Strategic Research and Innovation Agenda for Ocean Energy

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European Technology & Innovation Platform for Ocean Energy

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COVER PHOTO: Deployment of the PLAT-I tidal energy platform, courtesy of Sustainable Marine Energy

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Strategic Research and Innovation Agenda for Ocean Energy

This Strategic Research and Innovation Agenda (SRIA) for ocean energy outlines the priority research, development and innovation challenges that must be focused upon in the years ahead. The SRIA gives guidance to all funders of innovation – industry, EU, national and regional – by presenting concrete research and innovation actions that will allow ocean energy to meet its SET Plan targets.

Ocean Energy Europe

tecnalia

WavEC Offshore Renewables

THE UNIVERSITY of EDINBURGH

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Foreword

Fiona Buckley

Chair of the ETIP Ocean Steering Committee
Senior Expert and Project Manager, ENGIE

I am delighted to present to you the 2020 Strategic Research and Innovation Agenda (SRIA) for Ocean Energy.

Ocean energy has made remarkable progress in recent years. A record quantity of capacity has been installed and never-before-seen volumes of power have been produced. We now measure produced electricity in GWh instead of MWh.

This SRIA is the result of a comprehensive analysis of the technological improvements needed in the coming years. It builds on the achievements of the past and carves out the sector's path to industrialisation. For the first time, system integration of ocean energy arrays is identified as a priority. This highlights the sector's readiness to enter the market at a larger scale.

Technological push should be coupled with market pull mechanisms such as revenue support, to enable demonstrations and first pre-commercial farms. These projects will dramatically bring down costs and unlock private investment. These cost reductions are needed to reach the SET Plan targets of 10 ct€/kWh, which is a waypoint to even further cost reductions.

Ocean energy will play a key role in the future energy mix. With vast and varied resources, different technologies are needed to harness ocean energy in different markets across Europe and worldwide. Be it low currents, strong tides, large or small waves, ocean energy will meet the needs of a diversified and decentralised future energy system.

The European Commission recognises this potential and will present an Offshore Renewable Energy Strategy (which includes ocean energy) to accelerate the development of the sector. I commend the Commission for its continuing belief in ocean energy. With this far-sighted support, the European ocean energy sector will maintain its leadership at a global scale and maximise the benefits for European citizens.

On behalf of the ETIP Ocean Steering Committee, I would like to thank the ETIP Ocean team and members of the Technology Working Group for their efforts and expertise. They have brought together the whole ocean energy sector in a united knowledge-sharing community.

Executive summary

Ocean energy is part of the solution to decarbonise Europe

Electricity production in 2050 will need to be emissions-free, low cost and flexible. To reach that objective, we will need demand-side management, storage and most importantly, all flexible renewables at our disposal – whether established already or still innovative today.

Europe's ocean energy resource is considerable. By 2050, ocean energy can deliver 100GW of capacity – equivalent to 10% of Europe's electricity consumption today.

Flexible and predictable, ocean energy complements variable renewables such as wind or solar, that will dominate Europe's electricity system in 2050. Ocean energy will play an important role in smoothing production peaks and balancing Europe's electricity grid.

By 2050, the ocean energy sector will employ 400,000 Europeans, ensuring a just transition to a decarbonised economy. Europe's technological advantage in ocean energy will ensure European companies a large share of a strong global market, as they do on offshore wind.

With zero carbon emissions, ocean energy will help tackle climate change and achieve a cleaner, more sustainable and more prosperous Europe.

RD&I funding will deliver vital progress across all stages of development

Ocean energy technologies have reached different stages in their development:

- Wave energy is at full-scale prototype stage
- Tidal energy is already at demonstration stage with first pilot farms
- OTEC and salinity gradient are at R&I stage, and tidal range can be rolled out.

For each of these stages, this Strategic Research & Innovation Agenda (SRIA) identifies the main 'Challenge Areas' that will deliver the greatest cost reductions. For each Challenge Area, a number of 'Priority Topics' are presented, identifying what the ocean energy sector should work on during the next period of 4-5 years – see Table 1.

Photo: Wavepiston

Table 1. Challenge Areas and Priority Topics for ocean energy research, development and innovation.

DESIGN AND VALIDATION OF OCEAN ENERGY DEVICES

Demonstration of ocean energy devices to increase experience in real sea conditions
Demonstration of ocean energy pilot farms
Improvement and demonstration of PTO and control systems
Application of innovative materials from other sectors
Development of novel wave energy devices
Improvement of tidal blades and rotor

FOUNDATIONS, CONNECTIONS AND MOORING

Advanced mooring and connection systems for floating ocean energy devices
Improvement and demonstration of foundations and connection systems for bottom-fixed ocean energy devices

LOGISTICS AND MARINE OPERATIONS

Optimisation of maritime logistics and operations
Instrumentation for condition monitoring and predictive maintenance

INTEGRATION IN THE ENERGY SYSTEM

Developing and demonstrating near-commercial application of ocean energy in niche markets
Quantifying and demonstrating grid-scale benefits of ocean energy

DATA COLLECTION & ANALYSIS AND MODELLING TOOLS

Marine observation and modelling to optimise design and operation of ocean energy device
Open-data repository for ocean energy

CROSS-CUTTING CHALLENGES

Improvement of the environmental and socioeconomic impacts of ocean energy
Standardisation and certification

SRIA: targeting the actions which will bring the greatest cost reductions

Ocean energy projects are already showing drastic cost reductions: according to the European Commission's Joint Research Centre, tidal stream reduced its LCOE by more than 40% in the last three years. The SRIA actions will further lower the LCOE towards competitive levels and will allow the sector to meet its SET Plan targets[1].

Design & validation of devices

Given the harsh sea conditions within which ocean energy devices must operate and survive, robust technology must be designed and validated. Demonstration of ocean energy devices and pilot farms in real sea conditions for long periods of time are crucial in validating the technology and achieving high TRLs. Focusing on one or several key sub-systems is an option. This will significantly improve the overall reliability, energy yield, availability, operating cost and lifetime costs of complete ocean energy systems. This will then demonstrate cost-effectiveness, reduce risks and attract investors for future commercial projects.

Foundations, connections and mooring

To reduce operation time at sea and underwater, rapid connection and disconnection of mooring lines and foundations are needed. Foundations and moorings must also be able to survive heavy loads for a long period of time – up to 20 years depending on the lifetime of the device. For safe and efficient electricity transmission, power connections must be sea-tested and reliable. All of these improvements will help reduce both CAPEX and OPEX.

Marine operations

Devices must be easily accessible by the workforce, meaning they should be installed and maintained with minimal risk to personnel. This calls for tailored logistics and marine operations. Demonstration projects will generate valuable learnings and improve logistics and marine operations. This will in turn reduce the cost of installation, maintenance and decommissioning for upcoming commercial projects.

System integration

Ocean energy devices have the potential to serve as a flexibility mechanism for a future grid based on variable wind and solar. Evaluating ocean energy's system-balancing benefits in both national and smaller grids will pave the way to integrating ocean energy farms into the future European energy system.

Public funding will leverage private investment

Even at this early technological stage, much of the investment comes from the sector itself. Nevertheless, public funding is needed to reduce investors' risks and progress the technology towards a commercial product. Fully funding the innovation actions identified in this SRIA at EU and national level can leverage about €335m of additional private investment. SRIA actions will advance the technology and bring the sector closer to a place where private investment becomes the primary driver.

Financial instruments, including revenue support, also need to be in place to support demonstration and pre-commercial projects. Together with those instruments and the technology improvements brought by the SRIA, ocean energy will soon reach industrialisation.

[1] 10 ct€/kWh for tidal by 2030, for wave by 2035.

1. Ocean energy for a 100% decarbonised Europe

Photo: Andritz

1.1 European Green Deal

Decarbonisation between now and 2050 will fundamentally transform European society. This is why President of the Commission Ursula von der Leyen's European Green Deal goes beyond just technology changes.

The Green Deal will radically change the way we power our homes, manage our electricity systems, create prosperity, treat our fellow citizens, and work in harmony with our environment. Ocean energy can help deliver a cleaner, more prosperous, more equal and more sustainable world than the one we live in today.

The conclusion is clear: ocean energy will help power the European Green Deal.

Ocean energy will be an effective focus of stimulus spending, once the 2020 health crisis has passed. The sector's beneficial impact on exports, jobs, SME activity, technological leadership and innovation-based growth will help re-ignite the European economy. Both industrial centres and peripheral regions will feel the benefit.

Developing new forms of renewable energy that balance Europe's future electricity grid will boost productivity and deliver longer-term economic growth – all while still helping achieve the original objectives of the Green Deal.

Figure 1. Examples of how ocean energy will help deliver in all areas of the Green Deal.

Ocean energy will deliver large volumes of the renewable energy that Europe needs

100GW
Capacity

10% of Europe's electricity consumption

A decarbonised Europe will be a more electrified Europe. Renewable electricity will be used to decarbonise large chunks of the transport, industry and heating/cooling sectors. The European Commission sees electricity generation at least doubling by 2050 in most scenarios. In some scenarios the increase is even higher[2]. Solar and wind will play a key role, but other renewables are needed to help balance the grid.

Ocean energy can deliver 100 GW of capacity by 2050 – equivalent to 10% of Europe's electricity consumption today – all along the Atlantic coast from Portugal to Norway, along the Baltic sea and the periphery of the Mediterranean. With almost 45% of Europe's citizens living in coastal regions[3], ocean energy can be readily delivered where it is needed.

Ocean energy sector is led by European companies

European companies lead the world in ocean energy. In tidal stream, the world's first offshore array is located in Europe, as is the world's largest tidal array, and the world's largest tidal turbine. In wave energy, Europe remains the world leader with the largest amount of full-scale wave energy devices and 1,250 kW of capacity installed per year since 2010.

Europe has a chance to consolidate this lead and dominate a new global high-value market.

European companies
World leader in **tidal stream** and **wave energy**

Ocean energy will help deliver a just transition

Europe's decarbonisation efforts must benefit all segments of society. Ocean energy can create 400,000 jobs by 2050, all along the supply chain and across Europe. These jobs are created at a local level, revitalising the coastal communities that historically served for shipbuilding, fishing and the oil and gas sector. They are also created where the supply chain is, in countries such as Austria, Germany, Sweden and the Czech Republic.

Ocean energy can create
400,000 jobs
by 2050

Ocean energy works in harmony with local communities

Operates in harmony with the environment

Ocean energy has a very low visual impact, preserving the aesthetic and touristic value of the environment. Installed offshore, it leaves land use to other economic activities. Ocean energy has also a very limited environmental impact and in some cases can create new habitats or foraging areas for marine species.

EURO
GREEN

[2] European Commission's 'Long-Term Decarbonisation Strategy', Figure 22.
[3] European Commission, 2019, 'The EU Blue Economy Report. 2019'.

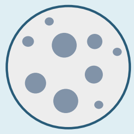
Ocean energy complements other renewables and balances electricity systems

Europe’s electricity system in 2050 will have massively more variable renewable energy, such as wind and solar. This will make it much more challenging to balance the grid. Ocean energy is flexible and predictable, and it will play an important role in balancing Europe’s electricity grid.

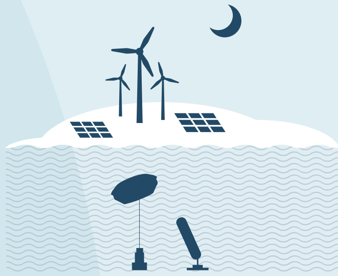
Regulated by the constant cycles of the moon, sun and earth, tidal stream is 100% predictable. System managers always know well in advance exactly how much tidal power will be available at any moment in time. Moreover, the time between tides is so short that even a small amount of storage can be used to enable non-stop, flexible tidal power – this is already happening today.

Waves follow a different pattern from wind and solar. Wave works particularly well with wind – the waves are built up by the wind, so when the wind dies down, wave energy can step in to maintain power production. Combined, wind and wave together produce an overall power output that is smoother, and more reliable.

Ocean energy will reduce the need for storage and make the electricity grid more efficient, more reliable, and more cost effective.



Driven by the moon
Tidal stream is
100% predictable
years in advance



Wave energy:
complements
variable renewables

Ocean energy will help deliver a prosperous transition

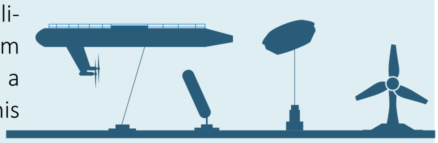
Ocean energy global market
€53bn / year
by 2050

Decarbonisation efforts must also provide citizens with opportunities for prosperity. Europe has the opportunity to be the first climate neutral continent and reap the benefits in the process. Competitiveness today means developing at home and exporting climate friendly innovations and practices to international markets.

Ocean energy is a perfect example: the global market is estimated at €53bn per annum by 2050, and Europe already has the technological lead. 66% of tidal energy patents and 44% of wave energy patents are held by Europeans.

The time for ocean energy is now

Ocean energy is on the brink of industrialisation. In order to maintain the European leadership and deliver all the benefits ocean energy has to offer, the European sector and policymakers must act without delay. The right support system will unleash the oceans’ potential in order to achieve a 100% decarbonised Europe. See Chapter 4 for what this could look like.



2. Ocean Energy Opportunities and Needs

Photo: Marine Power Systems

2.1 A sea of innovative solutions

The oceans have huge potential as sources of renewable energy. Several technologies are under development to harness that energy to power human activity. These technologies are tidal stream, wave, Ocean Thermal Energy Conversion (OTEC), salinity gradient and tidal range.

It is technologically challenging to develop these devices. They must operate in harsh environments with widely varying conditions – e.g. meteorology, temperature, salinity, depth and remoteness. The challenges outlined in this report focus on tidal stream and wave energy given their high market potential for Europe, commercial maturity, and Europe's current leading position in this sector [1].

Tidal stream – on the verge of industrial roll-out

Tidal stream turbines harness the flow of ocean currents, like underwater wind turbines. Tidal stream turbines can be mounted directly on the seabed or floating, moored to the seabed [2].

The method for extracting energy from tidal streams is approaching design convergence. Successful designs generally comprise two- or three-bladed **horizontal-axis turbines** (Figure 2). Alternative designs include **vertical axis turbines** (Figure 3) and **tidal kites** (Figure 4)[4].

Technologies are approaching commercialisation, with the deployment of full-scale devices in real sea conditions, as well as an increasing number of pilot farms.

[4] The rotors of a horizontal-axis turbine are turned by the tidal stream, much like a wind turbine's blades would be turned by the wind. The vertical axis turbines work under the same principles as horizontal axis turbines, except vertically. Tidal kites are tethered to the seabed with a turbine attached below its 'wing', and 'flies' to extract more energy from slower flows.

Figure 2. A horizontal axis tidal stream turbine (SIMEC Atlantis).

Figure 3. A vertical axis tidal stream device (GKinetic).

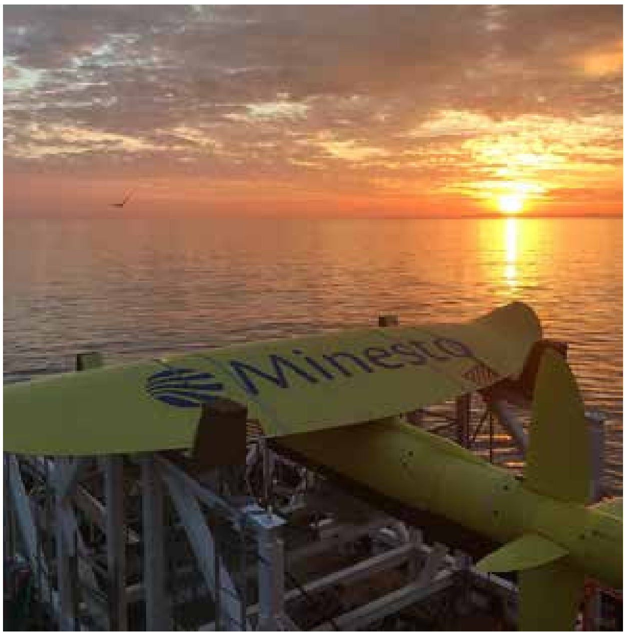


Figure 4. A tidal kite tidal stream device (Minesto).

Wave – several promising designs in development

Wave Energy Converters (WECs) harness the energy of the movement of the waves. WECs can be deployed both on, near or further away from the shoreline.

Wave energy technology remains at an earlier stage of development than tidal stream technology, with novel device prototypes – both scaled and full size – undergoing testing at sea. Wave energy is comparatively further from technological convergence. Unlike tidal, wave energy may converge to several different designs, each tailored to extract energy most efficiently from different local conditions.

Wave prototypes are currently found in three main forms: **point absorber** (Figure 5), **oscillating water column** (Figure 6) and **oscillating wave surge converter** (Figure 7)[5].

WEC developers are currently improving the performance of their devices through design improvements. This will allow proving of the technology at higher TRLs, and subsequent commercialisation [3].

[5] The point absorber is a floating structure that absorbs energy through the movement of the waves at the water's surface. The oscillating wave surge converter is usually mounted on the seabed in shallower water, and harnesses energy through an oscillating flap. The oscillating water column is a partially-submerged, hollow structure open to the sea water below the surface, trapping air above the water. The air is channelled through an air turbine.

Figure 5. A point absorber WEC (Laminaria).

Figure 6. An oscillating water column WEC (Ocean Energy Ltd).

Figure 7. An oscillating wave surge WEC (AW Energy).

Aside from wave and tidal stream, three other technologies are under development, at a range of maturity levels [4]:

- Ocean Thermal Energy Conversion (OTEC), including Sea-Water Air Conditioning (SWAC), exploits temperature differences found at different ocean depths (Figure 8).
- Salinity gradient exploits the osmotic pressure between seawater and fresh water.
- Tidal range harvests energy from the difference in sea level between high and low tides – just like hydropower.

Figure 8. A SWAC power station Thassalia (Engie).

2.2 Progress to date

2.2.1 Tidal stream

Tidal stream has reached a relatively high TRL of between 6 and 8, depending on device type [3]. Devices and their components and sub-systems are expected to reach competitive cost levels following an estimated decade of further research, development and real-sea deployments[6]. With appropriate support mechanisms, array-scale deployment is possible in Europe today.

The rated power of existing tidal turbines ranges between smaller scale devices of 0.1-0.25 MW, and larger scale of 1 and 2 MW, with scope to increase larger devices by 50% or more in the coming years [5]. Tidal stream's progress in recent years is demonstrated by the operating hours accumulated, capacity deployed and electricity generated. Since 2010, over 27.7 MW of tidal stream has been deployed in Europe. 10.4 MW of this is currently operating, and 17.3 MW has now been decommissioned following the successful completion of testing programmes [6].

An industrial supply chain is growing out of both existing practices, modified to suit the requirements of this technology, and the creation of new supply chains specific to the needs of tidal technology [7].

The first evidence of tidal stream's balancing role in future electricity systems is being demonstrated. Tidal stream's predictability has important grid-balancing benefits and places the technology in a strong position relative to alternative renewable energy sources. The periods between tides are always short, so the addition of small volumes of storage can deliver 24/7 power and extra flexibility to electricity systems.

Nova Innovation's Shetland Tidal Array has an integrated battery pack that can accommodate the full power of the array, for applications like load balancing [8]. Sabella's single turbine uses storage to balance the power fluctuations [7].


Photo: Green Marine

[6] The European Strategic Energy Technology (SET) Plan foresees tidal stream generating electricity at 10 ct€/kWh by 2030.

EU-FUNDED PROJECTS DRIVING PROGRESS

European-funded tidal stream prototypes are found in bottom-fixed turbine, floating turbine, and kite form.

EnFAIT

Figure 9. Nova Innovation's M100 tidal turbine.

Within the EnFAIT project and operated by Nova Innovation, an array of three turbines is deployed. The array will soon be doubled in capacity from 0.3 MW to 0.6 MW. The bottom-fixed array has achieved over 24,000 hours generating power to the grid [7].

SABELLA'S D10 TURBINE

Figure 10. Sabella's D10 turbine.

Sabella's D10 turbine, partly funded by the EU's regional funds, was France's first tidal turbine to connect to the national electricity grid [9].

FloTEC

Figure 11. Orbital Marine Power's SR2000 device.

Operating within the FloTEC project, Orbital Marine Power's floating 2 MW turbine achieved 12 continuous months of operation, generating more than 3.3 GWh of electricity [10]. This testing in real-sea conditions validated the technology, studied Operation and Maintenance (O&M) costs and demonstrated value to the potential market [10].

NEMMO

Figure 12. NEMMO project improves Magallanes Renovables' blade to reduce the cost of tidal energy.

The NEMMO project aims at improving performance and reliability by improving blade survivability and performance testing based on Magallanes Renovables' tidal turbine in modelled harsh conditions [11].

TiPA AND POWERKITE

Figure 13. Deployment of TiPA PTO for subsea testing.

Figure 14. Deployment of the Minesto device as part of the PowerKite project.

Innovative Power Take-Off (PTO) designs are undergoing sea testing at full- and reduced-scale under the TiPA and PowerKite projects [12] [13]. The TiPA project tested a 'direct drive' turbine that does not need a gearbox [14]. The PowerKite project saw the deployment of a 500kW device off North Wales.

2.2.2 Wave

Currently, wave technology TRL is at up to 7. Only onshore designs such as the OWC Mutriku Wave Power plant in the Basque Country have demonstrated consistent power production and can be placed at TRL 8 [15]. Since 2010, 11.8 MW of wave energy has been installed in Europe. Of this, 1.5 MW is currently in the water and 10.3 MW has been decommissioned due to the successful completion of testing programmes. Research continues into geographical resource profiles and potential markets [7].

An industrial supply chain is growing, with suppliers both focused on requirements specific to wave, and adapting their existing services to cater to the new technologies [7]. Knowledge and experience of survivable materials can potentially be found in other sectors, such as offshore wind or oil and gas.

The development of wave energy device prototypes has reached a more sustainable pace: phased development has helped mitigate the risk of large-scale prototype testing. Figure 15 illustrates the five stages of this technology development according to TRL, from concept validation through to pre-commercial stages [7].

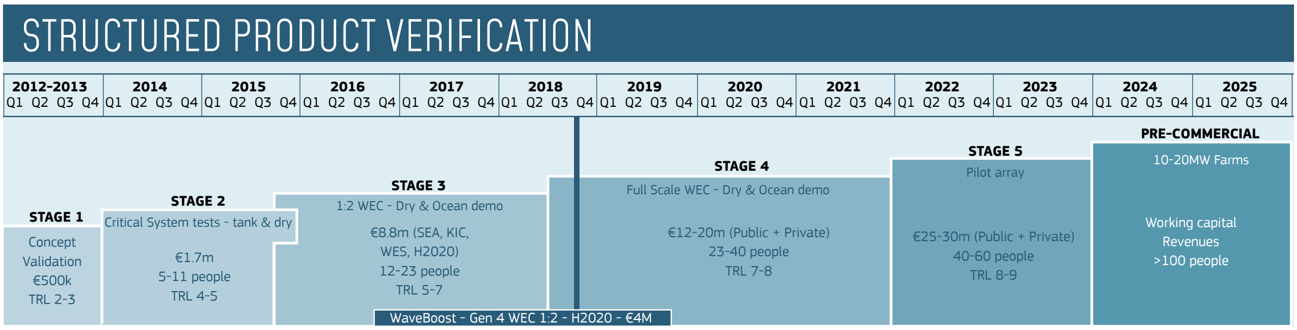


Figure 15. Example timeline for product verification in five stages according to IEA-OES / equimar best practice, (CorPower Ocean) [7].

EU-FUNDED PROJECTS DRIVING PROGRESS

European programmes are funding investigations into a number of areas important for the progression of wave technology. Several WECs have been progressed to full-scale demonstration stages, following successful reduced-scale testing in recent years.

WAVEBOOST

Figure 16. CorPower Ocean's half-scale demonstration project at EMEC test site.

The WaveBoost project developed and validated an innovative PTO technology that improved reliability and performance of CorPower Ocean's point-absorber buoy [16].

OPERA

Figure 17. The OPERA project improved IDOM's MARMOK-A-5 device.

The OPERA project, completed in 2019, validated and de-risked innovation in wave energy development and increased TRL by deploying a device in open-sea operating conditions and sharing the resulting data [17].

EMERGE

Figure 18. The EMERGE project has developed an innovative ballscrew-based PTO reaching TRL7.

Innovative PTO designs are undergoing sea testing at full- and reduced-scale. An example of this work is the repurposing of aerospace technology for novel PTOs, such as Umbra Cuscinetti S.p.A.'s EMERGE and IMAGINE projects [18] [19]. Umbra's Electromechanical Generator PTO was integrated into real-sea scale testing of the EEL Energy tidal device [20].

SEA-TITAN

Figure 19. The SEA-TITAN project is developing a second-generation Direct Drive PTO (first-generation PTO in the picture).

The SEA-TITAN project, coordinated by Wedge Global, is designing, building, testing and validating an innovative second-generation Direct Drive PTO that will maximise energy generation while protecting devices in extreme conditions [21] [7].

2.2.3 Other ocean energy technologies

OTEC is being demonstrated at plants in EU overseas territories [4]. Ocean ERA-NET has funded a project aimed at the development of advanced non-corrosive materials which will improve the survivability, durability and reliability of ocean thermal energy converters [22]. The technology can also be harnessed to deliver SWAC and desalination.

Salinity gradient technology requires further development of membrane materials [4]. Commercial plants require very large quantities of membranes, so more economic and efficient membranes need to be developed at large scale [23]. Countries around the world are developing and testing this technology – the Netherlands and Mexico are key participants [10].

Generation of power using **tidal range** began back in the 1960s [4]. European annual generation from tidal range is 500GWh, by La Rance Tidal barrage in France [24].

Photo: Seabased

3. Ocean energy achieving ambitious cost reduction

The ultimate aim of improving the technology is to reduce the LCOE to competitive levels. The SET Plan has set ambitious cost targets for ocean energy (Table 2) [1].

	2025	2030
Tidal stream	0.15 EUR/KWH	0.10 EUR/kWh
Wave	0.20 EUR/KWH	0.15 EUR/kWh

Table 2. SET Plan cost targets for ocean energy.

Research and innovation actions help to improve yield, reliability, availability and survivability, and to reduce risk and capital and operating expenditure. All of these are key levers to reduce the cost of every unit of ocean energy.

Research and innovation actions will always play an important role in this journey, but different types of actions will have the greatest impact on cost reduction at different stages of the sector's development.

Classic research actions will generate early reductions. Prototype-testing in tanks and test-sites will then establish 'proof of concept' and build investor confidence and secure cheaper capital. This phase will culminate in the deployment of the first demonstration arrays – several full-scale devices deployed in real-sea conditions for several years without interruption. These demonstration arrays will reinforce investor confidence and achieve further cost reductions via 'learning by doing'.

The large-scale deployment of ocean energy capacity in European waters will then deliver the most dramatic cost reductions – much like offshore wind. Research and innovation activities will continue in parallel, as new learnings from deployments are fed back to the laboratory to generate ever-improving performance.

Ocean energy's journey to 10 ct€/kWh with its cost reduction levers is illustrated in Figure 20.

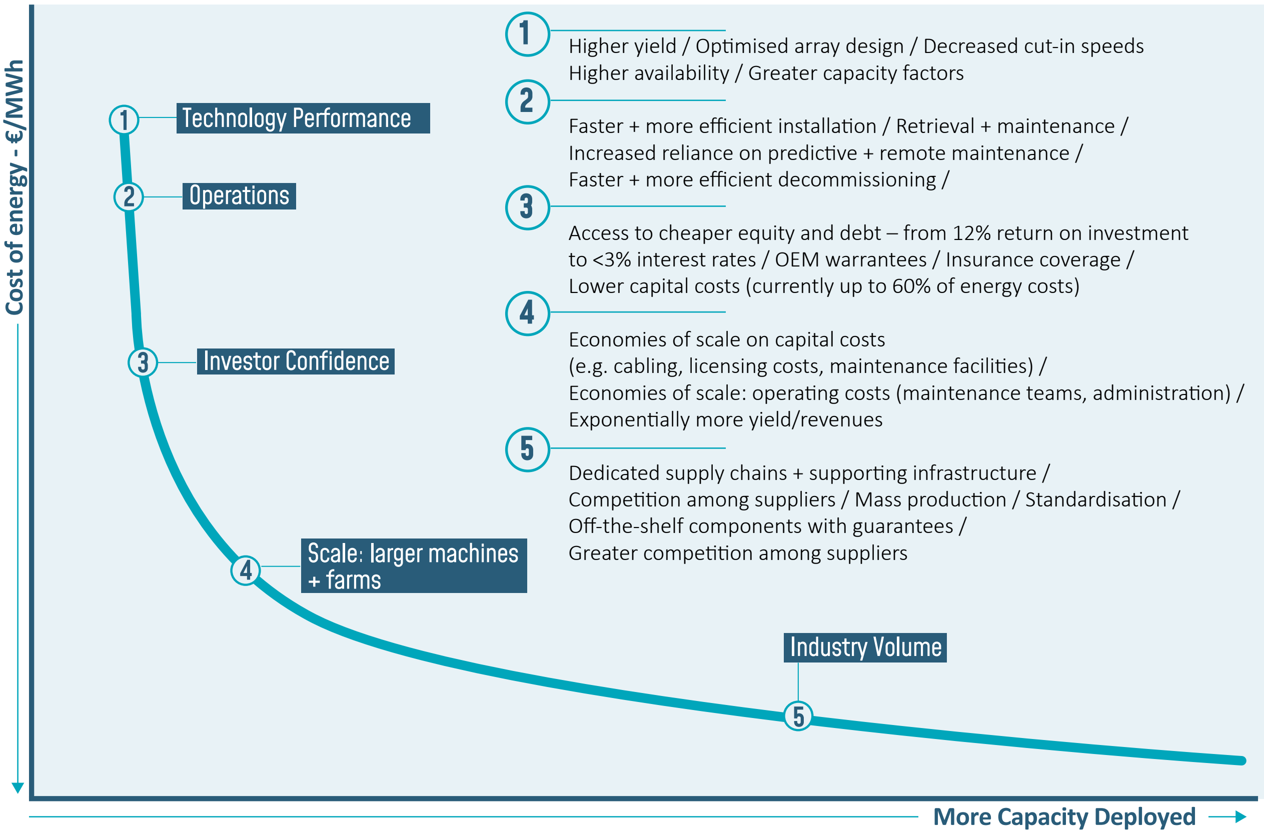


Figure 20. Ocean energy sector's cost reduction levers[7].

The toughest first steps have already been taken

Ocean energy projects are already delivering the cost reductions necessary to hit these targets. The European Commission's Joint Research Centre has found that tidal stream's 'LCOE has been cut by more than 40% in the last three years alone. The energy costs of today's tidal stream projects are well below expectations (Figure 21) [25].

As wave is circa five years behind tidal, less aggregate data is available on current energy costs. However, individual projects suggest that important reductions are being made. Recently concluded Horizon 2020 projects 'OPERA' and 'WaveBoost' reduced energy cost of their wave devices by 50% and 30% respectively [26] [16].

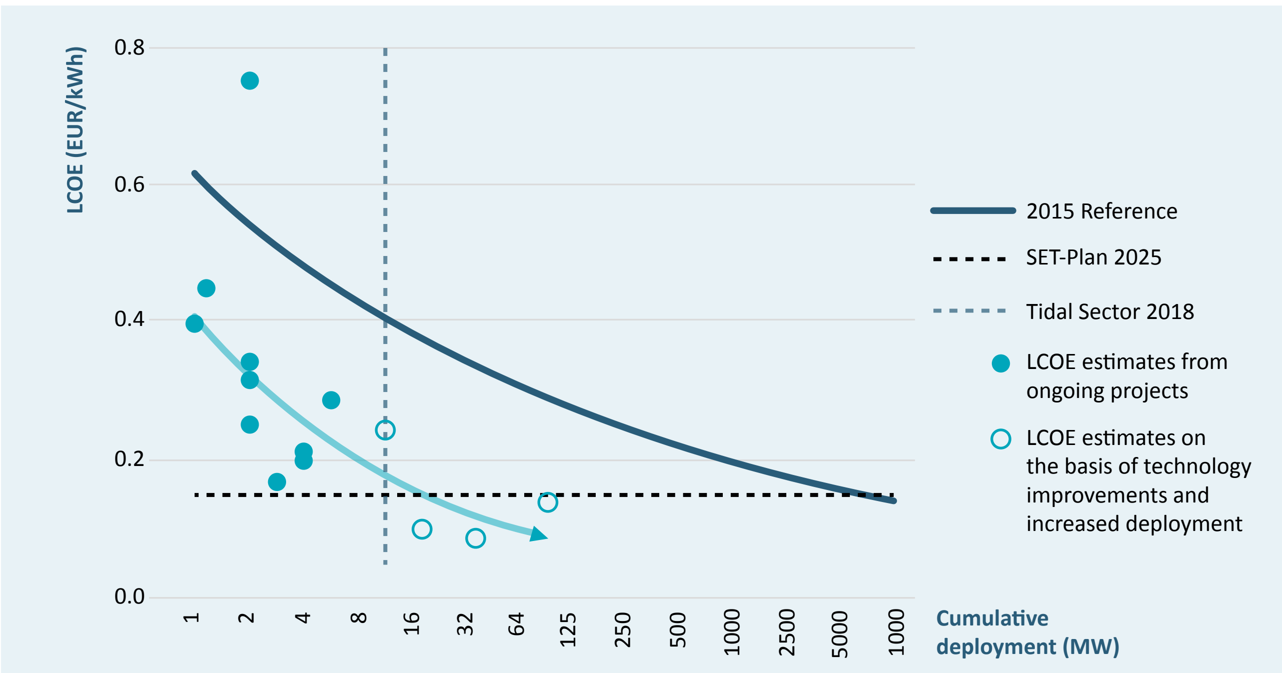
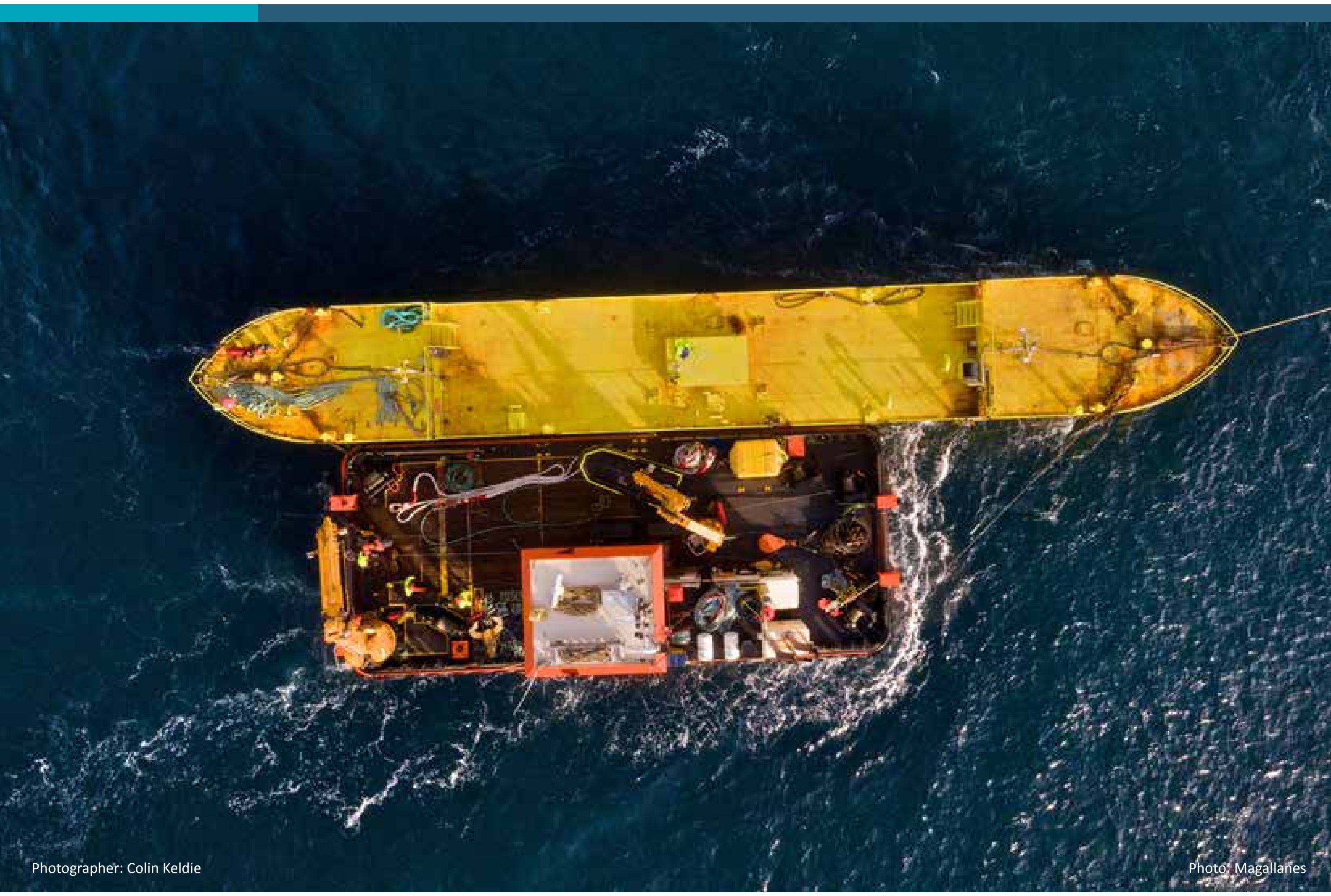


Figure 21. Cost-reduction curves for tidal energy and LCOE estimates from ongoing projects. Source: Joint Research Centre.

[7] Graph is illustrative - many of the different drivers of cost reduction will apply simultaneously and continuously as more capacity is deployed.

4. Public funding will leverage private investment



Photographer: Colin Keldie

Photo: Magallanes

Ocean energy's development will be at its fastest and most effective when public and private investors work together. The right EU and national level public funding at the right stages of development can attract and unlock significant volumes of private investments. €671m of public funding allocated to the identified innovation actions will leverage about €335m of private investment. A European Commission study has estimated that over €5bn of private funds have been invested into ocean energy across the globe, between 1978-2017 [27].

Table 3 shows the total budget required for each Challenge Area.

Table 3. Public & private budget needed to address all Priority Topics within each Challenge Area.

Challenge Areas	Priority Topics	Number and Size of actions[8]	Budget Required (million €)	
Design and Validation of Ocean Energy Devices	Demonstration of ocean energy devices to increase experience in real sea conditions	Around 10 large and 10 medium	150	700
	Demonstration of ocean energy technology at array scale	7 Projects at array scale	350	
	Improvement and demonstration of PTO and control systems	Around 10 medium and 5 small	60	
	Application of innovative materials from other sectors	A few medium and around 5 small	25	
	Development of novel wave energy devices	Around 10 small and 5 medium	45	
	Improvement of tidal blades and rotor	Around 5 medium and a few large	55	
	Development of other ocean energy technologies	A few medium	15	
Foundations, Connections and Mooring	Advanced mooring and connection systems for floating ocean energy devices	Around 10 medium	50	85
	Improvement and demonstration of foundations and connection systems for bottom-fixed ocean energy devices	Around 5 medium and around 5 small	35	
Logistics and Marine Operations	Optimisation of maritime logistics and operations	Around 5 medium and a few large	55	80
	Instrumentation for condition monitoring and predictive maintenance	A few medium and around 5 small	25	
Integration in the Energy System	Developing and demonstrating near-commercial application of ocean energy in niche markets	Several medium and a few large	80	86
	Quantifying and demonstrating grid-scale benefits of ocean energy	A few small	6	
Data Collection & Analysis and Modelling Tools	Marine observation modelling and forecasting to optimise design and operation of ocean energy devices	A few medium and around 5 small	25	35
	Open-data repository for ocean energy	Around 5 small	10	
Cross-cutting Challenges	Improvement of the environmental and socioeconomic impacts of ocean energy	Around 5 small	10	20
	Standardisation and certification	Around 5 small	10	
			TOTAL	**1,006**

Table 4 proposes a distribution of the budget needed by year and the source of funding (European funds, Member States and private funding).

Table 4. Suggested breakdown of budget needed per year and type of funding (million €).

	2021	2022	2023	2024	2025	TOTAL	%
EU	45	50	54	58	64	271	27%
Member States	70	75	80	85	90	400	40%
Private	57	62	66	72	78	335	33%
TOTAL	172	187	200	215	232	**1,006**	

[8] Size of projects include public and private funding with the following categories:
- Array scale: around €50m
- Large projects: over €8m
- Medium projects: between €2m and €8
- Small projects: €2m or less

In the short-to-medium term, the ocean energy sector must progress through the 'Commercial Valley of Death', where costs and risk are at their greatest. Public funding requirements of the sector will be at their highest at this stage.

Technological progress and learnings are also greatest at this stage, so passing through the Valley of Death will allow the sector to then significantly reduce the required contribution from EU and Member State sources.

Once the sector reaches industrial roll-outs, less public funding will be needed. The share of grants decreases as the TRL increases – technological and capital cost reductions mean that project revenues can cover a greater proportion of overall deployment expenditure.

Private investment will ultimately take over the basis for financing ocean energy projects, as they become commercially viable on a stand-alone basis.

These figures in Table 4 are consistent with estimations of resources devoted by the EU and Members States in previous years:

- Over the past 10 years, the European Commission has invested over €300m in ocean energy R&I through a multitude of funding programmes [28].
- Member States' R&I budget grew from an average of €5 m per year (1995-2008) to an average of €48m per year (2009-2015) [29].

The figures estimated in this SRIA (Table 3) are higher than the global budget for the period 2021-2025 of the SET Plan Implementation Plan, as they are based on an updated and a more detailed definition of challenges and actions. When concluding this period, progress by the sector should be assessed together with a revision of the Priority Topics which would be reflected in a new and updated SRIA.

To maximise private investment, the right type of R&I funding at the right stage is needed

A variety of funding instruments is needed, suited to ocean energy's different stages of development.

All stages of development benefit from R&I. Classic research actions are of particularly important at the early stages of technology development. Prototype devices and components must be first designed and tested in laboratories and tanks. This then allows real sea deployment, which generates invaluable learnings and lead to the validation of the technology. Learnings from more advanced stages are constantly fed back into new R&I activities, creating a 'virtuous cycle' of incremental innovation.

Currently, there are several different funding schemes in place providing support from R&I to pre-commercial stages. Many of these schemes can be applied to more than one stages, for example all the way from prototype to demonstration. Figure 22 gives examples of funding schemes at EU and national level.

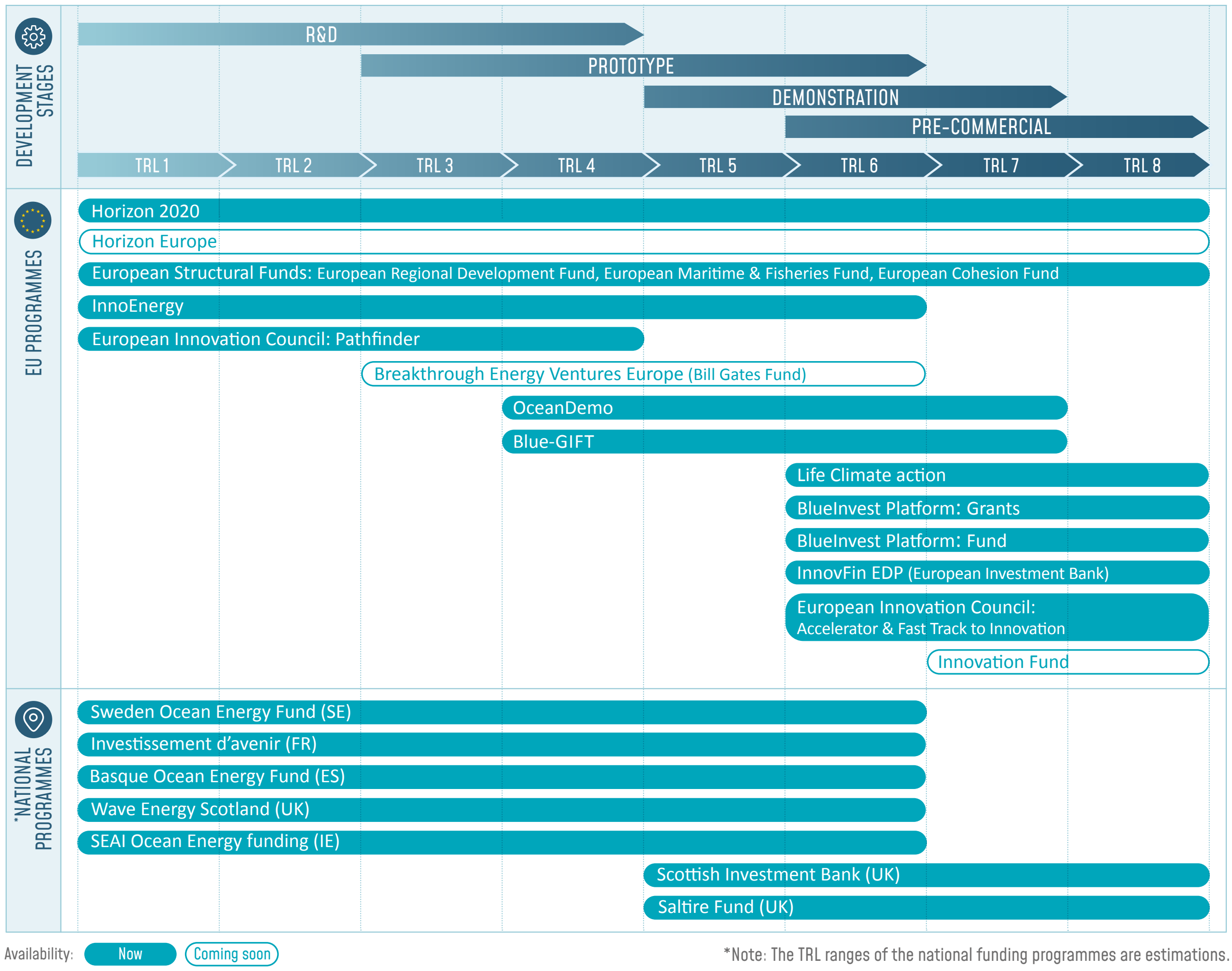


Figure 22. Examples of funding instruments at EU and national level.

The budget required for addressing the Priority Topics depends on the stage of innovation. Table 5 suggests a breakdown of budget required per stage of innovation based on the TRLs identified for the Priority Topics. This will help identifying the right funding instruments that ocean energy will need in the next years.

	R&I (TRL 1-4)	Prototype (TRL 3-6)	Demonstration (TRL 5-7)	Pre-commercial (TRL 6-8)	Industrial Roll-Out (TRL 7-9)	TOTAL
Million €	111	194	220	206	275	**1,006**
%	11%	19%	22%	21%	27%	**100%**

Table 5. Suggested breakdown of budget needed per stage of innovation.

Beyond R&I grant funding

Grants for R&I and prototype deployments will advance the technology up to a certain level. To reach full industrialisation, different support mechanisms in addition to grants are needed (Figure 23).

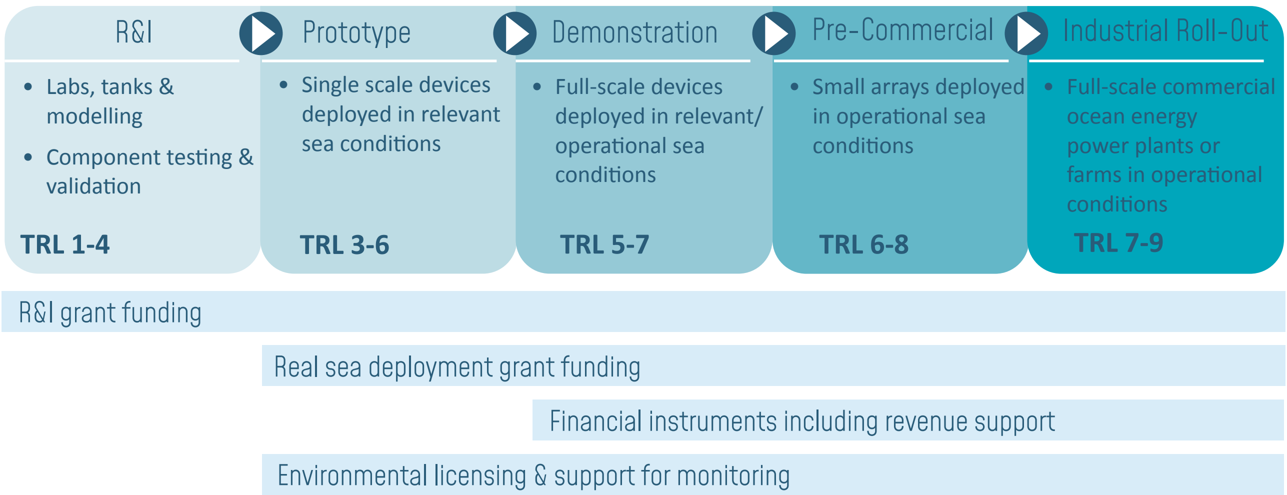


Figure 23. Stages of development with relevant support mechanisms.

The first two mechanisms are most relevant for SRIA Priority Topics: grant funding for R&I and real-sea deployment. Solutions for revenue support, financial instruments and environmental licensing & monitoring (Table 6) are discussed in detail in the ETIP Ocean 'Powering Homes' report[9]. These are necessary for demonstration projects to deploy multiple full-scale devices in real sea for extended periods of time.

Deployments in real-sea conditions over extended periods of time can deliver the greatest progress towards LCOE targets. R&I will deliver the technology that is to be deployed, but the right financial and licensing frameworks are needed to allow the deployments to happen.

Demonstrations and pre-commercial arrays still have high costs and grant funding is typically not enough to cover them. Instead, these projects need to generate revenues by selling the electricity they generate over a 15-20-year period. Revenue support – i.e. a 'top up' payment for each unit of electricity sold – covers the extra costs that market prices cannot. Financial instruments, such as publicly guaranteed debt, reduce the capital costs of these projects, and help narrow the 'financial gap' that needs to be closed.

All sea deployments need environmental licensing. Authorities are mostly focused on avoiding negative environmental impacts but often have limited experience of ocean energy. Approvals can therefore take a long time, have significant cost, and require evidence which can be disproportionate to the actual risk. Ocean energy projects can struggle and even fail due to excessive licensing requirements. Fit-for-purpose licensing frameworks are crucial to avoid these failures.

Financial instruments		Environmental licensing & monitoring	
• Revenue support • Publicly-guaranteed debt • Publicly-guaranteed equity	• Quasi-equity • Publicly backed guarantees • Public procurement	• Shared best practices • Adaptive Management • Marine Spatial Planning	• Support for environmental monitoring

Table 6. Support mechanisms as described in 'Powering Homes Today, Powering Nations Tomorrow – Policy Solutions to Deliver Ocean Energy Industrial Roll-Out'.

[9] 'Powering Homes Today, Powering Nations Tomorrow – Policy Solutions to Deliver Ocean Energy Industrial Roll-Out', ETIP Ocean, April 2019.

5. Description of Challenge Areas

Photo: Orbital

The Challenge Areas[10] represent a set of R&I fields that the ocean energy sector has identified as most worthy of investment during the next period of 4-5 years.

Ocean energy industry and research professionals agree that the **Design and Validation of Ocean Energy Devices** is the most urgent and crucial area to focus on. Addressing this area is the most important step to bring ocean energy to a level where private investment can gradually replace public supported projects in financing the further development of ocean energy. This is reflected in the larger number of Priority Topics projects in this Challenge Area.

The rest of the Challenge Areas focus on specific aspects of ocean energy systems, such as the **Foundations, Connections and Mooring**, **Logistics and Marine Operations, Integration in the Energy System, and Data Collection, Analysis and Modelling Tools.**

Finally, **Cross-cutting challenges** are intended to address the potential environmental and socio-economic benefits of ocean energy in the future energy mix.

[10] The Challenge Areas have been identified starting from the previous Strategic Research Agenda produced in November 2016. They have been updated taking into account the progress of the sector over the last years and in consultation with the ETIP Ocean Technology Working Group – see Annex for a full description of the process.

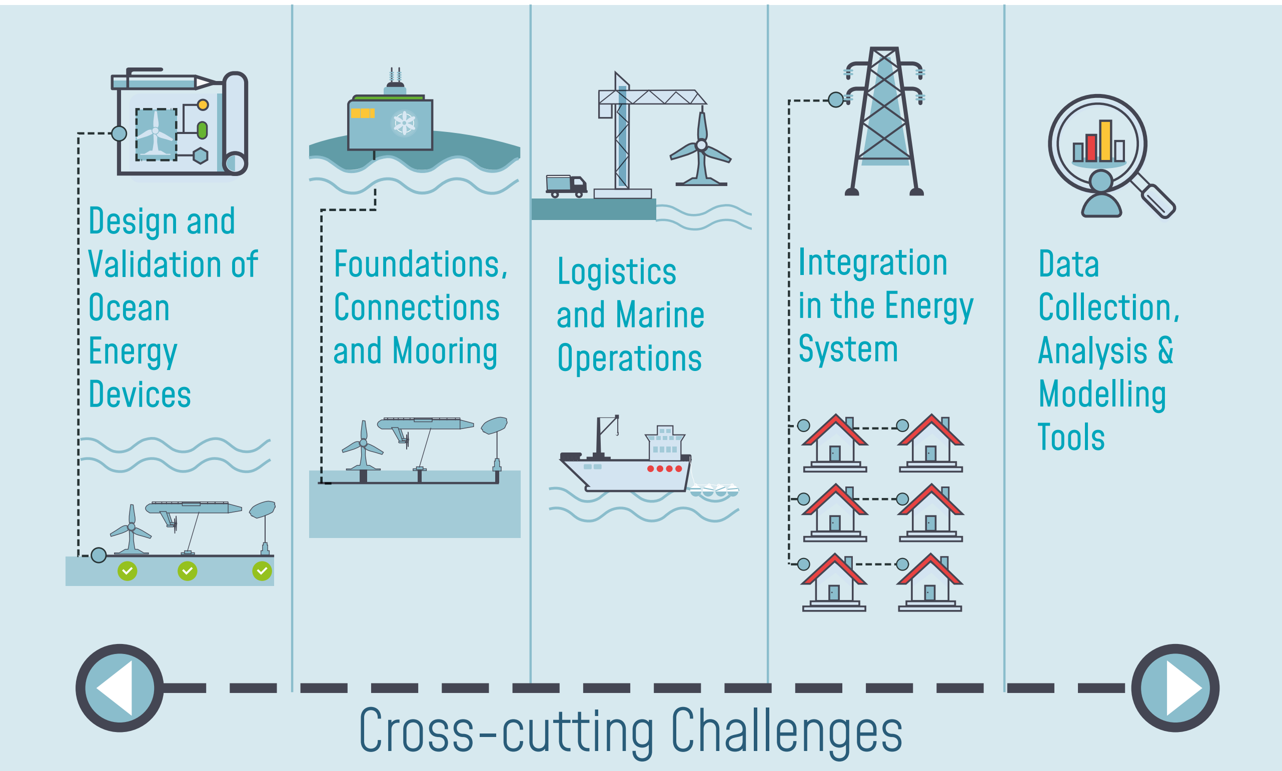


Figure 24. Challenge Areas of Ocean Energy.

Specific actions in each Challenge Area should all follow several key principles:

- Individual Priority Areas should **not be addressed in isolation** from the technology development of ocean energy devices or from other related sectors. A joined-up approach is essential. The need for knowledge exchange between the Challenge Areas is specifically identified in their descriptions.
- The implementation of these six challenge areas should be driven by a **systemic innovation approach that contributes to a clean and circular economy**. Transition to a higher level of circularity in the economy requires fundamental changes in the value chain, from product design and technology to new business models and new ways of preserving natural resources. Future technology developments in ocean energy should respect as far as possible these wider principles of sustainability.

The **optimal balance between open data and confidentiality** must be found. Accelerating development of the whole sector requires some degree of sharing experience and information. But fostering competitive European companies in the emerging supply chain requires intellectual property and some confidentiality. Previous EU-funded projects , such as the OPERA project [17], have shown that with the right planning and dialogue, it is possible to enroll private companies to participate in public-funded projects and deliver valuable open data while respecting their existing IP and confidentiality requirements.

- Condition public support upon explicit and demonstrable commitment from project leaders and their marine contractors to **publish detailed documentation and data on publicly-funded actions**. This will often require budgeting dedicated, possibly third-party staff and deck space or berths for documenting operations. This should not exclude companies with valuable background IP and confidentiality requirements, both of which should be respected.
- Fund some of the marine operations for ongoing open-sea deployments, which could be otherwise funded from other sources, as well as instrumentation to monitor their execution, in exchange for open access to data obtained from all or part of those operations. Respect the confidentiality of privately-funded experience.

In addition to these principles and the expected impacts described in each Priority Topic, projects funded under each Challenge Area should demonstrate a wider impact on European Green Deal objectives (Figure 1):

- **Climate Law:** help the EU reach the target of net zero greenhouse gas emissions by 2050.
- **Offshore Renewable Strategy:** demonstrate that ocean energy is ready for large-scale development, can bring grid-balancing benefits and help Europe decarbonise its electricity system.
- **Circular Economy Action:** respect the circular economy perspective in the design of technologies throughout life-cycles.
- **Just Transition:** create jobs in coastal regions that have suffered from the decline of traditional industries such as shipbuilding or fishing.
- **Industrial Strategy**: lead the world in ocean energy with the potential to dominate the high-value global market and keep Europe sustainable and competitive.
- **Biodiversity Strategy:** function in harmony with marine wildlife and with little or no visual impact.
- **SME Strategy:** involve innovative SMEs that contribute to a climate-neutral & socially sustainable economy.

5.1 Design and Validation of Ocean Energy Devices

This Challenge Area encompasses the research, design, development, demonstration and validation of ocean energy devices and their subsystems. The primary focus of this challenge is demonstration of wave and tidal energy technologies.

Design and validation of ocean energy devices involves extensive testing – from tanks in laboratory to deployment of scale and full-size prototypes in real sea conditions, as well as first pilot farms. There is currently widespread research infrastructure in place[11] but specific funding is required to develop and operate the devices that are deployed in these testing facilities.

Ocean energy devices need to be deployed in real sea conditions to validate and optimise key performance metrics. This will allow validation of the next generation of ocean energy technologies. The continued refinement of sub-systems, improved operational procedures, reduced risk through demonstrated performance, and economies of scale will drive down cost and increase the bankability of ocean energy projects.

Focusing on one or several sub-systems will significantly improve the overall reliability, energy yield, availability, operating cost and lifetime costs of complete ocean energy devices. Simultaneously, integrated design approaches to the control system within a device and other aspects of the device design will contribute to higher performance, reduced fatigue, simpler and more cost-effective maintenance and improved survivability. Transition to the highest level of circularity will be achieved by considering a system approach in the design of ocean energy technologies.

Innovative designs together with real operational experience will reduce existing uncertainties and risks, thus increasing the reliability, availability, maintainability and survivability of devices. Survivability is particularly important as ocean energy technologies need to withstand extreme weather conditions and loads. Reliability is fundamental for all ocean energy technologies, as project life cycles are long (target deployments are 20/25-year) and the environment they operate in is challenging. Maintenance operations can be very costly and difficult to perform. Devices are also subject to marine growth which increases maintenance needs.

Data and reports from demonstration projects are currently available, but knowledge exchange should be promoted while respecting the protection of company IP. Information should be made easier to find, access and reuse, in order to support technology development. Collaborative working, knowledge exchange, good practices, successful approaches and generic problem-solving techniques will accelerate the commercialisation of the sector.

Finally, demonstration of ocean energy technologies will build on Europe's global lead in this sector by accelerating commercialisation of the Europe's world-leading ocean energy technologies, companies and projects.

BRIEF STATE OF THE ART OF **TIDAL STREAM** CONVERTERS

- Tidal stream technologies are approaching commercialisation, with the deployment of full-scale devices and arrays in real conditions at sea. With a suitable market mechanism, European developers are now ready to build out in Europe and overseas.
- Tidal energy designs for high velocity currents have reached a high level of technological maturity and convergence. They generally comprise horizontal axis turbines, both bottom-fixed and floating, with power rating ranging between 100 kW to 2 MW per device.
- Tidal kite devices are being developed for medium to low velocity currents. The possibility for employing vertical axis turbines in river streams has also opened up the market for these concepts.
- Bottom-mounted and floating tidal turbines are better suited to different locations, and face slightly different challenges.
- Europe is a global leader in this sector. Turbines developed by Nova Innovation, Andritz Group, Orbital Marine, Schottel, SIMEC Atlantis and Tocardo have been operational in demonstration and pre-commercial projects in Europe and Canada.
- To prove the reliability and resilience and de-risk the technology further, long-term operation of arrays is required.
- An industrial supply chain is growing, adapting existing practices and creating new knowledge.
- For the sector to be competitive with other low carbon renewables, research and innovation is still required in order to improve performance, reliability and costs.
- Opportunities for innovation could come from technology transfer from other sectors, such as offshore wind, and lead to CAPEX reductions and improved reliability.

[11] For example the infrastructure coordinated through MaRINET2.

BRIEF STATE OF THE ART OF **WAVE ENERGY** CONVERTERS

- Wave technology remains at an earlier stage of development than tidal energy technologies, with scaled and full-size prototypes undergoing testing at sea. Novel devices are still being developed and alternative generation methods are investigated.
- There is currently no dominant design in wave energy. Convergence may result in several different designs, focused on different wave energy locations (e.g. onshore, nearshore, offshore) and markets.
- Shoreline devices such as those in breakwaters (e.g. Mutriku wave energy plant) have been reliably operating for several years, but costs need to come down to allow commercial deployment in niche markets.
- Single devices have been deployed by different technology developers including Wello's Penguin and Seabased as demonstration projects; IDOM's Marmok, CorPower Ocean's C3, Wedge's W1, Demowave, SinnPower, Nemos and Ecowavepower as prototypes. Ocean Energy and Laminaria are expected to deploy their technology soon.
- The most common types of devices are point absorbers, oscillating wave surge converters (OWSC) and oscillating water columns (OWC). Even within a device class there are significant differences based on how devices are operated and on the conversion system (PTO) employed.
- Phased development has replaced higher-risk large-scale prototype testing.
- An industrial supply chain has not yet consolidated. Suppliers are focusing on the adaptation of existing production chains to cater to the needs of the sector, as well as cultivating a new chain devoted to this technology.
- Survivability and reliability need to be improved to reduce costs. Ongoing research into PTO and control systems could be supplemented with focus on increasing efficiency and reliability.
- Opportunities for innovation in materials can come from technology transfer from other sectors, such as offshore wind, and lead to CAPEX reductions and improved reliability.

BRIEF STATE OF THE ART OF **OTHER OCEAN ENERGY TECHNOLOGIES**

- OTEC is shifting closer onshore to reduce costs and benefit from economies of scale.
- Beyond power production, SWAC is already servicing commercial districts and data centres in Europe.
- Small scale salinity gradient prototypes aim to prove the technology and reduce cost to enable scaling-up.
- Tidal range is a proven technology, but new projects face strict environmental measures.

Priority Topics	WAVE	TIDAL	OTEC/SALINITY	TRL
Demonstration of ocean energy devices to increase experience in real sea conditions	✓	✓		MEDIUM-HIGH
Demonstration of ocean energy pilot farms	✓	✓		HIGH
Improvement and demonstration of PTO and control systems	✓			MEDIUM-HIGH
Application of innovative material from other sectors	✓	✓		MEDIUM-HIGH
Development of novel wave energy devices	✓			LOW-MEDIUM
Improvement of tidal blades and rotor		✓		MEDIUM-HIGH
Development of other ocean energy technologies			✓	LOW-MEDIUM

Table 7. Priority Topics on Design and Validation of Ocean Energy Devices.

5.1.1 Demonstration of ocean energy devices to increase experience in real sea conditions

SCOPE

Demonstration of ocean energy devices in real sea conditions for long periods of time provides invaluable learnings. It is the only way to properly validate the technology and an essential step to commercialisation. Risk can be mitigated by a comprehensive dry testing of subsystems. Onshore testing should be carried out before any at-sea deployment of complete devices. Several successful programmes have assisted in this process, such as MaRINET, FORESEA and Blue-GIFT. Complemented by onshore testing, more real sea experience is required to demonstrate performance, reliability, availability, maintainability and survivability. Common issues could be then identified and addressed through further R&I actions.

APPLICABILITY

Wave and Tidal energy converters including shoreline, offshore bottom-fixed and offshore floating devices.

ACTIONS

- Testing at onshore and offshore facilities in Europe.
- Demonstration of scalability.
- Optimisation of key PTO components.
- Real sea, long-term deployment of full-scale devices.
- Definition of performance, reliability, availability, maintainability and survivability KPIs.
- Facilitation of knowledge transfer and cross-sector collaboration.
- Pre-normative research to provide guidelines and technical specifications to assist in the certification process.

EXPECTED IMPACT

- Demonstrate improved performance, reliability, availability, maintainability and survivability.
- Contribute to LCOE reduction approaching SET Plan targets
  (actions should clearly state estimated LCOE at project start and end).
- Reduce risk and uncertainties.
- Reinforce the industrial supply chain.
- Improve manufacturing readiness levels.
- Knowledge and data exchange, respecting the protection of company IP.
- Better knowledge of environmental impacts.
- Attract private investors to the sector and reduce the cost of this investment to projects.

TRL MEDIUM-HIGH

Projects should enter with at least TRL5 and finish with TRL7 or higher.

BUDGET REQUIRED €150M

Around 10 large projects and around 10 medium size projects are required under this topic.

5.1.2 Demonstration of ocean energy pilot farms

SCOPE

Deployment of ocean energy pilot farms in full operational conditions for long periods of time is essential to advance this sector. It is the only way to achieve high TRLs while reducing costs, reducing risks and attracting investors for future commercial projects. Pilot farms, even with a small number of devices, require higher investments with uncertain returns, due to the inherent uncertainties of technology development and deployment. To focus on the technologies with the greatest chances of success, ocean energy devices should have been satisfactorily demonstrated at full scale before this action. The innovation component should mainly lie on the pilot farm subsystems and activities that enable a cost-effective pilot farm. Where established, stage-gate processes can help ensure that this approach is followed.

Projects funded under this Priority Topic **should not include the development of single devices**, which is within the scope of the previous Priority Topic. At the same time, projects funded under this Priority Topic should show clear progress beyond the state of the art.

APPLICABILITY

Wave and Tidal energy converters.

ACTIONS

- Support for demonstration of full-scale wave and tidal devices in small pilot farms at open sea.
- Demonstration of interactions between devices.
- Optimisation of shared electrical components, e.g. power cables, subsea hubs and substations.
- Demonstration of other potential shared equipment such as foundations and mooring lines.
- Optimisation of installation procedures and means, e.g. vessels, remote operated vehicles and equipment.
- Demonstration of improved manufacturing and assembly techniques.
- Optimisation of operation and maintenance techniques, including data analytics and other digital techniques.
- Definition of performance, reliability, availability, maintainability and survivability KPIs at array scale.
- Facilitation of knowledge transfer and cross-sector collaboration.
- Monitoring campaigns to better understand environmental impacts.
- Socio-economic impact assessments.
- Power quality and energy system integration studies.
- Integration of storage technologies or combination with other uses such as hydrogen production, desalination or other offshore renewable sources.
- Pre-normative research to provide guidelines and technical specifications to assist in the certification process at array scale.

EXPECTED IMPACT

- Contribute to LCOE reduction approaching SET Plan targets (actions should clearly state estimated LCOE at project start and end, and in following deployment stages).
- Demonstrate improved performance, reliability, availability, maintainability and survivability for the whole pilot farm.
- Improve operation and maintenance strategies
- Better definition of risk and uncertainties for future deployment stages.
- Reinforce the industrial supply chain and identify supply gaps.
- Achieve high manufacturing readiness levels for all the components and equipment at array scale with the capability in place to begin full rate production.
- Knowledge and data exchange within the sector but also collaborating with other sectors, respecting the protection of company IP.
- Better knowledge of environmental impacts at array scale.
- Understand socioeconomic benefits of deploying ocean energy projects.
- Estimate potential benefits to the global energy system due to the integration of wave or tidal resources.
- Understand dismantling and recycling operations introducing eco-design requirements from the first stages of development with a circular economy approach.
- Attract private investors to the sector and reduce the cost of this investment to projects.

TRL

HIGH

Projects should enter with at least TRL7 and finish with TRL8 or TRL9.

BUDGET REQUIRED €350M

7 pilot farm projects are required under this topic.

Photo: Green Marine

5.1.3 Improvement and demonstration of PTO and control systems

SCOPE

PTO and control systems (including gearboxes, electric generators and power electronics) are key subsystems of wave energy converters. PTO and control systems can be improved to increase the efficiency of the whole converter, to increase reliability and to avoid extreme events that might compromise device survivability. Control systems dynamically adapt to and mitigate the forces of the continually changing ocean conditions. This can prevent damage during extreme events, contribute to increased performance and the viability of the technology. The manufacturing and testing of prototypes are relatively costly, and it is imperative that data from the demonstration are available to avoid repeating early engineering mistakes. Verification in realistic environments at small scale for longer periods could make best use of scarce resources. Onshore testing and controlled lab testing can provide significant information. Development and demonstration of PTO technology should be combined with control strategies as their requirements are inherently coupled.

APPLICABILITY

Wave Energy Converters.

ACTIONS

- Demonstrate the reliability, robustness and performance of PTO and control systems.
- Optimisation and simplification through standardisation, modularity and scalability of key PTO components.
- Validation of 'wave-to-wire' models[12] to facilitate global optimisation of ocean energy devices.
- Improvement of control strategies to reduce the impact of the stochastic nature of the input (e.g. reduce extreme loading, increase production).
- Uncertainty assessment of loads and strengths on critical components to derive lifetime, safety factors and reliability.
- Demonstrate delivery of grid-compliant power including short-term energy storage solutions to smooth power output when needed.
- Improve understanding of the limitations in scaling-up PTO components.
- Cooperation between technology developers and key vendors to develop interoperability between systems (e.g. standardisation and unification of SCADA system requirements).
- Pre-normative research to provide guidelines and technical specifications to assist in the certification process.

EXPECTED IMPACT

- Improve performance, reliability and survivability.
- Convergence (standardisation) and simplification of designs to allow a reduction in maintenance costs.
- Reduce fatigue on components, unexpected failures, unplanned maintenance and thus increase availability.
- Improve manufacturing readiness levels.
- Better knowledge of environmental impacts.
- Contribute to LCOE reduction approaching SET Plan targets (actions should clearly state estimated LCOE at project start and end).
- Knowledge and data exchange, respecting the protection of company IP.
- Reinforce the EU supply chain.

TRL — MEDIUM-HIGH

Some projects should enter with at least TRL3 and finish with TRL6 while others should have a higher TRL ambition (from TRL4-5 to TRL7-8).

BUDGET REQUIRED €60M

Around 10 medium size projects focused on high TRLs and around 5 small projects focused on medium TRLs are required under this topic.

[12] Mathematical model that incorporates the entire chain of energy conversion from the hydrodynamic interaction between the ocean waves and the wave energy device to the electricity feed into the grid.

5.1.4 Application of innovative materials from other sectors

SCOPE

Components and systems used in ocean energy devices need to be resistant to corrosion and the heavy loads they are subject to. Significant experience has been accumulated by other offshore industries which use many materials and coatings in the ocean. Materials such as reinforced concrete, polymers, composites, and concrete-steel/composite-steel hybrids systems have demonstrated some advantages in other offshore sectors, such as reduced costs. Demonstrating the potential benefits of these new materials in ocean energy converters, moorings and foundations whilst ensuring structural integrity and durability is required. Increased access to test facilities may also be needed.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Transfer of innovative materials, anti-fouling coatings, and manufacturing processes that are generally applicable to multiple ocean energy devices and processes.
- Characterisation and experimental testing of innovative materials properties.
- Demonstration of materials that ensure long durability in sea water (ideally up to the project lifetime).
- Demonstration in relevant and operational environments to understand survivability and reduce risks.

EXPECTED IMPACT

- Improve survivability, reliability and affordability by reducing biofouling and corrosion and extending lifetimes.
- Reduce CAPEX and OPEX.
- Contribute to LCOE reduction approaching SET Plan targets (actions should clearly state estimated LCOE at project start and end).

TRL — MEDIUM-HIGH

Project should enter with at least TRL5 and finish with TRL7 or higher.

BUDGET REQUIRED €25M

A few medium size projects and around 5 small projects are required under this topic.

Photo: Tocardo

5.1.5 Development of novel wave energy devices

SCOPE

There is a continuous flow of new ideas and concepts to harness wave energy, coexisting with several more developed technologies. This topic aims to support radical improvements in key device functions – such as energy capture or energy transformation – which could provide a step change in the overall wave energy technology performance. Identification of novel concepts should use internationally agreed evaluation criteria via structured product verification approaches that build on prior knowledge and experience (e.g. a stage-gate approach). Several international initiatives are currently defining a methodology to assess wave energy technologies at various stages of development (e.g. H2020 DTOceanPlus tools and IEA-OES Task 12 evaluation framework). This will provide a framework within which novel device research can be sustainably funded.

APPLICABILITY

Wave Energy Converters.

ACTIONS

- Numerical modelling and simulation of novel wave energy concepts and subsystems demonstrating a step change from current benchmarks.
- Experimental validation of novel concepts at laboratory (scaled prototype) against global metrics.
- Demonstration of technology in relevant environment.
- Verification following standards for stage progression through scale testing.

EXPECTED IMPACT

- Breakthrough innovations, including key enabling technologies and whole concepts, with very high potential for cost reduction.
- Encourage convergence to successful technologies by streamlining the whole sector's knowledge and experience.
- Contribute to LCOE reduction beyond SET Plan targets (actions should clearly state estimated LCOE at project start and end).
- Concentrate funding on the most promising concepts.

TRL — LOW-MEDIUM

Projects could enter in TRL3 or even below and finish TRL6 maximum.

BUDGET REQUIRED €45M[13]

Around 10 small projects and around 5 medium size projects are required under this topic.

[13] This budget does not include the European Pre-Commercial Procurement Programme for Wave Energy Research & Development launched within the H2020 call LC-SC3-JA-3-2019..

5.1.6 Improvement of tidal blades and rotor

SCOPE

There are different blade solutions under development in terms of shape and material. Certain tidal turbine blades are made of composite material to ensure the correct strength and lowest possible weight. Blade edges can erode rapidly, facilitating water ingress, accelerating fatigue and the risk of failure. Failure in a blade can create long downtimes, which reduces annual energy production and increases operating costs. Improving the seaworthiness of blades will reduce the likelihood of this type of failure. There is also a need for further technology investigation and demonstration of improved reliability and efficiency of tidal turbine blades and rotor, including pitch and yaw control.

APPLICABILITY

Tidal Energy Converters.

ACTIONS

- Structural tests to verify performance of materials in tidal blades over their expected lifetime.
- Better modelling of the turbulences and their impact on the blades.
- Characterisation of novel materials.
- Improved manufacturing processes to produce tidal blades.
- Long-lasting coatings or antifouling materials to reduce operation and maintenance costs.
- Cooperation between technology developers and key vendors for the development of control techniques of tidal turbine blades and rotor.
- Demonstration of blades and control systems in real sea conditions

EXPECTED IMPACT

- Improve performance and reliability.
- Reduce fatigue due to cyclical loading.
- Contribute to LCOE reduction approaching SET Plan targets (actions should clearly state estimated LCOE at project start and end).

TRL

MEDIUM-HIGH

Projects should enter with at least TRL4 and finish with TRL6 or higher.

BUDGET REQUIRED €55M

Around 5 medium size projects and a few large projects are are required under this topic.

Photo: AW Energy

5.1.7 Development of other ocean energy technologies

SCOPE

Reflecting the priority on tidal stream and wave energy in the SET Plan Ocean Energy Implementation Plan, this report has not focused on OTEC, SWAC, salinity gradient and tidal range energy. They are at different stages of development, and research priorities are varied. Lower cost, lower maintenance or higher performance membranes are a priority for salinity gradient energy. For OTEC, industrial interest is now focussed on onshore devices that would harness synergies with aquaculture, cooling or desalination to improve the business case. Tidal range is a mature technology but environmental concern for sensitive inter-tidal zones have thus far limited deployment. Most projects are located in specific countries; a European approach is needed.

APPLICABILITY

OTEC, SWAC, salinity gradient and tidal range energy.

ACTIONS

- OTEC: design of the intake and outlet pipes including hydrodynamics, seaworthiness and materials, using ejectors to increase pressure ratio across turbine.
- OTEC: alternative working fluids, dedicated turbine design, improved thermal and hydraulic design of heat exchanger, materials for heat exchangers.
- OTEC: environmental-friendly layout, biofouling issues and extreme events.
- Salinity gradient: Lower cost membranes that can be produced at scale.
- Tidal range: New design of lower cost installations for coastal lagoons.
- All: Environmental monitoring.
- All: Demonstration of alternative energy use (hydrogen production, desalination, cooling/heating).
- In addition to the possible actions above, any action that demonstrates high potential for cost reduction in any of these ocean energy technologies can be considered.

EXPECTED IMPACT

- Lower technical risks.
- Reduce CAPEX and OPEX.
- Increase performance and reliability.

TRL — LOW-MEDIUM

Projects could enter at any low-medium TRL and finish at TRL6.

BUDGET REQUIRED €20M

A few medium size projects are expected to be funded under this topic.

5.2 Foundations, Connections and Mooring

This refers to device mooring and foundation (floating or bottom-fixed), offshore structures other than the device itself, and connections. Non-electrical power transmission such as hydraulic lines or pipes are also included.

These aspects share many similarities with those of existing marine structures for coastal defence, offshore wind and offshore oil and gas. However, ocean energy imposes novel functional requirements for which optimised solutions must be developed and thoroughly tested at sea.

Many aspects of this Challenge Area cannot be addressed in isolation and should be considered together with the demonstration of devices. Aspects related to improving installation should be considered together with the Challenge Area on Logistics and Marine Operations.

Optimising design for foundations, connections and mooring will reduce cost of components and installation and increase energy yield, thus reducing CAPEX. Operating experience will reduce OPEX by improving installation, operation and maintenance, reducing uncertainties and risks and improving reliability, availability and survivability.

BRIEF STATE OF THE ART

- Solutions for foundation and station-keeping from offshore wind and offshore oil and gas are used in existing ocean energy deployments.
- Limited experience with ocean energy deployments results in uncertainties in structural requirements, which in turn requires costly overdesign to ensure survivability.
- Existing offshore structures are designed to move as little as possible when impacted by waves. But wave energy devices are typically designed to move dramatically in response to wave excitation. For example, a floating oil rig move as little as possible with waves, whereas for a wave energy converter the reverse is often desired. This results in higher loads and load cycles on dynamic electric cables and connectors, mooring lines, mooring connectors, anchors and their interaction with the bottom.
- Tidal devices typically must withstand higher currents than any existing offshore structure, resulting in new requirements for foundation, station keeping, anchoring and seabed interaction.
- There is still limited experience in managing the discrepancies between 'as-built' versus 'as-designed' balance of plant, which result in additional risk during operational life and reduction in extracted energy due to positioning errors.
- Several R&I projects funded under the H2020 programme have begun to address the development of cost-effective moorings and electrical systems up to TRL6.

Priority Topics	WAVE	TIDAL	TRL
Advanced mooring and connection systems for floating ocean energy devices	✓	✓	MEDIUM
Improvement and demonstration of foundations and connection systems for bottom-fixed ocean energy devices	✓	✓	MEDIUM-HIGH

Table 8. Priority Topics on Foundations, Connections and Mooring.

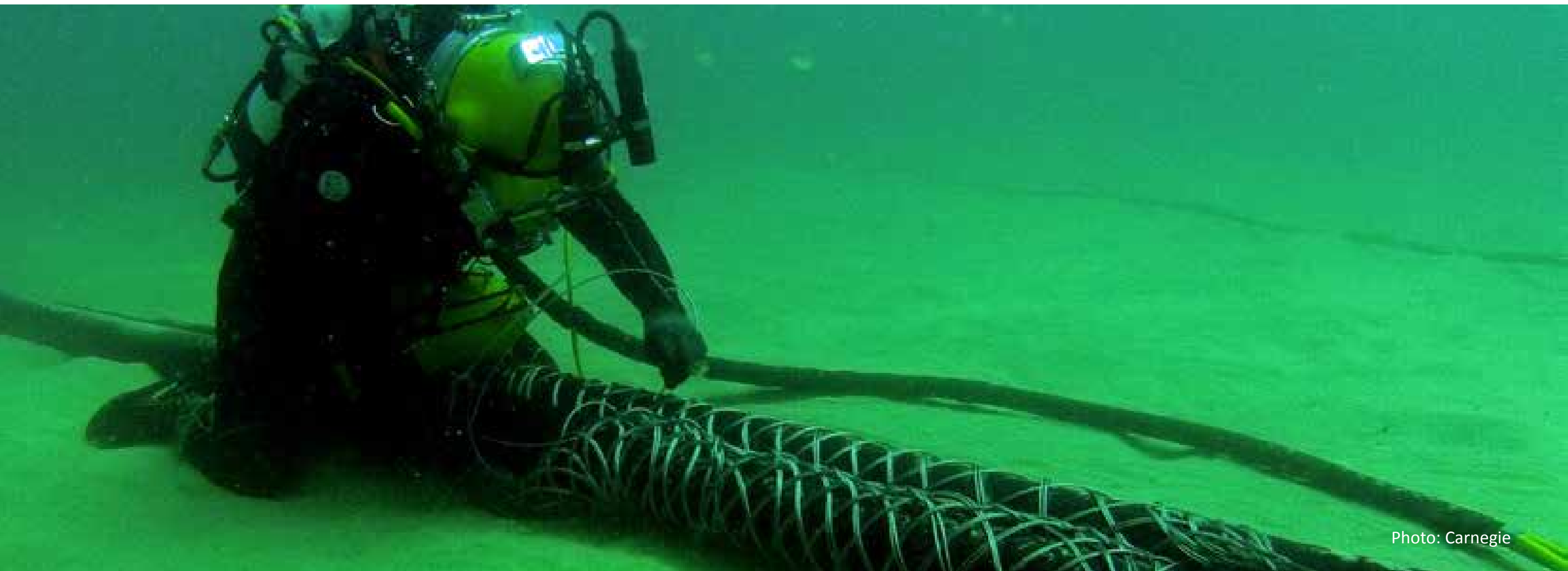


Photo: Carnegie

5.2.1 Advanced mooring and connection systems for floating ocean energy devices

SCOPE

Floating systems offer the potential to harvest wave or tidal power in deeper areas. However, large current and wave responses of these devices result in loads on mooring and connections systems that are more challenging than for existing floating structures. Tailored solutions for this challenge must be developed, optimised and tested at sea.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Advance the design of tailored mooring and connection of electrical or other power transmission systems for floating wave and tidal requirements.
- Reduce the cost of cabling by applying innovations from other sectors or developing novel applications tailored to ocean energy.
- Develop or apply advanced simulation of the mooring system and its installation to reduce uncertainties and margins in the design.
- Advance combined mooring and electrical connectors or hydraulic power transmission to reduce component cost and number of connection operations, included in systems for sharing an anchor between devices in arrays.
- Develop novel systems for safe and quick connection/disconnection that do not require large vessels and diving teams.
- Reduce maintenance requirements of station-keeping systems.
- Reduce station-keeping interference with power performance requirements.
- Develop new materials with improved fatigue, damping, stiffness, bio-fouling management or other cost-reducing characteristics (This should be coordinated with 5.1.3 Application of innovative materials from other sectors).

EXPECTED IMPACT

- Reduce CAPEX and OPEX.
- Contribute to LCOE reduction according to SET Plan targets (actions should clearly state estimated LCOE at project start and end).

TRL

MEDIUM

Projects should enter in TRL3 or TRL4 and finish TRL6

BUDGET REQUIRED €50M

Around 10 medium size projects are required under this topic.

5.2.2 Improvement and demonstration of foundations and connection systems for bottom-fixed ocean energy devices

SCOPE

The engineering of bottom-fixed foundations for ocean energy devices presents its own set of challenges. These include developing and reducing costs of bespoke electrical connection and cabling, designing foundations optimised for the installation and operating conditions of ocean energy arrays, and improving installation operations and maintenance. For tidal energy, the central challenge that governs design typically is high currents and their loads and effects on the foundation and cabling. For wave energy, design is typically governed by the largest wave expected during the device's deployment.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS[14]

- Reduce the cost of electrical connection of device. These could be improvements to existing methods or novel solutions, such as low-cost, high reliability, low maintenance connectors. At-sea power conversion or other approaches can be considered if potential for cost reduction is demonstrated.
- Reduce cost of, or need for, secondary steel structure for electric cables or other form of power transmission to shore. Overall cost reduction should be considered, i.e. not only manufacturing but also installation, maintenance and other costs associated with a particular solution.
- Tidal only: design robust and optimised foundations that can be installed cost-effectively in the conditions of tidal farms, which may include hard seabed, strong currents, short operating windows for installation in slack tide. These may be novel solutions or improvements to existing foundations types such as monopiles, jackets or gravity-base.
- Improve installation of wave and tidal devices, including novel designs, procedures and tools. New dedicated tools could address the conditions of tidal or waves sites that pose challenges not currently addressed by offshore industries.
- Design, develop or validate foundation and connection systems designs that optimise installation in wave or tidal site conditions.
- Demonstrate high cost-reduction potential by improving foundations or power transmission to shore.

EXPECTED IMPACT

- Reduce CAPEX.
- Contribute to LCOE reduction according to SET Plan targets (actions should clearly state estimated LCOE at project start and end).

TRL

MEDIUM-HIGH

Medium size projects should enter with at least TRL4 and finish with TRL6 or higher, smaller projects or small parts of larger projects can enter at any TRL.

BUDGET REQUIRED €35M

Around 5 medium size projects for the higher TRLs and around 5 small projects for the lower TRLs are required under this topic.

[14] In actions where improvements in installation and marine operations are involved, coordination with actions under the Challenge Area on Logistics and Marine Operations should be considered.

5.3 Logistics and Marine Operations

This challenge includes technology development and demonstration of marine operations related to installation, operation, maintenance and decommissioning of ocean energy devices or arrays. Due to the limited number of devices and projects deployed to date, ocean energy does not yet have a dedicated and specialised supply chain. In addition, and particularly for wave energy, the variability in designs makes the development of generally applicable procedures difficult.

Ocean energy devices typically need to operate for a lifetime of at least 20 years, so operation and maintenance significantly impacts cost of energy.

Demonstration projects will generate valuable learnings and improve logistics and marine operations. This will in turn reduce cost of installation, maintenance and decommissioning for upcoming commercial projects.

BRIEF STATE OF THE ART

- The share of marine operations in the levelised cost of ocean energy, once mature, is expected to approach that for offshore wind, i.e. in the range of a quarter to a third of total costs.
- Ocean energy activity is not yet sufficient for a dedicated supply chain of marine contractors to develop, or for investment in bespoke vessels to be profitable. Vessels for oil and gas or other maritime activity are used, staffed with divers and technicians from these sectors. The most suitable vessels are rarely available near the sites of ocean energy deployment, so mobilisation and sail time often take up a disproportionate share of costs. The development of specialised companies and especially of new, dedicated equipment for ocean energy deployment are seen as having significant cost reduction potential.
- In some cases, bespoke installation methods have been developed, usually based on the know-how of contractors whose experience and main markets are other maritime activities, often offshore oil and gas.
- Experience with prototype deployment has shown an extremely steep learning curve for ocean energy marine operations. For some operations, costs have reduced by as much as an order of magnitude. One challenge for ocean energy is ensuring this know-how is not lost between projects that can be few and far between. Available experience must be documented and shared effectively to accelerate industry learning.
- Digitalisation, including data streams from ever more numerous sensors, new analysis methods such as big data or machine learning, and applications such as digital twins, are expected to become increasingly important. This will be particularly the case for the optimisation of maintenance, as it is applied now in the offshore wind and energy sector as a whole.

Priority Topics	WAVE	TIDAL	TRL
Optimisation of maritime logistics and operations	✓	✓	MEDIUM-HIGH
Instrumentation for condition monitoring and predictive maintenance	✓	✓	MEDIUM-HIGH

Table 9. Priority Topics on Logistics and Marine Operation.

5.3.1 Optimisation of maritime logistics and operations

SCOPE

Vessel logistics and costs for ocean energy installation and operation is an area with potential for dramatic and early cost reductions. For example, unclear safety requirements increase downtime of vessels and equipment for operations, greatly impacting costs. Selectively adapting good practices form other sectors, developing bespoke operations and tools, and documenting and sharing experience will be crucial to rapidly reducing these costs. It is thus essential that actions within this Priority Topic be well coordinated with those in the Challenge Area for demonstration of devices, to ensure focus on solving real and specific problems encountered during open-sea deployments. The emphasis should be on "learning by doing".

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Select, adapt and implement techniques and approaches from other sectors.
- Identify novel requirements specific to ocean energy, and design bespoke methods and tools. This could include heavy hardware where such developments show promise for important cost reductions.
- Develop modelling tools to simulate marine operations, including complex multibody systems and accidental events such as collision with ships for risk analysis.
- Evaluate existing remote maintenance technologies and apply where appropriate.
- Better define operating limits such as maximum wave height, wind and current velocity for operations involved in ocean energy. Activities could include applying new sensor technology to monitor environmental conditions such as wind, wave and current conditions or to monitor installation operations such as tow line loads, device motion, anchor trajectory, penetration or holding capacity. This could also feed into modelling tools that simulate marine operations.
- More generally, any action that demonstrates high potential for reducing costs through improved marine logistics and operations should be considered.

EXPECTED IMPACT

- Demonstrate reduction in cost of marine operations and maintenance.
- Improve know-how and data available to industry and future projects for marine operations necessary to ocean energy, reducing risks, uncertainty and costs.

TRL — MEDIUM-HIGH

Projects should enter with at least TRL4 and exit with at least TRL6.

BUDGET REQUIRED €55M

Around 5 medium size projects and a few of large projects are required under this topic.

5.3.2 Instrumentation for condition monitoring and predictive maintenance

SCOPE

The combination of smaller and cheaper sensor technology with telecommunication (Internet of Things) has opened new opportunities for significant cost reduction in the operation and maintenance of energy assets, particularly offshore. For ocean energy, these technologies also offer the possibility to fast-track industry learning to reduce maintenance requirements and operating costs.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Apply recent advances in condition and structural health monitoring from other sectors to ocean energy – particularly those currently developed for offshore wind.
- Apply latest sensor technology to existing ocean energy deployments.
- Document and share experience on sensors performance and reliability, and methods for adapting them to the harsh ocean energy environment.
- Improve transmission or storage of data collected from sensors, such as underwater data transmission.
- Develop common guidelines to facilitate transfer of device-specific sensor and monitoring systems across technologies.
- Identify novel solutions for ocean energy monitoring and develop, test and deploy bespoke instrumentation.
- Improve conditions-based and predictive maintenance with analysis of data streams, application of big data methods and machine learning, including artificial intelligence, or digital twin models training with existing operating data.
- Take advantage of ongoing, separately-funded ocean energy deployments at sea and fund additional activities. Monitoring/analytical equipment and activity is funded in exchange for open access to the generated data. Budget allocation discussed here concerns additional costs related to introducing specific sensors and the analysis of their data.
- In addition to the above, any action to develop or apply instrumentation, or analyse their data, that has demonstrably high potential to reduce costs for ocean energy should be considered.

Note: data transmission, storage, management and distribution aspects must be considered as per actions described in Section 5.5.2 Open-data repository for ocean energy, rather than under this Priority Topic.

EXPECTED IMPACT

- Reduce OPEX by optimising O&M.
- Increase energy production by improving availability and improved survivability by early detection of failure risk.
- Contribute to LCOE reduction according to SET Plan targets (actions should explain how this cost reduction is achieved).

TRL

MEDIUM-HIGH

Projects should enter with at least TRL4 and exit with at least TRL6.

BUDGET REQUIRED €25M

A few medium size projects and around 5 small projects are required under this topic.

5.4 Integration in the Energy System

This Challenge Area includes actions that will assist and speed-up the integration of ocean energy arrays into the European energy system. The research focus will differ between farms connected to the national grids and those feeding into smaller grids, such as islands deployment. The actions in this Challenge Area will evaluate electricity system-balancing benefits of ocean energy deployment in both grid types.

BRIEF STATE OF THE ART

- Ocean energy's variability is correlated and out-of-phase with that of wind and solar power. This is a major advantage for managing high penetration of renewables on the European grid. For farms that feed into the national grid, research is needed to quantify the benefits of the high predictability of tidal power and, for wave power, its complementarity with wind and solar power. This means less requirements for storage, transmission and demand-response which are starting to take up a significant share of the investment needed for the energy transition. Quantifying this benefit of ocean energy will require multi-annual, system-wide grid simulation including weather and climate variability, similar to those that are conducted for solar and wind power integration.
- In smaller grids such as island deployments, wave and tidal farms may contribute to a significant share of generation. Their deployment will be accompanied by storage and demand-response roll-out, and their potential to complement solar and wind power must be assessed. These integration assessments for island deployment are one very promising pathway for ocean energy commercialisation.
- 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. Possible markets for wave energy include the desalination market, powering remote areas (diesel displacement) and powering offshore oil and gas platforms.

Priority Topics	WAVE	TIDAL	OTEC/SALINITY	TRL
Developing and demonstrating near-commercial application of ocean energy in niche markets	✓	✓	✓	HIGH
Quantifying and demonstrating grid-scale benefits of ocean energy	✓	✓		HIGH

Table 10. Priority Topics on Integration in the Energy System.

5.4.1 Developing and demonstrating near-commercial application of ocean energy in niche markets

SCOPE

Ocean energy is closer to cost-competitiveness in certain niche markets. Public support can remove the remaining obstacles to industry-led growth in those markets and allow scale and competition in the private sector to deliver further cost reductions in the nearer-term. Actions in this Priority Topic should aim to deliver sufficient deployment for a sufficient time to de-risk the technical pathway to the individual niche markets.

APPLICABILITY

Wave and Tidal Energy Converters, Ocean Thermal Energy Conversion.

ACTIONS

- Identify the best niche applications for first near-commercial deployment of ocean energy. These could include micro-grids and islands or isolated applications such as aquaculture or desalination. A key criterion to evaluate niche markets is the overall value proposition of ocean energy relative to alternatives available to this particular market. Advance tailored solutions for these initial niche applications.
- Deploy and demonstrate in the niche market(s), where ocean energy is closest to competitive with alternatives. Selected technologies should have demonstrated technology and manufacturing readiness as well as near-cost competitiveness for this application.

EXPECTED IMPACT

- De-risk commercial development of ocean energy in special applications.
- Availability of open-access information and data to developers interested in the niche market.
- Steppingstone to market-driven deployment expanding from the initial niche market out.
- Contribute to LCOE reduction before SET Plan targets are achieved (actions should clearly state estimated LCOE at project start and end).

TRL — HIGH

TRL7 required at entry with objective to achieve TRL8-9 within project. Manufacturing readiness should also be considered.

BUDGET REQUIRED €100M

Around 10 medium size projects and a few large projects are required under this topic, preferably supporting at least one of tidal, wave and OTEC systems.

Photo: Carnegie

5.4.2 Quantifying and demonstrating grid-scale benefits of ocean energy

SCOPE

The correlation of ocean energy intermittency with that of solar and wind power will reduce the need for storage, transmission and demand-response. Other benefits such as grid resilience to security threats may also be significant. Providing reliable estimations of these benefits would help better inform policy and investment decisions.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Identify technical issues and solutions with the introduction of wave or tidal-generated power on the European grid in the foreseeable range of deployment scenarios. This could include a cost benefit analysis with consideration for power quality, predictability, intermittency, market price fluctuations, and costs of curtailment and under-production.
- Quantify the benefits in terms of reduced requirements for transmission infrastructure, demand-response and storage, due to variability that is out-of-phase and correlated to solar and wind power. Provide estimates of cost of energy that account for this benefit of ocean energy. Previous and ongoing projects combining multiple renewable energy sources as well as storage assets should be included for an up-to-date approach to this issue, including virtual power plant applications where appropriate. Quantifying benefits in terms of grid resilience in general and to security threats in particular should be considered.
- Engage with utilities and regulators to include their perspective and their evaluation of challenges, solutions and benefits.
- In addition to the above, any action should be considered that can demonstrate a high potential to better inform policy-makers and grid managers on the costs and benefits of significant penetration of ocean energy in the European energy mix.

EXPECTED IMPACT

- All remaining issues on pathway to grid-scale integration clearly identified.
- Reliable estimates of cost of energy that account for ocean power's lesser requirements for storage, transmission and demand-response, for the range of deployment scenario that can be reasonably expected.

TRL — HIGH

TRL7 required at entry with objective to achieve TRL8-9 within project, as similar studies were already conducted for various wind and solar power penetration scenarios.

BUDGET REQUIRED €6M

A few small projects are required under this topic.

Photo: HydroQuest

5.5 Data Collection & Analysis and Modelling Tools

This Challenge Area addresses the generation of information and tools that are critical for other Challenge Areas. The actions will accelerate R&I by facilitating information sharing through standardised data management and storage, and access to data repositories with information for the design and operation of devices.

BRIEF STATE OF THE ART

- While several projects have generated or are generating data from operating experience at sea, there are challenges associated with the accessibility and use of this data.
- Data management can help optimise design and installation procedures and reduce uncertainties.
- Significant research is being carried out on resource modelling but usually not oriented to a standard definition of sites or defining design requirements in terms of performance and reliability.
- Within research, there are limitations to the gathering, distributing, employing and protection of data.

Priority Topics	WAVE	TIDAL	TRL
Marine observation modelling and forecasting to optimise design and operation of ocean energy devices	✓	✓	MEDIUM-HIGH
Open-data repository for ocean energy	✓	✓	HIGH

Table 11. Priority Topics on Data Collection and Analysis and Modelling Tools.


Photo: GEPS Techno

5.5.1 Marine observation, modelling and forecasting to optimise design and operation of ocean energy devices

SCOPE

Meteorological and marine observation, modelling and forecasting for ocean energy are largely similar to those of existing coastal and offshore activities, but certain promising applications require specific research, innovation and new methodologies.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS[15]

- Forecast near-field and real-time waves or currents for real-time and predictive control of devices, including wave-to-wave where appropriate. This will increase production, optimise operation and improve prediction of loads for blades, prime movers or PTO.
- Estimate impact on power production of device-induced changes in the wave and current fields. These changes include wake and wave shadows or turbulence, and wave-current interaction.
- Observe, model and forecast intra-site and small-scale variability in waves/currents. This could include mean regime studies for yield prediction or fatigue design, and extreme regime (storms) for safer and optimised design.
- Develop applications of cheaper and easily deployed wave and current instruments and novel developments such as X-band radars that are used to measure waves and currents.
- Improve communication or storage of the data collected.
- In addition to the above possibilities, any action should be considered that can demonstrate high cost reduction potential by way of improved characterisation of the ocean environment.

EXPECTED IMPACT

- Deliver marine and meteorological data that improve performance, reliability, availability and survivability through better designs and more efficient operations.
- Contribute to LCOE reduction according to SET Plan targets (actions should explain how this cost reduction is achieved).

TRL — MEDIUM-HIGH

Applications range from low TRL to near market-ready, medium-high TRL technology may provide the best cost to benefit ratio in the near term.

BUDGET REQUIRED €25M

A few medium size projects and around 5 small projects are required under this topic.

[15] Instrumentation for monitoring device operation is considered in Section 5.3.2.

5.5.2 Open-data repository for ocean energy

SCOPE

It is difficult and time-consuming to find, access and process the data necessary to design and improve ocean energy devices and operation. This adds costs, slows down design improvements and constitutes an important barrier for new entrants. New technologies allowing better collection, analysis and processing of large datasets are an important opportunity for ocean energy. Activities should be coordinated and should avoid redundancy with existing repositories such as the WTKN (Wave and Tidal Knowledge Network) or WES knowledge library.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Develop tools to facilitate identification, access and reuse of data produced by ocean energy projects; promote open source access of such tools and support online access and query service. These may include digital twin platforms and unified SCADA for data handling.
- Apply recent advances in automation and data collection, pre-processing, protocols, storage and communication.
- Coordinate existing data repositories and databases, provide support as appropriate, and create new repositories and databases, where relevant.
- Classify data based on needs of various types of users, e.g. high-level processed data for policymakers and the general public, down to raw-level data for particular R&I needs. This data should be categorised by application and/or by sensor technology or project.
- Take advantage of existing formats commonly used in similar fields when possible, while minimising overhead on data providers. If needed, generate new tailored templates for ocean energy data collection, sharing and use.

EXPECTED IMPACT

- Accelerate R&I on ocean energy and public access to information of interest.
- Contribute to LCOE reduction according to SET Plan targets (actions should explain the potential impact on cost reduction using experiences from other sectors).

TRL HIGH

It could be a non-research project, in line with the approach of Horizon 2020 “Coordination and Support Actions”.

BUDGET REQUIRED €10M

Around 5 small projects are required under this topic.

Photo: GKinetic

5.6 Cross-cutting Challenges

Tidal and wave energy have important environmental and socio-economic benefits, beyond their contribution to a cleaner and more secure energy future. Demonstrating and quantifying these benefits will help better inform policy and financial decisions regarding their contribution to the future energy mix. Another cross-cutting challenge is to increase the range and reduce the cost of private capital that can be accessed by the emerging ocean energy sector. It will therefore be useful to advance towards more widely accepted standards and certification, bearing in mind the need for innovative and thus non-standard approaches until the required cost reductions are achieved.

BRIEF STATE OF THE ART

- There is limited direct evidence on the environmental impacts of ocean energy due to the small volume of installed capacity to date. However, it is expected that good construction practices from offshore wind that improve net environmental impact will be largely applicable to ocean energy.
- On the other hand, it has been documented for offshore wind farms and areas closed to fishing that the de facto marine reserve effect dramatically increased local marine biodiversity and overall ecosystem health and resilience. It is expected that future wave and tidal farms will bring about similar benefits, but precise estimates are yet to be available to guide policy making.
- Along with solar power, offshore wind has been shown to have the highest job-creation potential of power generation technologies. It is expected that wave and tidal farms will have similar job-creation potential. These include local employment which does not require extensive formal education, and which is often a priority for those European coastal areas that are most promising for ocean energy. This would breathe new life into under-used port and harbours in peripheral regions. Reliable estimates of job creation potential must be provided to policy makers.
- Tidal and especially wave energy projects have thus far only access to specialised capital. This is partly due to the lack of established practices and standards which other investors need. For offshore wind, access to capital from commercial banks and institutional investors, with a majority taking some of the construction risk, has enabled rapid reduction in the cost of capital and thus played an important role in delivering the dramatic reduction in levelised cost of energy observed in the last few years.
- Accelerated access to more private funds for ocean energy by facilitating the development of appropriate and widely accepted standards and certification processes.

Priority Topics	WAVE	TIDAL	TRL
Improved knowledge of the environmental and socioeconomic impacts of ocean energy	✓	✓	MEDIUM-HIGH
Standardisation & certification	✓	✓	HIGH

Table 12. Priority Topics on cross-cutting challenges.

5.6.1 Improved knowledge of the environmental and socioeconomic impacts of ocean energy

SCOPE

Analysis of the lifecycle environmental impact of ocean energy and comparison with other renewables should be continuously updated as the technology evolves. Research, dissemination and enforcement of good practices will reduce or eliminate individual negative environmental impacts. It is important to also focus efforts on enhancing the overall positive environmental impacts of ocean energy developments. Monitoring equipment and field work such as seabed observation and samples are costly and will significantly impact the economics of initial ocean energy projects, so they may be a particularly suitable target for R&I activities.

Available job creation studies suggest that employment created by ocean energy will be a decisive benefit of these technologies. These studies must be updated with new data from real deployments, especially first arrays and near commercial applications, in order to provide reliable numbers to policy makers. Practices that enhance or reduce the job creation potential of ocean energy should be identified and documented for application in upcoming projects.

Actions within this Priority Topic should be coordinated with those in the Challenge Area for design and validation of devices, and the design of devices should consider lifecycle environmental impacts in a circular economy perspective.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Conduct lifecycle analysis of ocean energy and standardisation of methodologies across ocean energy projects, comparison of lifecycle impacts with other renewables
- Assess and monitor impacts of ocean energy projects (based on the experience of OES-Environmental's tasks) including seabed disturbance, scour, noise, changes to marine currents and the wave climate, as well as their impact on local habitats and biology, sediment transport and coastal morphodynamics. Apply relevant metrics identified in previous studies.
- Adapt good practices from offshore wind to reduce environmental impact of construction. This may include identifying pre-existing habitats, species, sensitive areas and seasons and bubble curtains (though piling noise is expected to be less common for wave and tidal foundations) and reducing the risk of introducing undesirable or invasive species.
- Assess the de facto marine reserve effect of ocean energy arrays, with e.g. species counts and monitoring, valuating them for ecosystem services such as fisheries and tourism, and interfacing to policy-making with actionable information for integrated coastal area management.
- Assess the applicability of good practices that enhance the biodiversity benefits of the marine reserve effect, such as low-cost modifications to marine structures that facilitate colonisation by target species, or collecting boulders cleared for turbine foundations and cable routes to form artificial reefs.
- Ensure that consultation and communication with organisations and communities that use, benefit and care for the local environment are prioritised, budgeted and scheduled for in the planning of supported projects. Open access to environmental observations and data should be required from all supported projects.
- Identify and improve knowledge and management of, issues for local communities that are specific to ocean energy and that have not come up thus far in deploying other renewables.
- Apply existing tools such as marine spatial planning and develop a customised version for ocean energy, to better share the marine space with other activities and users.
- Quantify the job creation potential of various scenarios of ocean energy deployments, with a focus on metrics of most relevance to policy-making. An important information for policy-making, and an aspect where ocean energy appears to have significant advantages, would be a distinction between cash flow to capital and cash flow to job creation, with particular attention to local labour deprived of other opportunities. The full range of possible deployment scenarios should be explored, and proposed advances over previous studies clearly stated.
- Identify which deployment or development pathways have the highest job creation potential and generate actionable information for policy makers.
- In addition to the above possibilities, this Priority Topic could be addressed by activities within projects in other Challenge Areas.

EXPECTED IMPACT

- Reduce negative environmental impacts of upcoming ocean energy projects and enhance positive environmental impacts such as target species repopulation or habitat and refuge for species that are threatened from overfishing outside the farm.
- Reliably quantified job benefits from ocean energy will inform policies both at EU, national and local level.
- Consideration of all stakeholders' and their priorities from project inception, resulting in better social acceptance and reduced project risk and delays.

TRL

Environmental aspects: HIGH

Socio-economic aspects: MEDIUM-HIGH

For environmental aspects: High. These technologies are mature and commercially applied in other marine activities. Some of the proposed work may only be feasible when ocean energy arrays reach a sufficient scale to have measurable environmental impacts.

For socio-economic aspects: Medium-High. There are well-established methods for evaluating job creation. To tailor these to ocean energy applications, assumptions that are supported by information from existing and future deployments are required.

BUDGET REQUIRED €10M

Around 5 small projects are required under this topic.

5.6.2 Standardisation and certification

SCOPE

The applicable guidelines, standards and procedures for ocean energy technologies are relatively limited. Guidelines and technical specifications have been mainly developed for power performance assessment of wave and tidal energy. There is a lack of consensus on testing requirements and other evaluation criteria beyond power performance. Experience and results from previous publicly funded projects should contribute to advancing towards more widely accepted standards and associated certification procedures. This in turn will facilitate coherent development and assessment of technologies and avoid unnecessary costs and risks.

APPLICABILITY

Wave and Tidal Energy Converters.

ACTIONS

- Gather best practices from laboratory testing of sub-systems to final system validation in the relevant marine environment.
- Assess guidelines, specifications and standards in real-case, open-sea projects, and apply experience gained in other industries.
- Develop internationally recognised standards that are proportionate to the level of development of new technology areas, practical and widely used, in collaboration with international bodies working on this field such as IEC-TC114, IECRE, DNVGL, BV.
- Involve investors and utilities, insurance providers and regulators in the definition of standards, e.g. in steering committees or equivalent, in order to ensure that the certification process reduces the cost of capital and insurance.

EXPECTED IMPACT

- Improve technical specifications, guidance and standards as appropriate to the sector's technological development.
- More widespread application of those specifications, guidance and standards.
- Reduce costs of insurance and capital for projects.

TRL HIGH

It could be a non-research project, in line with the approach of Horizon 2020 "Coordination and Support Actions".

BUDGET REQUIRED €10M

Around 5 small projects are required under this topic.

6. Future Outlook

Photo: Sabella

Ocean energy will deliver large volumes of the renewable energy that Europe needs for decarbonisation. It will help balance the electricity system by complementing variable renewables. Led by European companies, the ocean energy sector will create thousands of jobs in Europe. This leadership can be translated into export success and dominance of the global market.

Addressing the challenges described in this SRIA will help the sector advance and approach industrial roll-out. Reliability, survivability and energy yield of ocean energy devices will improve while the lifetime costs will go down. More full-scale devices will be put in the water and the array deployment will accelerate – more clean electricity will be fed into the grid, powering European homes.

Public funding is essential to mobilise private investment. This SRIA gives guidance on what is needed to leverage that investment and bring the technology to maturity. Revenue support is then needed to allow the deployment of demonstration and pre-commercial projects. These efforts together will help deliver a decarbonised Europe powered by ocean energy.

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Acronyms

CAPEX: Capital Expenditure

ERA-NET: European Research Area Network

ETIP Ocean: European Technology and Innovation Platform for Ocean Energy

EU: European Union

H2020: Horizon 2020, the EU Framework Programme for Research and Innovation

IEA-OES: International Energy Agency – Ocean Energy Systems

IP: Intellectual Property

JRC: Joint Research Centre

KPI: Key Performance Indicator

LCOE: Levelised Cost of Energy

O&M: Operation and Maintenance

OPEX: Operational Expenditure

OTEC: Ocean Thermal Energy Conversion

PTO: Power Take Off

OWSC: Oscillating Wave Surge Converters

OWC: Oscillating Water Column

SCADA: Supervisory Control And Data Acquisition

SET Plan: Strategic Energy Technology Plan

SME: Small and Medium Enterprises

SRIA: Strategic Research and Innovation Agenda

SWAC: Sea-Water Air Conditioning

TRL: Technology Readiness Level

TWG: Technology Working Group

WEC: Wave Energy Converter

Definitions[16]

ACTION
Set of funded activities leading to measurable progression of technology in the priority topic of interest. Depending on the level of ambition, one or several Actions could be grouped to make up a Project.

BUDGET REQUIRED
Estimated mix of public and private funding to address the challenges of a specific Priority Topic. It should not be considered as a spending ceiling but as the best estimation from the authors at the moment of preparing this SRIA. This funding should be spread out in several projects of different sizes[17] and technology readiness levels.

CHALLENGE AREA
R&I field identified as most worthy of investment during the next period of 4-5 years.

EXPECTED IMPACT
Final goal of a funded R&I project when it finishes or with additional efforts clearly defined by a project outcome. In the context of this SRIA, a research project should always try to achieve something which helps the sector meet the SET Plan targets. The expected impact should be one of the most important metrics to evaluate R&I projects.

FUNDING INSTRUMENTS
Public support for R&I projects at EU, national and regional level. These funding instruments are usually combined with in-house and/or private funding.

PRIORITY TOPIC
A relevant technical topic within a Challenge Area according to the opportunity for the sector in Europe and the urgency to be overcome.

PROJECT
One or several actions with measurable objectives beyond the state of the art, producing clear outputs and with a well-defined expected impact. It will usually require a mix of public and private funding.

STATE OF THE ART
Starting point for all R&I projects derived from this SRIA. Funded projects should clearly demonstrate a progress beyond this starting point.

TECHNOLOGY READINESS LEVEL
This term referring technology maturity is usually well known in R&I projects, but SRIA uses the following terms:

- **Low TRL** means TRLs between 1 and 3
- **Medium TRL** means TRLs between 4 and 6
- **High TRL** means TRLs between 7 and 9
- **Entry TRL:** initial level of technology maturity when starting a project
- **Final TRL:** TRL achieved at the end of a project

[16] This section intends to clarify the meaning of some terms specifically used in the context of the SRIA with the goal of helping its reading. It does not include terms that are well known by the ocean energy sector, or without a specific meaning for the SRIA.

[17] Array scale ~€50m; Large projects >€8m; Medium size projects between €2m and €8m; Small projects: <€2m.

Annex: Prioritisation Methodology

The SRIA follows the Strategic Research Agenda for Ocean Energy (2016) (SRA) in presenting technological priority areas, objectives and actions that will encourage the commercialisation of ocean energy in Europe. The SRIA used the SRA as the basis for a prioritisation exercise carried out in 2019. The resulting Report outlines an updated list of prioritised technological challenges to the commercialisation of wave and tidal energy.

The updated list derives content from a wide range of reports and roadmaps released since the publication of the SRA, such as the Joint Research Centre's (JRC) Ocean Energy Status Report, 2016 and ETIP Ocean's Deliverable 8.5: Report on presentation of stakeholder engagement results workshop [30] [31]. One significant source was Energy Innovation Needs Assessment Workshop Report (2019), by the Carbon Trust in association with the UK Department for Business, Energy and Industrial Strategy [32]. A review of these sources revealed both new and previously-prioritised challenges, which were added to the list.

The updated list is comprised of 61 challenges within 11 Challenge Areas. The challenges were prioritised according to: (i) the degree to which they are currently an obstacle to the development of the sector; and (ii) the extent of opportunity offered to Europe to overcome the challenges. These two criteria were divided into sub-criteria (Table 13). Corresponding questions on which to score each criterion between 1 and 5 were developed. Finally, the weighted scores from the respondents were averaged out to give a single score for each challenge.

The weighting of each criterion has been adapted from the original deliverable, D2.1 of ETIP Ocean's first iteration [33], on which this list is based. The original weightings underwent validation by the ETIP Ocean platform. The subsequent, amended scoring criteria presented in this report, has again been validated through engagement with the ETIP Ocean Technology Working Group.

All challenges sit towards the top right-hand corner of Figure 25. This demonstrates that all the challenges identified in this piece of work are appropriate for further research and will require attention in the short and medium term. The reason for this lack of diversity in the scores is that they have all already undergone prioritisation in previous studies. Any low priority challenges have been eliminated at an earlier stage. The consistent scoring in this exercise demonstrates the continued validity of the source material.

Assessment Criterion	Description	Weighting (%)
Sector urgency	How important is it to the sector that the challenge is tackled rapidly?	20
Cost reduction potential (impact on CAPEX)	What impact will tackling the challenge have on ocean energy project CAPEX?	20
Cost reduction potential (impact on OPEX)	What impact will tackling the challenge have on ocean energy project OPEX?	20
Impact on performance (energy yield and efficiency)	What impact will tackling the challenge have on the energy yield and efficiency performance of ocean energy systems?	15
Impact on reliability, technical risk and survivability	What impact will tackling the challenge have on reliability, technical risk, and survivability of ocean energy systems?	15
Cross-cutting	How diverse is the range of other ocean energy technologies and other sectors that stand to benefit from the resolution of this challenge?	10
Dedicated funding stream	To what extent does this challenge require funding to be overcome?	33
European capability to deliver the solution	How well-placed is the sector in Europe to deliver the solution to this challenge?	33
Risk of duplication	To what extent is work not already being carried out to overcome this challenge?	33

Table 13. Sub-criteria for assessing the dependence of the sector on this challenge being overcome, and the opportunity afforded Europe to play a significant role in overcoming the challenge.

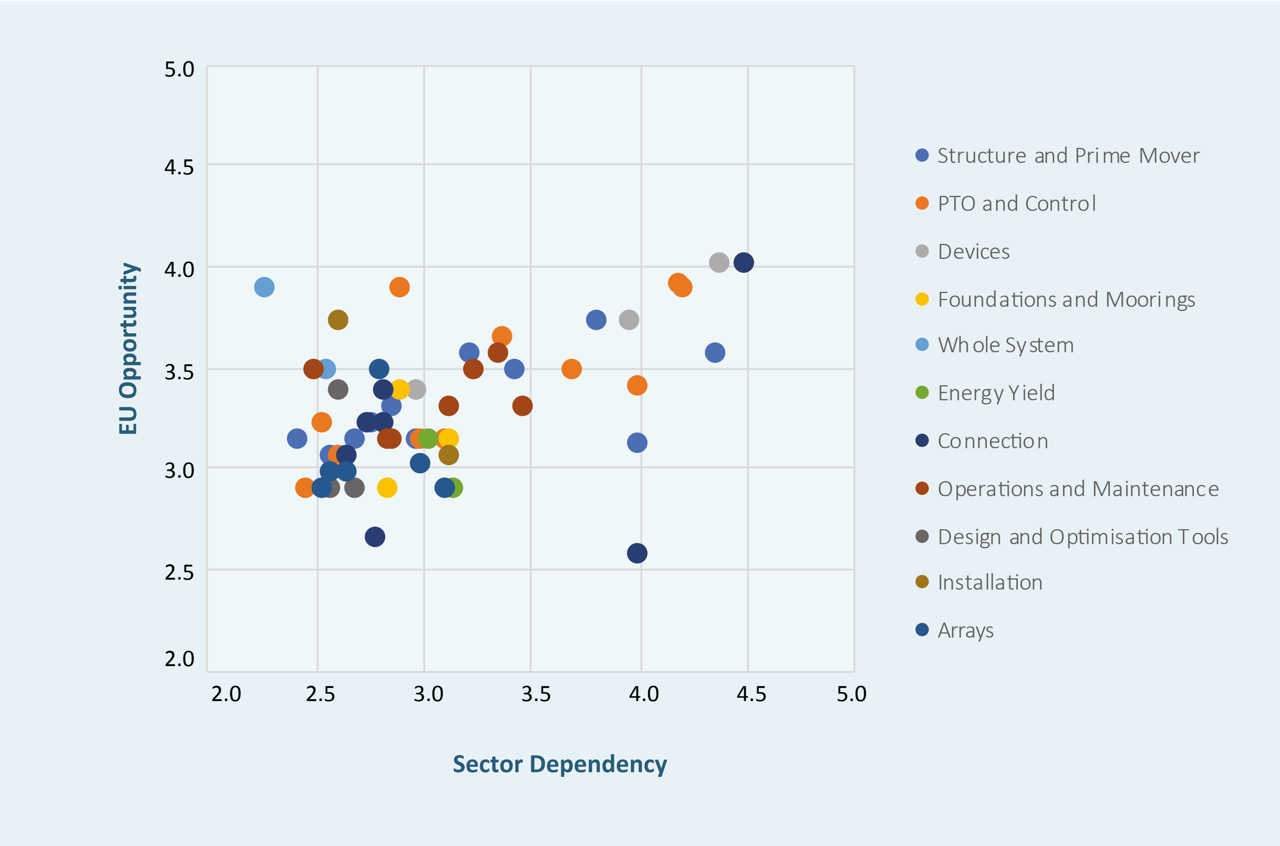

Figure 25. Prioritised Technology Challenges plotted across the two axes.

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The European Technology and Innovation Platform for Ocean Energy (ETIP Ocean) is a recognised advisory body to the European Commission, and is part of the EU's main Research and Innovation policy the Strategic Energy Technology Plan (SET Plan). ETIP Ocean defines research and innovation priorities for the ocean energy sector and promote solutions to the industry, European and national policy makers. ETIP Ocean also informs and supports the SET Plan's 'Ocean Energy Implementation Plan'.

From 2016-2018 ETIP Ocean has been managed by Ocean Energy Europe (OEE) in partnership with the University of Edinburgh, which represents the European Energy Research Alliance (EERA).

ETIP Ocean's mandate was renewed by the European Commission for 2019-2021. For this phase OEE and the University of Edinburgh have been joined by TECNALIA and WavEC.