducing peak loads on mooring (30% less CAPEX)
- Composite blades (30% CAPEX reduction)
- MV Power conversion – reduced cabling (CAPEX and Opex reduction 5%)

#### 4.3.3.3 Status and updates

Scotrenewables began the development of their technology in 2003. In 2011 they deployed the SR250 device at EMEC (sea trials of scaled device rated at 250 KW). In 2016 the SR1-

2000 device (rated 2000 kW) was deployed at EMEC as part of the FloTEC project. The device has already feed over 2 GWh to the grid. A second 2 MW device, the SR2-2000 (second generation device developed with the learning from the SR1-2000) is expected to be deployed in 2019 to form the first array demonstration. No information is currently available on planned duration of the array testing. The company is already developing its project pipeline (Figure 11). In 2018 Scotrenewables was rebranded to Orbital Marine Power.

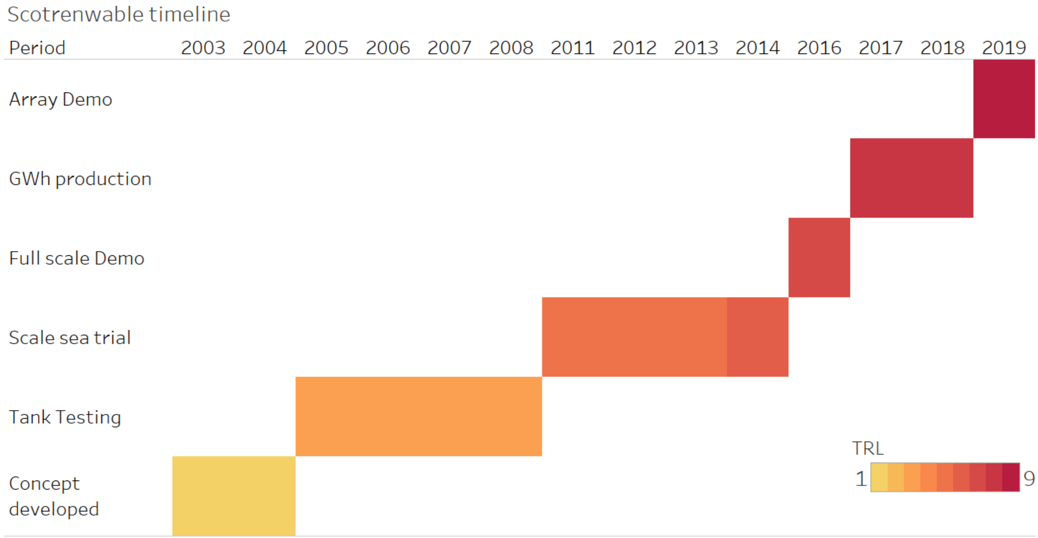


*Figure 11 Timeline of Scotrenewables/Oribital development*

### 4.3.4 InToTidal

The InToTidal project, designed to support Tocardo develop a semi-floating platform, has been funded under H2020 FTIPilot (Fast Track Innovation). The project started in January 2017 and was expected to terminate in June 2018. The project has been hindered by a number of delays.

### 4.3.5 Ocean_2G

The Ocean_2G projects aims at the development of a floating tidal platform equipped with 2 contra-rotating turbines developed by Magallanes Renewables. The project aims to test, validate and pre-certify a full size tidal energy harnessing prototype system that will demonstrate the capabilities of an innovative 2 MW pre-marketable platform which will become a worldwide reference in the production of energy from tidal currents. The project has reached its half-term progress without any delays.

In the first half of the project, the 2MW device, picture in Figure 12, testing of the device in controlled environment have taken place. The aim of these activities was to prepare for the deployment of the 2 MW device at EMEC in autumn 2018. The device is expected to be operational at EMEC for at least 12 months. Preliminary tests carried out in Galicia have demonstrated that systems and subsystem work adequately well, and that the platform is stable for deployment.

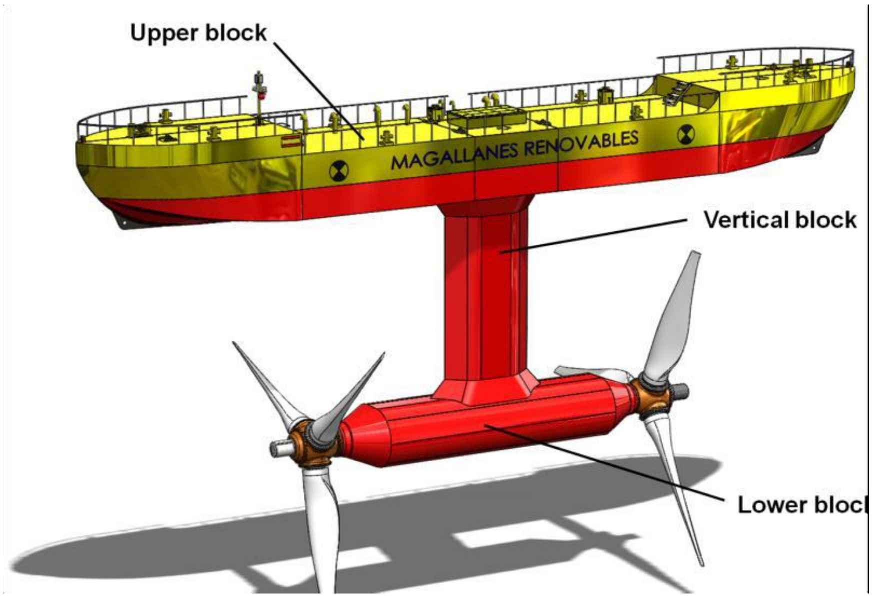


*Figure 12 Shape of the Magallanes tidal energy device*

## 4.4 Wave Energy R&D

The EU supports the development of wave energy R&D through four H2020-LCE projects and four H2020 SMEs projects (Table 15).

*Table 15 H2020 projects on low TRL wave energy technologies and related ETIP Challenges*

| Main Technology | Device Class | Project | ETIP Challenge |
|---|---|---|---|
| Electro-Mechanical Generator (UmbraGroup, IT) | N/A | IMAGINE | Power Take off and efficiency |
| Wedge (ES) | Point Absorber | SEATitan | Power Take off |
| C3 (Corpower, SE) | Point Absorber | PowerKite | Power Take off, Device reliability Improving costs and efficiency |
| Marmok (Oceantesc ES) | OWC (Point Absorber) | Opera | Power Take off |
| Symphony (Teamwork UK/NL) | Point Absorber | WETFEET | Power Take off, Device reliability Investigating novel devices |
| Butterlfy (*Rotary Waves, ES*) | Other | Butterfly (SME) | |
| Infinity WEC (Ocean Harvesting Technologies, NO) | Point Absorber | OHT (MSE) | |
| Wavepiston (*DK*) | Other | Wavepiston (*SME)* | |
| eForcis (Smalle Technologies) | Point Absorber | eForcis BeForcis (SME) | |

### 4.4.1 Waveboost

Waveboost is a project working on the optimisation of the Corpower C3 device, focusing on identifying control strategies and developing an innovative braking module with a Cyclic Energy Recovery System (CERS) to increase the energy extraction from the resonant device.

#### 4.4.1.1 Expected impacts

- Increase in annual energy output by 25%
- Reduction LCOE by more than 30% compared to the state of art.

#### 4.4.1.2 Innovations

During the project, a half-scale prototype (25 kW to 250/500 kW full scale) was built and has underwent dry PTO testing since May 2017. The C3 device was later installed at EMEC and tested in real sea conditions.

In terms of survivability the device has withstood wave heights of up to 2.56 m (5.12 m in full scale). The device has also operated in survival mode, a mechanism developed similar to blade-pitching in wind energy designed to reduce the load in storm conditions, showing that load shredding is possible.

The cascade gearbox developed by Corpower has been patented and it's sold for other applications outside of the ocean energy market.

### 4.4.2 Opera

OPERA is a research and innovation project at low TRL where a floating OWC device has been deployed in Spanish waters. The project employs the Oceantec Marmok device.

Different turbines developed by OceanTEC and Kymaner are tested. Prior to development at sea, the innovative turbines are tesed in one of the chambers of the Mutriku power plant. The Marmok device has been deployed at Bimep since December 2016, and has been recently retrieved for monitoring and installation of the 30 kW turbine developed by Kymaner.

#### 4.4.2.1 Expected impacts

- Reducing cost of energy by 30%.
- Availability of operational data from two year of open-sea testing
- TRL progression from TRL3 to TRL5.

#### 4.4.2.2 Key innovations Elastomeric tethers

- New bi-radial turbine with increased performance (50% more effective)

#### 4.4.2.3 Status and update

The Marmok device has been deployed at Bimep since December 2016. In doing so it has survived two winters, and withstanding wave conditions of with maximum wave heights of 14 m (significant wave height of 7.5 m).

The device was first equipped with 2 15 kW turbines developed by OceanTEC, while a new bi-radial turbine developed by Kymaner. The new turbine has been tested at Mutriku (Figure 13), where it showed significant performance increase compared to conventional Wells turbines (conversion upgrade target of 50% can be reached).


*Figure 13 Kymaner turbine at Mutriku for testing*

### 4.4.3 Wetfeet

Wetfeet is a low TRL projects that assess the potential breakthrough for the cost-reduction of wave energy. It investigates these breakthroughs by working with OWC floating and Symphony device, a point absorber WEC based developed on the experience of the AWS device.

The project terminated in April 2018.

#### 4.4.3.1 Expected impacts

The aim of the project was to identify breakthroughs in wave energy converters in particular by addressing:

- Reliability of PTO and technical components.
- Survivability of the entire system.
- Shared mooring configurations.
- Identification of road-to-market for wave energy technology.

#### 4.4.3.2 Key innovations

Two main technologies were considered in the project, the sparbuoy OWC (similar to the one deployed at Bimep as part of the Opera project) and the Symphony device.

OWC: The consortium has identified 6 different breakthroughs which address:

- Enhanced added mass (EAM);
- Negative spring (NS);
- Survivability submergence (SS);
- Shared moorings (SM);
- Dielectric elastomer generator (DEG);
- Tetra-radial turbine (TRT).

The combination of Enhanced added mass, negative spring and survivability submergence can be implemented to develop a more efficient and reliant structural design. Shared moorings were found to have an impact on the total cost of a WEC array. Improved power output is expected with the development of the tetra-radial turbine and the use of dielectric elastomer generator, a technology that has been highly analysis in the LCEO FET report.

In particular, it was found that the implementation of DEG PTO (using membranes rather than conventional OWC turbines) would reduce the PTO cost of 16%. The tetra-radial turbine is expected to have higher conversion efficiency than impulse and self-rectifying turbines, however non cost data are available for this type of turbine yet. This option may have relevance for ongoing OWC studies, such as Opera project (consortium partners are similar).

Symphony: For the symphony device, which is at early stage of development, breakthroughs have been identified as follows:

- Dielectric elastomer generator (DEG);
- Water turbine (WT);
- The structural membrane (SMemb);
- Control Cocoon – Continuous Submergence (CS).

The structural membrane and the control cocoon are expected to provide a more efficient and resilient structural designed. Dielectric elastomers and water turbine, fully designed in the project, were considered for improved power output.

The selection of PTO for the symphony, which is a fully submerged device, fell on the water turbine. Such concept was not yet available, and preferred to linear generator. The risk of high maintenance has informed the design of the water turbine, which was completed in April 2018, and is yet to be tested.

Shared moorings. The consortium also investigated the possibility of sharing mooring configurations for both OWC and Symphony farms. 5 MW farms were considered. Since many WEC arrays are expected to be formed by multiple devices, this study may be applied to other farms and not only to sparbouy/symphony devices. Four different shared mooring configurations were investigated (ropes and anchoring points).

The implementation of share mooring configurations could have a significant effect on the LCOE of the array. The shared mooring configuration of the OWC leads to a reduction of 13 % of CAPEX compared to the reference case, an increase of capacity factor of 16 %and an overall LCOE reduction of 20-25 %. Using DEG on OWC would result in a lower capacity factor and an increase of LCOE. DEGs are still emerging technologies so their effects could change if appropriate breakthroughs in this technology take place.

The application of breakthroughs in the Symphony device could lead to significant cost-reductions (60 %) compared to the reference case. This is related to the identification of both a reliable PTO (water turbine) and the employment of shared mooring configuration.

#### 4.4.3.3 Status and update

The twin-rotor turbine (tetra-radial) is a new patented design (Figure 14) developed by Istituto Superiore Tecnico in Libson. The OCEANERA-NET CAPTOW project (2017-2019) will further validate the design of the turbine and includes manufacturing and dry-testing of one 18 kW twin-rotor turbine prototype.

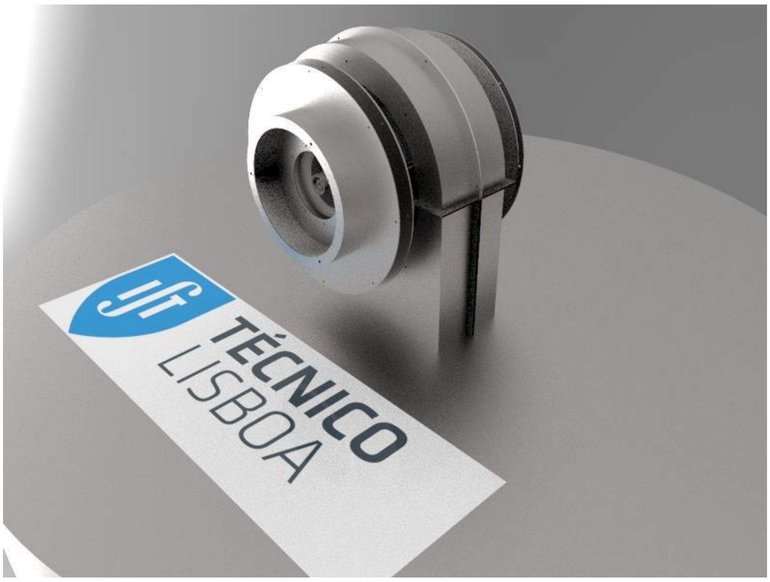


*Figure 14 New patented Twin-rotor turbine*

### 4.4.4 Imagine

The Imagine project, launched in March 2018, aims at developing a new Electro-Mechanical Generator (EMG) proposed by Umbragroup S.P.A.. The EMG is designed f for wave energy applications, at it could help decreasing by over 50% the CAPEX of current PTO technologies, while increasing average efficiency above 70% and lifetime to 20 years. The technology has already received support through the Wave Energy Scotland PTO programme. The working principle of the EMG has been discussed in detail in the LCEO FET report.

#### 4.4.4.1 Expected impacts

- Design, development and fabrication of a 250kW EMG prototype, with CAPEX reduction of over 50% with respect to current PTO.

#### 4.4.4.2 Status and updates

The project has started recently, an initial analysis of 22 wave energy technologies and their PTOs, potential competitors as well potential clients.

The review included the analysis of WECs developed and a selection of 4 types of converters that will be further investigated, taking into account potential operation with the EMG PTO developed as part of the project.

### 4.4.5 Sea-Titan

The SEA-TITAN project aims at designing, building, testing and validating a direct drive PTO solution to be used with multiple types of wave energy converter.

The focus is the development of a new configuration and geometry of a first generation Multitranslator Linear Switched Reluctance Machine employed in the Wedge wave energy converter currently deployed at Plocan in Spain.

The consortium will investigate the application of the new PTO not only to the WEDGE device but also to other WECs. Corpower, is also involved in the project, and collaborating on the identification of control strategies. The project started in April 2018.

#### 4.4.5.1 Status and updates

Wedge (ES) has tested a point-absorber device equipped with linear direct drive generator in the Canary Island for the past 4 years. The device is designed for Island (e.g. diesel displacement). The expectations are LCOE of 30cEUR/kWh to compete with diesel in islands condition.

### 4.4.6 Others

Butterfly, OHT, WavePiston and eForcis are some of the ongoing H2020 projects.

Danish developer WavePiston has shown progression in their sea-trials in Denmark. A bigger device is currently under development. The TRL of the technology is low, but the development has benefited from sea-trials in benign conditions in Denmark which has allowed for significant learning (dealing with mooring failures, material failures and fishermen). The company has recently received further backing through a crowdfunding campaign.

The objective of the Butterfly project was to carry out a technical and commercial feasibility of the Butterfly WEC. The technology aims at maximising wave energy capture (90 % efficiency) and power generation. The device is a terminator, where different flaps react to incoming waves pressurising a smart pump system which activate an hydraulic PTO located onshore.

The OHT project focused on the development of the Infinity WEC with integrated energy storage. As a result of the feasibility study OHT has decided to focus on the development of the hydraulic PTO since they expect that energy storage won't be able to compete against batteries.

## 4.5 Wave Energy Demonstration

The EU supports 3 wave energy projects as for technology at TRL7-9 as shown in Table 16. One project is dedicated to the demonstration of a wave energy farm, on supported by the Life programme to the demonstration of a novel wave energy converter and one to optimisation and scaling up of the PTO subsystem.

*Table 16 H2020 wave energy projects at TRL>7p and related ETIP Challenges*

| Main Technology | Device Class | Project | ETIP Challenge |
|---|---|---|---|
| Penguin | Rotating Mass | Cefow | |
| Wave Roller | OWSC | MegaRoller | |
| Life | Point Absorber | LifeDemoWave | |

### 4.5.1 Cefow

The project aims to deploy 3 Penguin WECs in Scotland by 2020. One 1MW device was installed in 2017 and a second one has been manufactured (WEC2) in 2019 and is ready for deployment.

#### 4.5.1.1 Expected impacts

- Improving the availability and performance of the Penguin wave device;
- Tailoring the solution with low life-cycle cost in mind for long term deployment; and
- Creating a cost efficient supply chain to support much larger wave energy deployments in the future

#### 4.5.1.2 Key innovations

- Manufacturing second device in Estonia
- Generates electricity from smaller waves
- WEC2 to improve 15%
- Subsea station, possibly 3 devices attached. Cables are difficult
- 6 mooring lines, with gravity base solution

#### 4.5.1.3 Status and updates

Wello Penguin 2 is currently being built. To reduce cost of the device, Wello has modified the structure and employs concrete. 95% of the structure is expected to be built using concrete, including the rotator.

WEC1 was deployed in March 2017, and could withstand winter storms. In the first nine months of operation mooring lines required no O&M, however the dynamic cable required replacement following the first three months of operation.

The device has been able to generate for over 360h over 30 days, with an availability of 50 %.

WEC2 is currently being manufactured in Estonia, and is expected to be deployed at EMEC in the first trimester of 2019. Compared to WEC1, WEC2 is bigger and is expected to have an annual energy production of 1400 MWh compared to the 900 MWh of WEC1.

### 4.5.2 Megaroller

The Megaroller project, which started in May 2018, aims at developing a 1 MW PTO for the oscillating wave surge converter Megaroller which is based on the WaveRoller energy converter developed by AW-Energy.

### 4.5.3 Life DemoWave

The Life DemoWave project is a wave energy demonstration project funded through the Life programme of the EU. The main objective of tje DemoWave project is to demonstrate the viability of two wave energy converter (WEC) devices from the developer Gelula, which have already been researched and patented, for electricity generation.

The two prototypes, each one scaled at 25 kW, will be manufactured, installed and tested to demonstrate their technical and socio-economic viability, as well as the transferability potential.

#### 4.5.3.1 Expected impacts

- Demonstration of the technical viability and survival capacity of two WEC prototypes
- Demonstration of the energy efficiency, power quality and high generation ratio of the systems.
- Demonstration of the electricity generation potential of these systems in comparison with other solutions.

#### 4.5.3.2 Status and updates

The Gelula device was deployed in the Galician cost in June 2018. The consortium is expected to gather operational and environmental data for one year since deployment. A second device should be deployed, however no information are currently available with regards to its construction. If viability and operability are proven, the consortium expects to scale-up the device to 500 kW.

## 4.6 Key takeaways

The development of ocean energy technology benefits from EU support. A wide range of tidal and wave energy technologies, mostly developed in EU benefits for support at low and high TRL.

### 4.6.1 Tidal energy R&D

Tidal energy R&D projects focus on the optimisation of the PTO for tidal energy application. There's a certain level of convergence and similarity within the project that facilitate knowledge exchange. Wet-gap direct drive PTOS under development can be considered to be at TRL4-5, with the technology expected to complete TRL5 by end of the project. Tidal kites are at TRL6. The impact in terms of LCOE cannot be fully assessed as performances and costs are still estimates, and as in the case of the DeepGreen device could see spike in costs for particular bespoke components.

### 4.6.2 Tidal energy demos

Six different tidal energy technologies receive funds for demonstration projects at TRLs up to 7/8. Financial difficulties are hindering the execution of the projects. In at least two cases (InToTidal and Octarray) final investments decisions are based also on technical performance which appeared to be beyond expectations.

Information on costs of technology were provided for floating tidal concepts, indicating that the LCOE could be lower than expected at this stage. Further validation of performance and construction of second device could provide further details on the cost-reduction of tidal energy technologies.

### 4.6.3 Wave energy R&D

The main focus of wave energy R&D is the development of reliable PTO for wave energy conversion. Most projects put significant emphasis on this aspect. Results from TRL5 experiments (Waveboost, Opera and Wetfeet) indicate that performances are on par or even better than expectation. Other aspects, such as survivability and moorings, offer significant crossover among the projects, with results benefitting the whole sector. Control systems are investigated in different projects and more global assessment could also provide key advances at sector-level.

### 4.6.4 Wave energy demo

Three wave energy demonstration projects are currently supported by EU funds in H2020 and Life programme. Only the Cefow project has been operative for over a year, with results below expectations. The Gelula device has been only recently deployed as part of the Life DemoWave project and the Megaroller project has started.

The expectations is that the lessons learnt from the first deployment of Penguin WEC1 and the WaveRoller would help driving the efficiency of the new devices being developed under the Cefow project and of the new 1 MW PTO in the Megaroller

### 4.6.5 ETIP Priorities

Most of the H2020 projects address one of more ETIP priority challenges. Challenges related to the development of improved PTO and improved reliability and survivability of the device are addressed the most. Other key challenges addressed, although not listed a key priorities, are cost-effective moorings and cost-effective electrical subsystems. As seen in this section considerable progress has been made by the projects in these areas and with solutions validated at TRL6. It's recommended that the viability of these solutions are explored further. Table 17 present an overview of ETIP priorities are assessed and recommendations for future support.

*Table 17 ETIP challenges and H2020 key lesson. Colour code identifies if priority is addressed in current H2020 projects: green –many projects, yellow – few projects, red - not addressed*

| Priority | Challenge | Current focus in H202 | Key takeaways | Recommendation |
|---|---|---|---|---|
| A.1 | Developing novel concepts for improved power take-offs (PTOs) | 🟢 | Key areas of ongoing H2020. Projects Focus mainly at TRL6-7 | Maintain support for higher TRLs, possibly in line with priority A.5 |
| A.2 | Increasing device reliability and survivability | 🟢 | Focus of many projects, especially IA actions. | Support needed, reliability and survivability issues not solved yet. May require definitions of KPIs |
| A.3 | Investigating alternative materials and manufacturing processes for device structures | 🟡 | Few projects are investigating this topic. WES is undertaking a more detailed study at low TRL. Investigated by FET report | This is a low TRL topic, developers are investigating the topic for improving their conversion technologies. Low TRL call based on FET/WES study could provide broader results to the sector |
| A.4 | Investigating novel devices before moving towards convergence of design | 🟢 | Very few projects address the same technology. | No changes recommended to H2020 calls |
| A.5 | Defining and enforcing standards for stage progression through scale testing | 🔴 | Not addressed by H2020 | Development of Wave Energy Europe and Stage-gate metrics as part of SET-Plan implementation plan would address the topic. |
| A.6 | Developing and implementing optimisation tools | 🟡 | DTOceanplus project started recently | |
| B.1 | Building on existing guidelines and standards for third-party verification and testing | 🔴 | Not addressed by H2020 | It may be beneficial to address this topic gathering the experience of the past 5 years of ocean energy (similarly to the old FP7 Equimar project) |
| B.2 | Developing improved, more cost effective mooring and foundation systems | 🟡 | Addressed by few project, significant potential for shared knowledge | Support further R&D on the topic. |
| B.3 | Implementing suitable condition monitoring systems | 🟡 | Addressed by few project, significant potential for shared knowledge | Support further R&D on the topic., or coupled with IA projects |
| B.4 | Improving the efficiency and cost-effectiveness of electrical subsys-tems and power electronics | 🟡 | Addressed by few project, significant potential for shared knowledge | Support further R&D on the topic. |
| B.5 | Optimising offshore operations and maintenance missions | 🔴 | Issues are not fully addressed due to delays in getting devices in the water. Demotide and Octarray would have addressed this topic. | Requires more demonstration projects. Currently hindered by lack of projects going in the water. |
| B.6 | Developing dedicated vessels and tools | 🔴 | Not addressed by H2020 | Requires certain convergence of design and pipeline of projects to be addressed. Might be a R&D project in the transport programme before the commercial roll-out phase. |
| C.1 | Developing expertise related to the manufacture of ocean energy technologies | 🔴 | Manufacturing is addressed, blindly in some SME projects and some business cases. | Addressing manufacturing issues requires a design-freeze and project pipeline. May be valuable to explore as a work package part of IA projects. |
| C.2 | Scaling up from single device deployments to arrays | 🟡 | Many projects currently focus on single devices. | If projects at TRL6-7 are successful, this topic may need to be explored as a follow-upstage of development of the technologies. |

# 5 TECHNOLOGY DEVELOPMENT OUTLOOK

The development of ocean energy sector requires that significant cost reductions are achieved in order for wave and tidal energy technologies to become competitive with other renewable energy sources. Whilst in the long term expectations are that ocean energy could contribute up to 10% of the EU energy needs. However, in the short term, the sector need to reduce its costs: The targets sets for wave and tidal energy technologies means that the costs of generating electricity from the ocean need to be reduced of 65 % by 2025.

Since 2016, ocean energy converters have made stride forwards, with tidal energy technologies showing that cost-reductions and continuous generations are possible.

In this section, costs trend for ocean energy technologies are analysed and future deployment scenarios presented.

Assumptions for the analysis are similar for both wave and tidal energy, so these are presented jointly, whilst analyses are separated.

## 5.1 Cost reduction assessment

The critical KPI for the assessment of the cost-reductions needs for ocean energy technology is the LCOE. By 2025, LCOE for tidal energy should reach 15 cEUR/kWh against the current reference of 40 cEUR/kWh, whilst for wave energy the target is of 20 cEUR/kWh against the current 60 cEUR/kWh.

Three key parameters affect the LCOE, the capital expenditure (CAPEX) of a project/device expressed in EUR/MW, the operational expenditure (OPEX) expressed in EUR/MW/year, and the annual energy production (AEP) which is dependent on the capacity factor.

As seen in the previous chapter, in some cases LCOE estimates are provided, in other cases AEP and CAPEX estimates are provided. Other factors such as discount rate, are not defined, so in order to allow for comparison of the data we will consider discount rate of 12 %, learning rate of 12 %, Opex of 5 % of CAPEX, and lifetime of 20 years.

It is important to note that the reduction of costs is dependent by the deployment of technology. Thus, the high costs of today's technology are also influenced by limited deployment.

Other factors concur in driving cost reduction [Abell & Hammond 1986, Grubler 1955- 1998]:

- Learning by doing, which refers to the learning achieved through methodological improvements, increased efficiency and specialisation.
- Learning by research, as a result of R&D investments and introduction of new materials or components.
- Learning by interaction, achieved through knowledge sharing and knowledge diffusion.
- Learning by upscaling, referring to increase manufacturing capabilities.
- Learning by upsizing of the product, e.g. increased power rating of a turbine.

## 5.2 Future deployment scenario – assumptions

The JRC-EU-TIMES [Simoes et al. 2013] model offers a tool for assessing the possible impact of technology and cost developments – a note to explain the main features of the model is included in a dedicated annex. It represents the energy system of the EU28 plus Switzerland, Iceland and Norway, with each country constituting one region of the model. It simulates a series of 9 consecutive time periods from 2005 to 2060, with results reported for 2020, 2030, 2040 and 2050. The model was run with three baseline scenarios:

- Baseline: Continuation of current trends; no ambitious carbon policy outside of Europe; only 48 % CO2 reduction by 2050
- Diversified: Usage of all known supply, efficiency and mitigation options (including CCS and new nuclear plants); 2050 CO2 reduction target is achieved
- ProRES: 80 % CO2 reduction by 2050; no new nuclear; no CCS. For this analysis we use the scenario employed by Sgobbi et Al, as validated through peer-review [Sgobbi et al. 2016].
- Set-Plan: The Set-plan scenario evaluates the potential deployment of wave and tidal energy technology under the assumption that they meet the 2025, 2030 and 2035 targets. This scenario has been created since with the current conditions no deployment of wave and tidal energy technology is expected in the other scenario aside from the ProRES scenario. Calculations have been based on learning factors employed in [Tsiropoulos et al. 2018].

In addition, a further 13 sensitivity scenarios were run. This technology development report focusses on the 3 baseline scenarios and the associated sensitivity runs for the high and low learning rates, considering the EU as a whole. Further analysis including country breakdowns will be included in the companion LCEO technology market report.

## 5.3 Tidal energy

Information on the cost of tidal energy has been retrieved from H2020 deliverables and other public information where available. The current 2018 JRC reference for LCOE if of 400 EUR/MWh, given with a CAPEX of 6390 kEUR/MW and a capacity factor of 33%. This is based on the 2015 JRC forecasts, and calculated based on cost-reduction for cumulative deployment between 2015 and 2018.

The data available indicate that the technologies developed by the aforementioned developers currently have a LCOE in line or below the JRC forecasts. In particular, it shall be highlighted that new generation devices developed in the H2020 programmes are expected to have a significant lower LCOE. Whilst operational data are not yet available, this indicates that the costs of tidal energy technology are decreasing rapidly.

It shall be noted, that the CAPEX of tidal energy technology should reach about 2750 kEUR/MW by 2025 for the technology to meet the SET-Plan targets (CF of 37%).

Figure 15 shows minimum required capex for tidal energy technologies to enter the EU energy market as modelled by the JRC-EU-Times model. The model foresees that a CAPEX of 2700 kEUR/MW or below would see tidal energy entering in a competitive manner in the EU energy system. Meeting the SET-Plan targets would ensure that these cost-reduction trajectories could be met.

shows that, if the conditions of the SET-Plan scenario are met, 6 GW of tidal energy capacity could be deployed in Europe by 2030, reaching a total capacity of 28 GW (108 TWh) by 2050. The JRC-EU-Times model indicates that even without meeting the cost-reductions foreseen by the SET-Plan declaration of intent, tidal energy would make a significant impact in the EU energy system in 2050 under the assumption of the Pro-RES scenario.

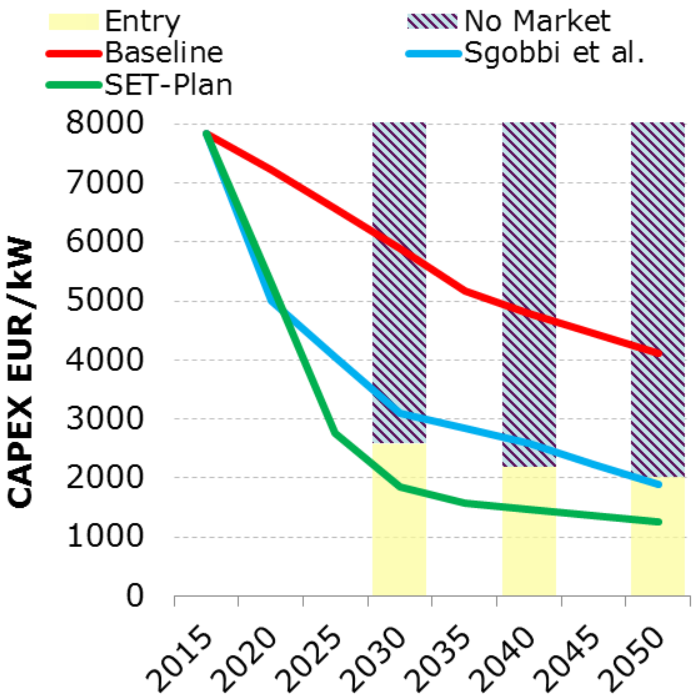


*Figure 15 Entry CAPEX for tidal energy modelled by JRC-EU-Times model.*

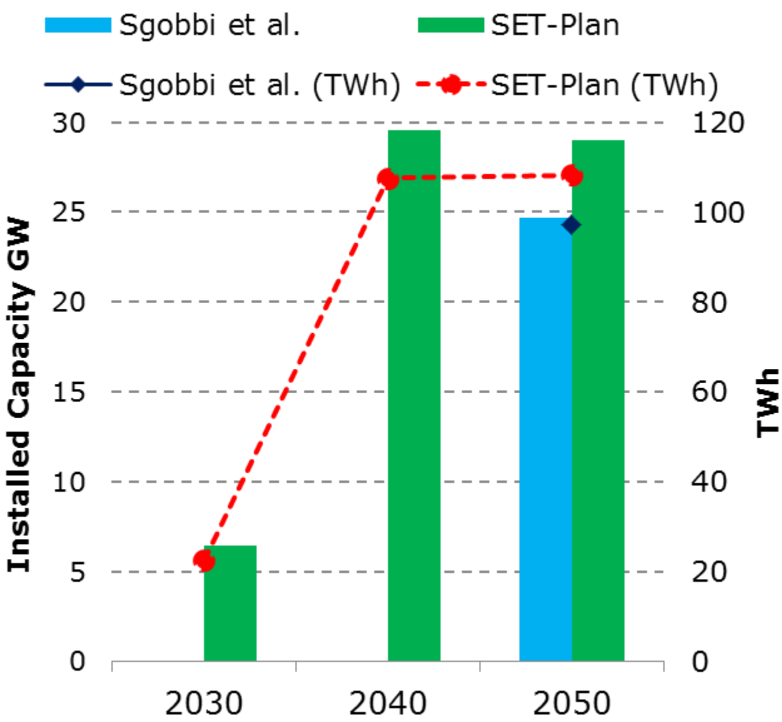


*Figure 16 Expected tidal energy installed capacity*

## 5.4 Wave energy

In comparison to tidal energy projects, information with regards to the cost of wave energy technology is somewhat more limited. As seen earlier only one wave energy technology is currently deployed for demonstration as part of the H2020 programme, providing indication of expected performances. Further information on costs of wave energy technologies have been gathered from investment prospects of Wello Oy and Seabased, since both companies have recently launched crowdfunding campaigns.

The current 2018 JRC reference for LCOE is of 560 EUR/MWh, given with a CAPEX of 6970 kEUR/MW and a capacity factor of 25%. This is based on the 2015 JRC forecasts, and calculated based on cost-reduction for cumulative deployment between 2015 and 2018.

The limited data available suggest that th technologies developed have a LCOE in line or below the JRC forecasts. In particular, it shall be highlighted that new generation devices developed in the H2020 programmes are expected to have a significant lower LCOE.

The CAPEX of wave energy technology should reach 3350 kEUR/MW by 2025 for the technology to meet the SET-Plan targets (CF of 37%).

Figure 17 shows minimum required CAPEX for wave energy technologies to enter the EU energy market as modelled by the JRC-EU-Times model. The model foresees that a CAPEX of 2000 kEUR/MW or below would see wave energy entering in a competitive manner in the EU energy system by 2050. Meeting the SET-Plan targets would ensure that these cost-reduction trajectories could be met.

Figure 18 shows that under the SET-Plan scenario, 18 GW of wave energy capacity could be deployed in Europe by 2050. Steep cost-reductions are needed for the technology to be competitive. While indications from the projects are that costs are coming down, the lack of validated operational information does not allow further verification of these claims.

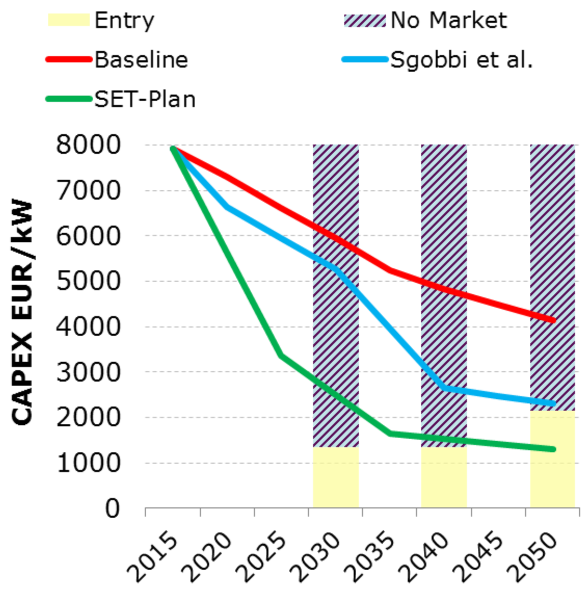


*Figure 17 Entry CAPEX for wave energy modelled by JRC-EU-Times model.*

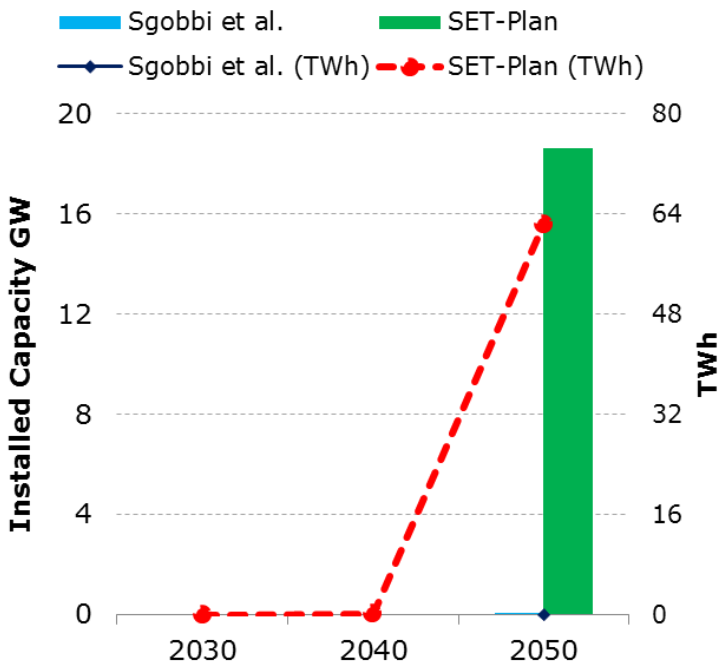


*Figure 18 Expected wave energy installed capacity modelled by JRC-EU-Times model.*

# 6 CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Summary

Ocean energy has significant untapped potential for electricity generation in the EU. The sector is growing again thanks to progress in technology and successful demonstration projects. The EU hosts 78% of global wave and tidal energy capacity, which has itself doubled between 2017 and 2018. The European Commission has supported a variety of ocean energy projects through different instruments, such as the R&D framework programmes, investing of EUR 864 million in total.

The SET-Plan Ocean Energy Implementation Plan indicates that continued support is needed for low TRL R&D and for demonstration projects for both wave and tidal energy technologies. This report's review of the H2020 projects running in 2018 indicated that the technologies under investigation at low TRL are matching their KPIs, whilst demonstration projects are hindered by mainly market-related issues.

More funding has been allocated to ocean energy during H2020 than any previous funding programme. Nevertheless, higher TRL actions, which require private investments, are not taking off in the required time-frame, highlighting that a lack of investor confidence and non-technical barriers are also hindering technology development.

Most of the EU funded wave energy projects have a strong focus on R&D, while tidal energy projects tackle more equally the research and demonstration levels. Thanks to the contribution of Horizon 2020, wave energy developers are optimising the design of their devices, in particular in terms of critical components such as power take off and moorings. Through these technological advances, developers have identified ways to reduce costs, in particular:

- Moorings solutions adopted in many floating tidal and wave energy devices have been optimised and cost-effective solutions identified.
- PTO is the focus of many projects. Significant improvements in the efficiency of PTOs of 25 % or more are highlighted in many projects.

The status of demonstration projects is more varied. In some cases, the TRLs have been overestimated by developers, with consequent delays in the deploying the devices, and re-direction of funds improving components or developing new ones. This has been particularly true for the Octarray/Octtic, InToTidal and the Cefow projects.

On the other hand, ongoing demonstration projects such as FloTEC, Oceang_2G, TIPA and Meyegn are showing that cost-reduction is possible. Data from the projects indicate that the LCOE of tidal energy technology ranges between 0.34 and 0.38 EUR/kWh (Figure 19)[6], down from 0.60 EUR/kWh in 2015. This corresponds to reduction of more than 40% in three years. The current value is below the 2015 reference cost-reduction curve, which indicated that LCOE would reach 0.40 EUR/kWh with the current deployed capacity.

These high cost reductions are related to the increasing reliability of the devices deployed in first-of-a-kind demonstration projects. These technologies are still in pre-commercial phase and operational strategies being implemented, tested and optimised. The ongoing demonstration projects show that it is possible to generate electricity continuously, and that capacity factors of 37 % or higher are achievable. Know-how acquired through the deployment of multiple devices is also reducing the capital expenditure through more efficient installation

[6] JRC Calculation based EC restricted data. Assumption: 12% learning rate and 12% discount rate

techniques. Optimisation of operation strategies is reducing O&M costs. For wave energy technologies, continued support in Horizon 2020 and Horizon Europe can help generate similar cost-reductions.

Overall, the status of ocean energy development can be seen as a positive, in particular in terms of cost-reduction. Cost-reduction is taking place, and Capex of both wave and tidal energy technologies are lower than expected at this stage of development.

JRC-EU-TIMES scenarios indicate that the total ocean energy capacity that could expected by for 2050 is between 28-46 GW provided that the current rate of development is maintained and that the sector receives sufficient support.

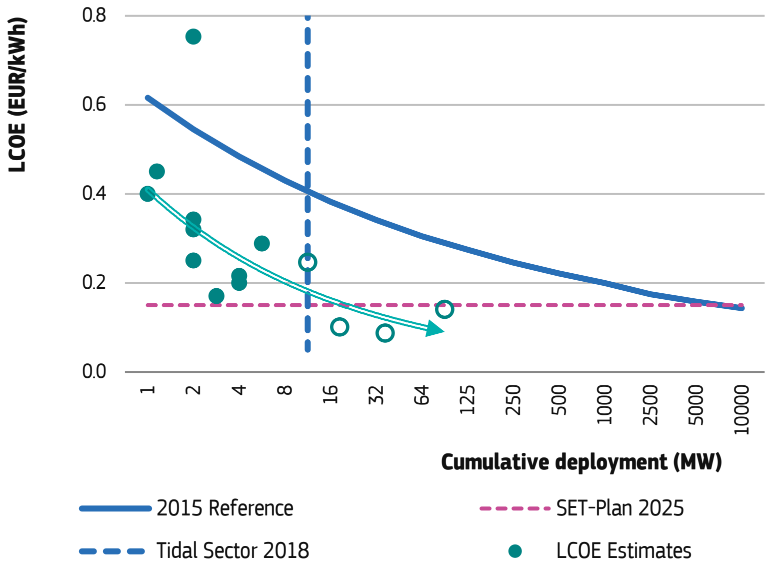


*Figure 19 Cost-reduction curves for tidal energy and LCOE estimates from ongoing projects. Solid dots represent data from ongoing demo projects, while hollow dots indicate developers' estimates on the basis of technology improvements and increased deployment.*

## 6.2 Policy Considerations

The EU is the current leader in ocean energy. Most of the global wave and tidal energy operational capacity is deployed in the EU or employs EU technology. Over the past decade, the EU (Commission and Member states) has supported ocean energy R&D and demonstration projects for a total of EUR 1.1 bn (including EUR 850 m public funds). Internationally, no country has supported the development of ocean energy with similar funds.

Whilst the review of the H2020 projects offer many positives, some barriers remain to be overcome, both in terms of technology development and market creation, and that need to be addressed.

**Technology wise** – ocean energy is still an expensive business. Progress is taking place; however it's difficult to measure it properly. Of the 9 demonstration projects considered here, 5 have been hindered by considerable delays, and 3 started less than 6 months from the time of writing.

Delays are related to both financial investment decisions, but also to technology limitations as in the case of InToTidal, Octarray and to a certain extent Cefow.

The expectation is that ongoing demonstration projects and R&D activities will further reduce the cost of ocean energy. For tidal energy technology, the 2025 SET-Plan targets could be reached sooner than previously expected, provided that the current cost-reduction trajectory holds and that announced deployments become operational.  By 2021, 160 MW of tidal capacity could be deployed and a further 1.5 GW is planned to be installed by 2025.

Implementing stage gate metrics and pre-commercial procurement, as indicated in the SET-Plan Implementation plan, could lead to proven technology getting funded for higher stage deployments. Considerable efforts is taking place at international level to develop consensus on  Stage Gate Metrics, with Wave Energy Scotland, the US Department of Energy and The European Commission working together within the IEA Ocean Energy Systems TCP. Importing these learnings in EU supported projects and the development of Wave Energy Europe will likely increase the rate of success and technology development that can be achieved through EU Co-funded projects.

**Market wise** – The lack of clear support schemes for demo projects is proving hard to manage for ocean energy developers. This limits the possibility of developing a business case, and of identifying viable ways to develop technology and deploying it. Solutions to this issue are discussed more in detail in the LCEO ocean technology market report.

The creation of investment support funds and of an EU insurance and guarantee fund as foreseen in the SET-Plan Implementation Plan could facilitate the deployment of ocean energy demonstration and pre-commercial farms. Such actions can reduce the risks faced by technology and project developers and pave the way to commercialisation. Cost reduction and market uptake will not take place without further deployment.

## 6.3 Research and Innovation Recommendations

Many projects have highlighted progress made in terms of power take off, moorings and other key components. Some of the projects have been able to quantify the cost-reduction of their innovations. It is recommended that a more in depth assessment of these innovations takes place, either through joint workshops or through a common study. In particular an assessment of the effort needed to take innovative PTO and mooring solutions to the next stage of development (TRL7-8) would be beneficial.

Specifically designed calls are needed to help technologies move from TRL5-6 to TRL6-7 for both wave and tidal energy. This however should take into account realistic time scales for manufacturing, deployment and optimisation of a device. A two-stage approach, where deployment support is granted only upon meeting certain requirements (e.g. dry-testing for PTO, designed optimised for the test-location and consent for the specific installations), could avoid projects being suspended or delayed.

The development of small-size tidal and wave energy converters (<500 kW) and of floating technologies tapping also other resources, highlights the need for  further studies on the technical/economic potential of ocean energy technologies, in the line of what was done in the 2014 Strategic Initiative for Ocean Energy (SI Ocean). An particularly important aspect would be understanding alternative markets for ocean energy, such as for offsetting diesel-generators on islands or for small coastal communities.

The R&I actions foreseen by the Ocean Energy SET Plan Implementation Plans are still extremely relevant, and further backing should be gathered at national level to build on the European Commission's support to ocean energy development.

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# APPENDIX A: LIST OF EC-FUNDED PROJECT AND AREAS OF RESEARCH

*Table 18 List of EU co-fund projects identified for the scope of this report. The table presents also which sub-technologies were investigated by the projects, and the specific R&D areas of investigation*

| Instrument | Project Acronym | Technology Dev | Device 1 | Wave | Tidal | Wind | Coordination Activitiy | Standardisation | Demonstration | Testing | Multiplatform | PTO | Device | Structure | Optimisation | Resource | Training | Consenting | Grid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SME | BUTTERFLY | YES | Butterfly (Rotary Waves) | ● | | | | | | | | | ● | | | | | | |
| IA | CEFOW | YES | Wello Penguin | ● | | | | | ● | ● | | | ● | | | | | | |
| SME | D2T2 | YES | Nova Innovation | | ● | | | | | | | | | | | | | | |
| **IA** | **DEMOTIDE** | **YES** | **Atlantis** | | ● | | | | ● | | | ● | ● | | ● | | | | |
| SME | Direct Drive TT | YES | Nova Innovation | | ● | | | | | ● | | ● | | | | | | | |
| SME | DP Renewables | YES | Design Pro (River Turbine) | | | | | | | ● | | | | | | | | | |
| IA | DTOceanPlus | YES | Multple for validation | | | | | ● | ● | ● | | | | | ● | | | | |
| SME | eForcis and BeForcis | YES | Eforcis | ● | | | | | | | | | | | | | | | |
| IA | EnFAIT | YES | Nova Innovation | | ● | | | | ● | | | | | | ● | | | | |
| CSA | ETIP OCEAN | NO | | | | | ● | | | | | | | | | | | | |
| SME | FFITT | | | | | | | | ● | ● | | ● | | ● | ● | | | | |
| IA | FloTEC | YES | ScotsRenewable | | ● | | | | | | | | | | | | | | |
| SME | HydroKinetic-25 | YES | Design Pro (river) | | | | | | | ● | | | | | | | | | |
| RIA | IMAGINE | YES | Umbra | | ● | | | | | | | ● | | | | | | | |
| FTIPilot | InToTidal | YES | Tocardo | | ● | | | | ● | | | ● | ● | ● | | | | | |
| RIA | MARINERGI | NO | | ● | ● | ● | | | | ● | | ● | | | | | | | |
| RIA | MARINET2 | NO | | ● | ● | ● | | | | ● | | ● | | | | | | | |
| RIA | MegaRoller | YES | Waveroller | ● | | | | | ● | ● | | ● | | | | | | | |
| MSCA | MoWE | NO | | ● | | | | | | | | | | ● | | | | | |
| CSA | MUSES | NO | | ● | ● | | | | | | | | | | | | | ● | |
| FTIPilot | OCEAN_2G | YES | Magallanes | | ● | | | | ● | | | ● | ● | | | | | | |

| Instrument | Project Acronym | Technology Dev | Device 1 | Wave | Tidal | Wind | Coordination Activitiy | Standardisation | Demonstration | Testing | Multiplatform | PTO | Device | Structure | Optimisation | Resource | Training | Consenting | Grid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSA | OCEANERA-NET COFUND | NO | | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **IA** | **OCTARRAY** | **YES** | **Openhydro** | ☐ | ● | ☐ | ☐ | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| RIA | OCTTIC | YES | Openhydro | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ● | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| SME | OHT | YES | Ocean Harvesting Technologies | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| RIA | OPERA | YES | OceanTEC | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ● | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| MSCA | OpTiCA | NO | | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ● | ☐ | ☐ | ☐ | ☐ |
| RIA | PowerKite | YES | Minesto | ☐ | ● | ☐ | ☐ | ☐ | ● | ● | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| RIA | RealTide | YES | Sabella | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ● | ● | ☐ | ☐ | ☐ |
| SME | SEAMETEC | YES | Enerocean | ● | ● | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ |
| RIA | SEA-TITAN | YES | Wedge Global | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| SME | SUBPORT | YES | Current2current | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | LIFE DEMOWAVE | | | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| RIA | TAOIDE | YES | ORPC | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ● | ☐ | ● | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| RIA | TIPA | YES | Nova Innovation | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ● | ☐ | ● | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| SME | WATEC | | | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| RIA | WaveBoost | YES | Corpower | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | Wavepiston | YES | Wavepiston | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | WETFEET | YES | Symphony | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ● | ● | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

# APPENDIX B: ENTRY TRL OF TECHNOLOGY PROJECTS

| Project Acronym | Technology Development | Device 1 | Device 2 | TRL1 | TRL2 | TRL3 | TRL4 | TRL5 | TRL6 | TRL7 | TRL8 | TRL9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BUTTERFLY | YES | Butterfly (Rotary Waves) | | | | ● | ● | ● | | | | |
| CEFOW | YES | Wello Penguin | | | | | | | | ● | | |
| D2T2 | YES | Nova Innovation | | | | | | | ● | ● | ● | |
| DEMOTIDE | YES | Atlantis | | | | | | | | | ● | ● |
| Direct Drive TT | YES | Nova Innovation | | | | | | ● | ● | | | |
| DP Renewables | YES | Design Pro (river) | | | | | | ● | ● | | | |
| eForcis and BeForcis | YES | Eforcis | | | | | ● | ● | | | | |
| EnFAIT | YES | Nova Innovation | | | | | | | | | ● | ● |
| FFITT | | Fish Flow | | | | ● | ● | | | | | |
| FloTEC | YES | ScotsRenewable | | | | | | | | | ● | ● |
| HydroKinetic-25 | YES | Design Pro (river) | | | ● | ● | | | | | | |
| IMAGINE | YES | Umbra | | | | | | | ● | ● | | |
| InToTidal | YES | Tocardo | | | | | | | | ● | ● | |
| MegaRoller | YES | Waveroller | | | | | | | | ● | ● | |
| OCEAN_2G | YES | Magallanes | | | | | | | | ● | ● | |
| OCTARRAY | YES | Openhydro | | | | | | | | | ● | ● |
| OCTTIC | YES | Openhydro | | | | | | | | ● | ● | |
| OHT | YES | Ocean Harvesting Technologies | | | | | ● | ● | | | | |
| OPERA | YES | OceanTEC | | | | | | ● | ● | | | |
| OpTiCA | NO | | | | | | | | | | | |
| PowerKite | YES | Minesto | | | | | | | ● | ● | | |
| RealTide | YES | Sabella | | | | | | | | ● | ● | |
| SEAMETEC | YES | Enerocean | | | | | | ● | | | | |
| SEA-TITAN | YES | Wedge Global | | | | | | | ● | | | |
| SUBPORT | YES | Current2current | | | | | ● | ● | | | | |
| LIFE DEMOWAVE | | Life Demo | | | | | | ● | ● | | | |
| TAOIDE | YES | ORPC | | | | | | ● | ● | | | |
| TIPA | YES | Nova Innovation | | | | | | | | ● | ● | |
| WaveBoost | YES | Corpower | | | | | | ● | ● | | | |
| Wavepiston | YES | Wavepiston | | | | ● | ● | | | | | |
| WETFEET | YES | Symphony | | | ● | ● | | | | | | |

# APPENDIX C: ETIP OCEAN TECH KEY R&I AREAS

| Priority | Challenge | Description |
|---|---|---|
| A.1 | Developing novel concepts for improved power take-offs (PTOs | Work to improve the performance, reliability and cost of PTOs will help maximise energy capture. |
| A.2 | Increasing device reliability and survivability | Improving resilience of devices, e.g. using control systems. Control systems act to optimise power production and reduce stress and fatigue on components by allowing devices to adapt to changing ocean conditions. |
| A.3 | Investigating alternative materials and manufacturing processes for device structures | Alternatives to traditional structural materials such as steel and concrete may overcome the limitations of these materials and offer improvements in cost, performance and survivability. |
| A.4 | Investigating novel devices before moving towards convergence of design | Further investigation of novel device concepts (particularly for wave technologies) is required to provide a step-change before moving towards a consensus on the best concepts to pursue in the longer term. |
| A.5 | Defining and enforcing standards for stage progression through scale testing | Small scale testing in controlled environments allows thorough investigation of specific conditions and underlying physical characteristics before progression to larger scale, more realistic and riskier testing. |
| A.6 | Developing and implementing optimisation tools | Optimisation tools allow the planning of optimal array designs, providing greater certainty of success in an open water environment and a method of assessment and comparison in stage-gate programmes. |
| B.1 | Building on existing guidelines and standards for third-party verification and testing | Third-party verification and testing is required to validate technologies and meet commercial investment criteria. Guidelines and standards allow for comparison between technologies and improved knowledge exchange. |
| B.2 | Developing improved, more cost effective mooring and foundation systems | Mooring and foundation systems (particularly their installation and maintenance) currently represent a very significant portion of overall project costs. |
| B.3 | Implementing suitable condition monitoring systems | Condition monitoring allows for condition based maintenance systems, streamlining O&M and delivering high reliability. |
| B.4 | Improving the efficiency and cost-effectiveness of electrical subsystems and power electronics | The method by which electricity is transmitted throughout an array and then exported to shore is subject to efficiency losses and significant infrastructure costs, both of which stand to be reduced. |
| B.5 | The method by which electricity is transmitted throughout an array and then exported to shore is subject to efficiency losses and significant infrastructure costs, both of which stand to be reduced. | |
| B.6 | Optimising offshore operations and maintenance missions | Manned offshore O&M missions are expensive, risky and time consuming. Periods of suitable weather conditions for O&M missions can be short and infrequent, potentially leading to extended downtime for array components. Remote O&M systems may mitigate such issues. |
| B.7 | Developing dedicated vessels and tools | Tools and vessels tailored to the specific needs of ocean energy O&M missions will allow more optimal use of limited weather windows. |
| C.1 | Developing expertise related to the manufacture of ocean energy technologies | Manufacture of ocean energy array components must move from custom designs to mass production to enable cost reduction, supply chain engagement and sufficient volume output. Increased supply chain engagement presents a significant economic opportunity. |
| C.2 | Scaling up from single device deployments to arrays | Significant cost reductions can be achieved through economies of scale while utility scale developments are of greater commercial appeal. |

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