Technology Collaboration Programme
by iea

Ocean Energy and Net Zero

An International Roadmap to Develop 300GW of Ocean Energy by 2050

A Policy Guidance Report Developed by Ocean Energy Systems, the International Energy Agency's Technology Collaboration Programme for Ocean Energy.

OES | OCEAN ENERGY SYSTEMS

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Front cover image: Orbital O2 operating at EMEC test site in Orkney (Source: Orbital Marine Power)

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Foreword

Magallanes Renovables ATIR installation (Source: Magallanes Renovables / Colin Keldie)

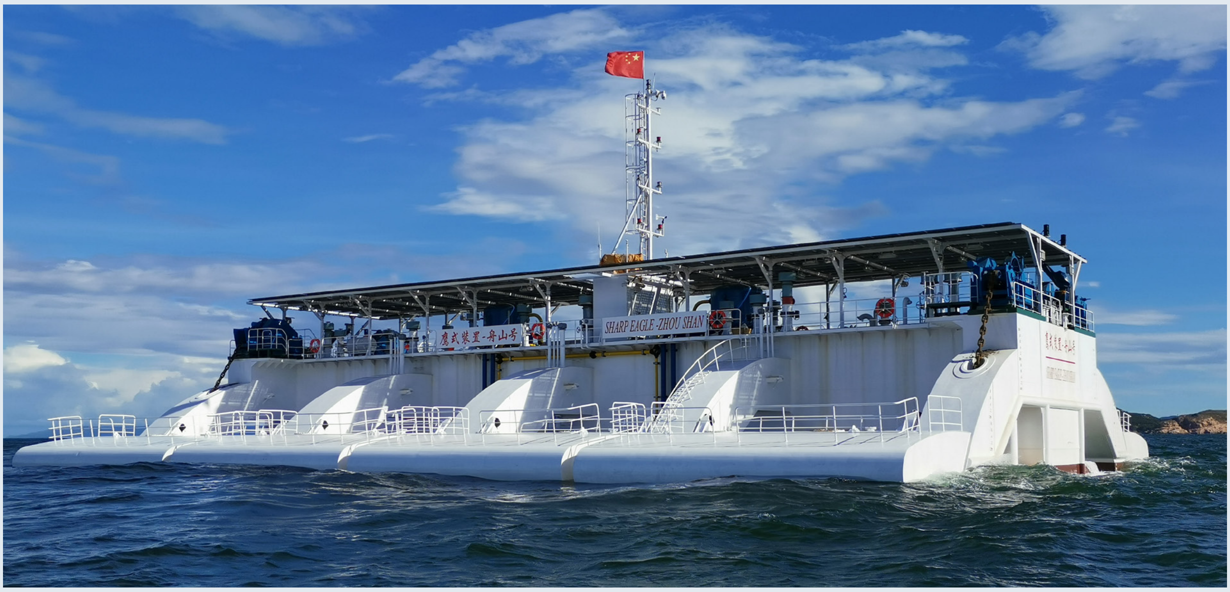
Foreword

The summer of 2023 saw new record-high temperature extremes set across the planet, with the shared impacts of climate change becoming increasingly frequent, severe and deadly. Many global governments and institutions are now in agreement that the world is situated in the critical decade for climate action, and as a result, the scientific consensus for a rapid and comprehensive response to mitigate the worst outcomes of the climate crisis has become the defining challenge of our lifetimes. In this moment, there has never been a stronger or clearer case for the transformation of the global energy system in line with Net Zero requirements. The recent International Energy Agency (IEA) Net Zero Roadmap makes it clear that transforming the global energy system in line with limiting global warming to 1.5°C will be a challenge that is addressed across multiple fronts. The IEA Net Zero Roadmap also identifies that there will need to be at least a tripling of global installed renewable energy capacity by 2030, coupled with future-proofing of infrastructure and supply chains, to achieve this goal.

With this target in mind, Ocean Energy Systems (OES), the IEA's Technology Collaboration Programme for ocean energy, is publishing its own roadmap, with the aim of outlining the steps that will be required to unlock the significant potential of the global wave and tidal stream energy sectors, enabling them to contribute to global Net Zero commitments.

This report will quantify the level of financial investment, delivered via sustained policy support, that will be required to ensure that these emerging renewable technologies achieve commercial deployment on a global scale. This report will pay particular attention to the impact of market pull and technology push policy mechanisms and the role that they play in accelerating innovation across the wave and tidal stream sector, while maintaining cost-effective levels of investment. This report will also consider how the construction or upgrading of existing ports and harbors to accommodate for a range of key ocean energy infrastructure and future development metrics should be approached, culminating in a future scenario case study detailing port infrastructure requirements for the mid 2040s. Finally, this report will examine the regulatory and legislative frameworks that govern both the design and development of ocean energy standards and the licensing and consenting of ocean energy technologies, examining how their evolution and future design should be supported to ensure that this growing sector receives sustained levels of support.

This roadmap will make clear that without global collaboration, sustained financial support and immediate action, the pathway towards achieving a globally commercial ocean energy sector will be increasingly difficult to follow. The political will, the societal momentum and the economic argument for a radically transformed global energy system, where ocean energy plays a vital role, has coalesced into a resounding challenge for action. The following summary of the key results from the IEA-OES Roadmap, coupled with the policy actions collated at the end of this report, will illustrate clearly how the ocean energy sector can hope to embrace and overcome this challenge.



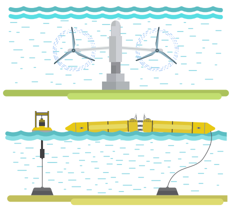
Zhoushan Sharp Eagle (Source: GIEC)

Executive Summary

IEA-OES Roadmap Key Results

By 2050, the OES Roadmap targets have outlined that there is the potential for wave and tidal stream technologies (referred to collectively as ocean energy technologies) to contribute **300GW of renewable energy generation capacity** to the global Net Zero transition. This installed capacity of ocean energy also has the capability to **create 680,000 jobs, generate $340 billion in gross value added (GVA), and prevent over 500 million tonnes of carbon emissions.**

300GW of Ocean Energy



680,000 Jobs

$340 Billion in Gross Value Added

A 500 Million Tonne Reduction in Carbon Emissions

Market Pull Policy Requirements

The global cost of a market pull policy support mechanism to **deploy 180GW of wave energy** varies depending on the effectiveness of technology push funding to drive sustained innovation and cost reductions:

- **An optimal cost reduction rate of 15% will achieve WMP† parity by the mid-2040s** at a total market pull investment of **approximately $74 billion**;
- **A moderate cost reduction rate of 12.5% will achieve WMP parity by the late-2040s** at a total market pull investment of **approximately $170 billion**;
- **A sub-optimal cost reduction rate of 10% will not achieve WMP parity by 2050**, by which point a total market pull investment of **approximately $378 billion** will have been required.

The global cost of a market pull policy support mechanism to **deploy 120GW of tidal stream energy** varies depending on the effectiveness of technology push funding to drive sustained innovation and cost reductions:

- **An optimal cost reduction rate of 15% will achieve WMP parity by the mid-2040s** at a total market pull investment of **approximately $56 billion**;
- **A moderate cost reduction rate of 12.5% will achieve WMP parity by the late-2040s** at a total market pull investment of **approximately $132 billion**;
- **A sub-optimal cost reduction rate of 10% will not achieve WMP parity by 2050**, by which point a total market pull investment of **approximately $275 billion** will have been required.

It is important to note that these significant costs represent the total accumulated value of individual market pull policy mechanisms pursued by leading nations in the ocean energy sector. Encouraging effective collaboration between nations is one of the most effective ways to reduce the contribution required from each country.

Policy Action: Market pull support is the foundation of a comprehensive policy programme

- Led at a country-by-country level, the immediate application of a long-term and sustained market pull policy mechanisms is key to strengthening and accelerating the progress of the ocean energy sector.

† WMP – wholesale market price

Technology Push Policy Requirements

The levels of investment required to deliver a comprehensive technology push programme can be dramatically reduced by engaging in a collaborative innovation framework with other countries:

Full collaboration – funding is shared across 20 countries for wave and 9 countries for tidal stream:

- The funding required to deliver a comprehensive technology push programme for wave is predicted to be a maximum of **$11 million per country per year**, dropping to **approximately $7 million per country per year by the early-2030s**;
- The funding required to deliver a comprehensive technology push programme for tidal stream is predicted to be a maximum of **$22 million per country per year**, dropping to **approximately $14 million per country per year by the late-2020s**.

Partial collaboration – funding is shared across 10 countries for wave and 6 countries for tidal stream:

- The funding required to deliver a comprehensive technology push programme for wave is predicted to be a maximum of **$22 million per country per year**, dropping to **approximately $14 million per country per year by the early-2030s**;
- The funding required to deliver a comprehensive technology push programme for tidal stream is predicted to be a maximum of **$32 million per country per year**, dropping to **approximately $20 million per country per by the late-2020s**.

Policy Action: Accelerated innovation is key to enabling long-term cost reductions

- A well-funded and comprehensive technology push policy programme, actively pursuing international collaboration, is vital to ensuring that technological innovation occurs at a significant rate and helps to lower the overall investment required to provide a long-term market support mechanism.

Balancing Market Pull and Technology Push

A comprehensive and well-balanced policy programme provides the financial and technological support required to bring the ocean energy sector closer to commercial-scale deployment.

Policy Action: An optimal balance of market pull and technology push funding must be struck

- While long-term support for market pull policy support mechanisms is key to achieving a commercial ocean energy sector, the overall cost of attaining this target can be massively reduced through the application of sustained innovation, achieved through coordinated support for technology push policy support mechanisms.

Ocean Energy Infrastructure Requirements

Having identified a range of ocean energy infrastructure and future development metrics, this report forecasts that the following future infrastructure developments should occur:

- To meet the OES Roadmap targets, this report projects that there will need to be **the equivalent of 100 new or upgraded ports, shared between the 20 leading nations, with capacity to deploy 300 MW per year by the mid-2040s**. Planning for this infrastructure development should **begin immediately** to mitigate long lead times and should consider the possibility of sharing infrastructure with other developers, such as the floating offshore wind sector;
- Based on current sector projections and stakeholder interaction, the global annual requirements infrastructure development will require the construction or upgrading of **3000 ha of new manufacturing/fabrication space** and **1000 ha of new laydown space by the 2040s**;
- To encourage engagement from port operators, it is essential to have clear policy timelines and use public-private partnerships to facilitate efficient infrastructure build-out. Regular auditing should be used to ensure funding agencies are on track and aligned with government objectives.

Policy Action: Immediate action on infrastructure development is vital

- While existing infrastructure is well-positioned to handle the short-term requirements of the sector, the rapid expected growth will require large-scale global infrastructure development projects to begin immediately.

Executive Summary

Regulation and Legislation Requirements

- The design and development of ocean energy standards can benefit from measures such as the adoption of international consensus-based standards, third party testing and earlier integration and alignment of standards in the development process.
- Licensing and consenting of ocean energy devices can be made more efficient through measures such as the use of adaptive management processes, integration of environmental monitoring at test sites, clear consenting schemes and earlier engagement of project stakeholders.

Policy Action: The regulatory and legislative framework should help, not hinder

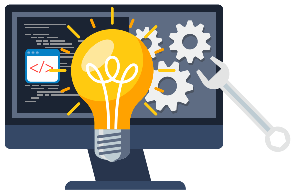
- The ocean energy sector should be underpinned by a robust and efficient regulatory and legislative framework that provides the levels of support required to ensure that sector growth happens in line with forecasted timelines.

The analysis and forecasting that underpins the key results and policy actions for Market Pull, Technology Push, Infrastructure and Regulation & Legislation will be discussed in turn throughout this IEA-OES Roadmap.

Market Pull

The total cost of a global ocean energy market pull policy could cost as little as $28 billion up until 2050

Technology Push



Effective innovation is essential to compliment and reduce the overall market pull policy investment

Infrastructure

The growth of the sector could require 100 dedicated ports installing 300MW per year

Regulation & Legislation

Adaptive management and third-party testing will allow safe and sustainable growth in the sector

CalWave device trial off the coast of San Diego (Source: CalWave Power Technologies)

1 Introduction

The UniWave200 unit installed offshore Tasmania (Source: Wave Swell Energy)

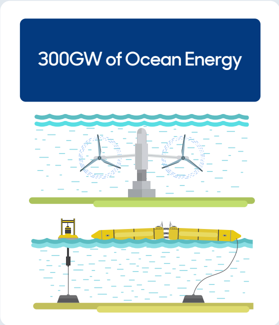
Introduction

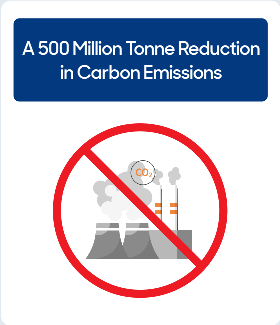
The global energy sector is currently facing unprecedented pressure to urgently transition towards carbon neutral energy supplies as the world seeks to mitigate the worst outcomes of the ongoing climate crisis. At the same time, there is a growing consensus that the world's energy providers must increasingly utilise a wide range of renewable energy sources, delivering an energy generation portfolio that is sustainable across its lifecycle and insulated from geopolitical shocks.

While the role that mature renewable energy technologies, such as wind and solar, will play in this global energy transition are well understood, this ocean energy roadmap will outline and forecast the role that the wave and tidal stream sectors have to play in accelerating the delivery of a global Net Zero future.

The objective of this report is to outline an international roadmap, where the individual and shared responsibilities of the leading countries in the development of wave and tidal stream technologies is quantified with the aim of achieving a globally commercial wave and tidal stream sector by 2050. Should the OES Roadmap target of **300GW of ocean energy by 2050** be achieved, the OES Roadmap targets also forecasts the following associated benefits:

- The creation of over **680,000 jobs**;
- The generation of over **$340 billion in Gross Value Added (GVA)** to national and international economies;
- A reduction of over **500 million tons** of carbon emissions.





However, these forecasted benefits will not be achieved without the implementation of both evidence-led policies and long-term financial support. Currently, ocean energy technologies have yet to achieve array-scale deployment and will require continued technological development and deployment support to become cost-and-performance-competitive with other, more mature, renewable energy technologies. While tidal stream devices have had some success in moving beyond prototype development, with a number of developers conducting live-sea array deployments across the globe, it is widely accepted that wave energy converters (WECs) are currently at a more nascent stage of technological development and, as such, are considered to be around 5 years behind tidal stream with regards to their overall development. Therefore, the development of both wave and tidal stream technologies will require large-scale and well-coordinated processes of international co-operation and collaboration, where accelerated technological innovation is viewed as a priority. In addition to this, existing policy programmes and frameworks will need to be adapted to provide the long-term financial support and legislative guidance required to meet the OES Roadmap targets.

This report will now establish a potential implementation strategy for the ocean energy sector and will cover market pull & technology push policy mechanisms **(Section 2)**, infrastructure and future development **(Section 3)** and legislation & regulation **(Section 4)**. This report will also utilise a number of case studies as a way to illustrate how different aspects of the implementation strategy can be applied to the wave and tidal stream sectors. Finally, the forecasted values for the future deployment of wave and tidal stream technologies that underpin the analysis contained withing this report, have been developed in consultation with the IEA OES modelling team.

2 Market Pull & Technology Push

Orkney vessel trials project (Source: Aquatera)

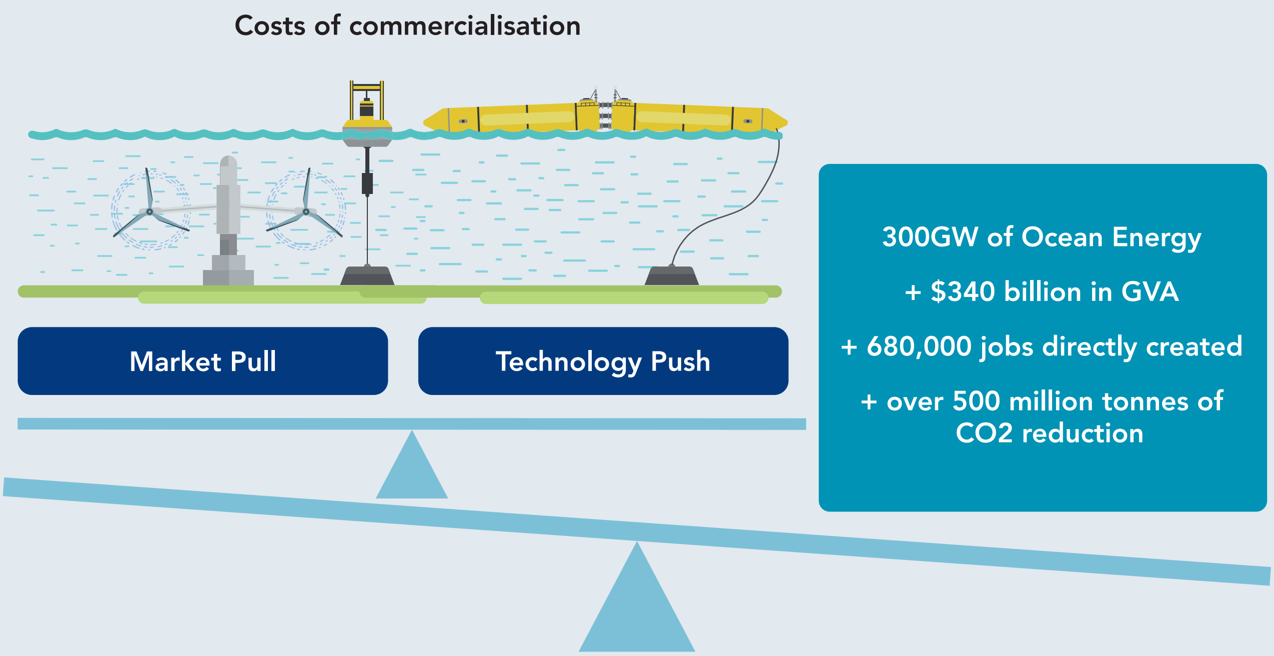
Market Pull & Technology Push

In order for renewable energy technologies to replace existing forms of carbon-intensive energy production, there is a need for targeted policy support mechanisms that can facilitate the delivery of the financial investment required to achieve commercial-scale deployment. For the wave and tidal stream sectors, this challenge is further compounded by the fact that these technologies are also competing with mature and established renewable energy technologies, such as wind and solar. For these nascent technologies, policy mechanisms that can help to deliver long-term and consistent deployment trajectories, coupled with an accelerated cost reduction rate, are vital to ensure that they achieve commercial viability. These support mechanisms can be broadly described as being either market pull or technology push:

- Market pull policy support mechanisms, which include Feed-in Tariffs (FiTs) and Contracts for Difference (CfDs) schemes, help to accelerate commercial-scale deployment and underpin investor confidence by providing long-term revenue support over the devices lifespan.

- Technology push policy support mechanisms, which include government R&D grants and loans, help to drive forward technological innovation and accelerate overall cost reductions.

Striking the right balance between the cost of these policy support mechanisms and the benefits to society that a commercial ocean energy sector can bring (i.e. the GVA to the economy, jobs created or a reduction in overall emissions), while still delivering a cost-effective return on taxpayers investment, is a complex task. Ensuring that individual countries are able to achieve this optimal balance of both technology push and market pull policies is key to ensuring that the OES Roadmap targets are met by 2050.



Market Pull & Technology Push

Market Pull Analysis for Wave and Tidal Stream

The following analysis forecasts the potential financial investment that would be required to develop a global market pull mechanism capable of enabling the deployment of 180GW of wave and 120GW of tidal stream by 2050.

Market pull polices are the foundational policy tool that is available to provide long-term price stabilisation to emerging technologies, keeping them market-competitive and ensuring that private capital is encourage to invest and underpin these technologies as they mature and reach parity with the wholesale market price. The unique financial and policy landscape of each country pursuing a commercial ocean energy sector will mean that a range of market pull policy mechanisms, from FiTs to CfDs, are brought forward, tailored to the specific strengths of any one nation. So, while this roadmap does not seek to compare the effectiveness of one market pull policy mechanism against another, what is clear from the analysis that will follow, is that the sustained financial support that they provide is essential to increasing the market-competitiveness of both wave and tidal stream technologies.

The following analysis provides an estimate, for both wave and tidal stream, of the total global costs associated with funding an international market pull policy. Three different cost reduction rates are examined for both wave and tidal stream. For each technology, this report has assumed 3 cost reduction rates as follows:

- 10% – sub-optimal global cost reduction rate
- 12.5% – moderate global cost reduction rate
- 15% – optimal global cost reduction rate

Market Pull Analysis – Wave

As previously outlined, it has been assumed that wave energy technology is currently 5 years behind tidal stream development:

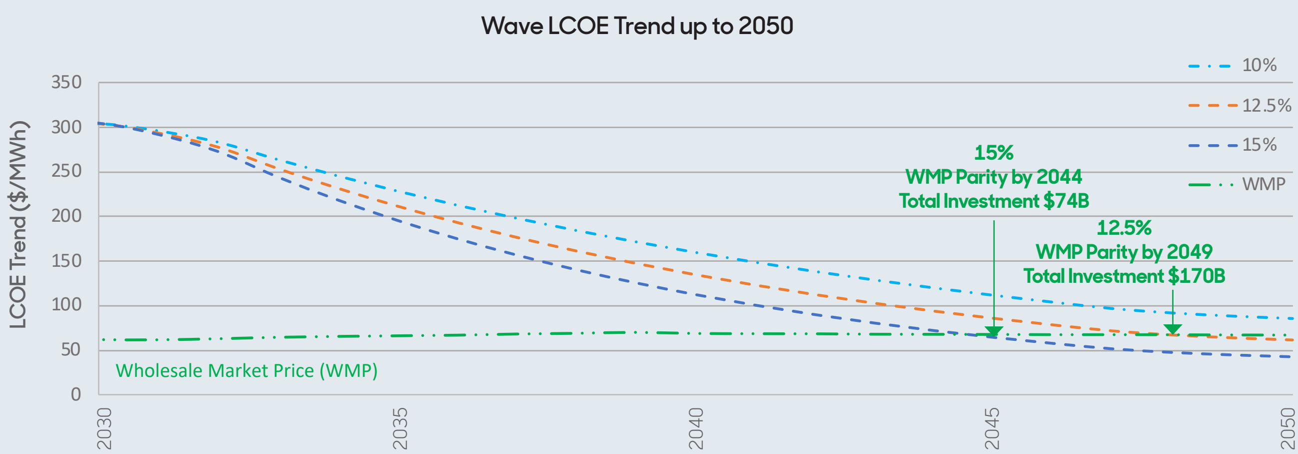


Figure 2.1: LCOE trend at different market pull policy starting price for the tidal stream sector

Key Result

The global cost of a market pull policy support mechanism to **deploy 180GW of wave energy varies** depending on the effectiveness of technology push funding to drive sustained innovation and cost reductions:

- **An optimal cost reduction rate of 15% will achieve WMP parity by the mid-2040s** at a total market pull investment of **$74 billion**;
- **A moderate cost reduction rate of 12.5% will achieve WMP parity by the late-2040s** at a total market pull investment of **$170 billion**;
- **A sub-optimal cost reduction rate of 10% will not achieve WMP parity by 2050**, by which point a total market pull investment of **$378 billion** will have been required.

It is important to note that these significant costs represent the total accumulated value of individual market pull policy mechanisms pursued by leading nations in the ocean energy sector. Encouraging effective collaboration between nations is one of the most effective ways to reduce the contribution required from each country.

Market Pull Analysis – Tidal Stream

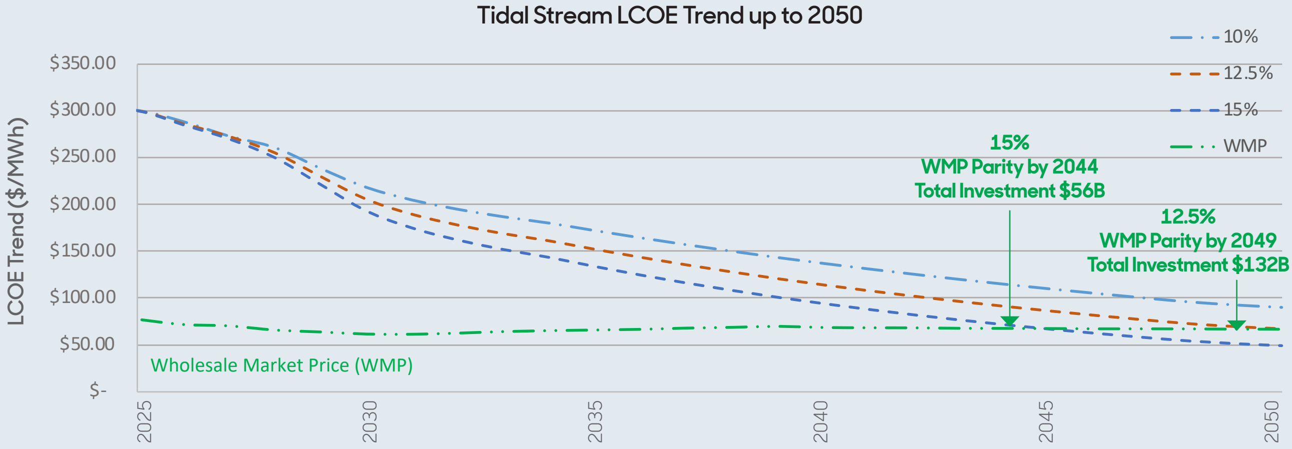


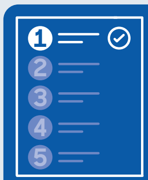
Figure 2.2: LCOE trend comparison for different cost reduction rates for tidal stream technology

Key Result

The global cost of a market pull policy support mechanism to **deploy 120GW of tidal stream energy** varies depending on the effectiveness of technology push funding to drive sustained innovation and cost reductions:

- An optimal cost reduction rate of **15% will achieve WMP parity by the mid-2040s** at a total market pull investment of **$56 billion**;
- A moderate cost reduction rate of **12.5% will achieve WMP parity by the late-2040s** at a total market pull investment of **$132 billion**;
- **A sub-optimal cost reduction rate of 10% will not achieve WMP parity by 2050**, by which point a total market pull investment of **$275 billion** will have been required.

It is important to note that these significant costs represent the total accumulated value of individual market pull policy mechanisms pursued by leading nations in the ocean energy sector. Encouraging effective collaboration between nations is one of the most effective ways to reduce the contribution required from each country.



Policy Action: Market pull support is the foundation of a comprehensive policy programme

- Led at a country-by-country level, the immediate application of a long-term and sustained market pull policy mechanisms is key to strengthening and accelerating the progress of the ocean energy sector.

Market Pull & Technology Push

Market Pull Summary

This analysis has underlined the role that a consistent, long-term market pull policy support mechanism has to play in achieving the OES Roadmap targets, delivering 180GW of wave and 120GW of tidal stream by 2050.

This analysis has also demonstrated the impact of different cost reduction rates over the lifetime of a sustained market pull policy support mechanism. A higher cost reduction rate, achieved through increased technology push funding, provides greater overall cost reductions and **significantly reduces the total investment required to support each market pull policy**. By assuming three different learning rates: 10%, 12.5%, and 15%, maintained across the duration of the market pull policy mechanisms lifetime, our analysis indicates:

- That maintaining a cost reduction rate of **15%** across the duration of the market pull policy support mechanism will result in a **total cost of $130 billion**;
- That maintaining a lower cost reduction rate of **12.5%** across the duration of the market pull policy support mechanism will result in a **total cost of $302 billion**;
- That maintaining the lowest cost reduction rate of **10%** across the duration of the market pull policy support mechanism will result in a **total cost of $653 billion**, without reaching WMP parity by 2050.

As can be seen from Figures 2.1 and 2.2, any cost reduction rate will require a commitment to sustain market pull policies for a number of years. Therefore, **it is vital that any market pull policy is started immediately** to ensure that the eventual cost reductions can be realised as quickly as possible. This is further compounded when we consider that the overall effectiveness of a global market pull policy is reliant on the individual contributions of each country.

As can be seen from Figures 2.1 and 2.2, any cost reduction rate will require a commitment to sustain market pull policies for a number of years. Therefore, it is vital that any market pull policy is started immediately to ensure that the eventual cost reductions can be realised as quickly as possible. This is further compounded when we consider that the overall effectiveness of a global market pull policy is reliant on the individual contributions of each country.

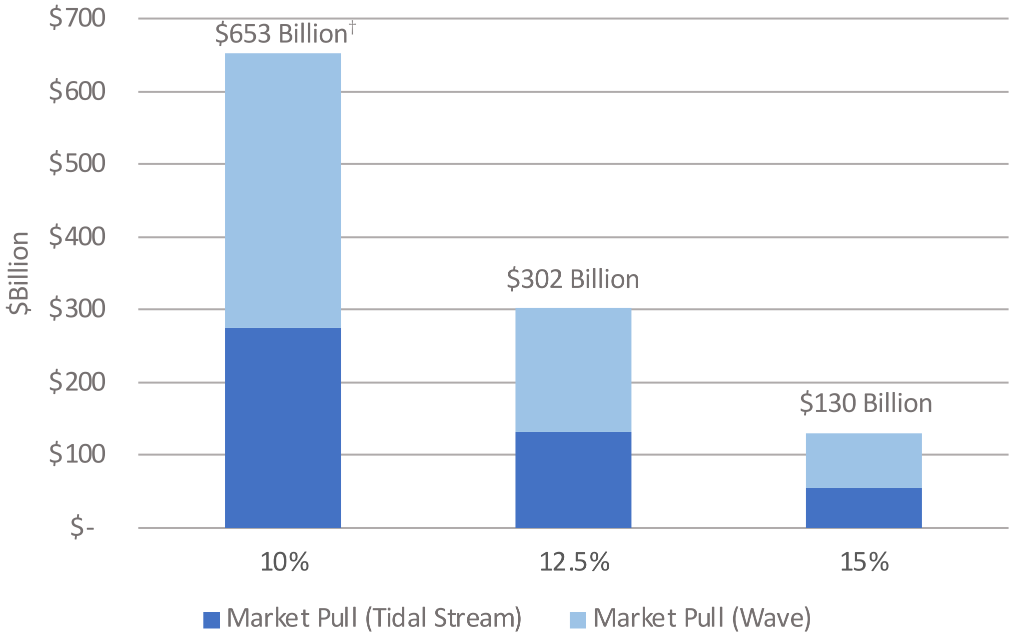


Figure 2.3: Required Investment commitment at different cost reduction rates for both wave and tidal stream

† Under the modelling and WMP assumptions, the 10% cost reduction rate scenario does not meet cost parity by 2050.

Technology Push Analysis for Wave and Tidal Stream

As outlined in the previous section, the effectiveness of long-term financial support to ensure the continued development of wave and tidal stream technologies, is highly dependent on achieving an effective cost reduction rate as a result of sustained technological innovation. The following section will now examine the importance of a well-funded, collaborative technology push policy program, as a way to minimize costs through increased innovation.

Ensuring that high levels of innovation are maintained is key to delivering the sustained and accelerated cost reductions necessary to bring the global wave and tidal stream sector closer towards full commercial scale competitiveness. At the same time, the costs associated with the development of ocean energy technologies can be further reduced per country by implementing a coordinated and collaborative international research framework. This can be reinforced by ensuring that the leading ocean energy technology nations work together to tackle shared challenge areas, as identified by evidence-led technology roadmaps The importance of this international collaborative process cannot be understated and as such the impacts of increasing the levels of global collaboration will form the basis of the analysis in this section.

The following section will outline the potential breakdown of global technology push funding required to drive effective technology innovation and accelerate cost reductions for wave and tidal stream devices. The total budget required to provide this funding will be quantified per country under the criteria outlined in the **full collaboration** and **partial collaboration** scenarios below:

- **Full Collaboration** – the maximum number of countries leading the development of wave and tidal stream technologies contribute to sector funding: **20 countries for wave** and **9 countries for tidal stream**;
- **Partial Collaboration** – a reduced number of countries leading the development of wave and tidal stream technologies contribute to sector funding: **10 countries for wave** and **6 countries for tidal stream**.

It is forecasted that the total public innovation funding required to achieve commercial deployment for both wave and tidal stream development will change over time as the technology improves and certain innovation stages are reached. The following analysis predicts the levels of innovation funding that could be required at different development stages for both wave and tidal stream technologies as they get closer to full commercialisation.

Stage 1 – The levels of funding required to address all of the main technology development areas, **including** demonstration arrays, as identified by sector roadmaps;

Stage 2 – Funding for technology innovation continues, however there is a significant reduction in the costs associated with array demonstration projects, as wave and tidal stream technologies move successfully towards large-scale commercial arrays, funded through market pull policy support mechanisms;

Stage 3 – To deliver sustained innovation, reduced levels of overall funding are now required as wave and tidal stream technologies continue to mature;

Stage 4 – Now at a fully commercial status, technology developers still continue to innovate, but with an increasing amount of overall technology push funding coming from the private sector.

Market Pull & Technology Push

Technology Push Analysis – Wave

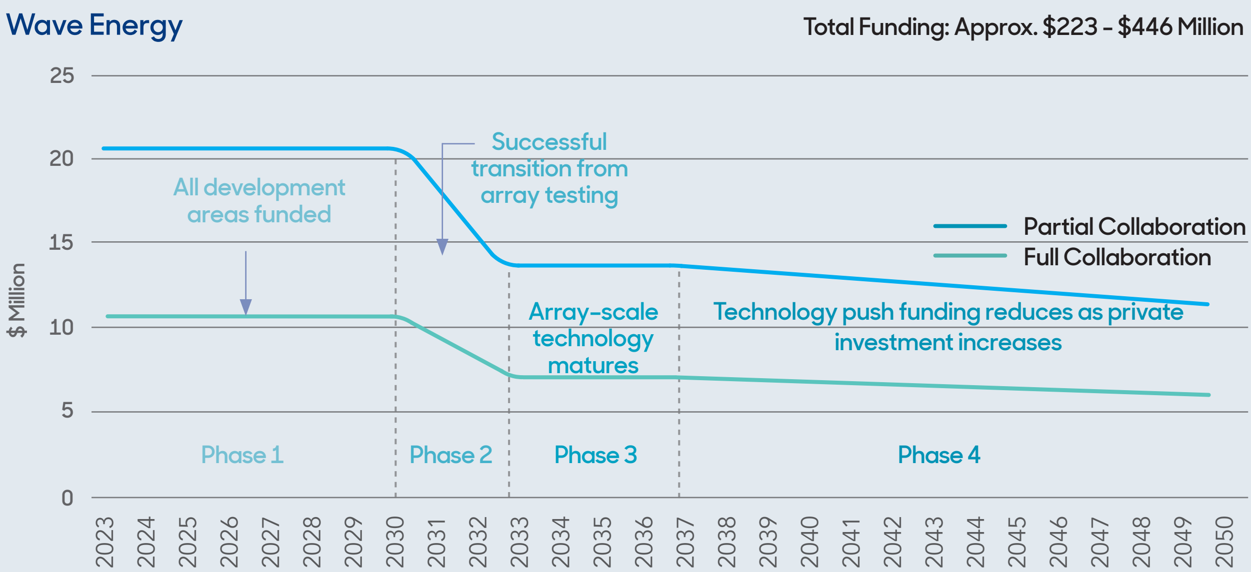


Figure 2.4: Proposed wave energy technology push funding per country 2023-2050

	Phase 1	Phase 2	Phase 3	Phase 4
Full Collaboration ($Mil per country year)	11	11 – 7	7	7 – 6
Partial Collaboration ($Mil per country per year)	22	22 – 14	14	14 – 12

Key Result

Full collaboration – a maximum of **$11 million per country per year**, dropping to **approximately $7 million per country per year by the early-2030s** will be required to fund technology push policies that deliver an accelerated cost reduction rate for wave technologies;

Partial collaboration – a maximum of **$22 million per country per year**, dropping to **approximately $14 million per country per year by the early-2030s**, will be required to fund technology push policies that deliver an accelerated cost reduction rate for wave technologies;

Technology Push Analysis – Tidal Stream

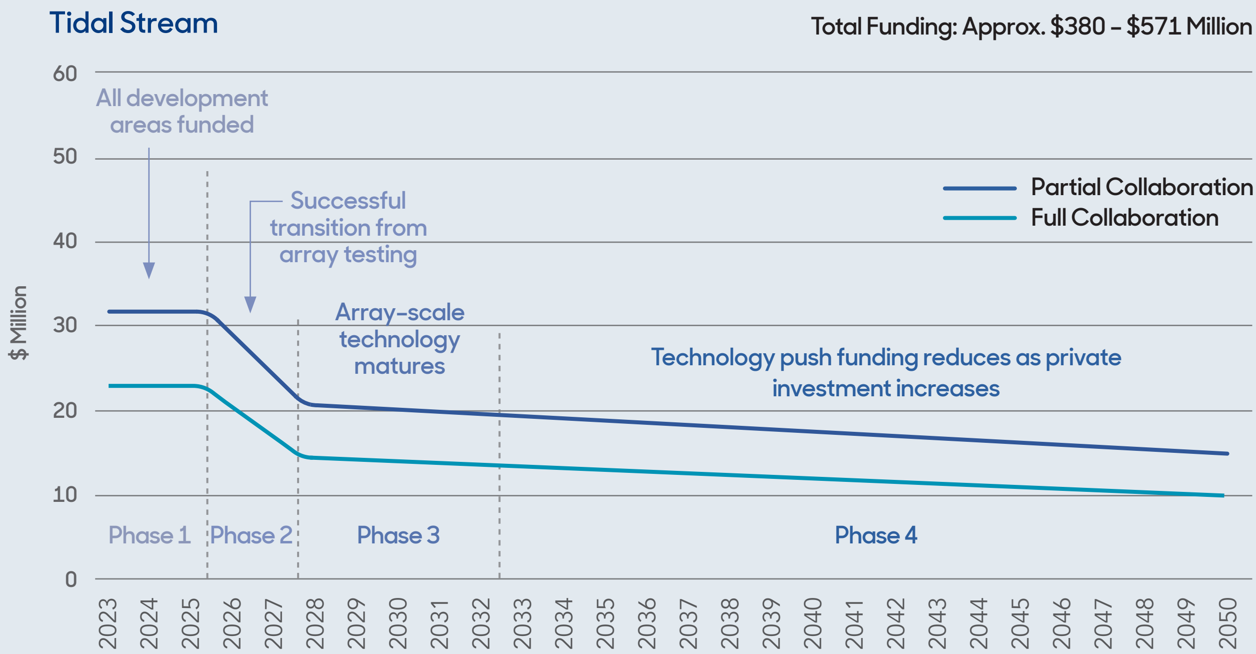


Figure 2.5: Proposed tidal stream technology push funding per country 2023-2050

	Phase 1	Phase 2	Phase 3	Phase 4
Full Collaboration ($Mil per country year)	22	22 – 14	14	14 – 10
Partial Collaboration ($Mil per country per year)	32	32 – 20	20	20 – 16

Key Result

Full collaboration – a maximum of **$22 million per country per year**, dropping to **approximately $14 million per country per year by the late-2020s**, will be required to fund technology push policies that deliver an accelerated cost reduction rate for tidal stream technologies;

Partial collaboration – a maximum of **$32 million per country per year**, dropping to **approximately $20 million per country per year by the late-2020s**, will be required to fund technology push policies that deliver an accelerated cost reduction rate for tidal stream technologies.

Market Pull & Technology Push

Technology Push Summary

Our analysis has shown that that sustained funding for technology push policy mechanisms is a critical requirement to ensure that accelerated innovation continues to occur across all development stages of the wave and tidal stream sector. Targeting specific technology development areas as part of a collaborative cross-nation approach will also be key to ensuring that this innovation is delivered in a cost-effective manner. Under the conditions established in our **full collaboration** and **partial collaboration** scenarios we have shown the following:

Full collaboration – funding is shared across **20 countries for wave** and **9 countries for tidal stream**:

- The funding required to deliver a comprehensive technology push programme for wave is predicted to be a maximum of **$11 million per country per year**, dropping to **approximately $7 million per country per year by the early-2030s**;
- The funding required to deliver a comprehensive technology push programme for tidal stream is predicted to be a maximum of **$22 million per country per year**, dropping to **approximately $14 million per country per year by the late-2020s**;

Partial collaboration – funding is shared across **10 countries for wave** and **4 countries for tidal stream**:

- The funding required to deliver a comprehensive technology push programme for wave is predicted to be a maximum of **$22 million per country per year**, dropping to **approximately $14 million per country per year by the late-2030s**;
- The funding required to deliver a comprehensive technology push programme for tidal stream is predicted to be a maximum of **$32 million per country per year**, dropping to **approximately $20 million per country per year by the late-2020s**.

Policy Action: Accelerated innovation is key to enabling long-term cost reductions

- A well-funded and comprehensive technology push policy programme, actively pursuing international collaboration, is vital to ensuring that technological innovation occurs at a significant rate and helps to lower the overall investment required to provide a long-term market support mechanism.

Orbital O2 operating at EMEC test site in Orkney (Credit: Orbital Marine Power)

Market Pull and Technology Push Summary

As section 2 has outlined, establishing the optimal balance of market pull and technology push policy requirements is a key step to ensuring that a commercial wave and tidal stream sector is achieved in the most cost-efficient manner possible. The key results listed throughout section 2 help to quantify how the large-scale investment that will be required to sustain market pull policy mechanisms across the globe, can be greatly reduced by a relatively small investment per country into technology push policies that are designed to accelerate the innovation process. By ensuring that a collaborative and targeted technology innovation programme is adequately resourced and funded, a commercial wave and tidal stream sector that aligns with the goals of this roadmap, is eminently achievable.

Considering a best-case scenario, where the global wave and tidal stream sectors **have achieved the optimal cost-reduction rate of 15%** and the **leading countries involved in wave and tidal stream development engage in full collaboration**, the following costs can be expected:

- For wave, the total cost of market pull policy support mechanisms to deploy 180GW by 2050 **will amount to approximately $74 billion and will achieve WMP parity by the mid-2040s**. The funding required to deliver a comprehensive technology push programme for wave is predicted to be a maximum of **$11 million per country per year, dropping to approximately $7 million per country per year by the early-2030s**;

- For tidal stream, the total cost of market pull policy support mechanisms required to deploy 120GW by 2050 **will amount to approximately $56 billion and will achieve WMP parity by the mid-2040s**. The funding required to deliver a comprehensive technology push programme for tidal stream is predicted to be a maximum of **$22 million per country per year, dropping to approximately $14 million per country per year by the late-2020s.**

In this best-case scenario, the costs associated with achieving a commercial wave and tidal stream sector are **much lower than those associated with a sub-optimal learning rate or partial levels of collaboration**. However, this best-case scenario will only be achieved by ensuring the following:

- The implementation of individual market pull and technology push policy mechanisms **should happen immediately**, in order to maximise the rate of sector cost reductions;

- That financial support for innovation is provided in a **targeted and sustained manner**;

- That future innovation, development and deployment prioritize a collaborative approach, where international co-operation and information sharing is implemented to address disparities in regional progress.

Should these requirements be met, the ocean energy sector has the potential to add significant GVA to regional and national economies, provide skilled jobs and employment to coastal communities, contribute system balancing benefits to national energy systems and contribute meaningfully to the global drive for Net Zero.

Policy Action: An optimal balance of market pull and technology push funding must be struck

- While long-term support for market pull policy support mechanisms is key to achieving a commercial ocean energy sector, the overall cost of attaining this target can be massively reduced through the application of sustained innovation, achieved through coordinated support for technology push policy support mechanisms.

3 Infrastructure & Future Development

AWS Ocean Energy deploying the Archimedes Waveswing at EMEC (Source: Colin Keldie / EMEC)

Infrastructure & Future Development

Having outlined the levels of investment associated with funding both market pull and technology push policy mechanisms, this report will now look at the future development of the supporting infrastructure essential to delivering 180GW of wave and 120GW of tidal stream by 2050. Section 3 will outline a number of ocean energy infrastructure and future development metrics, whose future growth is considered vital to providing adequate support to the ocean energy sector and ensuring that it can fabricate, manufacture deploy and maintain ocean energy devices at commercial scale volumes. To underline the importance of these metrics, this section will conclude with a future scenario case study outlining the potential infrastructure requirements of a port harbor complex with the capability of supporting the deployment of 300MW of ocean energy annually by the mid-2040's.

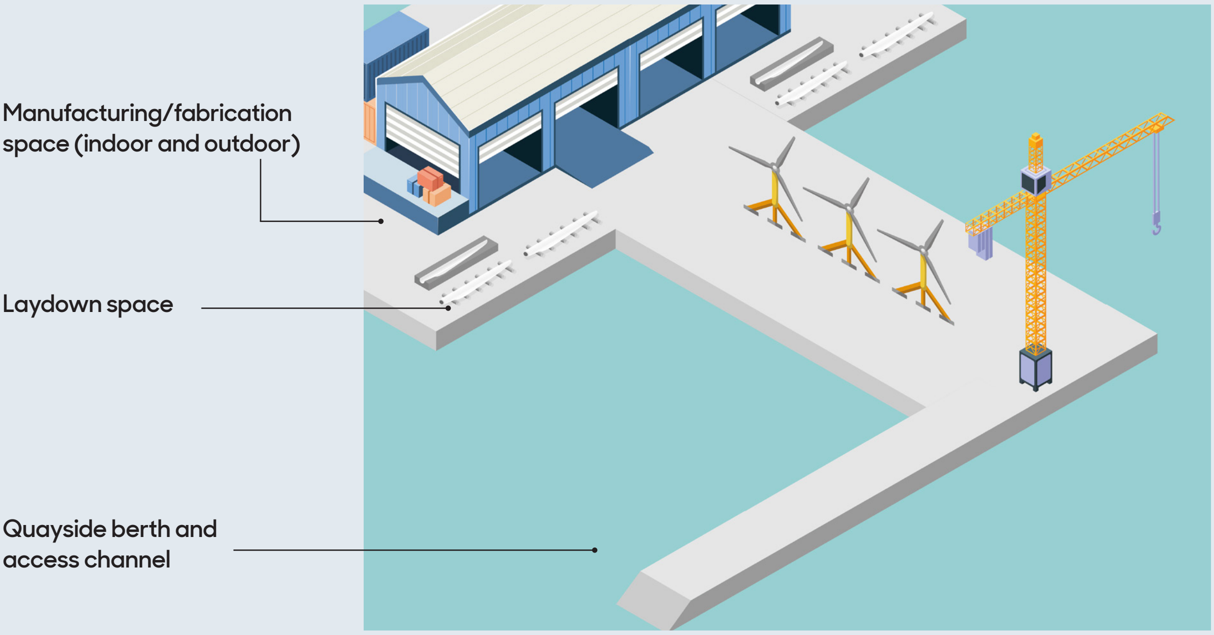
Ocean Energy Infrastructure and Future Development Metrics

The following section covers the physical infrastructure and ancillary industries that are vital for successful ocean energy deployment. The future development of the ocean energy sector must consider the entire project lifecycle from fabrication to decommissioning, with ports, harbors, and onshore facilities all identified as being critical for sustained supply chain growth, flexible deployment, and long-term energy security.

To meet global ocean energy deployment targets within the required timescales, existing ports must be upgraded and new ports constructed to prevent potential supply chain bottlenecks that will arise as the sector, and its requirements, continue to grow. Plans should consider project timelines and funding policy structure, both of which directly impact port operators' ability to access national support and meet OES targets.

This section considers infrastructure metrics related to existing and new ports and harbors and considers their future development with regards to the deployment targets outlined in the OES Roadmap. These metrics were informed by and based upon comparisons made with the offshore wind industry, as well as discussions with technology developers and infrastructure planners. Metrics identified as particularly relevant to the future development of ports and harbors for the ocean energy sector are identified below:

- **Manufacturing/fabrication space:** Used for the manufacture and fabrication of device hulls, nacelles and blades. This is often split between indoor and outdoor areas.
- **Laydown space:** Area to store devices and components before moving to the deployment site.
- **Quayside berth length/draft:** Dimensions to accommodate deployment vessels/ devices.
- **Access channel width/clearance:** Minimum dimensions for open sea access for deployment vessels/ devices.



Infrastructure & Future Development

Metric 1 - Manufacturing and Fabrication Space

At an international level, a significant amount of both manufacturing and fabrication space (indoor and outdoor) will be required to construct and deploy annually, the increasing number of devices required to meet the OES Roadmap targets. Figure 3.1 below shows how the total fabrication space required for the ocean energy sector could grow up to the mid-2030s. Although the total manufacturing and fabrication space required remains relatively modest up until the mid- 2030's, from that point on the number of annual installations will need to increase significantly to keep pace with the expected growth in the deployment of wave and tidal stream devices. This will require the adaptation of existing ports and harbors to accommodate this increased volume and in some cases, it will require the construction of new facilities dedicated to wave and tidal stream deployments.

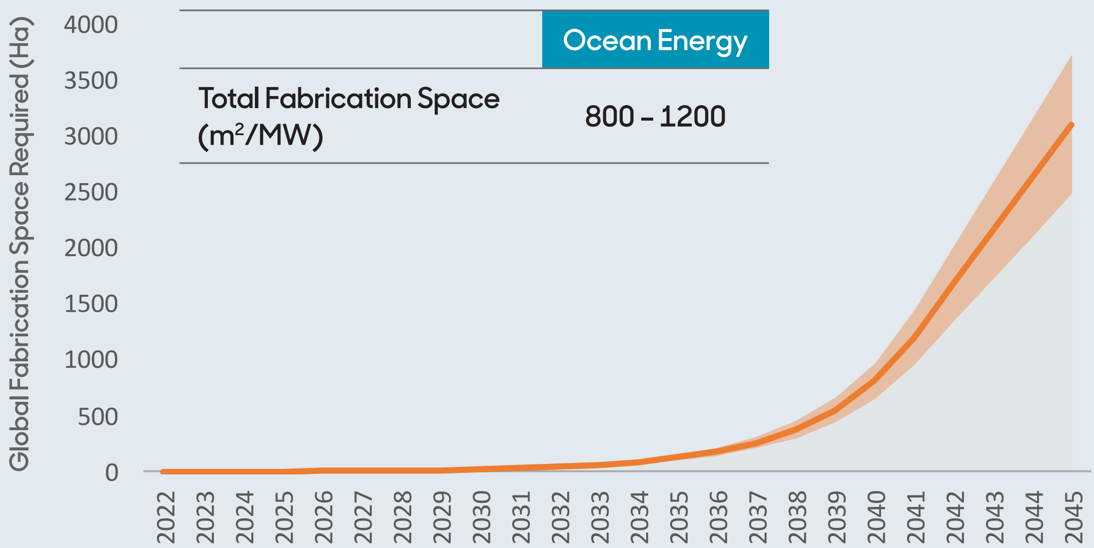


Figure 3.1: Total fabrication requirement for ocean energy up to 2045

Key Result

Based on current sector projections and stakeholder interaction, the global annual requirement for manufacturing/fabrication space is projected to require the construction or upgrading of **3000 ha of new infrastructure globally by the 2040s**.

While current infrastructure will be able to handle sector growth in the short-term future, the rapid growth expected in the medium-to-long-term underlines the need for immediate action to ensure that manufacturing and fabrication space scales to meet demand.

Metric 2 - Laydown Space

Laydown space, with adequate bearing capacity, is an important consideration for an active port or harbor that will be involved in the manufacture, deployment and maintenance of ocean energy devices and consideration should be given to providing ample storage for components and subassemblies. With laydown space dictating the throughput of any port or harbor, space, ease of access and consideration of the evolving requirements of the ocean energy sector should be considered when plans for high-volume manufacture are being established. Proximity of ports and harbors to both deployment areas and component and raw material supply hubs should also be considered.

As with manufacturing and fabrication space, the total global requirement for laydown space, shown in Figure 3.2, remains relatively modest up until the early 2030s and existing global infrastructure may be able to keep up with the demand at that time. However, by the mid 2030's and early 2040s, the incorporation of large laydown spaces into new dedicated or upgraded facilities will be required to keep pace with the demands of the ocean energy sector.

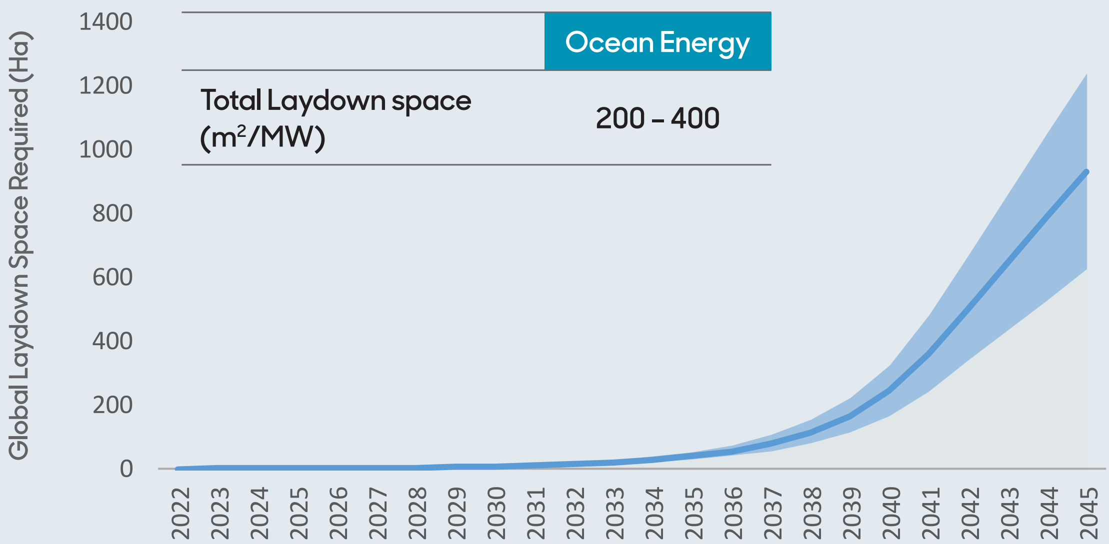


Figure 3.2: Total Laydown area requirement for ocean energy up to 2045

Key Result

Based on current sector projections and stakeholder interaction, the global annual requirement for laydown space is projected to require the construction or upgrading of approximately **1000 ha of new infrastructure globally by the 2040s**.

While current infrastructure will be able to handle sector growth in the short-term future, the rapid growth expected in the medium-to-long-term underlines the need for immediate action to ensure that laydown space scales to meet demand.

Infrastructure & Future Development

Metric 3 – Quayside Berth Size & Access Channel Size

Ensuring that port infrastructure dimensions are adequate to allow for the safe, efficient and reliable access to dockside by the growing number of vessels that are responsible for the deployment and O&M of ocean energy devices is essential to ensuring that these ancillary services scale at an appropriate rate to deliver the OES Roadmap targets. Quayside berth size and access channel size will become an increasingly important consideration for new and upgraded ports and harbors as the ocean energy sector continues to evolve, both in device size and shape and the potential increased use of floating device deployments.

The quayside berth size and access channel size are dictated by the size of the vessel and the installation method used. Some devices may be transported on vessel decks whilst other devices may be towed to the deployment location. If the device is to be towed, quayside berth size and access channel size will then be determined by the length, width and draft of the device and vessel together.

By analysing previous ocean energy installations and future project plans, these factors were used to determine a range of values based upon the types of vessels and devices that will be used in previous deployment and maintenance periods: This allowed for a range of values to be determined that could provide recommendations for the optimal quayside berth and access channel sizes for ocean energy projects.

Quayside Berth Size (Length/Draft)

- The length of vessels used ranges between 50m to 150m
- The associated draft used ranges from 3m to 10m

Access Channel Size (Width/Clearance)

- The minimum width of access channel ranges from 20m to 100m
- The clearance of access channels used could range between 15m to 50m

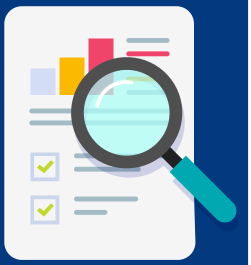
These estimated values have then been used to inform the following case-study analysis:

Ocean Energy's wave energy buoy being tested at Wave Hub off the Irish coast (Source: Ocean Energy Limited)

CorPower Ocean's wave energy device (Source: CorPower Ocean)

Infrastructure & Future Development

Case Study



Forecasting Port Infrastructure Requirements for the mid-2040s

Having analyzed the ocean energy infrastructure requirements in detail and outlined how the various ocean energy infrastructure requirement metrics evaluated can impact the future growth of the ocean energy sector, this section will now utilise these findings to present a future scenario case study:

It is projected that by the mid-2040s, **the global deployment of wave and tidal stream energy devices** could exceed 30GW each year. This case study assumes that by this point, the responsibility for development and deployment of wave and tidal stream devices has been **shared between 20 leading nations**, as described in the full collaboration scenario outlined in section 2.

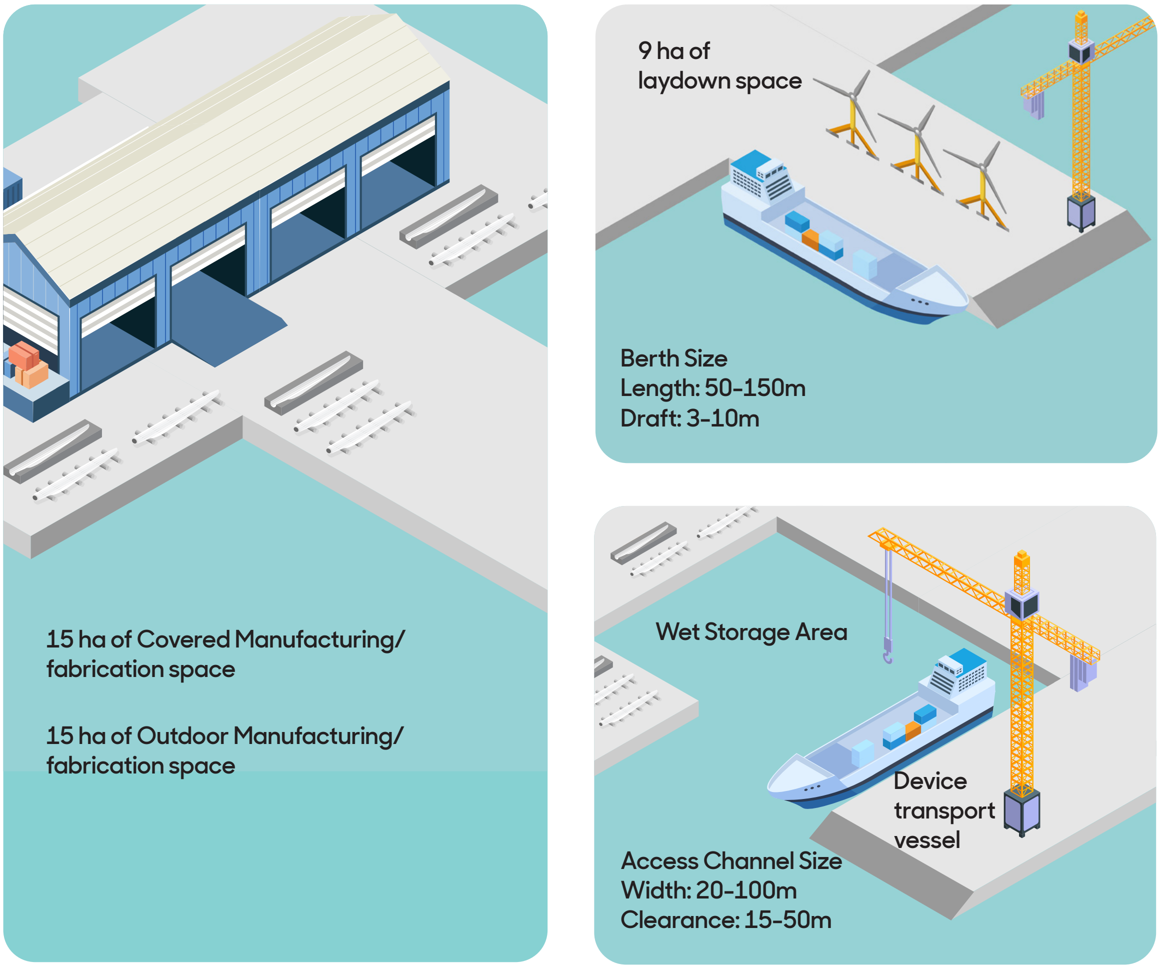
Assuming an equal share, this means that the mid-2040s global output of 30GW will correspond to **each nation deploying 1.5GW per year**. Assuming an **average annual deployment capability of 300MW** for each of the ports and/or harbors that underpin this scenario trajectory, **each of the leading nations will need to construct or upgrade 5 port and/or harbor infrastructure facilities**.

While this report has indicated that deployment of wave and tidal stream devices up to the early 2030s could be covered by existing infrastructure, given the long lead times normally associated with large-scale construction projects, this report **recommends that the upgrading to or construction of entirely new port and harbor facilities should begin imminently**, if the OES Roadmap targets for ocean energy deployment are to be met.

Based on the estimation of an **average port or harbor deployment capacity of 300MW**, this future scenario case study projects the following requirements:

- 30 hectares of manufacturing and fabrication space, with around half of this being covered;
  - Approximately 15 hectares of indoor manufacturing and fabrication space;
  - Approximately 15 hectares of outdoor manufacturing and fabrication space;
- 9 hectares of outdoor laydown space to store devices prior to installation;
- Easy access to large-scale cranage, employee welfare facilities and adequate road or rail transport links nearby.

These requirements, detailed in the graphic below, provide an evidence-led example of a port capable of deploying 300MW per year by the mid-2040s that is compliant with the identified ocean energy infrastructure and future development metrics. While this graphic details a scenario where a new port is constructed and dedicated to the requirements of the ocean energy sector, **the possibility that the wave and tidal stream sectors could share manufacturing and fabrication space with ports designed for floating offshore wind should also be considered**, given the overlaps in technology, materials, deployment and O&M.



Key Result

To achieve the OES Roadmap targets, this report projects that there will need to be the equivalent of 100 new or upgraded ports, shared between the 20 leading nations, with capacity to deploy 300MW per year by the mid-2040s. Planning for this infrastructure development should begin now to mitigate long lead times and should consider the possibility of sharing infrastructure with other developers, such as the floating offshore wind sector.

Infrastructure & Future Development

Infrastructure and Future Development Summary

It is clear from section 3 that the future development of ocean energy supporting infrastructure has a vital role to play in delivering the OES Roadmap targets. While device innovation and deployment are of course the priority area for policymakers and government finance, given the long lead time in construction and the logistical challenges that could be posed by the construction of new port and harbor facilities, the challenges associated with future infrastructure development must be tackled concurrently to those of device innovation. **To mitigate the issues arising from long lead times in the construction or upgrade of new ports and harbor facilities, planning should begin effective immediately and should consider the possibility of sharing infrastructure requirements with other sectors, such as floating offshore wind.** With the challenges associated with the growth in ocean energy that is forecasted for the early 2040s, this will ensure that the sector as a whole is able to adhere to a realistic deployment timeline, in turn increasing investor and government stakeholder confidence that this is a sector that will achieve commercial scale deployment.

In order to achieve this, the development of the ocean energy sector should be guided by a robust national and international infrastructure strategy, with clear policies and achievable milestones. The sector should also be provisioned with the necessary investment funds, sourced from a combination of public-private partnerships, which can be responsibly utilized to encourage port operators to support government aims to implement greater amounts of renewable energy and drive efficient infrastructure roll-out. Finally, regular audits should be implemented to ensure funding agencies remain on target and aligned with government aims and where possible funding management should allow for the value-based dissemination of resources, for example through competitive bids.

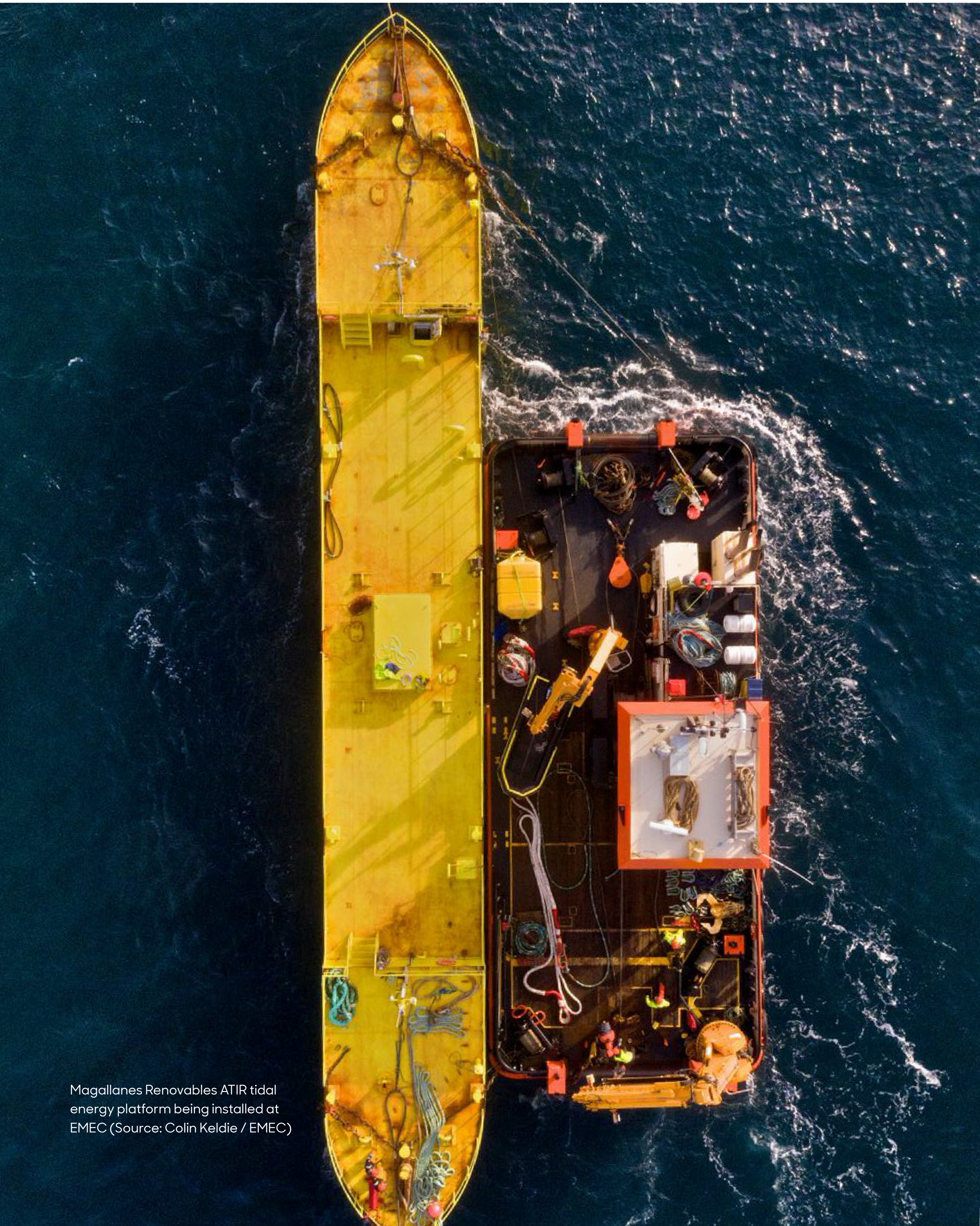
Key Result – Infrastructure and Future Development

Key Result

- To achieve the OES Roadmap targets, this report projects that there will need to be 100 new or upgraded ports, shared between the 20 leading nations, with capacity to deploy **300MW per year by the mid-2040s**.
- Based on current sector projections and stakeholder interaction, the global annual requirement for manufacturing/fabrication space is projected to require the construction or upgrading of **3000 ha of new infrastructure globally by the 2040s**.
- Based on current sector projections and stakeholder interaction, the global annual requirement for laydown space is projected to require the construction or upgrading of approximately **1000 ha of new infrastructure globally by the 2040s**.
- Planning for this infrastructure development should begin now to mitigate long lead times and should consider the possibility of sharing infrastructure with other developers, such as the floating offshore wind sector.
- To encourage engagement from port operators, it is essential to have clear policy timelines and use public-private partnerships to facilitate efficient infrastructure build-out. Regular auditing should be used to ensure funding agencies are on track and aligned with government objectives.

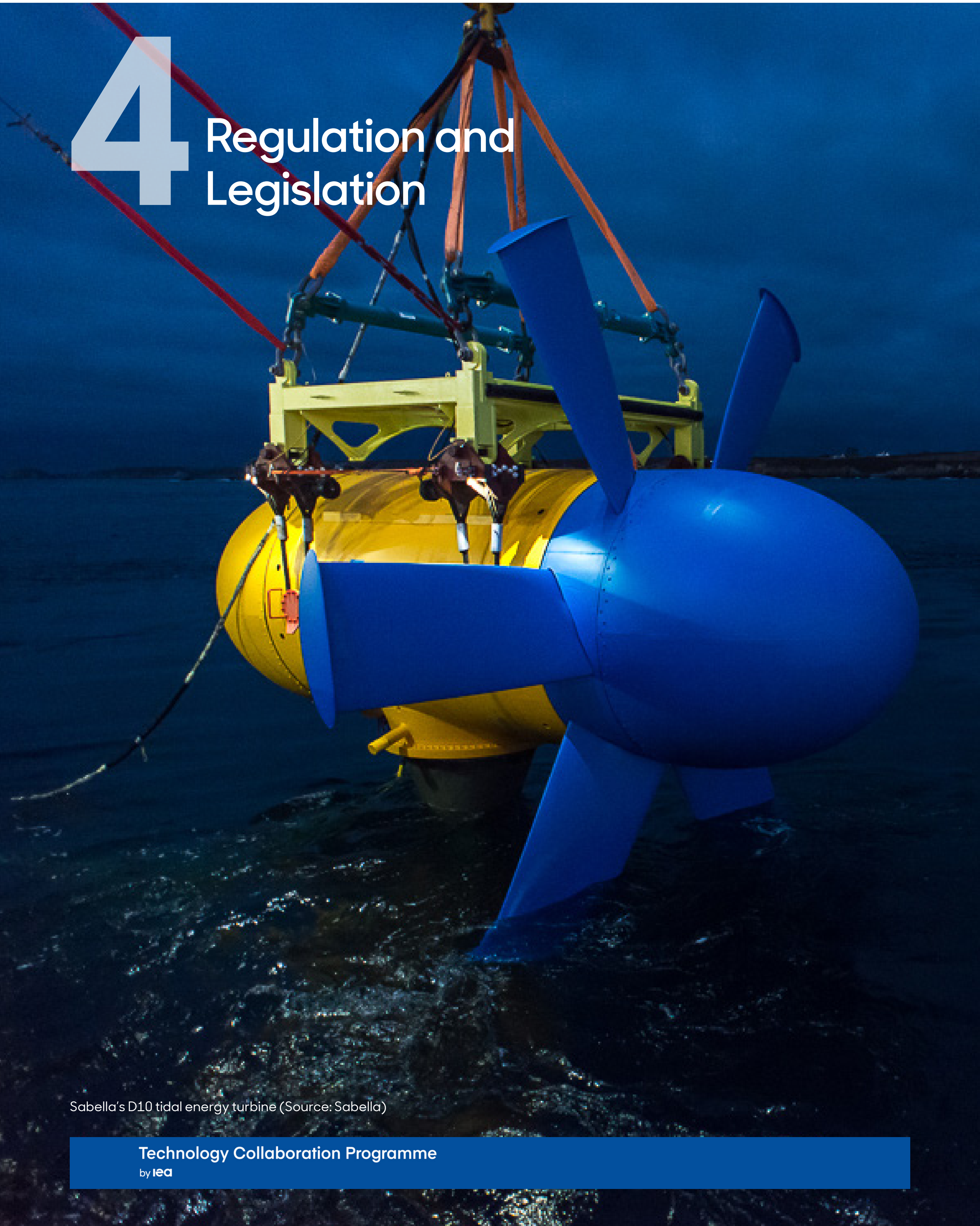
Policy Action: Immediate action on infrastructure development is vital

- While existing infrastructure is well-positioned to handle the short-term requirements of the sector, the rapid expected growth will require large-scale global infrastructure development projects to begin immediately.



Magallanes Renovables ATIR tidal energy platform being installed at EMEC (Source: Colin Keldie / EMEC)

4 Regulation and Legislation



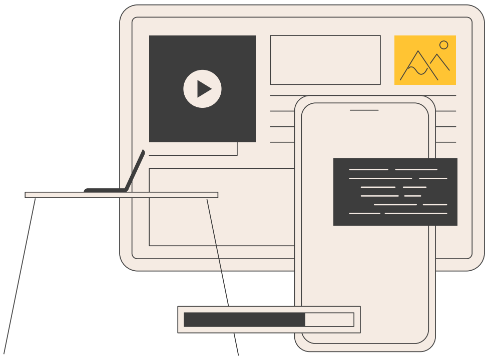
Sabella's D10 tidal energy turbine (Source: Sabella)

Regulation and Legislation

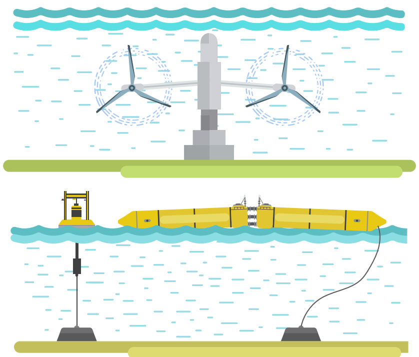
The following section of this report will provide an overview of the regulatory and legislative frameworks that govern both the design and development of ocean energy standards and the licensing and consenting of ocean energy technologies. Increasing the overall efficiency of these process is vital to ensure that the ocean energy sector continues to develop at the pace require to meet the OES Roadmap targets.

This section will also present a case study of the consenting process that currently exists within the USA, outlining examples of best practice and providing a review of potential lessons that can be learned. Finally, this section will conclude with a summary of different guidelines, distilled from a broader range of case studies, not included in this report.

Design and Development of Ocean Energy Standards



Deployment Licensing and Consenting



Design and Development of Ocean Energy Standards

The ocean energy sector's regulatory and legislative needs demonstrate the importance of technical standards, as well as licensing, and consenting best practices, to support the development and deployment of commercial array-scale ocean energy devices. International, consensus-based standards and third-party verification of compliance to those standards, utilising a global conformity assessment system like the IECRE, play a critical role in achieving GW-scale deployment of ocean energy. Specifically, standards and conformity assessment help reduce risks for technology developers, project developers, regulators, investors, and insurers, while simultaneously ensuring that projects safely deliver performance as expected. The use of a global conformity assessment system ensures the mutual recognition of test reports, conformity statements and certificates, and reduces barriers to market entry, while preventing costly and inefficient repeat testing and verification in each new market.

The International Electrotechnical Commission (IEC) primarily develops the international, consensus-based standards and technical specifications that guide the design and development of wave and tidal stream energy devices. The IEC has a dedicated Technical Committee, TC114, who deal exclusively with wave and tidal stream energy converters. As a result, the development of standards and technical specifications for the ocean energy sector is at an advanced stage, with a diverse community of subject-matter experts guiding and informing on a suite of well-structured technical requirements. This has set the scene to ensure that the deployment of array-scale devices can proceed with reduced risks for project developers, regulators, investors and insurers, while maintaining adequate levels of project performance and high safety and environmental standards.

Regulation and Legislation

Deployment Licensing and Consenting

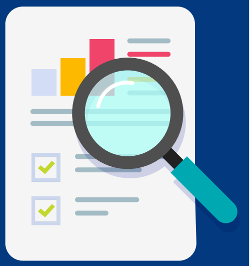
In terms of licensing and consenting, the ocean energy sector is a nascent industry that faces a range of regulatory challenges associated with potentially negative environmental impacts. Currently there is a great deal of uncertainty concerning the scale of these potential impacts and as such, there is a growing need to coordinate research that can advance the industry in an environmentally responsible manner.

The development of open-sea testing facilities and deployment sites is an important priority area for ocean energy policy development. Offshore testing infrastructure encourages ocean energy development by enabling technology developers to gain practical experience installing, operating, maintaining, and decommissioning components and full-scale prototypes. It also helps to develop ancillary services and streamline at-sea procedures, both of which are critical to ensuring the health and safety of the operations team and environment. In order to meet the OES Roadmap targets, it will be necessary to expedite the roll-out process to allow project developers to more readily access the available resource and avoid project bottlenecks.

However, given the unique geographical challenges that come from the deployment of ocean energy technology, countries around the world need to design and implement fit-for-purpose licensing and consenting processes. This can be a long and arduous process, where challenges can evolve over the lifetime of the project. One method that can be utilised to decrease the associated licensing timelines through standards-based measurement approaches, is adaptive management. This will allow the ocean energy industry to develop a better understanding of the continually evolving interactions between technology and the marine environment, expediting the deployment of array-scale ocean energy technologies.

Minesto's Dragon Class device (Source: Minesto)

Case Study



United States Consenting Process

Using a recognised best practice provides a more structured and efficient route for regulators to justify research and development activities for commercialisation of ocean energy technologies. As is the current practice, each country uses an independent and unique consenting process, which can increase the possibility that valuable lessons learned would not be incorporated into the design life cycles, and costly health and environmental mistakes could be repeated internationally. In an attempt to identify a process of best practice, this section will now present a case study example of the licensing and consenting process in the US.

Within the US there is no single agency responsible for the entire marine energy permitting process. The Federal Energy Regulatory Commission (FERC) and the Bureau of Ocean Energy Management (BOEM) are the two agencies with overarching authority over licensing and leasing activities for grid-connected projects, and the US Army Corps of Engineers (USACE) has overarching authority over non-grid-connected activities.

In 2020, the Water Power Technologies Office (WPTO) published The Handbook of Marine Hydrokinetic Regulatory Processes, which outlines the marine energy consenting process in the US. The sequential steps are dependent upon the location of the project and whether it will be connected to the grid. FERC allows prospective developers to apply for a preliminary permit, which gives the developer first rights for the development of a site, but it is not required to obtain a FERC hydrokinetic pilot project or commercial license.

There are five scenarios in which these different permits and licenses, distributed by USACE, FERC and BOEM are necessary:

- Non-grid-connected hydrokinetic pilot project in state waters (USACE);
- Grid-connected hydrokinetic pilot project in state waters (FERC);
- Commercial-scale project in state waters (FERC);
- Any project on the OCS non-competitive lease process (FERC and BOEM);
- Any project on the OCS competitive lease process (FERC and BOEM).

In addition to this, a National Environment Policy Act (NEPA) analysis is required prior to any action taken by a federal agency to ensure that they always thoroughly evaluate the potential environmental impacts of any proposed action and outlines any reasonable alternatives.

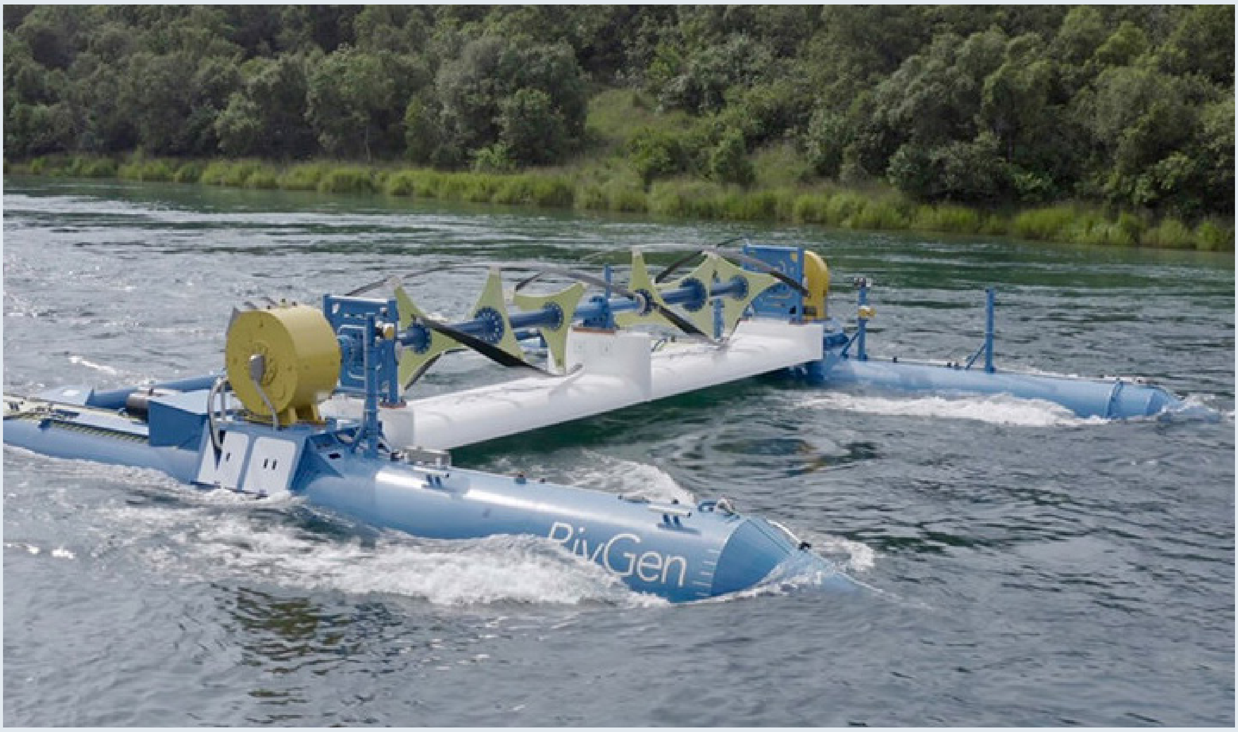
The results of the NEPA analysis, along with multiple consultations that occur before permits, leases and licenses are issued, are often used to generate monitoring or mitigation requirements that must be implemented as a condition of the license. The FERC pilot project guidance places large emphasis on post-deployment environmental monitoring, while the standard commercial licensing process places a larger emphasis on environmental studies conducted before the license application is filed.

Lessons Learned and Recommendations from US Case Study

US regulators place a high value on stakeholder consultation, and this consultation is performed at multiple stages of the consenting process. Because stakeholder consultation is required by the consenting process, marine energy developers can address the needs of key groups before a marine energy device is deployed in the water. To receive a USACE permit, FERC license or a BOEM lease, a series of mandatory consultations are performed, usually in conjunction with the NEPA analysis.

In the US, marine energy developers are required to develop rigorous environmental monitoring plans that span from testing to decommissioning. Unfortunately, there are no standardised methodologies for data collection, and it is challenging for marine energy developers to use data transferability from one site where data was collected to another site. This overall process can be streamlined if a 'one window committee' approach is employed, where a single organisation is given responsibility for overseeing the consenting proves. Efforts from marine energy developers are underway to determine a way to leverage OES-Environmental to provide meaningful data to address regulators' environmental monitoring concerns. This has given rise to an increased role for practices such as adaptive management – where deployments are used to inform, guide and accelerate the overall learning process - and risk retirement – where the status and nature of identified risks can be recategorised to accelerate, where appropriate, the deployment process.

While the consenting process in the US and other countries is thorough and comprehensive, this can lead to long lag times between project inception and eventual deployment. While the need for thorough assessment of environmental and safety standards cannot be understated, the US, like other nations, is facing a shared challenge to ensure that the regulatory and legislative framework surrounding the wave and tidal stream sector does not disproportionally impact planned deployment and diminish the overall impact that the sector can have in achieving a global Net Zero energy system.



ORPC Inc.'s first river energy project, RivGen® Power System (Source: ORPC)

Regulation and Legislation Summary

This section has discussed the necessary regulatory and legislative frameworks that will need to be developed to ensure that the OES Roadmap targets are achieved. In addition, it has also presented a best- practice case study analysis of the consenting process as it applies to a leading nation in the ocean energy development sector. Building upon this case study, this section will conclude by providing a set of guidelines distilled from a broad range of case study analyses that can help to guide the formation of regulatory and legislative policy relating to the deployment of wave and tidal stream technologies:

Design and Development of Ocean Energy Standards

- Adopt international consensus-based standards (for resource assessment, technology qualified design, testing, etc.) and promote a culture of quality, risk management, standards, and compliance;
- Implement third-party testing and certificate within an international conformity assessment system for global recognition of test reports, conformity statements, and certificates;
- Integrate standards and formulate certificates plans early in tidal stream and wave energy technology development;
- Promote alignment among regional and national standards bodies by endorsing identical versions of IEC TC 114 standards whenever feasible.

Deployment Licensing and Consenting

- Adopt an adaptive management approach to understand technology-environment interactions and support sector growth as the ocean energy sector advances;
- Utilize test sites as essential hubs for environmental monitoring in the ocean energy industry, enabling iterative testing, data collection, and efficient at-sea procedures;
- Implement a clear consenting scheme when feasible. If multiple agency consultations are necessary, opt for a 'one window committee' approach where a single agency oversees the ocean energy consenting process;
- Engage project stakeholders early in development to address questions and concerns before deploying ocean energy devices;
- Ensure data transferability to handle site-specific regulatory issues. Utilize OES-Environmental to offer meaningful data for addressing such concerns;

Policy Action: The regulatory and legislative framework should help, not hinder

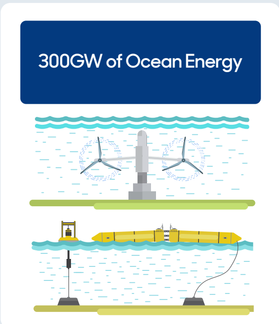
- The ocean energy sector should be underpinned by a robust and efficient regulatory and legislative framework that provides the levels of support required to ensure that sector growth happens in line with forecasted timelines.

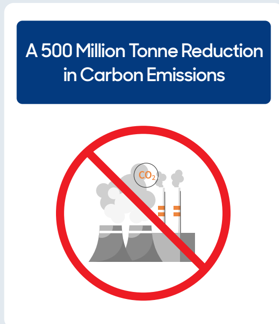
Policy Recommendations to Achieve the IEA-OES Roadmap Targets

The ocean energy sector stands poised, ready to play a substantial role over the coming decades, as global efforts to transform the energy sector in line with the requirements of the climate crisis intensify. This IEA-OES ocean energy roadmap presents a pathway through which the wave and tidal stream sector can grow to become both a significant enabler of a global Net Zero energy system and stimulate socio-economic returns across the globe.

As the opening pages of this report have outlined, a forecasted global deployment of 180GW of wave and 120GW of tidal stream has the potential to achieve the following high-level outcomes:

- The creation of over **680,000 jobs**;
- The generation of over **$340 billion in Gross Value Added (GVA)** to national and international economies;
- A reduction of over **500 million tons** of carbon emissions.





The speed at which the global energy system will need to transform is unprecedented, a challenge exacerbated by the ever-diminishing time-scales under which this can be accomplished. There is now a growing understanding of the vital role that wave and tidal stream will play as one of the many renewable technologies that will comprise this new energy system. Despite the clear socio-economic benefits and Net Zero potential on offer, wave and tidal stream technologies face a number of challenges in their bid to reach commercial deployment. The high-level analysis, key results and policy recommendations contained within this IEA-OES Roadmap present a clear pathway by which these potential benefits can be realised and these challenges overcome. Harnessing the desire and momentum for a global Net Zero energy system and transforming it into proactive, visible and coordinated policy support mechanisms is the first step on this journey. It is time for the leading nations in the ocean energy sector to ensure that innovation and collaboration places the sector at the heart of the global drive for Net Zero.

Five policy recommendations are now offered, expanded from the policy actions detailed in previous sections. These are designed to inform the reader on how the forecasts and targets presented throughout this IEA-OES roadmap can be achieved:

1. Market pull support is the foundation of a comprehensive policy programme:

Led at a country-by-country level, the **immediate application of a long-term and sustained market pull policy mechanism is key** to strengthening and accelerating deployments in the ocean energy sector. The exact form of which a policy pull mechanism takes should be decided at a national level, however ensuring it is applied immediately, continuously and visibly is key to ensuring that all nations feel the shared obligation to follow a similar route. A market pull policy support mechanism, supporting a technology that has achieved an optimum cost reduction rate, **should be considered a priority of any government wishing to establish a commercial ocean energy sector** and is vital to stimulating ocean energy deployment across the globe.

However, market pull policies alone are not enough to achieve the targets outlined in this report. The following policy actions highlight the holistic approach that will be required:

2. Accelerated innovation is key to enabling long-term cost reductions:

A well-funded and sustained technology push policy programme, actively pursuing international collaboration, **is vital to ensuring that technological innovation occurs at a significant rate** and helps to **lower the overall investment** required to provide a long-term market support mechanism. Any technology push policy should be focussed to target identified challenge areas that will increase overall device performance and reduce development, deployment maintenance and disposal costs. Technology push policy support mechanisms are well-suited for international collaboration, where **active engagement in collaborative learning across multiple nations is essential** to drive accelerated cost-reductions.

3. Policy Action: An optimal balance of market pull and technology push funding must be struck:

While **long-term support for market pull policy support mechanisms is key** to achieving a commercial ocean energy sector, the overall cost of attaining this target can be **massively reduced through the application of sustained innovation**, achieved through coordinated support for technology push policy support mechanisms. Striking the correct balance between both market pull and technology push mechanisms is a complex task, **but it is vital to minimising the overall associated costs.**

4. Immediate action on infrastructure development is vital:

While existing infrastructure is well-positioned to handle the short-term requirements of the sector, the **rapid expected growth will require large-scale global infrastructure development projects to begin immediately**. Opportunities to share space, resources and skills with the offshore wind sector should be actively investigated, given the significant overlap in technology. This large-scale global infrastructure development will need to begin immediately, to ensure that long lead times and unexpected delays, potentially resulting from a shortage of workers or raw materials, **do not hinder the progress of the overall ocean energy sector**.

5. The regulatory and legislative framework should help, not hinder:

The ocean energy sector should be **underpinned by a robust and efficient regulatory and legislative framework** that provides the levels of support required to ensure that sector growth happens in line with forecasted timelines. The role of an effective regulatory and legislative framework in helping to overcome these challenges efficiently **should not be understated.** Where possible, individual nations should seek to form collaborative frameworks that acknowledge and incorporate instances of best practice, identified standards, clear consenting and make use of novel processes, such as adaptive management.

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