Technology Collaboration Programme
by iea

ANNUAL REPORT

AN OVERVIEW OF OCEAN ENERGY ACTIVITIES IN 2021

OES OCEAN ENERGY SYSTEMS

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Cover page: Orbital Marine Power's O2 at EMEC in Orkney (Courtesy Orbital Marine Power).

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CHAIRMAN'S MESSAGE

Yann-Hervé De Roeck
France Energies Marines
IEA-OES Chairman (2021 – 2022)

2021, year of the rebound?

These long months of pandemic, with their impact on the lives of our loved ones, our health, our habits and even our certainties, have made us aware of the need to activate all the levers of the energy transition, including ocean energy for those countries that benefit from this opportunity along their shore.

The multiple levers activated include :

- powerful investment aid for all renewable energy solutions, however very few specific to ocean energy,
- new policy frameworks that facilitate the deployment of ocean energy or hybrid systems. Indeed, more and more hybrid solutions, combining wave and wind energy or wave and solar photovoltaic energy, are developing rapidly.

Now, this was a daring move for this edition of the OES annual report: in order to better monitor the progress of the sector, a summary table of installed capacity and projects under construction is presented in this report, based on information provided by the member countries. The total operational capacity benefits from the contribution of the two large tidal range dams in Korea and France, which provide 498 MW out of a total of 517 MW. Barely 20 MW operational for wave and tidal may not seem like much. However, these systems are truly operational, with months or even years of operation and strong feedback. More than 50 MW of projects are under development, and another 30 are already authorised. This also allows us to monitor the progress that will be made in the years to come. The boom can only be spectacular, let's bet on it!

Let's also note that in a prestigious competition open to all energy conversion technologies, the Energy Globe Awards, a WEC was named the winner at the occasion of COP26 in Glasgow. More than envy, the sector should congratulate the Australian company Wave Swell Energy for this welcome spotlight!

Accelerating the advent of this bright future for ocean energy, sea trial sites are multiplying in various latitudes, equipped with new infrastructures, offering the possibility of demonstration in various environmental conditions, showcasing in front of their respective national markets. The multi-scale demonstrators that will have visited these duly accredited sites, will soon be accompanied by a so-called 'technology passport' if the recommendations of the emblematic consensus work established by OES are applied: our 'International evaluation and guidance framework for ocean energy technology', published on January 2021 and echoed throughout the year at webinars and conferences.

Another area of collaboration is the message of our White Paper on OTEC, calling for political awareness of the need to work together to develop OTEC much faster than its current pace. It reminds us how relevant and available this basic sustainable solution is for many coastal and island communities in the inter-tropical zone, with another asset of being rich in co-activities.

About the Ocean Energy Systems (OES) Technology Collaboration Programme (TCP) itself: its extension has been granted for 2022-2027, thanks to the excellent track record of the years of the last contract, Henry Jeffrey's leadership as chair whom I have the honour to succeed. It's also on the basis of a roadmap, another collaborative work of our Executive Committee members, which has been appreciated by the REWP CERT experts. Increased efficiency will be achieved through closer association of industry within the TCP, inter TCP studies, building on training. We share this Strategic plan publicly on our website.

Therefore, enjoy like us these good readings that give confidence in the future of ocean energy and in the transition of lifestyles on the planet, thanks to but also in total respect of the oceans.

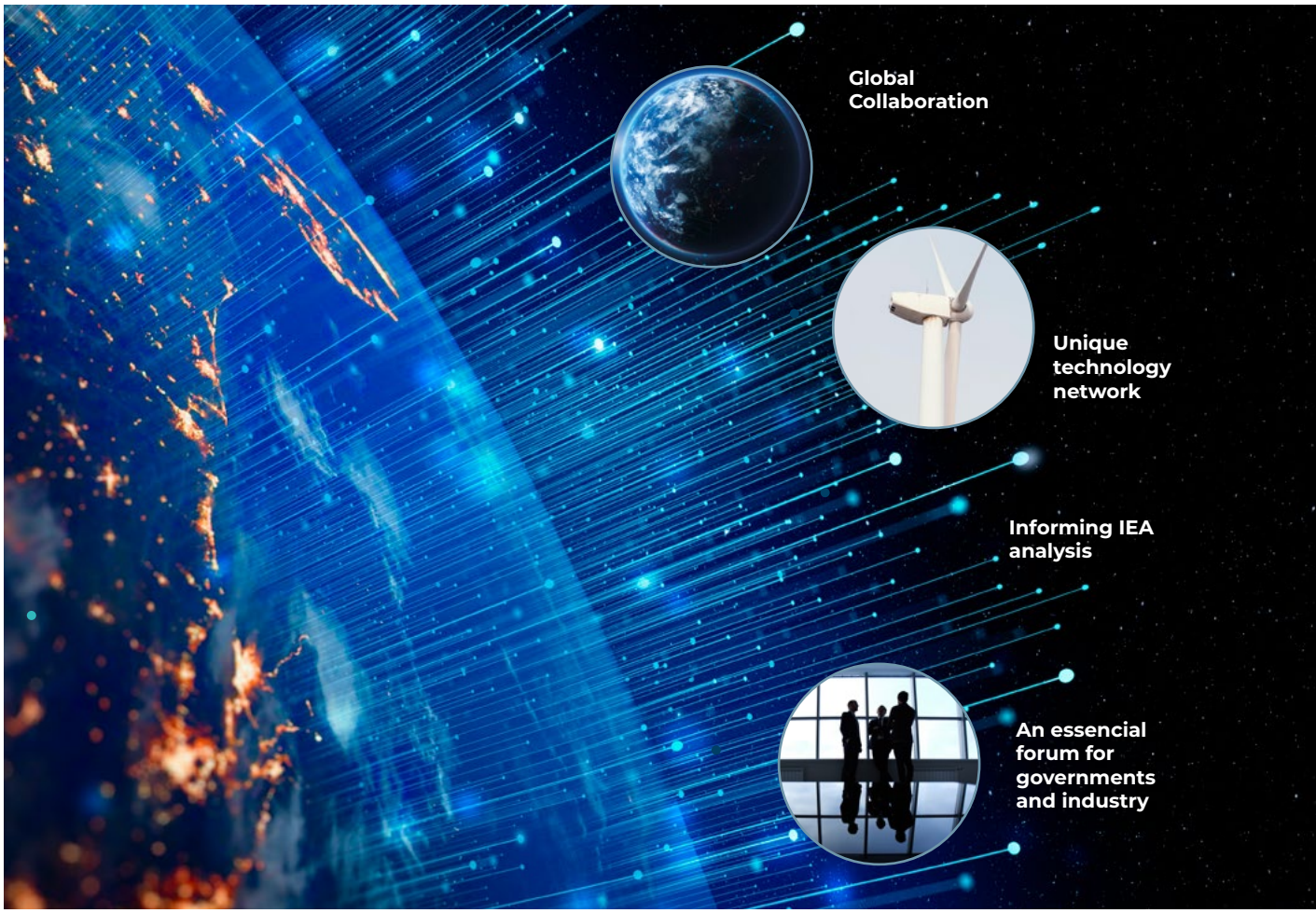
EXECUTIVE SUMMARY

Ana Brito e Melo
IEA-OES Executive Secretary

INTRODUCTION

IEA-OES is a **Technology Collaboration Programme (TCP) on Ocean Energy Systems** under the International Energy Agency (IEA).

The Technology Collaboration Programme supports the work of independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues. The experts in these collaborations work to advance the research, development and commercialisation of energy technologies. The scope and strategy of each collaboration is in keeping with the IEA Shared Goals of energy security, environmental protection and economic growth, as well as engagement worldwide.



The work of the IEA-OES covers all forms of energy generation in which sea water forms the motive power through its physical and chemical properties, i.e. wave, tidal range, tidal and ocean currents, ocean thermal energy conversion and salinity gradients. IEA-OES connects organisations and individuals working in the ocean energy sector to accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally acceptable manner.

As of December 2021, 22 Member Countries and the European Commission are members of the IEA-OES, providing a broad international base of information, sharing experience and knowledge and further a diversified representation of interests: members are from governmental departments, utilities, universities and research organizations, energy agencies and industry associations. This is one of the benefits of joining OES: participants gain an international perspective on ocean energy issues, opportunities and present challenges.

The twenty-three members are: Australia, Belgium, Canada, China, Denmark, European Commission, France, Germany, Japan, Korea, India, Ireland, Italy, Mexico, Monaco, New Zealand, Netherlands, Portugal, Singapore, Spain, Sweden, United Kingdom, and United States of America.

The IEA-OES international co-operation facilitates:

- Securing access to advanced R&D teams in the participating countries;
- Developing a harmonized set of measures and testing protocols for the testing of prototypes;
- Reducing national costs by collaborating internationally;
- Creating valuable international contacts between government, industry and science;
- Sharing information and networking.

This Annual Report presents an overview of progress made by the IEA-OES in 2021, including summaries of ongoing projects and updated country reviews prepared by the Delegates.

KEY ACHIEVEMENTS IN 2021

The overall programme of the IEA-OES is headed by an Executive Committee composed of representatives from each participating country and organisation. By the end of 2021, fifteen Tasks were established within the IEA-OES programme, of which ten are currently operational.

Throughout 2021, the following publications were released:

January: An International Evaluation and Guidance Framework for Ocean Energy Technology
March: Wave Energy Developments Highlights
April: Tidal Current Energy Developments Highlights
September: Six Interviews on Alternative Markets for Ocean Energy
November: White Paper on Ocean Thermal Energy Conversion (OTEC)
December: IEA-OES Strategic Plan 2022 – 2026

5
KEY PROJECTS

- OES-Environmental
- Performance Metrics
- Assessment of Jobs Creation
- Cost of Energy
- Alternative Markets

3
ACTIVE NETWORKS

- Wave Energy Modelling Group
- Tidal Energy Modelling Group
- OTEC group

4
DATABASES

- Tethys Database on Environmental Issues
- Consenting processes on ocean energy
- World Wide WebGis Database – ocean energy projects
- Open Sea Test Sites (under development)

The task on environmental issues - **OES-Environmental (OES-E)** – has now sixteen countries participating in this task and continues to be led by the US Department of Energy (DOE) and implemented by the Pacific Northwest National Laboratory. *Tethys*, the publicly accessible knowledge management system, has been updated and extended with papers, reports, and other media on environmental effects of marine renewable energy. There has been a continuous outreach and engagement to the marine renewable energy community through workshops, webinars, and conferences. The main focus in 2021 has been the development of the risk retirement process for simplifying consenting and licensing; and also assessing the information available on environmental effects of MRE in tropical, subtropical, and southern hemisphere waters and other underserved areas that represent OES nations.

OES has two tasks dedicated to the **modelling verification and validation of ocean energy technologies**, one led by Ramboll in Denmark, focused on wave energy, and a second one, focused on tidal energy, led by the Energy Research Institute at Nanyang Technological University, Singapore. Both groups have been collaborating with experts from universities, research institutions and companies and comparing results among different numerical codes.

A group of member countries – Japan, India, China, Korea, France and The Netherlands – have been working together on **OTEC** to assess the potential around the world and discuss the present status and plans for OTEC projects. A White Paper on OTEC was published in 2021 with a set of recommendations for widespread adoption of OTEC.

OES has been developing efforts on the topic of international performance evaluation of ocean energy technologies with strong inputs from the European Commission, the U.S. Department of Energy and from Wave Energy Scotland, aiming to support the definition of a fully defined set of metrics and success thresholds for ocean energy technologies and develop an internationally accepted approach. A report was published in January 2021: "**An international Evaluation and Guidance Framework for Ocean Energy Technology**", discussing the benefits of common evaluation approaches in the ocean energy sector to help build consensus.

A study commissioned in late 2019 to assess the **number of jobs related to the development of the ocean energy sector**, coordinated by France Energies Marines was concluded in 2021. A benchmark of the socio-economic methodology for the assessment of ocean energy jobs creation and a first global assessment was carried out in 2021, further discussed with other experts in this field. A summary is expected to be published in 2022.

OES commissioned to EMEC the development of a database for **open-sea testing**, in collaboration with the International WaTERS network, to exchange information on open-sea test facilities at a global scale. It is expected that during 2022 the website will be released.

Interest and outreach for new membership continued in 2021. IEA-OES is always looking for new members across the globe, and key representatives from potential new member countries are encouraged to attend the Executive Committee meetings as Observers.

COUNTRY HIGHLIGHTS

AN EVOLVING POLICY LANDSCAPE

Nearly all OES member countries have support policies in place to advance ocean energy, although with varying degrees of ambition and scope. Policies have continued to evolve, including strategic plans and roadmaps with key actions for ocean energy, research and innovation policies that help to develop emerging technologies, as well as regulatory schemes to simplify and improve the efficiency of permitting processes, and governmental support to offshore testing facilities.

In many countries, policymakers have continued to adapt legislation and revise policies for ocean energy, incorporating national targets, driven by the significant potential for economic growth, sustainability transition, and job creation.

Meeting the ambitions set in national plans requires commitment and continued support from all countries worldwide to move from pilot and demonstration phases towards commercialisation. Table 1 highlights relevant policies initiatives in member countries, with implications for ocean energy development.

Table 1. Selected examples of national policies relevant for ocean energy

Australia	**Australian National Offshore Electricity Infrastructure Bill 2021 approved** a strong step forward in support of Australian ocean energy development; it provides a policy framework for offshore electricity projects in Australian Commonwealth waters, supporting national planning.
Belgium	**"Blauwe Cluster" (Blue Cluster spearhead cluster)** a Flemish organisation aimed at developing and promoting economic activities linked to the sea, supported by the Flemish Agency for Innovation and Entrepreneurship (VLAIO); together with its members from industry and academic partners, an offshore renewable energy R&D roadmap has been revised.
Canada	**Blue Economy Strategy under consultation** to support the growth of ocean sectors through innovation, with a focus on ocean energy, recognizing the need for collaboration from all levels of government, as well as significant private sector investments. **Offshore Renewable Energy Regulations (ORER) Initiative** to develop safety and environmental protection regulations for exploration, construction, operation and decommissioning activities related to offshore renewable energy.
China	**The Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035** It was set out in 2021 and it promotes the large-scale development of ocean energy.

Denmark	**Future Energy Islands in the North Sea under discussion** identifying the North Sea as a strategic hot spot for offshore technology development; the future Energy Islands in Denmark provides a unique opportunity to integrate wave energy into the innovation environment around the islands for R&D and testing of wave energy solutions, in combination with future offshore wind farms and Power2X technologies.
European Commission	**Offshore Renewable Energy Strategy** recognising the role of ocean energy to contribute to the EU decarbonisation goal; the strategy foresees that a crucial but feasible step to reach commercial size by 2030 would be implementing the existing pipeline of 100 MW pilot-farms projects by 2025. **A new approach for a sustainable blue economy in the EU** providing coherence across the blue economy sectors and looking for synergies in the maritime space, further underlining the need for investment in research, skills and innovation.
France	**Innovative «experimentation contract» for renewable energies** especially for ocean energies and floating offshore wind, this measure created in 2019, under the Energy and Climate law, simplifies and accelerates the attribution of a feed-in tariff for small projects. **“Energy Pathways 2050” issued by the French TSO** a wide-ranging study on the evolution of the power system issued in 2021 proposing scenarios to achieve the balance between a growing electricity demand and a fully decarbonised production, in which the contribution of ocean energy to the energy mix was introduced.
India	**"Deep Ocean Mission" approved** to support the Blue Economy Initiatives of the Government of India, in which energy and freshwater from the ocean are relevant components. The Ministry of New and Renewable Energy (MNRE) is supporting the development of ocean energy, and NIOT under MoES is currently building an OTEC powered desalination plant in the country.
Ireland	**Maritime Area Planning Act 2021** to ensure that the new consenting model, as well as implementation of a new offshore grid connection policy that lines up with the Renewable Energy Support Scheme (RESS) auction timeframes, will ultimately deliver Ireland’s 2030 targets.
Italy	**Blue Italian Growth National Technology Cluster (BIG)** led by the Italian National Research Council is seen as a driving force for economic growth and for the relaunch of the shipbuilding industry in Italy, with strong support for progressing with marine renewable energies.
Korea	**2030 Ocean Energy Development Plan** a strategic plan for developing and disseminating ocean energy systems, including actions for the establishment of open-sea test sites, construction of large-scale ocean energy farms and supporting policies.

Mexico	**Technological Roadmap for ocean energy** focused on strengthening the technological capabilities required, including infrastructure, specialized human resources and technological services, to reach the 2030 goals for ocean energy in Mexico.
Monaco	**National Green Fund** dedicated to financing actions for the reduction of GHG emissions, energy efficiency and development of renewable energies.
Portugal	**National Ocean Strategy 2021-2030 launched in 2021** to enhance the contribution of the ocean to Portugal's economy developed around 10 objectives, including combatting climate change, decarbonize the economy and promoting renewable energy, stimulating scientific knowledge, technological development and blue innovation, with relevant actions for marine energies.
Singapore	**Sentosa Tidal Test Site funded by the government** aiming to showcase tidal energy extraction as a feasible and sustainable energy generating technology in Singapore, providing opportunities to develop local technologies.
Spain	**Roadmap for the Development of Offshore Wind and Energy in Spain** published in December 2021, this plan also sets for wave energy a goal to reach 40-60 MW in a 2030 horizon.
UK	**Fourth allocation round of the Contracts for Difference scheme** in which the UK government announced an investment of £20 million per year in tidal stream energy, giving the marine energy sector a chance to develop their technology and lower their costs in a similar way to the UK's world-leading offshore wind industry. **Wave Energy Scotland (WES)** continuing to use Scottish Government funding to develop solutions to the technical challenges facing the wave energy sector, driving a competitive stage-gate process for innovative technology projects towards commercialisation.
USA	**Infrastructure Investment and Jobs Act approved in 2021** a new legislation that will provide significant funding to a variety of infrastructure and clean energy projects across the country, including ocean energy. **The US Department of Energy funding opportunities** aiming to advance wave energy technologies toward commercial viability. DOE is funding a number of initiatives including Prizes (e.g Waves to Water Prize, Ocean Observing Prize), testing infrastructures and competitive calls dedicated to ocean energy.

OCEAN ENERGY RESEARCH, DEVELOPMENT AND INNOVATION

Throughout 2021 we have seen considerable progress in research, development, demonstration and validation of the ocean energy technology, driving the sector towards higher TRLs, as well as improving knowledge of potential impacts of devices on the environment.

Member countries highlighted key ongoing R,D&D activities, in a great variety of topics, that can be grouped under these research priorities[1]:

- Design and Validation of Ocean Energy Devices
- Foundations, Connections and Mooring
- Logistics and Marine Operations
- Integration in the Energy System
- Data Collection & Analysis and Modelling Tools
- Cross-Cutting Challenges

The European Commission launched in 2021 the new Horizon Europe which, like its predecessor, Horizon 2020, supports ocean energy research, development and innovation. Further, the new EU Innovation Fund published its first calls with deadlines in 2021, calling for demonstrations in real sea environments and innovative components to improve the overall lifetime, reliability, installability, operability and maintainability of ocean energy devices.

The US Department of Energy has been launching very relevant initiatives seeking innovators, with increased funding to R&D. The *Waves to Water and Ocean Observing* prize competitions will bring innovative ideas and explore the technical feasibility of new solutions for wave energy systems. Further calls announced in 2021 will support open sea testing, advanced designs, as well as new technological solutions for ocean energy.

Notable in 2021 is the launch of two projects – EU-SCORES and FORWARD-2030 – with €35m and €21m of grant support from the European Union's Horizon 2020 programme to develop a multi-vector energy system that combines ocean energy systems with wind or solar generation, grid export, battery storage and green hydrogen production. This represents a major step toward accelerating the commercial deployment of ocean energy technologies, as well as the ongoing Interreg funded project TIGER, driving collaboration and cost reduction in the UK and France.

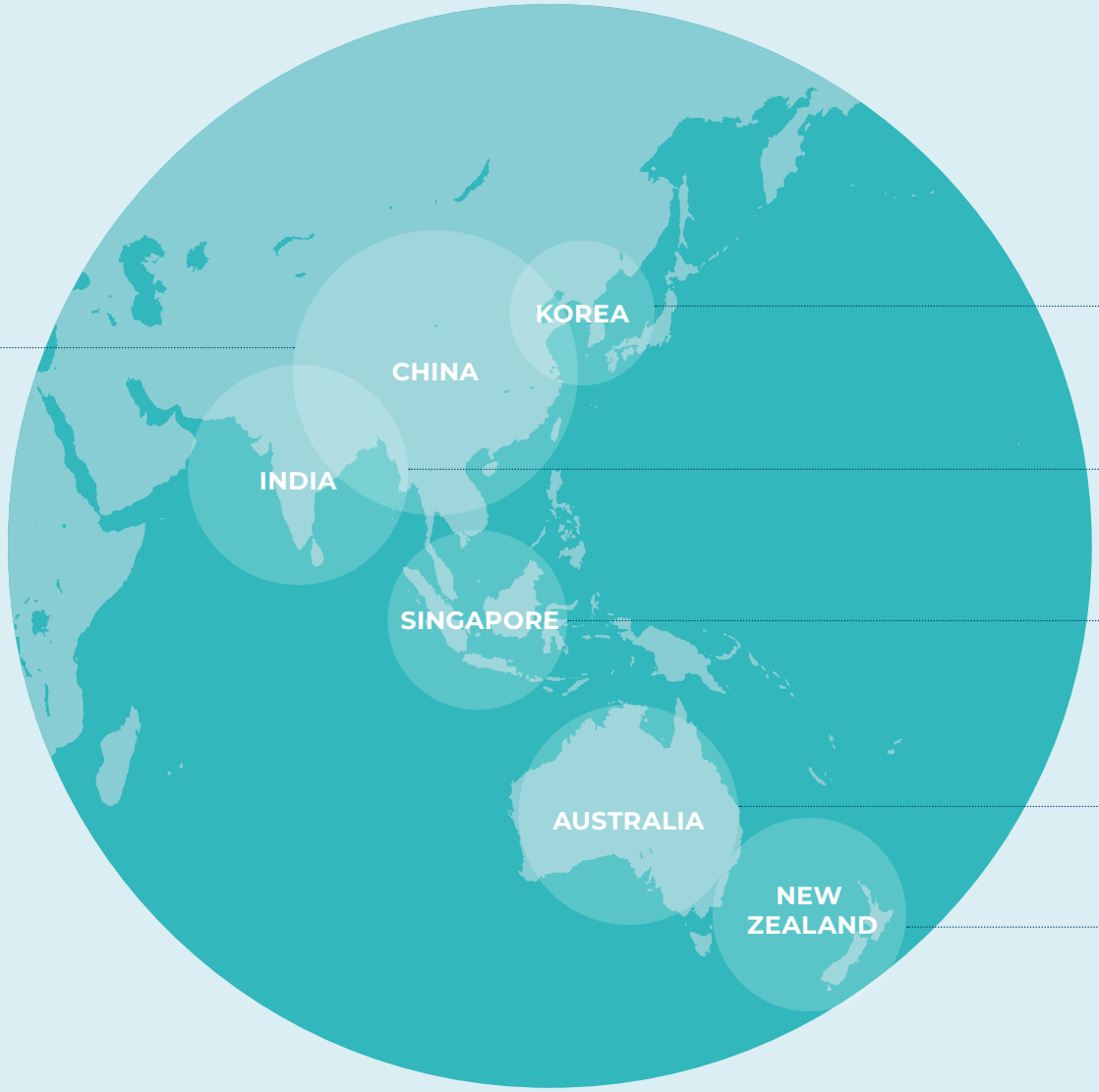
Another relevant initiative in 2021, with impact in the wave energy sector, is the new innovative Pre-Commercial Procurement (PCP) programme - EuropeWave - initiated by UK and Spain, co-funded by the European Commission. Originally pioneered by Wave Energy Scotland, this programme will provide a structured approach for the development of cost-effective wave energy systems, contributing further to international performance standards & metrics.

A number of testing facilities around the world continue to lead various research initiatives to gather knowledge about ocean energy technology and support project demonstration. Further collaborative initiatives such as TEAMER in USA or Blue-GIFT and OceanDemo in Europe, are providing device developers with access to a wide range of testing facilities, allowing for faster and more streamlined integration of physical testing and validation into the design process.

New centers have been developing new capabilities to support the growth of blue economy industries, bringing together different actors from industry, government, and academia. That is the case for the Blue Economy CRC in Australia and Cémie-Oceano in Mexico.

Worldwide, a very significant number of universities, research centers, national laboratories, private companies are building an impressive portfolio of research projects driving technological improvements to reduce the LCOE to competitive levels which is the ultimate goal of the research.

1. Strategic Research and Innovation Agenda for Ocean Energy, 2020



OCEAN ENERGY PROJECTS UNDERGO SIGNIFICANT MILESTONES IN 2021

2021 was a year of progress in ocean energy development showing a global interest in the field. Many companies are working hard to develop new improved prototypes and significant milestones were achieved by projects around the world. Improved devices were deployed at sea, several projects increased their operational periods with successful results and new deployments are moving forward in 2022. Below is a general snapshot showing how the projects are advancing in each OES country member:

CHINA

- **Zhoushan** 500 kW wave energy unit completed its first round of open sea testing and a second 500 kW unit.
- **Changshan**, has been deployed near Wanshan Island in April 2021.
- The semi-submersible aquaculture platform **Penghu** powered by wave energy and developed by GIEC completed 28 months of operation in the aquaculture base of Zhuhai city.
- The **LHD tidal current energy** project has exceeded 50 months of operation until December 2021 and the new turbine was completed to be deployed in 2022.

KOREA

- A 30 kW **OWC wave energy breakwater** was built by KRISO in Chuja island.
- KIOST has been developing a tidal energy converter combined with energy storage to supply energy to remote off-grid islands, which is planned to be installed in 2022 near the existing Uldolmok Tidal Pilot Power Plant.
- **Yongsoo OWC Pilot Plant** is being consistently upgraded using digital twin technology.
- A test site for tidal energy converters is under development, with a laboratory already built for testing tidal energy components.

INDIA

- There has been great progress on OTEC, with NIOT continuously assessing and improving the performance of OTEC components for the design of large-scale OTEC plants.
- The engineering of the **OTEC desalination plant in Kavaratti,** Union Territory of Lakshadweep, is being finalised, planned to be very soon fabricated and installed.
- Startup firms are now interested in the development of wave and tidal energy current projects in the country.

SINGAPORE

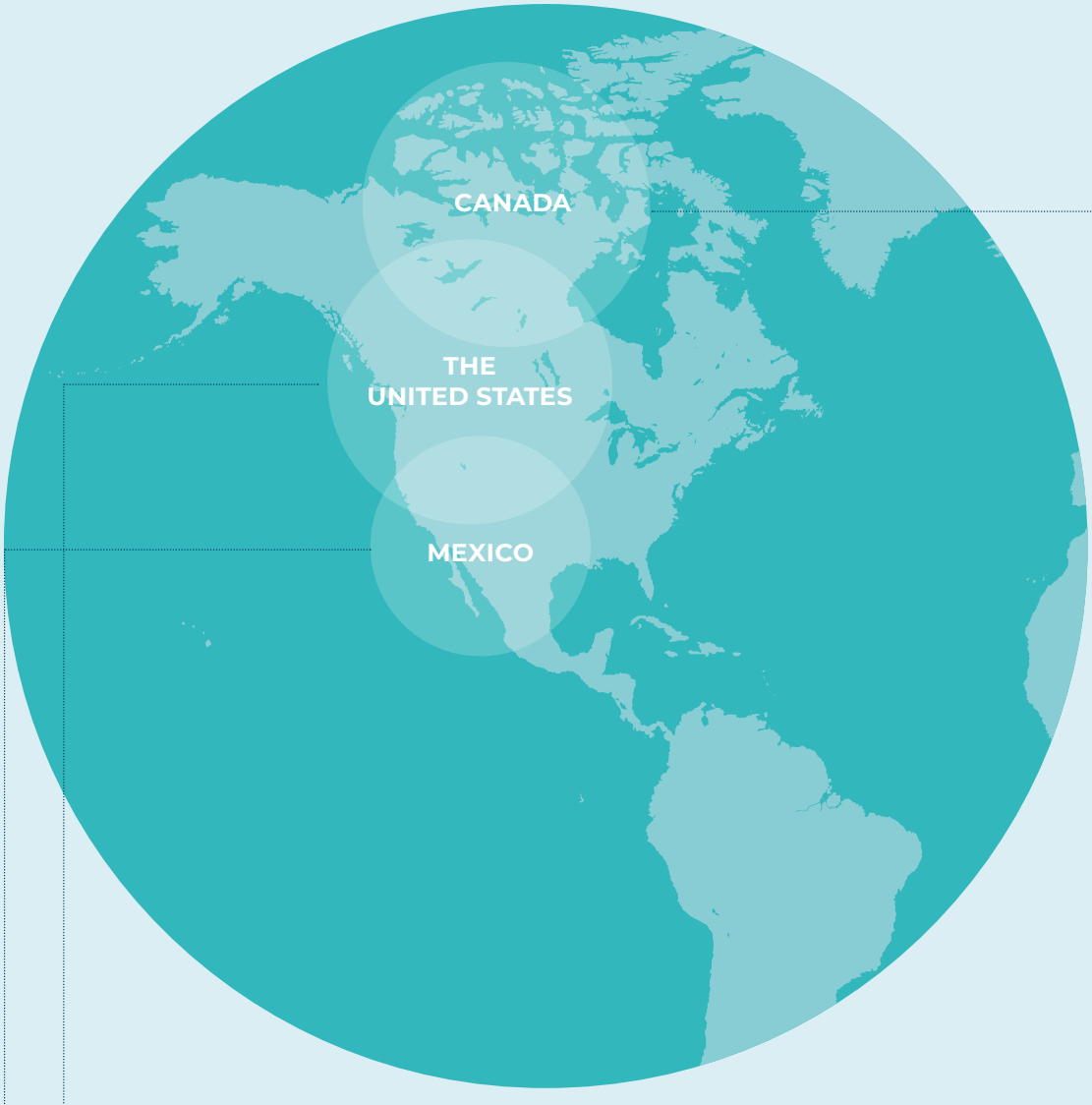
- The **Sentosa Tidal Test Site** continues to be promoted as a showcase for tidal energy projects, and there were recent developments on testing novel concepts such as floating solar systems and anti-biofouling coatings.
- Jurong Island is now planned to serve as a "living" testbed for sustainable solutions.
- The deployment of **floating solar PV systems** has been progressing: a 60 MWp floating solar PV system was completed in 2021 and there are further plans for two more floating solar projects with a combined capacity of 144 MWp, with other projects on the pipeline.

AUSTRALIA

- **Wave Swell Energy** floating OWC of 200 kW was installed at King Island, Tasmania in January 2021 and has been operating successfully since then. Wave Swell Energy was the winner of the Energy Globe Awards in the category of Energy Generation, announced at an official awards ceremony in Glasgow coinciding with COP26.
- Two Australian companies, **Carnegie Clean Energy** and **Bombora Wave Power** were selected as two of the seven companies for the new European Pre-Commercial Procurement Programme (EuropeWave PCP), led by Wave Energy Scotland (WES) and the Basque Energy Agency (EVE).
- Several other developers have been showing progress: **AZURA-EHL Australia** has 3 major projects under development, **Altum Energy** (formerly MAKO Tidal Turbines Pty Ltd) secured investment to move forward, **Smart Barge** team is developing a floating autonomous tidal energy system and **Cockatoo Island** Multi-User Supply Base is obtaining approvals to proceed.

NEW ZEALAND

- **Azura Wave Power** has a 20 kW device deployed for 18 months of grid-connected trials at the Wave Energy Test Site in Hawaii and a next-generation device of 500 kW is scheduled for deployment in 2023.
- **Ruka Marine Turbine** device developed by the Environment River Patrol-Aotearoa is planned to be deployed in 2022.
- **Aquantis** has two tidal current projects under development, in the US, and in Wales.



THE UNITED STATES

- **Verdant Power's** ½ scale demonstration tidal array operated continuously for 6 months in New York City's East River and by July 2021 it had generated more than 300 MWh.
- **Ocean Renewable Power Company (ORPC)** installed a second RivGen river turbine in Igiugig, Alaska.
- **Littoral Power Systems** designed and tested a new tidal turbine at the Bourne Tidal Test Site in Cape Cod, Massachusetts.
- **CalWave Power Technologies** commissioned a wave energy device off the coast of San Diego, California.
- The Alaska Center for Energy and Power tested the second generation hydrokinetic device developed by **Renerge** on Tanana River in Alaska.
- **C·Power** and **Oscilla Power** are preparing for deployment at the Hawaii test site.
- **PacWave South**, the United States' first accredited, grid-connected, open-ocean testing facility, is progressing steadily with the construction of its open water test berths for wave energy devices.

MEXICO

- **CEMIE-Océano** is planning two demonstration projects: a wave energy device in Ensenada, Baja California and an ocean current turbine in the Cozumel Canal, Quintana Roo.
- A natural laboratory for marine energy R&D projects is being installed in waters off Todos Santos Bay, near Ensenada, Baja California.

CANADA

- **Big Moon Power** announced that it had begun the assembly of its first device for deployment in the Bay of Fundy.
- **DP Energy** has been progressing with the planning of Phase 1 of the 9 MW Uisce Tapa project.
- **Jupiter Hydro** has continued planning for the development of its project in the Bay of Fundy.
- **NewEast Energy** has been working towards the deployment of its 800 kW project in the Bay of Fundy's Minas Passage.
- **Sustainable Marine** continues to work towards the development of its 9 MW Pempa'q project at FORCE.
- **Nova Innovation** received authorization for Phase 1 of their 1.5 MW tidal energy project in Petit Passage, Nova Scotia.
- At the Canadian Hydrokinetic Turbine Test Centre (CHTTC), **ORPC Canada** has been planning the deployment of an ORPC RivGen® power system, and **Waterotor Energy Technologies** deployed 5 kW and 4 x 1 kW systems.
- **Yourbrook Energy Systems** continues to work on its 500 kW Kamdis Tidal Power Demonstration Project in Masset Inlet, Haida Gwaii.

UNITED KINGDOM

- **Orbital Marine Power**'s O2 tidal turbine has commenced generation at the European Marine Energy Centre (EMEC) in Orkney.
- **Magallanes** second-generation 2 MW tidal platform, ATIR, was successfully reinstalled at EMEC.
- The **Perpetuus Tidal Energy Centre (PTEC)** continued its collaborative work with EMEC and have also entered into an agreement with Orbital Marine Power to use its O2 tidal stream turbine to deploy 15 MW by the end of 2025.
- **Nova Innovation** successfully deployed its commercial direct-drive tidal turbine 'Eunice' in its Shetland Tidal Array.
- UK continues to collaborate with France to deliver the **TIGER project**, the largest Interreg project yet awarded at €45.5m, to drive the growth of tidal stream energy, for a planned 8 MW of tidal energy capacity by 2023.
- **Mocean Energy's** Blue X wave energy prototype was deployed to EMEC's Scapa Flow test site in June 2021 for initial sea trials and the 10 kW device completed 154 days at sea.
- **AWS Ocean Energy** completed the construction of its WaveSwing device ready for 2022 sea trials at EMEC.

IRELAND

- After several deployments of OEBuoy at the Galway Bay test site during which the device accumulated over 24,000 hours of open water testing, New Wave Technology (trading as **Ocean Energy**) is progressing now to deploy a near full-scale model in the US Navy WETS facility in Hawaii.

SPAIN

- **Mutriku Wave Power Plant**, a multi-turbine wave energy facility integrated into BiMEP infrastructure continues its successful operation.
- The Finnish wave energy developer **WELLO OY** installed its PENGUIN2 prototype at BiMEP, feeding electricity to the national grid of the Basque Country.
- The Danish company **Wavepiston** installed two full-scale modules of its wave energy converter at PLOCAN test site.
- **Harshlab 2.0**, a laboratory for the evaluation of materials in real sea conditions was re-installed in the Port of Bilbao in November 2021 and the connection to BiMEP's submarine cable will take place in 2022.

PORTUGAL

- **Corpower's** HiWave-5 project has been progressing in northern Portugal. A facility in Viana do Castelo for final assembly and O&M became operational in 2021 and the first unit C4 is planned to be deployed at Aguçadora test site in 2022.

FRANCE

- **HydroQuest's** 1 MW tidal stream turbine was disconnected in April 2021 after 2-years of testing at Paimpol-Bréhat test site. HydroQuest is developing FloWatt, at the Raz Blanchard in Normandy, with a total capacity of 17.5 MW, planning to start the construction of the turbines in 2023.
- Nearby, the 12 MW **Nepthyd tidal stream project**, partnering with SIMEC Atlantis and Akuo, is waiting for a final investment decision.
- In the Fromveur passage, nearby Ushent island, **SABELLA** is planning to start its 3rd testing campaign with its grid-connected D10-1000 tidal energy converter.
- The Wavegem hybrid (wave, solar) platform designed by **GEPS Techno Offshore** also ended a testing period in November 2021 and plans to install a sea-water hydrogen electrolyser.
- **GUINARD Energies Nouvelles** succeeded in 2021 with two deployments, in France and Togo, of its 3.5 kW tidal current energy devices designed for isolated community markets.

MONACO

- Monaco makes use of the sea as a renewable energy source for the development of a **heat pump system**: two new thalossothermal loops connected to seawater heat pumps have been under construction.
- **SBM Offshore** is planning the development of a wave energy prototype in Monaco territorial waters in partnership with the Government.

ITALY

- **REWEC3** wave energy device in the port of Civitavecchia (Rome) and **OBREC** in the port of Naples are two distinct examples in progress, showing the development of wave energy converters integrated into breakwaters.
- **ISWEC**, a point-absorber wave energy converter suitable for mild climate seas is progressing under a joint industrial consortium of Italian companies.
- **Ocean Power Technologies (OPT)** PowerBuoy deployed in the Adriatic Sea since November 2018 by the Italian Oil&Gas company Eni is being used to investigate off-grid applications.
- **H-WEP 1** wave energy converter has been operated by Enel Green Power.
- Two tidal projects continue to progress: **GEM**, the ocean's kite and **GEMSTAR**, an evolution of GEM turbine.

DENMARK

- There are eight active Danish wave energy projects today, engaged and exchanging experience via the Partnership for Wave Energy.
- **EXOWAVE** has completed the engineering and manufacturing of its wave energy prototype planned to be tested at DanWEC test site in 2022.
- **Wavepiston** is also planning to install their first full-scale system at PLOCAN, Gran Canaria in 2022, for power production and desalination.
- **Floating Power Plant** is combining wave and wind power on a common floating platform and is involved in several development tracks including Power-to-X.

NETHERLANDS

- **Slow Mill** has commissioned a 40 kW wave energy device at the Port of Den Helder, after testing a prototype in the North Sea, in Texel Island.
- **SeaQurrent** has completed the grid-connected test site offshore the island of Ameland in the Wadden Sea ahead of the upcoming demonstration of its full-scale TidalKite device planned for 2022.
- **Dutch Wave Power** will test its device 12 km off the coast of The Hague, in 2022, after the completion of the series of tests at MARIN Research Institute.
- **REDstack** is generating blue energy from the difference in salinity between river water and sea water at the Afsluitdijk; this is the world's first salinity plant operating continuously since 2014.

BELGIUM

- In 2021 the renewed Blue Accelerator, a test platform operated by the Regional Development Agency West-Flanders, was inaugurated. This platform, installed in front of the port of Ostend, can be used for testing floating ocean energy devices.

SWEDEN

- **Novige** is developing NoviOcean wave energy converter; improvements on the 1/5 scale device have been made and the prototype, called NO2, was prepared to be deployed in Stockholm's archipelago for testing.
- **Minesto** has been successfully operating the DG100 tidal energy converter in Vestmannasund, Faroe Islands; the company has plans to install a 1.2 MW in 2022 as the first step towards a commercial array under development in the Faroe Islands and Wales.
- **Ocean Harvesting Technologies** (OHT) is preparing for a sea 1:3 scale trial project near Lysekil in Sweden.
- **CorPower Ocean** has been progressing towards its HiWave-5 flagship demonstration project in Portugal, and the project is on track to deliver the first unit in early 2022.

GERMANY

- **SCHOTTEL HYDRO** with its partner **Sustainable Marine** launched the second generation of the PLAT-I platform in Grand Passage in the Bay of Fundy, Canada, as part of the 9 MW "Pempa'q" Tidal Energy project planned at FORCE.
- The German bearing specialist **SKF** won the "Best of Industry Award 2021", following the success of providing two complete and fully integrated 1 MW drive trains for Orbital Marine Power's O2 tidal energy converter.
- **SINN Power GmbH** is progressing with the development of their SOcean hybrid platform, after the test phase in the Greek port of Heraklion, in Greece.
- **NEMOS GmbH** is progressing with its wave power project after the testing of a prototype in the Belgian North Sea.

OPEN SEA TEST SITES

Open sea test centres have become a common step in developing ocean energy in countries across the world and are seen as key innovation hubs for the ocean energy industry. Open sea testing facilities also encourage ocean energy development by enabling the practical experience of installation, operation, maintenance and decommissioning activities for prototypes and farms, as well as on services and streamlining procedures.

Today, there are many open sea test sites established across the world. Each has its own challenges, such as consenting issues, resource and operating environments. Test centres also provide very different service offerings to developers. Despite these differences, many are facing the same challenges on a day-to-day basis. The IEA-OES set up a collaboration with the International WATERS network[2] to create a centralised online database, populated with information on the infrastructure, equipment, services and test programmes available at each test centre. This database is expected to be launched in 2022.

2. The International WATERS (Wave and Tidal Energy Research Sites) Network was set up in 2013 by the European Marine Energy Centre (EMEC) and provides a forum for open sea tests in the marine energy space to discuss common challenges, explore collaboration opportunities and reduce duplication of efforts and resources.

OPEN SEA TEST SITES

NETHERLANDS

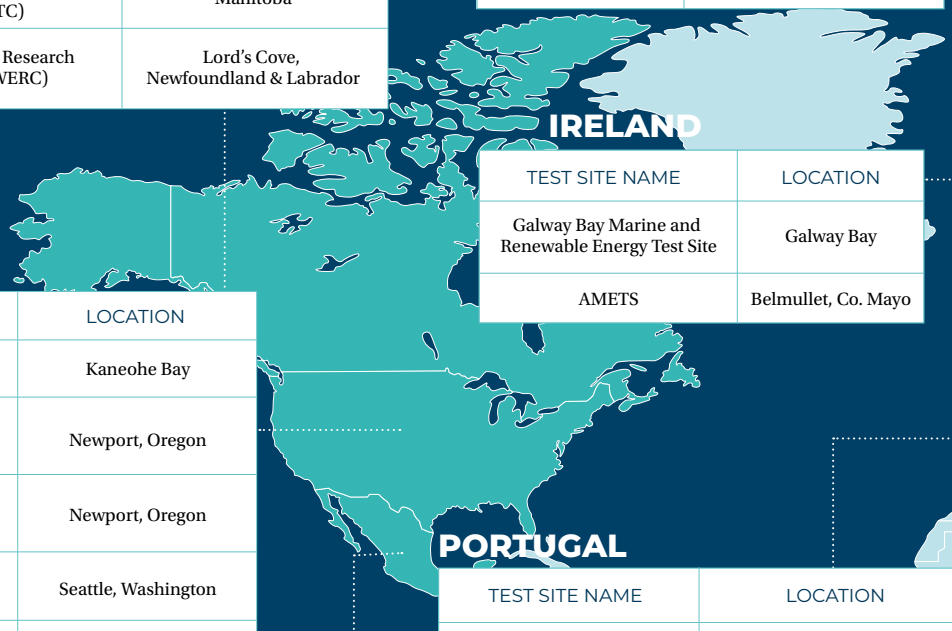
TEST SITE NAME	LOCATION
REDstack	Afsluitdijk
Tidal test site Ameland	Ameland
Wave test site Texel	Texel

UNITED KINGDOM

TEST SITE NAME	LOCATION
European Marine Energy Centre (EMEC)	Orkney, Scotland
FaBTest	Falmouth Bay in Cornwall
Marine Energy Test Area (META)	Milford Haven Waterway in Pembrokeshire
Morlais Tidal Demonstration Zone	West Anglesey
Perpetuus Tidal Energy Centre (PTEC)	South Coast of the Isle of Wight

CANADA

TEST SITE NAME	LOCATION
Fundy Ocean Research Centre for Energy (FORCE)	Minas Passage, Bay of Fundy, Nova Scotia
Canadian Hydrokinetic Turbine Test Centre (CHTTC)	Winnipeg River, Manitoba
Wave Energy Research Centre (WERC)	Lord's Cove, Newfoundland & Labrador



IRELAND

TEST SITE NAME	LOCATION
Galway Bay Marine and Renewable Energy Test Site	Galway Bay
AMETS	Belmullet, Co. Mayo

USA

TEST SITE NAME	LOCATION
U.S. Navy Wave Energy Test Site	Kaneohe Bay
Pacific Marine Energy Center PacWave North Site	Newport, Oregon
Pacific Marine Energy Center PacWave South Site	Newport, Oregon
Pacific Marine Energy Center Lake Washington	Seattle, Washington
Pacific Marine Energy Center Tanana River Hydrokinetic Test Site	Nenana, Alaska
Jennette's Pier Wave Energy Test Facility	Jennette's Pier, North Carolina
U.S. Army Corps of Engineers (USACE) Field Research Facility (FRF)	Duck, North Carolina
Center for Ocean Renewable Energy	Durham, New Hampshire
UMaine Offshore Intermediate Scale Test Site	Castine, Maine
UMaine Deepwater Offshore Renewable Energy Test Site	Monhegan Island, Maine
OTEC Test Site	Keahole Point, HI
Marine Renewable Energy Collaborative (MRECo) Bourne Tidal Test Site (BTTS)	Bourne, Massachusetts
Southeast National Renewable Energy Center - Ocean Current Test Facility	Boca Raton, Florida

PORTUGAL

TEST SITE NAME	LOCATION
Viana do Castelo test site	Viana do Castelo
Aguçadora test site	Aguçadora

SPAIN

TEST SITE NAME	LOCATION
BiMEP	Basque Country
Mutriku Wave Power Plant	Basque Country
Oceanic Platform of the Canary Islands (PLOCAN)	Canary Islands
Punta Langosteira Test Site	Galician coast

MEXICO

TEST SITE NAME	LOCATION
Port El Sauzal	Ensenada, Baja California
Station Puerto Morelos	Puerto Morelos, Quintana Roo

SWEDEN

TEST SITE NAME	LOCATION
The Lysekil wave energy research test site	Lysekil
Söderfors research site	Dalälven

DENMARK

TEST SITE NAME	LOCATION
DanWEC	Hanstholm
DanWEC NB	Nissum Bredning

NORWAY

TEST SITE NAME	LOCATION
Runde Environmental Centre (REC)	Runde Island

BELGIUM

TEST SITE NAME	LOCATION
Blue Accelerator	Port of Ostend

JAPAN

TEST SITE NAME	LOCATION
NAGASAKI-AMEC (Kabashima) floating wind Site	Goto, Nagasaki
NAGASAKI-AMEC (Naru) Tidal Site	Goto, Nagasaki
NAGASAKI-AMEC (Enoshima •Hirashima) Tidal Site	Saikai, Nagasaki

CHINA

TEST SITE NAME	LOCATION
National Marine Test Site (Wehai)	Weihai, Shandong Province
National Marine Test Site (Zhoushan)	Zhoushan, Zhejiang Province
National Marine Test Site (Zhuhai)	Zhuhai, Guangdong Province

REPUBLIC OF KOREA

TEST SITE NAME	LOCATION
KRISO-WETS (KRISO-Wave Energy Test Site)	Jeju
Korea Tidal Current Energy Centre (KTEC)	Undecided

FRANCE

TEST SITE NAME	LOCATION
SEM-REV, wave and floating offshore wind test-site	Le Croisic
SEENEOH estuarine and ¼ scale tidal site	Bordeaux
Paimpol-Brehat, tidal site	Bréhat
Sainte-Anne du Portzic, scaled wave and floating wind test-site	Brest

SINGAPORE

TEST SITE NAME	LOCATION
Sentosa Tidal Test Site	Sentosa island

1.

OVERVIEW OF OES

The International Energy Agency's (IEA) Ocean Energy Systems (OES) Technology Collaboration Programme is an intergovernmental collaboration between countries, to advance research, development and demonstration of technologies to harness energy from all forms of ocean renewable resources for electricity generation, as well as for other uses, such as desalination, through international co-operation and information exchange.

IEA-OES embraces the full range of ocean energy technologies:

- **Waves**, created by the action of wind passing over the surface of the ocean;
- **Tidal Range** (tidal rise and fall), derived from the gravitational forces of the Earth-Moon-Sun system;
- **Tidal Currents**, water flow resulting from the filling and emptying of coastal regions as a result of the tidal rise and fall;
- **Ocean Currents**, derived from wind-driven and thermohaline ocean circulation;
- **Ocean Thermal Energy Conversion** (OTEC), derived from temperature differences between solar energy stored as heat in upper ocean layers and colder seawater, generally below 1000 m;
- **Salinity Gradients**, derived from salinity differences between fresh and ocean water at river mouths.

Offshore wind, marine biomass or submarine geothermal, which occupy sea space but do not directly utilize the properties of seawater, are not included in the IEA-OES remit.

There is an opportunity for shared innovation in integrated energy systems, sharing infrastructure with other offshore energy conversion systems (such as offshore wind, floating PV, and other). Further, there are similarities between ocean current, tidal stream and river current technologies, and as such, there is an opportunity for knowledge or technology transfer.

NEW 5-YEAR TERM APPROVED

The IEA-OES operates in five-year terms. For each new term, requested for extension ("RfE") needs to be submitted to the IEA, with a Strategic Plan for the next term and an End of Term Report summarising key achievements on the past five years.

In 2021, the Executive Committee agreed on an extension for the period 1 March 2022 to 28 February 2027 and submitted to the IEA the Strategic Work Plan with proposed objectives for the coming five-year term and its End of Term Report. The 2022–2026 Strategic Plan was developed with the participation and approval of the IEA-OES Executive Committee. At the meeting on May 29th, 2021, the Executive Committee agreed on the vision, mission and strategic priorities for the new 5-years term. A request for an extension was submitted to the IEA and approved.

At the Working Party on Renewable Energy Technologies ("REWP") meeting held on 21-22 September 2021, the OES Chair made a presentation and the REWP Delegates commented on the outcomes of the IEA-OES. After review by the REWP, the CERT (IEA governing body) approved extending the term of the OES for the period 1 March 2022 to 28 February 2027.

VISION

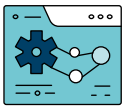
"As the authoritative international voice on ocean energy, we collaborate internationally to accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally sustainable manner".

MISSION

The OES mission is to support a framework of activities that:

Stimulate research, development and deployment of Ocean Energy Systems in a manner that is beneficial for the environment and provides an economic return for those involved.

Support governments, agencies, corporations and individuals in the development and deployment of Ocean Energy Systems.



Educate people globally on the nature of Ocean Energy Systems, the current status on development and deployment, and the beneficial impacts of such systems, improve skills and enhance research.

Connect with organisations and individuals working in the ocean energy sector for knowledge exchange to accelerate development and enhance economic and environmental outcomes.

STRATEGIC OBJECTIVES 2022 - 2027

Stimulate research, development and deployment

Objective 1: Stimulate collaborative work between OES country members to address challenges faced by the ocean energy sector avoiding duplication

- Foster and secure a strong commitment from all member countries and stimulate the participation of new countries in the OES to strengthen international collaboration and enhance OES's outreach worldwide.
- Continue to support and set up OES working groups on specific topics (wave and tidal modelling and OTEC development) with increased input from stakeholders (industry, government and research).
- Continue to work on developing strategic tasks such as LCOE, environmental issues, jobs creation and market opportunities.

Support governments, agencies, corporations and individuals to become involved

Objective 2: Enhance the impact of OES's work and remain the primary source worldwide of high-quality information

- Develop shared key messages (e.g. via position papers and policy briefs), incorporating outcomes of technology improvements and environmental integration.
- Stimulate policymakers regarding the social, environmental and economic benefits of ocean energy, and stress that government policies remain crucial to attract investment.
- Collect and share recent research, market, policy and technological updates, in ocean energy developments in OES Member countries.
- Provide valuable inputs to the REWP and the IEA network; contribute to relevant IEA publications, events and other initiatives.

Educate people globally on the nature of Ocean Energy Systems

Objective 3: Provide a platform for information exchange and discussion to increase awareness and understanding of the potential and benefits of ocean energy

- Collect and analyse information from country members on projects (WebGis Database), policies, consenting processes, capacity outlook, etc.
- Discuss and analyze good practices to achieve successful and cost-effective wide-scale deployment of ocean energy technologies, for utility-scale as well as niche markets, on a multi-country approach.
- Shaping the international discussion and continuing the series of public webinars/workshops and presence in international events; stimulate the participation of delegates in national events to spread OES activities worldwide.
- Highlight to stakeholders important developments, accomplishments in the ocean energy sector; provide relevant information and advice on ocean energy technologies and policies, from R&D to market deployment.

Connect with organisations and individuals and exchange information

Objective 4: Enhance cooperation with stakeholders and international organizations to share expertise and pool resources

- Expand interaction with research and industry in specific OES tasks.
- Increase cooperation with other TCPs to identify opportunities for knowledge transfer and joint tasks: address synergies, gaps and cross-cutting issues.
- Collaborate with international organizations, in particular, the International Renewable Energy Agency (IRENA), the World Ocean Council (WOC), the International Standards on Ocean Energy (IEC TC114), and support other multilateral initiatives engaged with ocean energy technologies such as International Network of Ocean Renewable Energy (INORE) a network of young researchers whose main focus is on offshore renewables.
- Continue to lead and host the International Conference for Ocean Energy (ICOE) series.

MEMBERSHIP

The International Energy Agency (IEA) Technology Collaboration Programme on Ocean Energy Systems (OES) was initiated by three countries in 2001 and has been growing steadily. As of December 2021, 22 Member Countries and the European Commission are active members of the OES.

National governments appoint a Contracting Party to represent the country in the Executive Committee (ExCo). The Contracting Party can be a government ministry or agency, a research institute or university, an industry association or even a private company. Governments also nominate alternates, who may represent the government at ExCo meetings, if the nominated representative is unavailable. Consequently, there is a diversified representation of interests in the ExCo, which is seen as a key strength of the organization.

CONTRACTING PARTIES

Year of Signature	Country	Contracting Party*
2001	Portugal	Instituto Superior Técnico (IST)
	Denmark	Ministry of Transport and Energy, Danish Energy Authority
	United Kingdom	Department of Business, Energy and Industrial Strategy
2002	Japan	Saga University
	Ireland	Sustainable Energy Authority of Ireland (SEAI)
2003	Canada	Natural Resources Canada
2005	United States of America	United States Department of Energy (DOE)
2006	Belgium	Federal Public Service Economy
2007	Germany	The Government of the Federal Republic of Germany
	Mexico	The Government of Mexico
2008	Spain	BiMEP - Biscay Marine Energy Platform
	Italy	Gestore dei Servizi Energetici (GSE)
	New Zealand	Aotearoa Wave and Tidal Energy Association (AWATEA)
	Sweden	Swedish Energy Agency
2010	Republic of Korea	Ministry of Oceans and Fisheries
2011	China	National Ocean Technology Centre (NOTC)
2013	Monaco	Government of the Principality of Monaco
2014	Singapore	Nanyang Technological University
	The Netherlands	Netherlands Enterprise Agency
2016	India	National Ocean Technology Institute (NIOT)
	France	France Energies Marines
	European Commission	European Commission
2018	Australia	Commonwealth Scientific and Industrial Research Organisation (CSIRO)

* as of December 2021

EXECUTIVE COMMITTEE

Overall control of the IEA-OES work programme is maintained by an Executive Committee (ExCo), which not only monitors existing projects, but also identifies new strategic topics in which collaborative efforts may be beneficial.

The ExCo is composed of representatives from each participating country and organisation. A list of the members of the ExCo is shown in Appendix 1. The ExCo meets at least twice a year and takes decisions on the management, participation and implementation aspects of the work programme.

All Contracting Parties pay an annual financial contribution to the OES Common Fund used for general administration and communication matters. The common fund may also support coordination of ongoing R&D projects, the launch of new projects, organisation of workshops on prioritised topics and commissioning of studies or reports. It does not cover R&D activities; research should be funded by participants involved in a specific task. The annual membership fee is €7000.

Together with the Secretary, the Chairman and Vice-Chairs form the Cabinet, which manages the day-to-day decision-making to implement the annual Work Programme. The ExCo Secretariat is based in Lisbon, Portugal and is run by WavEC Offshore Renewables. In 2021, Dr Purnima Jalihal, alternate member for India, was elected new Vice-Chair.

The COVID-19 outbreak has made it difficult for OES to organise the two usual ExCo meetings during the year. In 2021, 4 ExCo meetings took place online due to the ongoing restrictions imposed by the Covid-19 pandemic.

In 2021, the ExCo approved the extension of the IEA-OES for a new 5-year term and also updated its own legal framework in line with the IEA modernization initiative.

WORK PROGRAMME

The Collaborative research work carried out by the OES is structured into specific projects, using **two distinct approaches**:

- **Large projects** conducted by a group of countries interested in the topic to which only participants in the project contribute. Whenever three or more contracting parties support a proposal and sufficient funding is raised, a new research project can be established. One of the proposing parties will usually become the Operating Agent, accountable for the delivery of the project and management of its dedicated budget. Participation by ExCo members is voluntary and usually by cost-sharing, task-sharing or both – "Bottom-Up" approach.
- **Small projects** of interest to all members, usually financed by the Common Fund, so all members are effectively contributing equally to these deliverables. Usually, an interested volunteer member prepares the Terms of Reference of any proposed Task. The delegates are invited to bid to participate in this work; applications are evaluated and selected by a sub-committee of 3-4 voluntary ExCo members. The work is then undertaken by a group of members - both through cost- and task-sharing - and may include participation of external experts – "Top-Down" approach.

The following projects have been established within the IEA-OES:

Task No.	Title	Lead by	Status
1	Review, Exchange and Dissemination of Information on Ocean Energy Systems	Portugal	Active
2	Development of Recommended Practices for Testing and Evaluating Ocean Energy Systems	Denmark	Completed
3	Integration of Ocean Energy Plants into Distribution and Transmission Electrical Grids	Canada	Completed
4	Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal and Current Energy Systems	United States	Active
	The Exchange and Assessment of Ocean Energy Device Project Information and Experience	United States	Concluded
5	The Exchange and Assessment of Ocean Energy Device Project Information and Experience	United States	Concluded
6	Worldwide Web GIS Database for Ocean Energy	Germany	Active
7	Cost of Energy Assessment for Wave, Tidal, and OTEC at an International Level	UK	Concluded
8	Consenting Processes for Ocean Energy on Member Countries	Portugal	Active
9	International Ocean Energy Technology Roadmap	UK	Concluded
10	Wave Energy Converters Modelling Verification and Validation	Denmark	Active
11	Investigation and Evaluation of OTEC Resource	Japan	Active
12	Stage Gate Metrics International Framework for Ocean Energy	European Commission	Active
13	Tidal Energy Converters Modelling Verification and Validation	Singapore	Active
14	Ocean Energy Jobs Creation: Methodological Study and First Global Assessment	France	Active
15	Alternative Markets on Ocean Energy	The Cabinet	Active

OES has an internal prioritisation process for the selection of activities, which includes the analysis of the following points: how it fits with the OES Strategic Plan, the impact in Member Countries, the impact of the work and the relevance of the work being done by the OES. In many cases, before initiating a new project, the OES supports the organisation of workshops on a specific topic as a way to discuss the role that OES can play, as well as the format of the collaborative work.

2.

ACHIEVEMENTS IN 2021

COMMUNICATION & DISSEMINATION

IEA-OES has an ongoing task dedicated to collate, review and facilitate the exchange and dissemination of information on the technical, economic, environmental and social aspects of ocean energy systems. This task focus on the development of quality information products and effective communication mechanisms in support of the OES strategy. It further aims to provide adequate and accurate information to policy makers and other stakeholders. In this respect, the following main communication channels are used throughout the year:

- **Website** (www.ocean-energy-systems.org): is the primary source of communicating the activities of OES, publications and general outputs of each task to a wider audience. It includes a restricted area for the ExCo delegates with information to be discussed in each ExCo meeting and a repository of all presentations in meetings.
- **Social media**: in order to increase the OES programme's visibility, news are also promoted through LinkedIn and twitter.
- **Video available on YouTube channel** about ocean energy for the general public.
- **Annual Report**, the IEA-OES flagship document and a marker for industry development; it includes detailed information on national activities from country members.
- **Brochures:** in 2021, two brochures dedicated to wave and tidal current energy projects were released highlighting relevant recent developments in the sector.
- **Interviews to stakeholder published each year**; in 2021 the key topic for the publication with interviews was "new market opportunities for ocean energy".
- **Publications:** several publications were released during the year as outcomes of the Tasks and promoting ocean energy activities and projects.
- **Webinars:** three country webinars were organised with presentations from OES Delegates on country policies and projects.
- **Participation in Events:** the delegates usually contribute to a number of events promoting OES (conferences, workshops, forums, meetings, etc.).

2021

	Reports	Webinars	ExCo
01 Jan.	Performance Metrics		
02 February		Performance Metrics	
03 March	2020 OES Annual Report		ExCo 40
04 April	Wave Energy Highlights	Ocean Energy Outlook in USA, Canada and Mexico	
05 May	Tidal Energy Highlights		ExCo 41
06 June		Ocean Energy Outlook in UK, Denmark and Spain	
07 July			
08 August			
09 Sept.	Alternative Markets: Six Interiews		ExCo 42
10 Oct.	OTEC White Paper		
11 Nov.		Ocean Energy Outlook in Australia, Japan and China	
12 Dec.	OES 5-year Strategic Plan		ExCo 43

2021 WEBINARS

February

Evaluation and Guidance Framework for Ocean Energy Technology

Speakers:

- Matthijs Soede, European Commission
- Jonathan Hodges, Wave Energy Scotland
- Lauren Ruedy, US Department of Energy
- Patricia Comiskey, Sustainable Energy Authority of Ireland
- Tim Hurst, Wave Energy Scotland

April

Ocean Energy Outlook in USA, Canada and Mexico

Speakers:

- Yann-Hervé De Roeck, France Energies Marines, OES Chairman
- Tim Ramsey, U.S. Department of Energy
- Elisa Obermann, Marine Renewables Canada
- Rodolfo Silva Casarin, CEMIE-Océano, México

June

Ocean Energy Outlook in UK, Denmark and Spain

Speakers:

- Yann-Hervé De Roeck, France Energies Marines, OES Chairman
- Henry Jeffrey, Edinburgh University, UK
- Kim Nielsen, Ramboll, Denmark
- Yago Torre-Enciso, Biscay Marine Energy Platform (BiMEP), Spain
- Lotta Pirttimaa, Policy & Project Officer, Ocean Energy Europe (OEE)

November

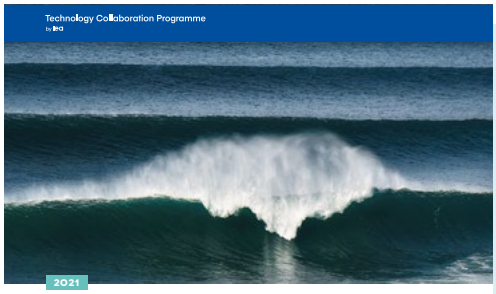
Ocean Energy Outlook in Australia, Japan and China

Speakers:

- Yann-Hervé De Roeck, France Energies Marines, OES Chairman
- Stephanie Thornton, Australian Marine Energy Taskforce (AMET)
- Yasuyuki Ikegami, Institute of Ocean Energy, Saga University, Japan
- Wang Ji, National Ocean Technology Center, China

Links to the presentation slides from these webinars can be found on the IEA-OES website page:
https://www.ocean-energy-systems.org/news-events/webinars/

NEW PUBLICATIONS



Wave Energy and Tidal Current Energy developments

Key Messages

- Great progress continues to be made by several wave energy developers. **Successful deployments** have taken place in all corners of the world from Australia, through Asia and Europe to North America.
- Several **full-scale devices** are currently in the manufacturing phase or **preparing for deployment**.
- The sector has been showing a **continuous evolution** along the TRL scale and first farms are being designed.
- A **number of potential breakthroughs** with significant impact on costs and energy production have been developed and have been already integrated in new prototypes.
- Wave energy might remain specific by developing simultaneously a wide variety of wave energy technologies, resulting from the **different ways in which energy can be absorbed** from the waves, and also depending on location and water depth.
- Wave energy projects are facing a crucial stage from demonstration to its first pre-commercial arrays of a few units; **extensive testing programmes are still required** in order to validate performance and reliability.
- Wave energy still require strong research and innovation programmes to fasten the pathway to full maturity. A **supportive policy framework** is fundamental on accelerating progress.

Key Messages

- The method for extracting energy from tidal streams is **approaching design convergence**. Horizontal-axis turbines have shown to be the most employed technologies. Alternative designs include vertical axis turbines and tidal kites.
- The technology is approaching **commercialisation**, with the deployment of full-scale devices and first arrays in real sea conditions.
- **Progress** in recent years is demonstrated by the operating hours accumulated, capacity deployed and electricity generated.
- There is a need for further **technology investigation** and demonstration for tidal current energy devices in real sea conditions for long periods of time providing invaluable experience regarding performance, reliability, availability, maintainability, survivability and environmental impact.

Alternative Markets for Ocean Energy - six in-depth interviews

Desalination projects using Ocean Thermal Gradient in India's Lakshadweep archipelago
Dr Purnima Jalihal

Wave powered desalination plant in Cape Verde
Mr. William Staby

CalWave XNode Ocean Science Platform
Mr. Marcus Lehmann

Penghu semi-submersible aquaculture platform
Mr. Peng Wei

Multiple-use of ocean space and multi-use platforms
Dr. Gordon Dalton

Blue Growth Farm multipurpose platform
Mr. Fabrizio Lagasco

PARTICIPATION IN INTERNATIONAL EVENTS ON BEHALF OF THE EXCO

Energy Innovation Emporium 2021
10 May 2021

This event was organised in the framework of COP26 in Scotland, by ETP, the Scottish academic research pool for energy, working in collaboration with innovation translators, industry and government to future-proof Scotland's position as a world-class centre of research excellence and globally competitive driving force in energy. The Chairman gave an overview of the OES.

Greening the Islands e_Convention - International Conference and Exhibition
19, 20 and 21 October 2021

The GTI e_Convention is the global event dedicated to innovative solutions for the self-sufficiency and sustainability of islands. The event, entirely digital, represents an opportunity for islands stakeholders around the world to connect with governments, corporates and academia sharing their common experiences through a digital platform, matching island needs and innovative solutions. The Chairman made a presentation focused on the recent study of OES on ocean energy in islands and remote coastal areas.

Exhibition Indonesia - New, Renewable Energy and Energy Conservation (EBTKE ConEx)
24 November 2021

Indonesia EBTKE ConEx is an integrated event dedicated to driving the growth and development of sustainable energy in Indonesia. Derived from the abbreviation of New, Renewable Energy and Energy Conservation as EBTKE, the event is an official annual agenda of the Indonesian Renewable Energy Society with full support from the Ministry of Energy and Mineral Resources of Indonesia. The Secretary presented IEA-OES at the ocean energy forum integrated with this event.

COLLABORATION WITH INTERNATIONAL INITIATIVES

OES promotes international collaboration fostering and enhancing the development and sustainable use of ocean energy, with a number of organisations, including the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA) and the International Network on Offshore Renewable Energy (INORE).

The following collaborative initiatives in 2021 are highlighted:

OPIN – Ocean Power Innovation Network

The Ocean Power Innovation Network (OPIN) is a 4-year initiative, running from 2019 to 2022 with financial support from the European Research and Development Fund (ERDF) through the Interreg North West Europe. The OPIN project encourages both cross-sectoral and cross-regional collaboration. In collaboration with the IEA-OES, OPIN organised a webinar on 15th of July 2021. The OPIN network is seen as a key network for the IEA-OES to inform and promote its work.

WECANET

WECANET is the first pan-European Network on an interdisciplinary marine wave energy approach contributing to large-scale wave energy array deployment by dealing with the current bottlenecks. The WECANet Action aims at a collaborative approach, as it provides a strong networking platform that also creates the space for dialogue between all stakeholders in wave energy. WECANet's main target is equal research, training, networking, collaboration and funding opportunities for all researchers and professionals, regardless of age, gender and country in order to obtain an understanding of the main challenges governing the development of the wave energy sector. Currently, 31 partner countries are active in this network. WECANET has a strong link with the OES task on wave energy numerical modelling.

International WATERS network

The International WATERS (Wave and Tidal Energy Research Sites) Network was set up in 2013 by the European Marine Energy Centre (EMEC) and provides a forum for open sea tests in the marine energy space to discuss common challenges, explore collaboration opportunities and reduce duplication of efforts and resources.

The OES set up a collaboration with the International WATERS network to create a centralised online database, populated with information on the infrastructure, equipment, services and test programmes available at each test centre globally. This aims to benefit technology developers by giving them an overview of what services and infrastructure are available to them to aid developers to choose relevant sites for testing. This activity was been developed throughout 2021.

International Conference on Ocean Energy (ICOE)

OES has a close link with the International Conference on Ocean Energy (ICOE), held every two years, and leads a competitive process to select the host team for this conference. ICOE focus on the industrial development of ocean energy.

The 8th edition of ICOE was planned for 2020, however, due to the impacts and uncertainty of the COVID-19 pandemic, it was postponed until 28-30 April 2021, as an online event, hosted by the United States National Hydropower Association (NHA), approved by the OES Executive Committee.

The International Steering Committee of ICOE includes the Chairman of the OES and several Delegates. OES manages a dedicated website with past ICOE conference material (www.icoeconference.com), thus providing the historical archive of all papers from previous conferences.

The Basque Energy Cluster and Ocean Energy Europe (OEE) are teaming up to deliver a joint event on ocean energy in 2022: **ICOE-OEE 2022**, will gather ocean energy professionals and decision-makers from all corners of the globe in San Sebastián – Donostia, in the Basque Country, Spain, from 18th to 20th of October.

International Electrotechnical Commission (IEC) Technical Committee (TC) 114, Marine Energy – Wave and Tidal Energy Converters

IEA- OES has a formal liaison with the IEC-TC 114 to develop international standards for wave and tidal energy technologies. Dr Purnima Jalihal, Delegate from India, has been nominated as the expert to coordinate, in particular, the collaboration with the working group "PT 62600-20 - General guidance for design and analysis of an Ocean Thermal Energy Conversion (OTEC) plant", on behalf of the OES. Further, a number of ExCo members serve as project leaders or participants in some of the TC114 working groups, providing technical information for future standards.

Collaboration with IEA

OES participated in the 2021 TCP Universal Meeting hosted by IEA in an online setting during October, as well as on the three TCP sessions scheduled on 26 and 28 October 2021:

Session 1: Enhancing collaboration among TCPs;
Session 2: Expanding global outreach of the TCPs; and
Session 3: Improving communication of TCP outputs to ensure a broader audience

OES-ENVIRONMENTAL ASSESSMENT OF ENVIRONMENTAL EFFECTS AND MONITORING EFFORTS

COORDINATOR
Samantha Eaves, US Department of Energy (DOE)/Allegheny Science & Technology

PARTNERS
Bureau of Ocean Energy Management (US)
National Oceanic and Atmospheric Administration (US)

TECHNICAL CONSULTANTS
Andrea Copping and Lysel Garavelli, Pacific Northwest National Laboratory

PROJECT DURATION
Phase I: 2010 - 2013
Phase II: 2013 - 2016
Phase III: 2016 - 2020
Phase IV: 2021 - 2024

The tasks performed by OES-E during 2021 included:

- Updating and expanding *Tethys* (https://tethys.pnnl.gov), the publicly accessible knowledge management system, with papers, reports, and other media on environmental effects of marine renewable energy (MRE);
- Developing an outreach and engagement plan for disseminating the contents of the *2020 State of the Science Report*;
- Continuing outreach and engagement to the MRE community through workshops, webinars, and conferences, with particular emphasis on researchers, regulators, advisors, and MRE device developers;
- Developing and compiling educational resources on environmental effects of MRE;
- Populating records of baseline data collection and monitoring efforts around deployed MRE devices, and relevant research studies (OES-E metadata forms);
- Continuing the development of the risk retirement process for simplifying consenting and licensing;
- Assessing the information available on environmental effects of MRE in tropical, subtropical, and southern hemisphere waters and other underserved areas that represent OES nations.

Sixteen nations are presently participating in Phase 4 of OES-E: Australia, Canada, China, Denmark, France, India, Ireland, Japan, Mexico, Monaco, Portugal, Singapore, Spain, Sweden, the United Kingdom (UK), and the United States (US). The US continues to lead the initiative, with Pacific Northwest National Laboratory (PNNL), one of the Department of Energy's national laboratories, serving as the Operating Agent and implementing the project.

Working with OES-Environmental Analysts

During 2021, PNNL continued to organize and lead meetings with the OES-E country analysts to coordinate cooperative work, approximately every 2-3 months. The purpose of these meetings is to discuss current OES-E activities, receive input and feedbacks from OES-E country analysts on these activities, and provide an opportunity to learn about current MRE development in each country. Each country analyst is asked to present updates on MRE development and environmental research in their respective countries and regions once every two years.

Dissemination of Information on Environmental Effects

Tethys continues to be used to collect, curate, and make accessible existing information on environmental effects of MRE, continuing to expand the platform and reach ever growing audiences. Currently, there are 3,674 documents that address environmental effects of MRE available on *Tethys* (an increase of 513 documents from 2020). A biweekly electronic newsletter, called *Tethys* Blast, is sent to the broad MRE community of more than 3,000 individuals. During 2021, use of social media continued as a means to reach interested parties on a regular basis. All accounts on all platforms (Twitter, Facebook, and Instagram) have seen consistent growth throughout 2021.

Facilitating Consenting Processes

During 2017, OES-E developed a regulator survey to gain an up to date understanding of regulatory knowledge of MRE technologies, challenges, and opinions. The survey has been deployed in eight of the OES-E countries (Canada, France, Ireland, Japan, Spain, Sweden, UK, and US). During 2021, work with OES-E country analysts continued to complete the survey in additional OES-E countries. Australia deployed the survey in late 2021 and will have results in early 2022.

Through an online webinar, regulators in Wales were presented with the guidance documents and asked for their feedback on how the documents might be applied to their consenting processes. OES-E will engage a larger group of regulators in early 2022, starting with regulators in the US and UK. Outreach to other OES-E country regulators will be carried out by their respective analysts, with support from PNNL staff.

As part of their work with OES-E, each nation's analyst continually shares information within their country, including introducing *Tethys*, gathering content for *Tethys*, and providing contacts with organizations in their country to identify relevant monitoring, data collection, research funding, and implementation activities. These activities set each analyst up as the ambassador for OES-E within their country. The OES-E analysts continue to engage their nation's regulators through a survey to determine regulator understanding, information needs, and challenges, and to present the risk retirement and data transferability processes. The analysts also reach out to colleagues in their respective fields to initiate investigations into key areas of environmental effects that will assist the MRE industry. The OES-E Analyst Activities Spreadsheet is available to be updated bi-annually by country analysts in order to organize and keep track of activities (such as document collection, webinars, *Tethys* Stories, etc.) that have been or will be completed.

Outreach and Engagement

Outreach and engagement efforts during 2021 focused on disseminating the results of the *2020 State of the Science Report* and conducting outreach to new audiences, particularly students engaged in STEM (Science, Technology, Engineering, and Mathematics) and the broader public. Through a series of webinars, workshops, and products, the *2020 State of the Science Report* was further amplified.

OES-E staff at PNNL have compiled educational materials and resources onto a new *Tethys* page, *Marine Renewable Energy Educational Resources*, to increase awareness and understanding of MRE and associated environmental effects, and to engage the future workforce. The materials and resources can be used by students of all ages and educational backgrounds. Educators, schools, aquariums and zoos, science camps, etc. may also want to use this page for activities, to enhance educational content, or to develop curriculum on environmental effects of MRE. The materials include a coloring book, downloadable images, short science summaries, and presentations for various education levels. The resource section highlights features of *Tethys* that may be of interest to a STEM audience. To help viewers understand which resources and materials best fit their educational level, a suggestion box is included.

OES-E has also developed a brochure titled "Marine Renewable Energy: An Introduction to Environmental Effects" to provide introductory material on environmental effects of MRE for use as training material for new regulators and advisors in a format that is easily

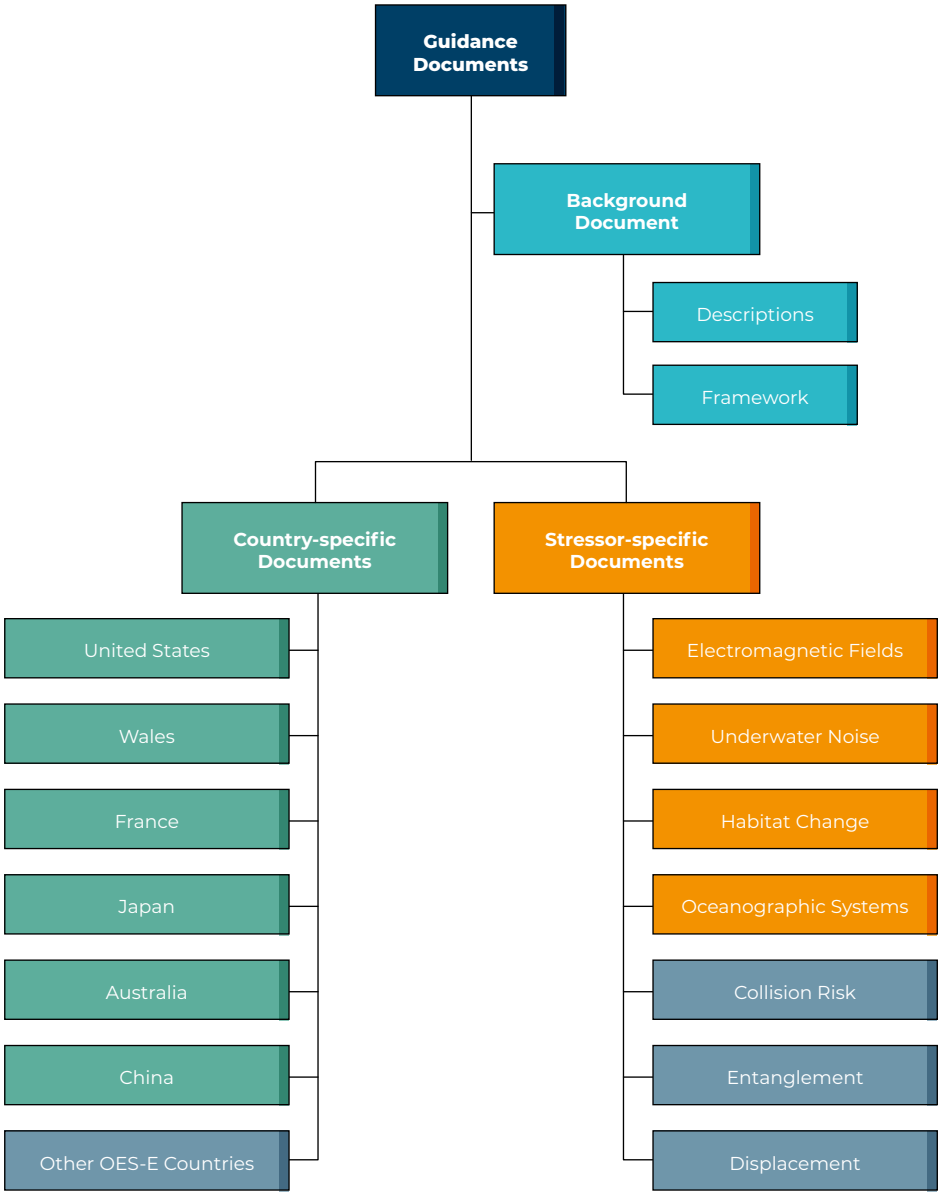
digestible. Links to additional sources for more information are featured.

For outreach to the broader public, efforts in 2021 focused on bringing the *2020 State of the Science* material to platforms that are more accessible to the public, including two podcasts: The Energy Transition Show (episode #155) and Wild About Conservation (S2 E12), both feature Andrea Copping (Senior Research Scientist, Pacific Northwest National Laboratory).

Risk Retirement

The process of developing documents and processes for risk retirement continued through 2021. First developed in 2018, the process is aimed at providing sufficient information to facilitate consenting for small numbers of MRE devices so that each potential risk needs not to be investigated for every new MRE project. The process includes the idea of data transferability - transferring data from already consented MRE projects, research studies, or analogous industries to inform potential environmental effects and consenting for future MRE projects. As part of the data transferability process, datasets are gathered and catalogued for easy retrieval in monitoring datasets discoverability matrix, which was stood up during 2020.

By the end of 2021, four key stressors from MRE devices were worked through the risk retirement process, with the aid of experts in workshops and online meetings. For small numbers of devices, it was agreed that underwater noise from MRE devices, electromagnetic fields (EMFs) from cables, changes in benthic and pelagic habitats, and



changes in oceanographic systems met the criteria for retirement. In order to bridge the gap from the science and evidence gathered for risk retirement to regulatory needs, a process for developing guidance documents was initiated, tailored for regulators, advisors, and developers, during 2020. The guidance documents are organized around the major types of regulation and legislation governing MRE consenting processes in all nations. In 2021, the overarching explanations for the guidance documents were completed, and OES-E country analysts developed country-specific documents to detail the relevant environmental regulations for MRE in their country. Currently, there are country-specific documents completed for the US, Wales, Japan, and China, with documents for Australia and France in development. Stressor-specific documents were also developed in 2021 for underwater noise, EMFs, changes in oceanographic systems, and changes in habitat. These documents provide an overview of current knowledge, existing data and information, and the pathway to risk retirement for each of these stressors. Each document is short and succinct and provides links to the necessary resources, evidence bases, and other material on *Tethys*. Next steps for the guidance documents include additional outreach and engagement to regulators and other key parties and developing additional country-specific and stressor-specific documents.

New Topics about Environmental Effects

For a number of years, OES-E has been working towards risk retirement for stressors that may affect marine animals and habitats, including collision risk, risk from underwater noise, EMF, etc. While the issues that surround these interactions with MRE devices have not been entirely solved with respect to consenting, the research and monitoring underway around the world is making great strides. During 2021, OES-E analysts began the process of expanding consideration of these topics, and have taken initial steps in five areas:

- Incorporating tropical and subtropical ecosystem considerations with those of temperate areas;
- Scaling up our understanding of potential effects from single MRE devices to arrays;
- Looking at ecosystem effects of MRE development, and implications for ecosystem services;
- Examining cumulative effects of MRE development with other anthropogenic activities and climate change; and
- The role that MRE arrays might play in displacement of marine animals from migratory routes and critical habitats.

The topics "Scaling up to arrays", "Ecosystem effects", and "Cumulative effects" are led by an OES-E analyst and each has a dedicated group of other analysts to assist. The outcome of each of these five new topics will be a white paper prepared before the end of 2022. These new topics are described briefly below.

Tropical and Subtropical

Most of the information available on environmental effects of MRE are from temperate regions, leaving little information on potential effects of MRE in tropical and subtropical regions. PNNL staff has been gathering papers and information from researchers and other contacts in tropical regions, and a literature review was conducted to assess the current available knowledge. As part of this effort, a case study in Oaxaca, Mexico, was developed to highlight available MRE resources and stressors-receptor interactions. This topic is led by Lysel Garavelli, PNNL.

Scaling to Arrays

This topic, led by Dan Hasselman (FORCE – Fundy Ocean Research Center for Energy, Canada), examines how to apply the current knowledge of stressor-receptor interactions around single devices to potential effects from arrays, with an emphasis on those interactions that are deemed not to be significant for single devices but which may become important once arrays are deployed. There is no robust definition of "arrays" in terms of MRE, but the group of analysts has chosen to focus on 10-30 tidal turbines or wave energy converters. They are identifying the stressor-receptor interactions that the most relevant to each type of array, and seeking knowledge that may be applied from analogous industries.

Ecosystem Effects

This topic, led by Nolwenn Quillien (France Énergies Marines, France) and her colleagues Georges Safi and Marie Le Marchand, focuses on understanding how the development and operation of MRE devices may affect the whole ecosystem into which they are deployed, and subsequently how ecosystem services are affected and/or assisted by MRE. For this topic, the group is developing a conceptual framework of an ecosystem approach applied to MRE.

Cumulative Effects

This topic, led by Beth Fulton (CSIRO – Commonwealth Scientific and Industrial Research Organization, Australia), aims at understanding the cumulative effects of MRE developments, both in isolation and combined with effects of other marine industries in a region. The

group is identifying tools and research studies that are needed to best assess these effects. For this topic, the group will use other sectors, such as fisheries, to assess the known effects and knowledge gaps in the MRE context.

Displacement

This topic, sometimes also referred to as barrier effect, is led by Andrea Copping, PNNL, and concerns moving animals from their preferred routes or habitats, due to the presence and operation of arrays of MRE devices. This stressor has not been investigated for single devices as there is perceived to be little risk from surface devices, anchors, or cables, until arrays create larger footprints in the sea. There is no robust definition of displacement, and no agreement upon means of researching interaction with this stressor. This work will begin that process, taking into account migratory marine animals like whales or sea turtles, as well as the smaller movement of crab, lobster, and other benthic animals between habitats.

Metadata on MRE Projects and Research Studies

During 2021, OES-E continued to collect and update information on new wave, tidal, and other MRE technology projects, as well as ongoing research studies, stored as metadata forms on *Tethys*. Existing metadata forms are updated annually by working with country analysts, developers, and researchers. There are currently 122 project forms and 57 research study forms on *Tethys*.

Workshops

OES-E hosted four online workshops during 2021 bringing together experts to further understand key interactions, work towards consensus on how research and monitoring information can inform consenting processes, and accelerate deployments for the MRE industry:

- Two online workshops were held in March 2021 that brought together experts and MRE practitioners for a structured discussion on the status of knowledge on collision risk and the challenges and barriers to improving understanding of collision risk for fish and marine mammals, including avoidance, evasion, and close encounters around turbines. The two workshops were well attended, with 41 experts from 7 countries attending the fish workshop, and 35 experts from 7 countries attending the marine mammal workshop.
- In April 2021, OES-E hosted an online workshop as part of the *Chile Riding the Blue Energy Wave* International Conference on the environmental effects of MRE and floating offshore wind from an international perspective as well as from the Chilean context.
- An OES-E workshop was also held on September 24th, 2021 in conjunction with the *Ocean Renewable Energy Conference 2021*, as a means to further disseminate information on risk retirement and the guidance documents. The main goal of the workshop was to receive feedback on the utility of the guidance documents. There were 27 participants from three countries.

Webinars

Four webinars were held by OES-E during 2021:

- In May 2021, OES-E delivered a webinar on environmental effects of MRE and the path forward represented by risk retirement to the Australian Cooperative Research Centre (CRD).
- In May 2021, a presentation was made to the University of Puerto Rico undergraduate engineering students on MRE and environmental effects. The students were particularly interested in understanding how device designs might have an impact on the marine environment.
- In June 2021, a webinar was held to discuss the guidance documents for risk retirement with regulators in the UK through the Wales Consenting and Strategic Advisory Group.
- In August 2021, a public webinar provided an overview of the risk retirement process and an update on the guidance documents. OES-E outreach efforts and feedback received from the MRE community in the development of the guidance documents were also highlighted, as well as the next steps for OES-E's efforts to increase understanding of environmental effects of MRE.

Conferences and Papers

PNNL personnel presented outputs from OES-E work at seven online conferences, during 2021:

- Presentation at the workshop on *Risk Retirement for Environmental Effects of Marine Renewable Energy*, hosted by Marine Energy Wales, January 2021. The presentation focused on risk retirement and the guidance documents.
- Invited speaker (Andrea Copping) at Supergen Symposium, January 2021, on marine renewable energy and the blue economy.
- Presentation at ICOE 2021, hosted by OES and the National Hydropower Association, April 2021. "Regulator Surveys to Aid Consenting Processes",

focused on the results of the OES-Environmental regulator survey outcomes and the actions they led to in risk retirement.

- Presentations at 8th PRIMaRE Conference, hosted by Bangor University, July 2021, "What we know (and don't know) about environmental effects of MRE development", focused on an overview of environmental effects and information from the 2020 State of the Science chapters, and "Are fish in danger? Review of effects of marine energy development on fishes".
- Presentations and poster at EWTEC 2021, hosted by Plymouth University, September 2021, "Moving from Scientific Research to Consenting Guidance for MRE Environmental Risk", and "Retiring environmental risks of marine renewable energy devices: the habitat change case".
- Presentation and poster at the AGU Fall Meeting, December 2021, "Environmental effects of marine renewable energy: from scientific evidence to regulation".

In addition, PNNL and other OES-E affiliates published two papers related to the OES-E work in 2021:

- Copping, A., L. Hemery, H. Viehman, A. Seitz, G. Staines, and D. Hasselman. 2021. *Are fish in danger? A review of environmental effects of marine renewable energy on fishes*. Biological Conservation. 262(13): DOI: 10.1016/j.biocon.2021.109297
- Hemery, L., A. Copping, and D. Overhus. 2021. *Biological consequences of marine energy development on marine animals*. Energies 12(24), 8460. DOI: 10.3390/en14248460.
- The US PRIMRE team (Portal and Repository for Information on Marine Renewable Energy https://openei.org/wiki/PRIMRE) hosted an international workshop on sharing of marine energy data. The workshop was attended by 24 professionals from 11 countries. There was a consensus that sharing of data internationally is vital, that additional resources are needed to make this a reality, and that the group wanted to meet periodically to facilitate data sharing and exchange new achievement in marine energy information management.

PERFORMANCE METRICS INTERNATIONAL FRAMEWORK FOR OCEAN ENERGY

COORDINATOR
Led by the European Commission and delivered by Wave Energy Scotland (WES)

BACKGROUND

A more rigorous technical review approach for the ocean energy sector has been recognised to be important at this stage, making use of improved evaluation methods and metrics that are currently applied in due diligence review and evaluation of ocean energy technologies. Considering the experience and lessons learned for more than two decades of ocean energy technology and market development, detailed monitoring of progress and success should have the following characteristics:

- Need to differentiate among the various needs of the development stages from R&D, Prototype, Demonstration, to Pre-Commercial and Industrial Roll-out;
- Need to define specific criteria to each development stage;
- A connection must be made between the performance criteria and the availability of certain types of support in the form of public and private funding;
- The process should use continued feasibility checks on the OE technology potential with an increasing focus on LCOE as the technology matures.

After an initial period of focusing on the technological feasibility where the only metric used was the successful technology evolution to higher TRL levels, economics and other social acceptance criteria have been identified to be considered at an early development stage for ocean energy technology.

OBJECTIVES

Task 12 - Stage Gate Metrics International Framework for Ocean Energy was initiated in 2017, as part of an ongoing collaboration to gain international consensus on a Technology Evaluation Framework to be used in ocean energy technology development programmes to objectively measure key, targeted areas and facilitate decision-making.

The main objectives to initiate this Task were:

- Build international consensus on ocean energy technology evaluation;
- Guide appropriate and robust activities throughout the technology development process;
- Share knowledge and promote collaboration;
- Support decision making associated with technology evaluation and funding allocation.

Consensus on technology evaluation and technology development activities will bring significant benefits for various stakeholders in the ocean energy sectors:

- Clarity in the expectations from different stakeholders during each stage of development, bringing clearer communication;
- Consistency in the use of terminology, and the process to evaluate technology, ensuring a level playing field;
- Stakeholders working together to build confidence and transparency in the sector;

- Efficient decision-making processes promoting direction of funding to the technologies with highest chances of commercial success;
- Technology development process consistent across the world, leading to more international collaboration more globally transferrable technology.

These objectives have been achieved by delivering a series of workshops, discussions, webinars and collaborations, resulting in the publication of the "IEA-OES International Evaluation and Guidance Framework for Ocean Energy" in February 2021.

The target users of the Framework are policy makers, public and private investors, technology developers and standards institutions. The Framework document represents a certain amount of international consensus. It has been the subject of significant stakeholder engagement with the IEA-OES contracting parties and all key user groups. However, in order to expand consensus and deliver its full value, the framework recommendations need wider uptake by the target user groups as well as other key stakeholders such as test centres and consenting bodies.

The group expected to be instrumental in driving wider uptake of the Framework is the public funders, whose application of the recommendations in public funding schemes would automatically drive uptake by applicant technology developers. However, to ensure this alignment between funders and developers, and to achieve a seamless transfer of technology developers from public funding schemes to compliance with standards, certification and the expectations of private investors, engagement with all users will be required.

In 2021, the ExCo approved the continuation of this Task, proposing the following objectives:

- To bring the Task 12 Framework to a stronger foundation of user acceptance, primarily with public funders and subsequently other users, achieving sufficient consensus and international adoption to warrant further developments;
- To identify, prioritise and deliver further developments and more detailed integration with other sector guidance;
- To develop the concept of a 'Technology Passport' - An internationally common development process and data package to facilitate simplified transfer of developers and technologies between national funding schemes and subsequently to private investors.

RESULTS

The next steps of Task 12 are expected to deliver the following results:

- **Immediate Framework improvement requirements identified and delivered, as required to allow wider uptake by public funders;**
- **Increased adoption by public funders achieved and foundations built for wider uptake by other target users;**
- **Further Framework improvement needs clarified, prioritised and delivered, including inclusion of sustainability considerations;**
- **Framework integrated with the work of standards and certification institutions and the concept of a 'Technology Passport' developed;**
- **Future Framework improvement and hosting arrangements defined.**

OCEAN ENERGY JOBS CREATION

COORDINATOR
Dr. Yann-Hervé De Roeck, France Energies Marines

PARTNERS
LOC Consortium, comprising LOC Renewables (including INNOSEA)
Fraser of Allander Institute from the University of Strathclyde

OBJECTIVES

This project aims at delivering a validated methodology for job assessment in the ocean energy sector and building up from the existing know-how developed on other renewable energies and other maritime sectors.

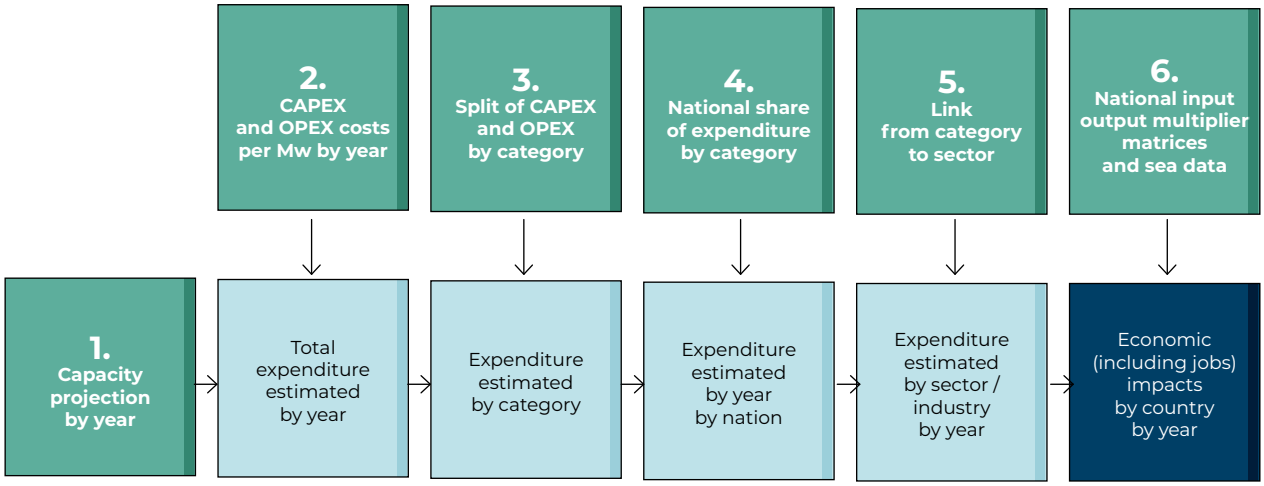
ACHIEVEMENTS

A state of the art of socio-economic methodologies used to assess the number of jobs created or maintained with the commercial deployment of ocean energy systems was prepared. There are different approaches used in the calculation of projected impacts, and so it is critical to review existing approaches before producing further quantitative estimates. A methodology developed will provide a result that relies on the approach used. Different methods would be likely to provide alternative results, which is why it is important that the choice of method is the most robust, transparent for users, and that policymakers and analysts are jointly aware of its limitations.

The main findings can be summarised as follows:

I. There are only a few examples of these methodologies being applied to ocean energy, however, applications from renewable energy technologies provide a framework which can be used to evaluate ocean energy technologies;
II. A number of different methods have been used to estimate the number of jobs supported by renewable energy technologies; the necessary inputs to each method has been identified;
III. Each method has properties that make them useful for answering specific questions relating to the employment effects of renewable energy, while each also has limitations.
IV. Recommendations for improved data gathering relating to the renewable energy sector and the need for data to be gathered on a consistent basis to economic accounts is provided. This may serve to improve the understanding of the links between ocean energy and the economy and to address how developments in ocean energy can help to meet nations and regions multiple objectives for energy ambitions.

Proposed methodology for estimating ocean energy jobs



Following the state-of-the-art report, the team suggested a methodology to be undertaken in this study: numbered items in green boxes are those where data is required, while the results of calculations are shown in black and white boxes.

The process could be separately implemented for each ocean energy technology (tidal, wave, OTEC) and for each country. Some of the required data for the study are explained below:

- **National share of expenditures by category:** local content achieved by category;
- **Link from category to sector:** allocation from general category to industrial sectors;
- **National input-output multiplier matrices:** matrices accounting for inter-industrial flows of goods and services (domestic and imports/exports);
- **SEA data:** relation between gross output and employment.

During 2021, data has been collected from all OES member countries, the methodology was applied and the results obtained were reviewed with regard to the most sensitive inputs, which are:

- CAPEX and OPEX annual cost reduction;
- CAPEX for OTEC;
- National share for national and international projects.

These inputs and their sources were discussed with other projects partners (e.g. ETIPOcean). TA sensitivity analysis was also conducted on these inputs. A validation of the methodology used was also carried out by comparing test case results to the literature. This comparison shows significant variation between studies results, and this brought to light a few considerations: results are really dependent on inputs definition assumptions and inputs about expenditures for future are still very uncertain. Therefore, it was concluded that the results achieved in this study have to be taken with caution, and always with regard to the inputs. In 2022 a report will be released summariring main achievements.

INTERNATIONAL WORKING GROUP ON WAVE ENERGY CONVERTERS MODELLING

COORDINATOR
Dr. Kim Nielsen, Ramboll, Denmark

PARTICIPATING COUNTRIES
Canada, China, Denmark, France, Ireland, Republic of Korea, The Netherlands, Belgium, Portugal, Spain, Sweden, UK, and USA

OBJECTIVES

The numerical modelling task on Wave Energy Converters (OES Task 10) was initiated in 2016 by experts from 13 countries with the objective to improve confidence in the prediction of power production from Wave Energy Converters using numerical tools.

The project focuses on numerical modelling of wave energy converters, to verify and validate the design and power production calculations, with the following long-term goals:

1. To establish confidence in the use of numerical models.
2. To identify uncertainties related to simulation methodologies.
3. To establish well-validated standards for evaluating wave energy converters concepts.

INTRODUCTION

"All numerical models are inaccurate, but some are easier to work with than others" someone said. To determine the errors associated with each modelling approach, one can compare the output of several numerical simulations, from different teams ideally spanning over a range of different modelling approaches. By comparing these results, an understanding of the variation in results and thereby the associated uncertainties are obtained.

Also, the speed of the simulation, the cost of the software and skills required to run the simulations are important parameters to monitor and identify. Some simulations are based on simplified assumptions – and even so give surprisingly realistic results even if the limits for the theory may be broken.

This project addresses several topics such as which wave theory to use, the influence of water depth – stroke limitations, end-stop forces and the scaling effects of air compressibility in the oscillating water column concept (OWC) and scaling of viscous drag on the structures.

ACHIEVEMENTS

Numerical simulation of "the KRISO OWC" a 1:4 scale model of the fixed shoreline OWC, was completed at the beginning of 2021 and the results were presented at a webinar in January and in the journal paper [6]. The experiments were carried out in the ocean basin at the Korea Research Institute of Ships and Ocean Engineering (KRISO) in 2019. The simulations showed that air compressibility should be considered – and that a well-defined and calibrated orifice model is important, but overall, a good agreement between measurements and simulations was obtained.

The dedicated experiments of the decay of the heaving sphere were also published in early 2021 [5]. These very accurate experiments were presented at Webinars and well received in the numerical simulation group as a means to benchmark numerical calculations. The experimental data made it possible to decisively compare, identify and differentiate the different numerical models.

During 2021, a new test case of an OWC was developed using existing test data from the Technical University of Denmark (DTU). The new test case is a small-scale OWC model with a side opening presented at webinars in early 2021. The OWC test data include tests using one-way venting – either on the up-stroke or the down stroke similar to the principle used by Wave Swell in Australia. Simulation activities have been ongoing during the second half of 2021.

SUMMARY OF PROJECT DEVELOPMENT

The sequence of test cases selected for this modelling work was based on the strategy to start with a simple test case, and from there evolve toward more complicated systems. The first test case, therefore, was selected as the heaving sphere, a case studied by Budal and Falnes in the early 1970's when the Point Absorber theory was developed [1]. The numerical modelling of a sphere (with a known theoretical solution) was described in two papers presented at EWTEC 2017 [2] and 2018 RENEW Proceedings [3].

Then, modelling of existing experimental data was initiated including modelling of a heaving float tested in the Mask Basin USA [4] followed by the KRISO OWC [5]. The experimental uncertainties from both test cases turned out to be large compared to the spread in the numerical results. However, the comparison between the numerical results with the existing experiments gave a feeling of reality and a guidance on how to compare numerical models within the confidence bounds of the experiments.

A dedicated experimental data set-up was prepared at Aalborg University, using very accurate experimental measurement equipment to assess the accuracy of different numerical models from the initial numerical simulations of the sphere [6].

ACKNOWLEDGEMENTS

This project has been supported by the NREL team, with thanks to Yi-Hsiang Yu and Thanh Toan Tran. Thanks also Morten Kramer and Jacob Andersen Aalborg University, and Harry Bingham from DTU for their leading roles in presenting the results in recent and upcoming journal papers. Thanks to the WECANET for support and cooperation, to EUDP for their continued support of the Danish team, and to the Swedish Energy Agency for supporting the Swedish team.

REFERENCES

[1] Ocean Waves and Oscillating Systems, Johannes Falness, Cambridge University Press 2002

[2] https://www.ocean-energy-systems.org/documents/59191-2017-ewtec-proceedings.pdf/

[3] https://www.ocean-energy-systems.org/documents/30887-2018-renew-proceedings.pdf/

[4] https://www.ocean-energy-systems.org/documents/55594-2019-journal-mar-sci-eng.pdf/

[6] https://www.mdpi.com/1996-1073/14/2/269

[5] https://www.mdpi.com/1996-1073/14/6/1718

INTERNATIONAL WORKING GROUP ON TIDAL ENERGY MODELLING VERIFICATION AND VALIDATION

COORDINATOR

Dr. Narasimalu Srikanth, Energy Research Institute @ NTU, Singapore

PARTICIPATING COUNTRIES

Australia, China, France, Germany, Indonesia, India, Ireland, Republic of Korea, Malaysia, Philippines, Sweden, UK and USA

OBJECTIVES

The numerical modelling task on Tidal Energy was initiated in 2018 by experts with the objective to improve confidence in the prediction of power production from tidal energy using numerical tools.

The project focuses on numerical modelling of tidal energy, to develop a standard methodology for modelling in harnessing tidal energy, with the following long-term goals:

1. Survey numerical modelling approach used in tidal-current based energy projects.
2. Verification and validation of modelling tools & methodology against specific case studies.

INTRODUCTION

Knowing the fact that the majority of the earth is covered with water, the extraction of tidal energy to generate electricity is augmenting the interests of the researchers and the method is being further enhanced. In the evaluation of tidal power resources, the cataloguing of appropriate sites and estimation of achievable energy are greatly important. Nations with long coastlines, having features like bays, estuaries etc., create a variation in the tidal currents. Also, these coastline properties possess high current velocities making them suitable sites for converting tidal energy into electrical energy. Models are being developed to identify the locations with high flow velocities and later analysing those areas

for the average power density. In this way, sites are being identified for installing tidal power plants. However, the correctness of these models is a function of the accuracy and the resolution of the input data required for these models. Further, the certainty also depends on the hydrodynamic phenomenon being examined by the various models to simulate the ocean flow. Like certain models, does 3-dimensional simulation while other does a 2-dimensional depth-averaged simulation. Still, these models serve the purpose of distinguishing the potential sites for tidal energy extraction which can be later verified by the field data.

As a great multitude of tools and techniques are used to determine the amount of tidal resources and to quantify the resources available in different parts of the world, establishing a standard in extractable resource modelling can pave the way in promoting the adoption of tidal energy among the various stakeholders, as it can provide confidence in the amount of available resources. International Tidal Energy Working Group was thus consequently formed as a part of Ocean Energy Systems (OES), an International Energy Agency Initiative and various international research teams conduct extractable resource studies to share their results and methodology, and work towards creating a standard report for modelling in harnessing tidal energy. Thus, the main objective of this initiative is to develop a simulation guideline report of tidal energy resource modelling through a common case study with various factors along with code-to-code comparisons of various modelling strategies that exist in different parts of the models. It would also involve comparison of models with experimental data and also discussion on various assumptions made in models such as seabed friction effects, etc.

The main goal of this project is to discuss and develop a standard methodology for modelling in harnessing tidal energy through the study of various factors which affect tidal modelling of an ocean site and the various underlying assumptions behind the simulations. The working group was formed as an international team of tidal energy researchers towards a joint exercise effort concentrating on the accurate modelling and reporting the guidelines towards tidal energy resources.

ACHIEVEMENTS

In 2021 as part of the tidal resource modelling, we had teleconferencing-based workshops & group meetings on 4th March 2021 and 15th October 2021. There were attendees from various international tidal energy working teams from all over the world such as Dr. Jérôme Thiébot and his team from University of Caen, France; Dr. Sam Fredrickson and his team from the University of Gothenburg, Sweden; Dr. Mathew Piggott and a team from Imperial College London, United Kingdom; Dr. Matt Lewis and a team from Bangor University, United Kingdom; Prof. Roger Falconer and his team from Cardiff University, United Kingdom; Dr. Philip Marsh and a team from University of Tasmania, Australia; Dr. Zhaoqing and a team from Pacific Northwest National Laboratory; Dr. Shuxiu Liang and the team from the Dalian University of Technology, China; Dr. Prasad and a team from National Institute of Ocean Technology (NIOT), India; Dr. Balaji Ramakrishnan and a team from IIT Bombay, India; Prof. Venugopal Vengatesan and a team from the University of Edinburg, UK; Dr. Craig Stevens from National Institute of Water and Atmospheric Research, New Zealand and Dr. Narasimalu Srikanth and his team from Energy Research Institute @ NTU, Singapore.

Based on the discussion on the workshops, the topics that need to be investigated further are as follows:

- Wind - Wave generation: Dominant wave types in terms of wave period/frequency and amplitude. Classification and effects of damping parameters.
- Wave-current interaction and wave breaking to address the following:
  - Resultant water surface elevation;
  - Resultant direction of current;
  - Basis for coupling between current and waves;
  - Influence on tidal energy.
- Modelling of the seabed and coastline depicting the quality of the sand in terms of its constituents for addressing the friction/drag force generated over the water flow.
- Effects of salinity and temperature in resultant tidal velocity and direction both qualitatively and quantitatively.
- Better methods of validating the ocean models.
- Available open-source ADCP and Tide gauges data for validation of tidal models.
- Hydrodynamic impacts of tidal current generation.
- Coupled 3d tide wave ocean models to parameterize realistic conditions to inform device scale studies.
- Parametrization of tidal turbines in the ocean model.
- Estimation of firm power and highest yield of tidal turbines as part of deterministic tidal resource prediction.
- Techno economics and Environmental aspects.

SUMMARY OF PROJECT DEVELOPMENT

The sequence of test cases selected for this modelling work was based on the strategy to start with a temperate test case, and from there evolve toward tropical test cases. The first test case, therefore, was selected as straits of Alderney Race, near Cherbourg, France with high tidal potential. Each international group used its ocean models to study the case site using common input data and presented the results in the workshops. The results were also compiled as a joint report and submitted to OES.

As further work, the international working group identified an Indonesian site of tropical waters with available validation data as a second case study. The International members were asked to include the various additional parameters such as wind-wave generation (as mentioned earlier) in the new case study and were asked to simulate based on their chosen codes and with their modelling expertise for numerical comparison study. This would help in further code-to-code comparison of various models along with experimental validation data. It would also help in comparing the prediction accuracy of both tropical and temperate waters using various ocean models. Based on the second case study, a high-level report is being planned for submission towards OES and further joint journal publications in Top tier journals.

ACKNOWLEDGEMENTS

This project has been well supported by all the international groups from various universities and industries from Australia, China, France, Germany, Indonesia, India, Ireland, Republic of Korea, Malaysia, Philippines, Sweden, UK & USA. Thanks to all the groups for their constant support and also towards journal paper publications.

REFERENCES

- Firdaus, Ahmad M., Guy T. Houlsby, and Thomas AA Adcock. "Tidal energy resource in Larantuka Strait, Indonesia." *Proceedings of the Institution of Civil Engineers-Energy* 173.2 (2020): 81-92.
- Lewis, M., Murray, R. O. H., Fredriksson, S., Maskell, J., de Fockert, A., Neill, S., & Robins, P. (2021). A standardised tidal-stream power curve, optimised for the global resource. Renewable Energy.
- Coles, D., Angeloudis, A., Greaves, D., Hastie, G., Lewis, M., Mackie, L., ... & Williamson, B. (2021). A review of the UK and British Channel Islands practical tidal stream energy resource. Proceedings of the Royal Society A, 477(2255), 20210469.
- Mejia-Olivares, Carlos Joel, et al. "Tidal range energy resource assessment of the Gulf of California, Mexico." *Renewable Energy* (2020).
- Thiébot, Jérôme, et al. "Numerical modelling of hydrodynamics and tidal energy extraction in the Alderney Race: a review." Philosophical Transactions of the Royal Society A 378.2178 (2020): 20190498.
- Thiébot, J., Djama Dirieh, N., Guillou, S., & Guillou, N. (2021). The Efficiency of a Fence of Tidal Turbines in the Alderney Race: Comparison between Analytical and Numerical Models. Energies, 14(4), 892.
- Thiébot, J., Guillou, S., & Droniou, E. (2020). Influence of the 18.6-year lunar nodal cycle on the tidal resource of the Alderney Race, France. Applied Ocean Research, 97, 102107.
- Neill, S. P., Haas, K. A., Thiébot, J., & Yang, Z. (2021). A review of tidal energy—Resource, feedbacks, and environmental interactions. Journal of Renewable and Sustainable Energy, 13(6), 062702.
- Bourgoin, Adrien CL, et al. "Turbulence characterization at a tidal energy site using large-eddy simulations: case of the Alderney Race." Philosophical Transactions of the Royal Society A 378.2178 (2020): 20190499.
- Mackie, L., Evans, P. S., Harrold, M. J., Tim, O., Piggott, M. D., & Angeloudis, A. (2021). Modelling an energetic tidal strait: investigating implications of common numerical configuration choices. Applied Ocean Research, 108, 102494.
- Warder, S. C., Angeloudis, A., & Piggott, M. D. (2021). Sedimentological data-driven bottom friction parameter estimation in modelling Bristol Channel tidal dynamics.
- Goss, Z. L., Coles, D. S., & Piggott, M. D. (2020). Identifying economically viable tidal sites within the Alderney Race through optimization of levelized cost of energy. Philosophical Transactions of the Royal Society A, 378(2178), 20190500.
- Novico, F., Sudjono, E. H., Egon, A., Menier, D., Mathew, M., & Pratama, M. B. (2021). Tidal Current Energy Resources Assessment in the Patinti Strait, Indonesia. International Journal of Renewable Energy Development, 10(3), 517-525.
- Srikanth, N., & Kannappan, L. (2021). Open-Source Code-Based Tidal Modeling of Tropical and Temperate Waters. FRONTIERS IN ENERGY RESEARCH, 9.

OCEAN THERMAL ENERGY CONVERSION WORKING GROUP

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PARTICIPATING COUNTRIES

China, India, Japan, Korea, France and USA

BACKGROUND

Under the aegis of OES, a task group on OTEC has been formed to promote dissemination and demonstration of OTEC. There are several roadblocks to the progress of OTEC both technologically and commercially. OTEC being a baseload power needs to be pursued and there is a need to disseminate information to all stakeholders. As these issues are of interest to policy makers, it was decided that a white paper on OTEC technologies should be jointly prepared to serve as a guide to international policy makers.

OBJECTIVES

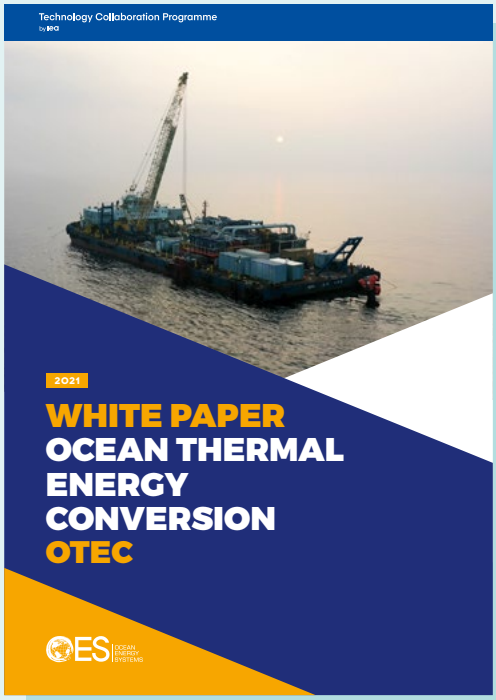
The overall work is carried out by two groups addressing the following topics:

1. Estimation of OTEC potential around the globe (led by China);
2. Present status and plans of OTEC projects (led by Korea).

A state-of-the-art report of OTEC activities and projects around the globe has been prepared as a first step to further define a full work programme under this Task. The identification of plans and new developments on OTEC in the various regions of the world would be important for the development of a future roadmap, which is one of the goals of this Task.

ACHIEVEMENTS

In 2021 the White Paper on OTEC was released with a set of recommendations for the adoption of OTEC technology.



WHITE PAPER ON OTEC
RECOMMENDATIONS

1. OTEC has the potential to make a major contribution to the energy transition process and worldwide decarbonisation.
2. Additional OTEC co-products includes the production of freshwater.
3. Simple and reliable technology has been proven in Hawaii and Japan - there is a well-established track record of infield performance, although presently at a relatively small scale.
4. The footprint requirements for OTEC plants are small.
5. The present state of proven pipeline technology is such that an island based 2.5 MW system is achievable toda and it is an an attractive concept for Small Island Developing States (SIDS).
6. Considering the significant technical developments over the last 15 years, a 10 MW floating OTEC is technically achievable but not yet commercia
7. Governmental support is required to encourage building and testig a demonstration plant of 2.5 MW
8. What is Missing to Scale up to 100+MW? Currently, the main is confidence that large diameter cold water intake pipes can be installed and will prove reliability over time.
9. The long-term potential for OTEC is enormous.
10. Need for Publicity and Education on OTEC's Potential and Benefits: while relatively high capital cost estimates have impeded OTEC commercial developments, another significant factor has been a lack of knowledge and understanding within the general public, governments and the investment community. OTEC and its potential deserves and requires more awareness.
11. It is envisaged that environmental & ecological impacts to ocean over long period is negligible. The existing small rating plants do not show adverse impacts, however, scaling up and its effect will need further detailed study.

OCEAN RENEWABLE ENERGY AND OFFSHORE AQUACULTURE

PROJECT TEAM
Pacific Northwest National Laboratory – Lysel Garavelli, Mikaela Freeman
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BACKGROUND

The growth of the blue economy will result in the increasing use of marine space and the potential for conflict with existing ocean uses, which can be partially addressed through the implementation of marine spatial planning (MSP). MSP seeks to manage competing marine uses while balancing environmental, social, and economic interests to support sustainable development of the oceans.[1] However, there is also potential to consider collaborating uses of the marine environment. One such combined potential use of the marine space is aquaculture and Ocean Energy.

Power for aquaculture is generally provided by diesel generation and occasionally by renewables, such as solar with battery storage. Aquaculture as a protein source already has significantly lower emissions than traditional meat based/western diets[2]. However, by replacing fossil fuels with marine renewable energy, the aquaculture industry could become an even more sustainable option for consumers and reduce the likelihood of potential harm to air and water quality via emissions and oil spills. There are a number of potential synergistic opportunities for co-location of aquaculture and ocean energy devices: for instance, wave farms could provide shelter in their lee to an offshore aquaculture facility; and aquaculture sites could provide suitable opportunities for technologies to test and demonstrate at smaller scales. However, there are some challenges such as the ideal environment for offshore aquaculture, often calmer, less energetic waters that may not always present the best resource for an ocean energy conversion system, and this may pose a significant challenge for some ocean energy technologies.

This study aims to identify the opportunities and challenges that may lie in targeting the offshore aquaculture sector as a key market for ocean renewable energy development.

OBJECTIVES

The main objective of the project is to provide an understanding of the potential of ocean energy to co-locate with offshore aquaculture and to supply energy for the sector. Developing and adapting ocean energy devices to provide power for aquaculture operations can provide an opportunity to contribute to the blue economy, move towards more sustainable aquaculture operations, and help the ocean energy industry develop while gaining much-needed revenue.

ACHIEVEMENTS

A review has been undertaken in order to inform the opportunities available to ocean energy in the aquaculture sector. This review has included an overview of aquaculture energy demand data available via published research and datasets as well as data collected from several countries. Case studies showcasing examples of co-located offshore aquaculture and ocean renewable energy, as well as solar PV or hybrid solutions, have been highlighted to provide lessons learned from research and pilot deployments. Challenges and opportunities have been identified for co-location and recommendations for future research efforts are provided. A final report will be published in early 2022.

1. OES State of the Science Report: https://www.ocean-energy-systems.org/publications/search/
2 https://www.oceanpanel.org/climate

3.

INTERNATIONAL ACTIVITIES ON OCEAN ENERGY

3.1 AUSTRALIA

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INTRODUCTION

Despite another challenging year due to covid, significant progress was achieved laying the building blocks for robust growth of Australia's ocean energy sector for 2022. Those building blocks, among other accomplishments, are highlighted in this report.

Key achievements include:

- New policy supports
- Commissioned wave energy technology deployment
- Portfolio of robust R&D initiatives
- Two (2) global awards for Australian wave energy technologies
- Comprehensive ocean energy market initiative launched

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY – POLICY SUPPORT

The Australian national Offshore Electricity Infrastructure Bill 2021 approved

The passing of this bill is a strong step forward in support of Australian ocean energy development. This provides a policy framework for the construction, operation, maintenance and decommissioning of offshore electricity projects in Australian Commonwealth waters. It supports state and national planning.

Of the three license streams in the Bill framework — 1) Commercial, 2) Research and Demonstration, and 3) Transmission and Infrastructure — stream 2 could provide opportunities for collaborative offshore wind and wave projects, as it is intended for small-scale projects to undertake research and testing to demonstrate emerging technologies. It also has the possibility to overlap with stream 1, indicating potential commercial opportunities.

National Marine Energy Standards Committee – EL066 – first year

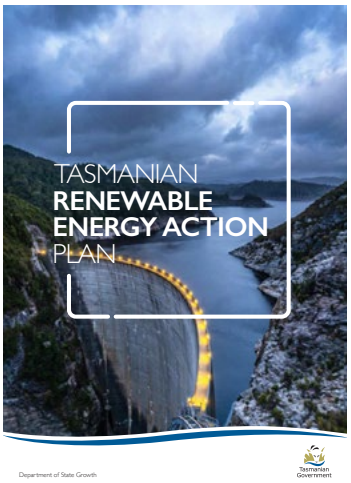
The National Marine Energy Standards Committee completed a full year of operation, after forming in 2020. The committee is now well-established. It is a Mirror Committee to the International Electrotechnical Commission on Marine Energy Standards, better known as IEC TC 114 Marine Energy – wave, tidal and other water converters. The Australian committee sits within Standards Australia which is the nation's peak non-government, not-for-profit standards organisation.

OE Policy initiatives by Australian states

The Tasmanian Renewable Energy Action Plan was released in December 2020, aiming to grow the renewable energy sector sustainably over the next 20 years. The plan includes a new interconnector to mainland Australia, so that the increased renewable capacity can be exported as green energy to mainland Australia. The aim is to attract new load and energy intensive industries to Tasmania for jobs growth. Tasmania's offshore resources are acknowledged as a possible new generation in support of the State's renewable energy goals. Ocean energy is specifically identified along with the Blue Economy CRC offshore renewable energy program research and development.

Victorian Draft Marine and Coastal Strategy was made available for comment in late 2021, building on the Policy released in 2020, including specific policies relating to marine and coastal industries. The final Strategy will be released in 2022, directly benefiting ocean energy initiatives in the State, with priority actions for the next 5 years.

The **Australian Academy of Science, Future Earth Australia** recently completed a national Sustainable Oceans and Coasts Strategy. Ocean energy development is fully recognized in one of the action items.



MARKET INCENTIVES

With maturing ocean energy technologies, test centres, and research and development growing in Australia, the industry is unbalanced in terms of supply and demand. While the ocean energy sector is strong on the supply side, it is weak on customer demand.

The industry group, Australian Ocean Energy Group (AOEG) initiated a comprehensive **Ocean Energy Market Development Program** to increase market demand. This is initiative is intended to address a lack of end-user awareness, accessibility to ocean energy experts and technology, affordability via business and financial models for varying applications of ocean energy and lack of an established commercial project delivery scheme – all addressing the incentives for end-users to transition to an ocean energy system. AOEG believes that demonstrating demand by Blue Economy customers will lead to the establishment of government market incentive support.

PUBLIC FUNDING PROGRAMMES

Several national funding programs are in place which supports ocean energy systems in Australia. Programmes with a track record of supporting ocean energy activities include:

Commonwealth Funding Bodies

The Australian Commonwealth funding bodies were described in detail in the 2020 report and include:

- The Australian Renewable Energy Agency (ARENA). http://www.arena.gov.au, which funds Australian participation in OES, and a technology project described in Section 1.4 below.
- Cooperative Research Centre (CRC) Program https://www.business.gov.au/assistance/cooperative-research-centres-programme which now includes the Blue Economy CRC described below.
- National Energy Resources Australia (NERA) http://www.nera.org.au provides funding for AOEG' Market Development Program.
- Australian Research Council (ARC) http://arc.gov.au which administers several active offshore renewable energy projects across several Universities, including UWA, Curtin University, RMIT, Swinburne University of Technology, University of Melbourne.
- Clean Energy Finance Council (CEFC) http://cefc.com.au to catalyse private sector investment in Australia's clean energy sector. To date, no ocean energy technologies have been supported by this fund, despite OE being identified as an eligible technology.

State funding

In addition to Commonwealth public funding programs, State Government public funds are growing and supported R&D for ocean energy development, most notable of these are Western Australia supporting Marine Energy Research Australia (MERA), New South Wales Net Zero Industry and Innovation Program (focused on supporting clean technology innovation) and Victorian Energy Innovation Fund supporting offshore renewable development.

RESEARCH & DEVELOPMENT

Investment in ocean energy R&D witnessed significant expansion in 2021 through the following initiatives:

Blue Economy CRC (BE-CRC)

The Blue Economy CRC is a 10-years AU$329m program launched in 2019, with the purpose of delivering innovation to support the growth of Australia's offshore aquaculture and renewable energy production, underpinned by a AU$70m grant from the Commonwealth CRC program. BE-CRC conducts research and training in offshore sustainable food production and renewable energy production. It manages a growing portfolio of research with direct benefits to industry. In a very short time, this CRC has built an impressive portfolio of research projects and continues to actively support a diversified range of new projects, to underpin the successful growth of ocean energy in Australia.

Marine Energy Research Australia (MERA)

MERA is a branch of the University of Western Australia and is located in Albany in Southwestern Australia. MERA is a laboratory for marine field operations closely linked to ocean engineering research activities, professional networks and facilities in Perth. The MERA facility also includes a visitor centre where extensive public education and outreach about ocean energy occurs.

In 2021, the Western Australian government and BE-CRC provided funding for MERA's 'M4 project'. M4 is short for 'Moored MultiModal Multibody' which describes the wave attenuator technology developed by the Wave Energy Research Centre's collaborators at the University of Manchester, UK. The M4 is aimed at demonstrating the region's wave energy potential to power the local aquaculture industry and will be developed and tested over a 30-month period.

Australian Institute of Marine Science (AIMS)

AIMS is committed to supporting a sustainable future for Australia's oceans and is working with AEOG and industry in exploring collaborative opportunities to integrate ocean energy technologies into AIMS-sea operations. Opportunities were identified throughout 2021 for development in 2022.

Carnegie Clean Energy - MoorPower Project

With support from the BE-CRC, Carnegie Clean Energy launched the MoorPower project in 2021. This project aims to incorporate core aspects of Carnegie's CETO technology into a novel wave converter system for use in offshore energy demand applications. The pilot project starts with a focus on the offshore aquaculture sector, with specific application to feed barge operations. The objective is to reduce and eventually eliminate the use of diesel.

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Wave Swell Energy King island

An Australian project was acknowledged as the first marine demonstration facility to generate electricity from the energy of waves. The Wave Swell Energy wave generator was installed at King Island, Tasmania in January 2021. This generator is providing electricity to the King Island grid and has been doing so since June 2021.

Special Technology Awards – Australian Technology Developers

Wave Swell Energy was the winner of the Energy Globe Awards in the category of Energy Generation. This award was announced at an official awards ceremony in Glasgow in November 2021, coinciding with COP26. The Energy Globe Awards, conducted annually since 2000, are one of the world's most prestigious awards for sustainability. For more details see: Winner 22nd Energy Glove World Award

Wave Swell Energy King island

EuropeWave PCP

Carnegie Clean Energy and Bombora Wave Power were selected as two of the seven companies for the new European Pre-Commercial Procurement Program (EuropeWave PCP). This program is a collaboration between Wave Energy Scotland (WES) — a subsidiary of the Scottish Government's Highlands and Islands Enterprise — and the Basque Energy Agency (EVE).

PLANNED DEPLOYMENTS

- **AZURA-EHL Australia –** The AZURA technology is a wave energy product of EHL, with locations in both New Zealand and Australia. The AZURA technology is pre-commercial and designed to provide both water and/or power. They have 3 major projects in development.
- **Altum Energy –** Formerly MAKO Tidal Turbines Pty Ltd. In 2021, Altum Energy successfully secured financial backing from a UK investor to move forward with Altum's range of smaller, modular tidal turbines optimised for slow-flowing tidal and river sites. Australia will remain as the technology development hub, whilst financial headquarters reside in London.
- **Smart Barge (Qld and NSW) -** The Smart Barge team is developing a fully independent, floating, autonomous, tidal energy electricity harvesting, storage and delivery system. The company has targeted the tidal-rich, high-energy Kimberley area in Northwest Australia as their target market region and plan to deploy a prototype in 2022.
- **Cockatoo Island tidal (Kimberley, WA).** This initiative is a multi-user, deep-water supply base and logistics hub on Cockatoo Island. The vision is to support oil & gas, mining, aviation and shipping operations, with much of their electricity demand supplied through tidal energy. KTVS, the developer, has already taken steps to secure expressions of interest from global tidal energy providers.

RELEVANT NATIONAL EVENTS

The OES Australia Working Group, established in October 2020 has continued as a successful method of knowledge-sharing. The working group consists of 12 members representing industry, government, and academia, and has met online twice in 2021. This working group activity has led to increasing the contribution of Australian ocean energy expertise to developments and OES projects while simultaneously increasing knowledge transfer to Australia from OES, helping to support industry growth.

In 2021 Blue Economy CRC held the annual participant workshop in March 2021 over 3 days. The CRC also held monthly webinars. Four of the monthly webinars focussed on ocean energy topics.

In 2021, AOEG partnered with the European Union — Australian Climate Business Network to host three successful forums:

- Global Ocean Energy: From technology push to market pull, in July 2021,
- Demonstration to Commercialisation: Market insights in the tidal sector in August 2021, and
- Capturing the Ocean Energy Opportunity: Integrated energy systems from utility-scale to near-shore microgrids in November 2021.

Planned ocean energy events in Australia 2022 include:

- Blue Economy Cooperative Research Centre (BE-CRC) annual participant workshop (May 2022)
- AOEG Ocean Energy Market Summit in conjunction with the BE-CRC workshop (May 2022)

3.2
BELGIUM

AUTHORS
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OVERVIEW

Ghent University is coordinating the European COST Action CA17105 "WECANet", an open pan-European Network for Marine Renewable Energy with a focus on wave energy funded by the European COST Association which involves 31 countries. WECANet targets scientific excellence and inclusiveness by fostering training, networking and collaboration in Europe for wave energy. The Coastal Engineering Research Group (CERG-UGent) is an international player in the field of Blue Energy with its pioneering research tools. CERG-UGent focuses on the research topics of wave and tidal energy, and offshore floating wind turbines and other floating structures, and is pioneer in investigating parks of energy devices.

Ghent University is a strategic partner in the H2020 MARINERG-i project coordinated by the MaREI Centre at University College of Cork Ireland, which brings together all the European countries with significant testing capabilities in offshore renewable energy.

The Flemish Agency for Innovation and Entrepreneurship (VLAIO) is supporting since 2018 the 'Blue Cluster' which was set up aimed at large companies and SMEs active in the blue economy sector, including marine energy.

The West Flanders Development Agency responsible for the implementation of the social-economic policy of the Province of West Flanders, is supporting developments in the blue energy field, promoting the development of ocean energy technology by the academic sector and private companies. The *Fabriek voor de Toekomst Blue Energy* of POM West Flanders was established by the province of West Flanders to give businesses in this industry every possibility to grow via innovation. Moreover, POM has introduced TUA West (Technical University Alliance West Flanders) with a focus on improving cooperation between the province's higher education establishments and making knowledge more readily available to the industry and especially the many SMEs in the region.

The Blue Growth Summer School organised by Ghent University is recognized by the European Commission as best practice example of innovative training. Already five years on row, the BGSS has fostered blue knowledge and received a variety of participants. The programme combines fundamental insights with hands-on sessions and site visits. Besides professors also business developers, entrepreneurs and industrial leaders share their expertise with Master and PhD students passionate about the seas and oceans.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Belgium's renewable energy policy is aligned with the EU 2020 targets. Belgium's land-based and offshore wind energy developments are essential for both the Belgian and European targets for energy development from renewable sources. For 2020, Belgium had a binding national target for renewable energy equal to 13% of the gross final consumption of energy.

By the end 2020, the total land-based installed capacity in Belgium has reached 3,000 MW, and an additional 2,292 MW are planned offshore for a possible total of 5,292 MW of wind power. A green energy certificate market is implemented to support onshore renewable energy production with Tradable Green Certificates (TGC). For each renewable technology, a stakeholder analysis is put forward to determine the level of support. A generic business case is constructed with input of the developer, the technology supplier, investors, banks, etc. This exercise will determine the cost of the renewable electricity and the matching value of the TGC in €/MWh. The business case is frequently updated in order to align the new TGC support with the technology evolution.

To maximize Belgium's own renewable electricity production, the federal government decided to increase the capacity of offshore wind installations in the second offshore wind zone, the Princess Elisabeth Zone, to a range between 3,15 and 3,5 GW. Together with the existing offshore wind farms, the total offshore wind capacity in Belgium can as such increase to 5,8 GW by 2030, almost tripling the current offshore capacity. By 2030, around 25% of the Belgian electricity production can come from the Belgian North Sea, saving in total 8,6 million tons of CO^2 per year. A first phase of 0,7 GW is to be installed by 2028 and the remaining 2,1 GW is to be taken into service by the end of 2029.

Marine renewable energy is seen as a new emerging industry, highly relevant for Flanders. There are several initiatives promoting the development of the blue economy, including marine energies.

The Flemish Agency for Innovation and Entrepreneurship (VLAIO) has been supporting the 'Blue Cluster' aimed at large companies & SMEs active in the blue economy sector, including marine energies. The Blue Cluster, a Flemish spearhead cluster focussed on the sustainable blue economy has, together with its members from industry and academic partners revised its offshore renewable energy R&D roadmap. It can be downloaded from the Blue Clusters website:
https://www.blauwecluster.be/sites/default/files/attachments/roadmap_hernieuwbare_energie_nov2020_met_annex.pdf

The **West Flanders Development Agency (POM West Flanders)**, is supporting developments in the blue energy field, promoting the development of ocean energy technology by the academic sector and private companies. The *Fabriek voor de Toekomst Blue Energy* of POM West Flanders was established by the province of West Flanders to give businesses in this industry every possibility to grow via innovation. Promotion, research, training and infrastructure. The partnerships aim to create an optimal breeding ground for a future-oriented economy. This is possible thanks to a close collaboration between education, science, industry and local government. One example is the periodic, structural meeting of the "core group" blue energy, organised by POM West Flanders, which brings together the main players in the blue energy field.

MARKET INCENTIVES

The first wind energy zone in the Belgian North Sea has been fully built within the set timeframe. The last two wind farms in this zone, Northwester II and SeaMade, were built and commissioned in spring and autumn 2020 respectively. With these two new wind farms, 8 wind farms are now operational in the Belgian North Sea, with a total installed capacity of 2,262 MW.

In 2020, Belgian offshore wind farms generated 6.7 TWh of electricity. This represents 8.4% of total electricity consumption in Belgium or the electricity consumption of around 1.9 million families. From 2021 onwards, the 8 wind farms will together produce around 8 TWh of renewable energy annually. This corresponds to the electricity

consumption of approximately 2.2 million families, which is almost half of Belgian households, or 10% of the total electricity demand in our country.

The Blue Cluster

The Blue Cluster is a not-for-profit cluster organization grouping over 200 private businesses and public partners, dedicated to the blue economy. Their mission is to strengthen the competitiveness of the blue economy in Belgium. The Blue Cluster is recognized by the Flemish government as a spearhead cluster, and is a strategic partner of Flanders Investment and Trade.

The Blue Cluster is focused on innovation an internationalisation trajectories to stimulate blue growth but acts also as a sector federation defending the stakes of a sustainable blue industry. The cluster is an important networking organization to bring together many companies that work (often partially) in a maritime context. By fully incorporating cutting-edge SME's in the cluster organization and the innovation projects, the Blue Cluster ensures that they can accelerate their growth. Besides its role in innovation and international development, the cluster takes the lead in the development of a blue strategy for Flanders, and provides policy advice to the Flemish authorities to implement this strategy.

In 2021, the third working year of the Blue Cluster, a total of 4 new renewable offshore energy projects have been approved by Flemish Agency for Innovation and Entrepreneurship (VLAIO), representing a total budget of € 3.285.617 (subsidy € 1.749.025). A total of 13 projects are running, from which 2 intercluster projects.

More information:
https://www.blauwecluster.be/about

The Fabriek voor de Toekomst Blue Energy

In order to help businesses in West Flanders to grow regionally and internationally via innovation, the Province of West Flanders established cluster platforms in the framework of the Provincial Development Agency West-Flanders (POM) to proactively prepare its industries for the future. The *Fabriek voor de Toekomst Blue Energy*, focusing on wind, wave and tidal energy, is situated at the Belgian coast and in the Ostend area. Through a partnership between all relevant actors at the local, provincial and Flemish level, SMEs are supported in their future-oriented and sustainable development: from practical services to promotion, research, training and infrastructure: the cluster platforms aim to create an optimal breeding ground for a future-oriented economy.

More information:
http://www.fabriekenvoordetoekomst.be/fabriek-voor-de-toekomst-blue-energy

PUBLIC FUNDING PROGRAMMES

Every year, POM West Flanders launches a call for projects called the “Quick Wins”, in which a number of short-term innovation cooperation projects are funded (50%) with the ambition to finalise with a pilot installation, test setup or prototype.

The Federal **Energy Transition Fund** in Belgium aims to encourage and support research and development in the field of energy. As part of the Energy Transition Fund, the Directorate-General Energy organizes each year a call for proposals in accordance with article 3, §1, of the Royal Decree of 9 May 2017 laying down the conditions for use of the Energy Transition Fund.

The current call aims to support innovative and research projects within five energy sectors with that of renewable energy in the Belgian exclusive economic zone of the North Sea being one of them.

The Energy Transition Fund aims at research and development in the field of energy. The budget of the Energy Transition Fund for the year 2022 amounts to 25 million euros, which can be awarded as a subsidy to projects that meet all relevant conditions and relate to research and development, investment in research infrastructure, innovation clusters or on innovation by SMEs.

The Blue Cluster has a dedicated budget from Flanders Innovation & Entrepreneurship to cofund industry driven R&D projects on the subject of offshore renewable energy. The projects have to involve at least 3 Flemish companies and have to respond to the roadmap mentioned above. The annual budget for co-funding R&D projects with the support of the Blue Cluster is 8 million Euro.

RESEARCH & DEVELOPMENT

Fundamental research projects at UGent-CERG dedicated to ocean energy research

The Coastal Engineering Research Group (UGent-CERG), situated within the Department of Civil Engineering has a large experience in the field of marine renewable energy and coastal and offshore engineering performing integrated research using physical and numerical modelling and field measurement campaigns. The main infrastructure includes prototype field measurements, wave flumes/basin for physical scale modelling, and numerical tools. The specialized staff members of the research group are involved in national and international projects on coastal defence, ocean energy conversion and offshore structures. UGent-CERG has a strong pioneering role in Belgium in marine renewables and offshore moored floating structures. Moreover, UGent-CERG is coordinating the start-up of the new Coastal & Ocean Basin (COB) and of the Blue Accelerator (BA) sea test site, which both have a focus on offshore renewable energy technologies and coastal and offshore structures.

The research within UGent-CERG focuses on wave-structure interaction, wave overtopping, offshore renewable energy, development of numerical models, experimental research in the laboratory and data analysis. UGent-CERG has supported a substantial number of fundamental research projects and PhD researchers on these topics, as these are core scientific topics for the group. The Research Foundation Flanders (FWO, https://www.fwo.be/) and the UGent Special Research Funds funded in 2021 nine PhD research projects and three post-doctoral Fellowships, carried out at UGent-CERG. All of these research topics focus on the numerical and experimental modelling of offshore moored floating energy devices and structures, and wave energy converter arrays/farms. Moreover, FWO (the Flemish Research Foundation) approved funding for developing and constructing WEC array scale models to be tested soon in the Coastal and Ocean Basin in Ostend.

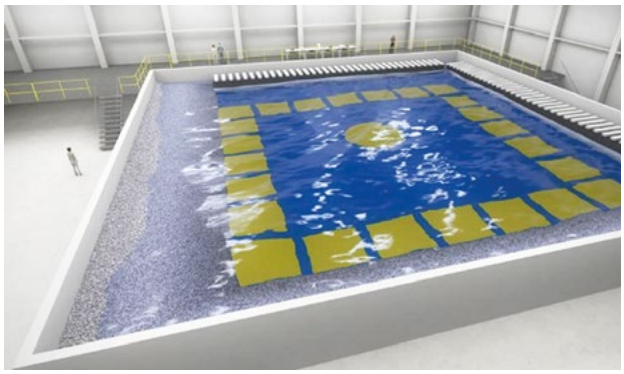
Coastal & Ocean Basin

The construction of the new Coastal and Ocean Basin (COB) (www.cob.ugent.be) in Ostend has been completed, and various systems (wavemaker, current generating system) are being installed. The facility is targeting the fields of renewable energy and coastal and offshore engineering and is co-funded by the Hercules Foundation, VLAIO (Flanders Innovation & Entrepreneurship) and the Flemish Ministry of Mobility and Public Works. The exploitation will be managed by Ghent University, KU Leuven and Flanders Hydraulics Research. The basin will be equipped with a unique combination of a narrow paddle wave generator in L-shape and a bidirectional current system, to achieve high quality short-crested waves at almost any relative angle with the current.

The COB is 30 m long by 30 m wide and has a variable water depth up to 1.4 m, allowing for test conditions from coastal to near offshore applications. A pit located in the middle of the basin allows experiments with mooring lines at a depth in excess of 4 m.

Ghent University is very active in the Blue Energy - Blue Growth - Blue Economy sectors, with the Coastal Engineering Research Group being specialized in Marine Renewable Energy, Marine Technology, and Coastal & Offshore Engineering. Ghent University recently presented the new COB facility through a new video available here:

https://www.offshore-energy.biz/presenting-the-new-coastal-ocean-basin-in-ostend/.



The Coastal & Ocean Basin, together with the new towing tank, forms the Flanders Maritime Laboratory, located at Ostend Science Park (Ostend, Belgium)

WECANet

The European COST Action CA17105 WECANet (www.wecanet.eu) is a network of 31 countries dedicated to Marine Renewable Energy, with a focus on Wave Energy. It is coordinated by the Coastal Engineering Research Group of Ghent University (UGent-CERG). WECANet is funded through the HORIZON2020 Framework Programme by COST (European Cooperation in Science and Technology, www.cost.eu), a funding agency for research and innovation networks. WECANet targets scientific excellence and inclusiveness by fostering training, networking and collaboration in Europe for wave energy. In 2021, WECANet has funded research collaborations through Short Term Scientific Missions, online international meetings, dissemination activities and scientific publications on wave energy. WECANet supports actively IEA-OES activities.

MARINERG-i

The Coastal Engineering Research Group of Ghent University (UGent-CERG) is a strategic partner in the H2020 MARINERG-i project coordinated by the MaREI Centre at University College of Cork Ireland, which brings together all the European countries with significant testing capabilities in offshore renewable energy. Ghent University is participating in MARINERG-i with marine energy technologies testing infrastructure which includes wave flumes and the new Coastal and Ocean Basin (www.cob.ugent.be).

The MARINERG-i - Offshore Renewable Energy Research Infrastructure, is setting out to become the leading internationally Distributed Research Infrastructure in the Offshore Renewable Energy (ORE) sector, with a network of test facilities spread across Europe. In June 2021 it was announced that MARINERG-i was from that moment onwards included in the ESFRI Roadmap as the new distributed infrastructure for dealing with Green Deal targets. ESFRI, the European Strategy Forum on Research Infrastructures, is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach.

ESFRI has established a European Roadmap for Research Infrastructures (new and major upgrades, pan-European interest) for the next 10-20 years, stimulates the implementation of these facilities, and updates the roadmap as needed. The ESFRI Roadmap arguably contains the best European science facilities based on a thorough evaluation and selection procedure. It combines ESFRI Projects, which are new Research Infrastructures in progress towards implementation, and ESFRI Landmarks successfully implemented Research Infrastructures enabling excellent science.

The new "Blue Accelerator" test platform

The Blue Accelerator project was recently introduced by the Flemish consortium of Ghent University (Coastal Engineering Research Group - UGent-CERG), the Public Provincial Economic Development Agency of West Flanders (POM West Vlaanderen), the Flanders Marine Institute (VLIZ), the Technical University Alliance for economic transformation in West Flanders (TUA West) and VITO NV. The Blue Accelerator project aims at providing a smooth development path for marine energy and maritime technology from early design stages to scaled models at the UGent wave flume and the Coastal & Ocean Basin (both managed by UGent-CERG), and to scaled prototype at the Blue Accelerator open sea test site. The Blue Accelerator is a maritime innovation and development platform and testing site for offshore blue economy research and industry projects. It is a versatile testing site, which allows to perform tests above, on, and underwater offering a broad range of services, e.g. marine sensors, fast and communications and transfer data system, energy supply in a secure and safe environment following the offshore industry standards and in-land storage space. POM West-Flanders holds a 15-year exploitation permit. The Blue Accelerator consortium is aiming at offering a grid connection by 2023 for offshore renewable energy projects.

The Blue Accelerator platform is located about 500 m off the port of Ostend. At this location, the average water depth is about 10 m and the tidal range 4 m. The testing zone is delimited by a circular area with a diameter of 440 m. The annual average significant wave height and the energy period, are 0.65 m and 4.9 s, respectively, with a wave power of 4.33 kW/m of wave-front (wave energy resource assessment from historically recorded data at 51.247°N, 2.928°E). A long-term statistical study has predicted extreme values up to 8.5 m of wave height when considering a return period of 100 years. Ocean currents between 0.15-0.9 m/s can be found at the Blue Accelerator testing site with values up to 1.87 m/s.

OWI-Lab

OWI-Lab (https://owi-lab.be/about-us) is the continuation of the R&D&I collaboration partnership between wind energy experts from Sirris, Vrije Universiteit Brussel and Ghent University within the IBN-Offshore Energy. The key pillars of the initiative

Location of the Blue Accelerator test site (right); The Blue Accelerator open sea test site at Ostend, Belgium (top).

are: (Test / Experiment) -Infrastructure, Expertise and the collaborative R&D&I Platform. Through technology expertise & infrastructure, innovation support services and international collaboration OWI-lab seeks to be a leading expertise centre that is supporting (international) innovation in the offshore energy sector. The R&D collaboration includes fundamental, applied and industry driven research & development and providing access to testing - and demonstration opportunities in real environments. OWI-lab provides access to unique and real-life test and demonstration infrastructure, operational insights and associated application knowledge to support R&D and innovation in our target group. This target group involves companies active in the onshore –and offshore wind energy business. The testing infrastructures and according expertise services are also available to international partners.

Power-Link

The energy knowledge platform Power-Link is a joint initiative of Ghent University and the Port of Ostend, founded in 2006 and located at Ostend Science Park in the inner port of Ostend. Power-Link plays an important role in the development of knowledge in the field of renewable and sustainable energy (RSE), bringing together energy expertise from all competent research groups at Ghent University and other (knowledge) institutions.

Power-Link actively meets a need by initiating, guiding and supporting scientific research on sustainable and renewable energy. Hence, Power-Link stimulates innovation in the renewable energy sector by introducing companies with research questions and researchers with valorisation demand to each other. Power-Link has a long track-record in cross-border project management and dissemination of this energy expertise and innovation in a structured way to a broad group of actors.

Power-Link is or has been involved in several projects (MET-CERTIFIED, ITEG, ENCORE, PhairywinD) with a focus on ocean and offshore energy. In the Interreg 2 Seas project ENCORE (https://www.energisingcoasts.eu), with a total project budget of 8.5 million euro, Power-Link is responsible for project communication and dissemination and for administrative coordination of UGent researchers. In close cooperation with project partners and other actors, Power-Link supports the development of e-learning courses for the offshore renewable energy sector and organizes dissemination and training events to transfer gained knowledge. In 2021, Power-Link and the ENCORE project cooperated with Marine@UGent for the organization of the Blue Science & Technology Summer Training and the public event Sea Your Future, where challenges for the offshore renewable energy sector were discussed.

ENCORE: Energising Coasts with Offshore Renewable Energy

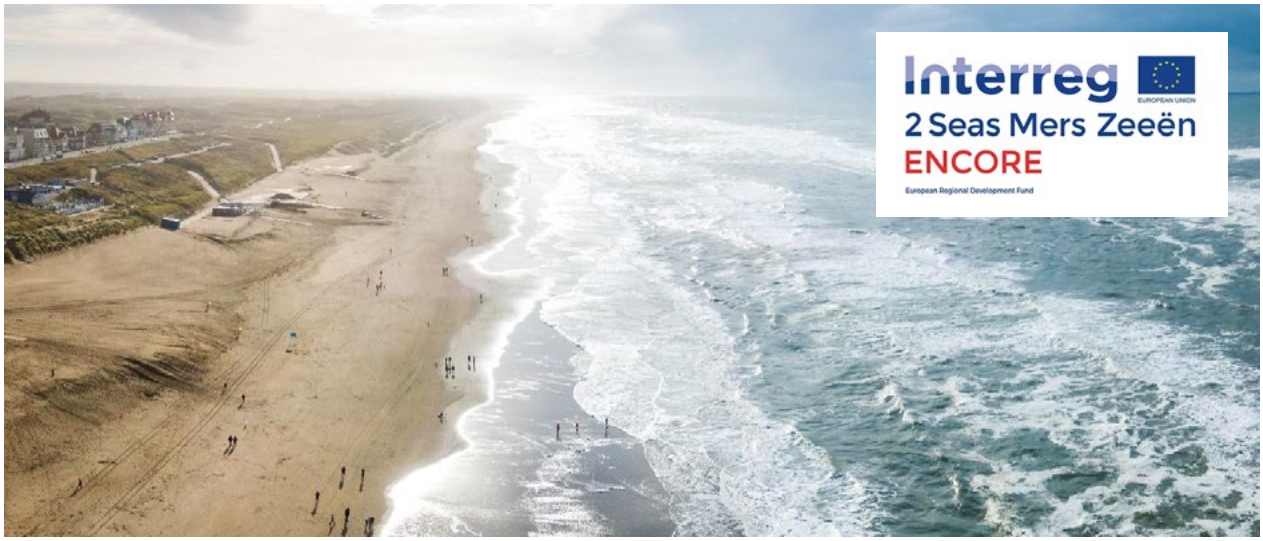
Through its Interreg 2 Seas Programme, Europe awards 5.9 million euro to the ENCORE project. The goal of the project is to advance the rapidly emerging ORE sector. With the ambition to become a global industry leader, the 2 Seas ORE sector needs support to successfully scale-up. ENCORE offers advanced technical and business support services to accelerate the ORE sector in the 2 Seas region. As part of the service portfolio, international certification schemes will be applied to reduce risks and increase investor confidence and to attract new capital to the sector. An education & training programme will be developed to train and prepare new young talent in the sector. In each country, regional impact campaigns will be set up to involve the supply chain and stakeholders in the project.

Services will be delivered to five next-generation ORE companies, covering new technologies; river current technology: Water2Energy (NL) and EEL Energy, offshore floating solar: Oceans of Energy (NL) and wave energy: Teamwork Technology (NL). To support the four ORE technologies, lead partner Dutch Marine Energy Centre (DMEC) brings together project partners from 4 European countries: the European Marine Energy Centre (UK), Artelia (FR), Bureau Veritas (FR), the Coastal Engineering Research Group (UGent-CERG) and Powerlink from Ghent University (BE), Inyanga (UK) and Deftiq (NL). From Belgium, Power-Link is responsible for project communication and dissemination and the UGent-CERG researchers are acting as service providers to the participating technology developers. In 2021, Power-Link and the ENCORE project cooperated with Marine@UGent for the organization of the Blue Science & Technology Summer Training and the public event Sea Your Future, where challenges for the offshore renewable energy sector were discussed.

More information at: www.energisingcoasts.eu.

BluERA - Blue Energy Resource Assessment (2020 – 2022)

The applied research within the BluERA project will improve understanding of the response of a number of different ocean energy technologies to the variability of the energy source. In addition, it will provide important risk assessment data that will help promoters and investors select potential technologies. The end results of BluERA are two online digital products, a digital ocean energy atlas and an energy yield evaluation tool. The project also provides for a demonstration and



verification of this atlas and the tool. Partners: IMDC, Laborelec and Otary RS NV. The Coastal Engineering Research Group (UGent-CERG) of Ghent University participates in the project as subcontractor.

CORDOBA (2021 – 2023)

This project is funded by the Blue Cluster (VLAIO). In the offshore energy sector, the aim is to achieve a cost-effective, holistic and sustainable design and operation of hybrid offshore connections (HOV) and offshore grids. A number of challenges still have to be overcome in this regard, such as the joint development and coordinated operation of HOV for the provision of network support services to multiple control areas. The partners within the CORDOBA project want to address these challenges in three main areas: by developing an optimisation model for the design of offshore networks, by developing a coordinated control model for HOV and by thoroughly examining the effect of system design on the network support services. Furthermore, an investment participation and remuneration model is being drawn up for HOV so that multiple investors can develop different parts of the hybrid offshore network at different times and earn back their investments in a reliable manner at the same time. Last but not least, the models are validated on two different test cases. The project has many payback effects for the Flemish economy, and an impact analysis by the partners has shown that a successful Cordoba project may trigger a growth in employment of around 26 FTEs and € 23 million in investments. Partners: Elicio, Marlinks, Yuso, Enersynt and KUL.

SMARAGD

The project "SMart Autonomous Reliable Aquatic Goods Drone" was initiated in April 2021 and will run until March 2023. The objective of the SMARAGD project is to create an autonomous vehicle in order to improve the efficiency and effectiveness of offshore maintenance activities and to provide a solution on an actual need for adequate support. The development of the SMARAGD will also lead to new developments and other usages such as monitoring works on the wind farm or on approach channels at sea, using build-in sensors. Partners: GEOxyz, MULTI.engineering, e-Bo Enterprises and ERPA Industrial Supplier.

OPIN

Sirris from Belgium is partner in OPIN (Ocean Power Innovation Network), an Interreg northwest Europe project from the European Research and Development Fund (ERDF). OPIN is a cross-sectoral collaborative network that aims to accelerate the growth of the ocean energy sector and its supply chains across the partner regions of Belgium, Ireland, the UK, France, the Netherlands and Germany.

NON-STOP

NON-STOP is an abbreviation for *New smart digital Operations Needed for a Sustainable Transition of Ports*, funded by the North Sea Region Programme (2014–2020). Belgian partners are: Port of Ostend, CRESCENT NV and Bluebridge. The project focuses on Small and Mediums sized Ports (SMP) within the North Sea Region, which have been working in a complex and rapidly changing world where society and businesses have experienced a digital transformation in numerous areas. The ultimate goal is to reduce the time of pre-defined logistical/maintenance port operations and lower port energy and pollution.

More information at:
https://northsearegion.eu/non-stop/about/

ITEG - Integrating Tidal Energy into the European Grid

ITEG, a €11 million Interreg North-West Europe project has been launched in Orkney to develop an all-in-one solution for the generation of clean predictable energy, grid management, and the production of hydrogen from excess capacity. Led by the European Marine Energy Centre (EMEC) in Orkney, Integrating Tidal Energy into the European Grid (ITEG) project brings together partners from across the UK, France, Belgium and the Netherlands to address energy-related carbon emissions in North-West Europe and tackle grid export limitations faced in remote areas such as Orkney. Power-Link from UGent had a role in communication and dissemination.

ELBEPlus project

ELBEPlus project Seven European clusters, including The Blue Cluster, join forces to shape a pan-European blue energy cluster with global ambitions. The focus is on wave energy, tidal energy and offshore wind energy, both fixed and floating. In addition, an analysis is carried out of the challenges for marine energy technologies, new value chains and opportunities for companies, also for companies that are not necessarily involved in this sector. This project is supported by the EU COSME programme.

More information at:
https://www.blauwecluster.be/project/elbe-plus-european-leaders-blue-energy

Soiltwin

Today we see an industry-wide mismatch between design expectations and the as built dynamics related to monopile foundations. This mismatch results in a sub-optimal (fatigue) design and ultimately a higher cost for offshore energy. It is the general consensus of both academia and industry that this is due to errors in the interaction between the monopile and the surrounding soil. Current soil-structure interaction models are not "tuned" to correctly assess the soil stiffness at small displacements for short and large diameter piles, i.e. monopiles. This project, a collaboration between Ghent University (UGent-CERG) and the Vrije Universiteit Brussel, therefore aims to calibrate those models by updating them based on Finite element analysis and lab-experiments at the Coastal and Ocean Basin (COB) and on-site measurements.

More information at: https://owi-lab.be/soiltwin

EnerGhentIC

EnerGhentIC is the interdisciplinary community of Ghent University researchers (38 professors, 210 FTE researchers, 5 faculties) working on the energy challenge. EnerGhentIC focuses on three main activities: (1) to stimulate research and valorisation in amongst other offshore wind, wave & tidal energy, (2) provide education and training for both professionals as well as master and Phd students and (3) to support and stimulate the energy transition. In this regard, EnerGhentIC engineered several strategic alliances, research collaborations and licensing deals with industrial partners for example IBN-Offshore Energy, Belgian Offshore Platform, OWI-LAB. Within specific projects, EnerGhentIC functions as the liaison between industrial and academic partners and as valorization manager during and after the project.

BlueBridge

BlueBridge (former GreenBridge) is an incubator/ innovation centre focused on blue growth located in West Flanders. Bluebridge is located in the high-tech knowledge hub Ostend Science Park (OSP) in the inner port of Ostend, covering marine and maritime topics. The R&D component is being represented at site through the expertise of Ghent University: the research groups StressChron and representatives of two consortia: Marine@UGent and EnerGhentIC. Their expertise encompasses stress physiology of fish, aquaculture, blue biotech, coastal defence and blue energy amongst many. A strong emphasis lies on industrial applications of the research and commercialization of fundamental research results.

More information at:
https://ostendsciencepark.be/bluebridge/bluebridge/

TECHNOLOGY DEMONSTRATION

PLANNED DEPLOYMENTS

In 2021 the renewed Blue Accelerator, a test platform operated by the Regional Development Agency West-Flanders in front of the port of Ostend was inaugurated. The Blue Accelerator consists of a monopile with a powerhouse on top, and a surrounding seabed test area of 220 m around the platform.

More information at:
https://www.blueaccelerator.be/

Tests planned in 2022 include two floating PV installations and an offshore mussel cultivation pilot.

RELEVANT NATIONAL EVENTS

2021

- **September 2021:** The Blue Growth Summer School organised by Ghent University and the WECANet COST Action CA17105
  https://www.marineatugent.be/blue-science-technology-summer-training
- **17-18 March 2020:** Belgian Offshore Days – Virtual conference on data driven innovation – organisation Belgian Offshore Cluster in collaboration with the Blue Cluster and the Inn2POWER partners

Planned in 2022

- **September 2022:** The Blue Growth Summer School organised by Ghent University and the WECANet COST Action CA17105
  http://www.bluegrowth.ugent.be/summerschool/
- **September 2022:** General Assembly of the WECANet COST Action CA17105 organised by UGent-CERG
  https://www.wecanet.eu/
- **September 2022:** ENCORE final conference organised by UGent-CERG and Power-Link
  www.energisingcoasts.eu
- **23-24 March 2022:** Belgian Offshore Days fair and conference

3.3
CANADA

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OVERVIEW

2021 was an important year in Canada for working towards future deployments and enabling R&D. Tidal energy developers active in Nova Scotia's Bay of Fundy achieved some significant milestones in manufacturing and fabrication of devices, environmental monitoring plans and technologies, and permitting. The sector is poised to see deployments moving forward in 2022. Canada's R&D and innovation ecosystem continued to provide important and essential enabling research and studies to support the growth of the sector.

The Government of Canada launched several important initiatives that will have implications for the future of the marine renewable energy sector including a consultation on the development of a national Blue Economy Strategy and further development of offshore renewable energy regulations that will govern activity on the federal seabed.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Government of Canada

In February 2021, the Government of Canada launched its consultation to develop a Blue Economy Strategy. Canada's vision for a sustainable blue economy supports the growth of ocean sectors through innovation. It provides good jobs and is inclusive, advances reconciliation with Indigenous peoples, respects regional differences and needs, and contributes to a clean and healthy ocean. Consultation included a focus on "ocean-based energy", recognizing that to take full advantage of oceans-based energy opportunities will require collaboration from all levels of government, as well as significant private sector investments to encourage investor funding, demonstrate projects, and enable commercialization.

The Government of Canada also continued efforts to develop its offshore renewable energy regulations through the Offshore Renewable Energy Regulations (ORER) Initiative. The ORER initiative aims to develop safety and environmental protection regulations that will apply to exploration, construction, operation and decommissioning activities related to renewable energy projects and power lines in Canada's offshore areas. The ORER will be developed under the Canadian Energy Regulator Act which came into force in August 2019.

This legislation enables the Canada Energy Regulator to review and authorize activities related to offshore renewable energy in Canada's offshore areas. These activities could include:

- Site characterization activities, such as, resource surveys, geoscience and geotechnical studies, and environmental surveys; and,
- Construction, certification, operation, maintenance and decommissioning of offshore renewable energy facilities and offshore power lines.

These regulations will not apply to tidal energy projects in Canada's Bay of Fundy, as these tidal projects fall primarily under the jurisdiction of the provincial government of Nova Scotia.

Phase Two of engagement on the ORER was initiated in late 2021 and focused on soliciting feedback on the technical requirements and proposed structure of the regulations.

MARKET INCENTIVES

Nova Scotia continues to be the sole province in Canada offering a targeted market incentive for marine renewable energy. Under Nova Scotia's Marine Renewable Energy Act, projects that receive a permit can also receive a power purchase agreement (PPA) of up to 15 years. Any utility in Nova Scotia is required to procure all electricity under the PPA.

Three projects at FORCE have approvals for Nova Scotia's feed-in tariff (FIT) for 53 cents/kilowatt hour which also allows them to enter into a 15-year power purchase agreement with Nova Scotia Power, the provincial electric utility: 1) DP Energy's Uisce Tapa Project; 2) Sustainable Marine's Pempa'q Project; and 3) Big Moon Power.

Projects in other areas of Nova Scotia and the Bay of Fundy have received an energy rate under Nova Scotia's demonstration permit program including NewEast Energy, Nova Innovation, and Jupiter Hydro who received approvals under Nova Scotia's permit program in 2018-2020.

PUBLIC FUNDING PROGRAMMES

Under its climate action plan, *"A Healthy Environment and a Healthy Economy,"* the Government of Canada launched the Smart Renewables and Electrification Pathways Program (SREPs) – a program providing up to $964 million over four years (from April 2021 to April 2025) for smart renewable energy and electrical grid modernization projects. This program is targeted at significantly reducing greenhouse gas emissions by encouraging the replacement of fossil-fuel generated electricity with renewables that can provide essential grid services while supporting Canada's equitable transition to an electrified economy. Marine renewable projects are eligible for this program, and registrations and applications are currently open. For further information, you can visit the website at

https://www.nrcan.gc.ca/climate-change-adapting-impacts-and-reducing-emissions/green-infrastructure-programs/smart-renewables-and-electrification-pathways-program/23566

SREPs supports marine renewable energy projects under an "Emerging Technologies" program stream. Projects must have a 4 MW capacity or greater. If the project is Indigenous-owned the minimize size requirement is 500 kW. Up to 30% of project costs can be covered under SREPs to a maximum of $50 million.

One of the five-Waterotor turbines manufactured this summer and installed at the CHTTC. A 3-turbine array will be operating coming winter at the CHTTC.

RESEARCH & DEVELOPMENT

Canadian Hydrokinetic Turbine Test Centre (CHTTC)

CHTTC has been working on several initiatives to help support the progression of community-scale marine renewable energy projects in Canada. R&D activities led by CHTTC have included:

- Deployment of five Waterotor turbines and assisted with the design, manufacture, and installation of a Waterotor micro-grid system to power an electric boat for the Canadian Navy.
- Assisted with the design and build part of a 5-kW BMT microgrid system at the CHTTC that integrates the BMT machine interface unit, a repurposed Nissan-battery pack, gasoline generator, 5-kW New Energy turbine, and solar PV panels. Testing of the BMT controller was performed at the CHTTC.
- Assisted with the design and build of a 500-kW BMT microgrid system to be installed in Grand Passage, Nova Scotia that integrates the BMT machine interface unit, a three-phase battery, diesel, Sustainable Marine PLAT-I platform, and solar PV panels. Testing of the BMT controller was performed at the CHTTC to commission the BMT interface before shipping to Grand Passage.
- Installed a SmartHydro turbine in Sagkeeng First Nation.
- Conducted flow measurement on Cochrane River, Manitoba, Garden Hills First Nation, and Baffin Islands.
- Supplied NRCan data to validate a novel satellite method to identify open areas in rivers that do not freeze in winter.

Fundy Ocean Research Center for Energy (FORCE)

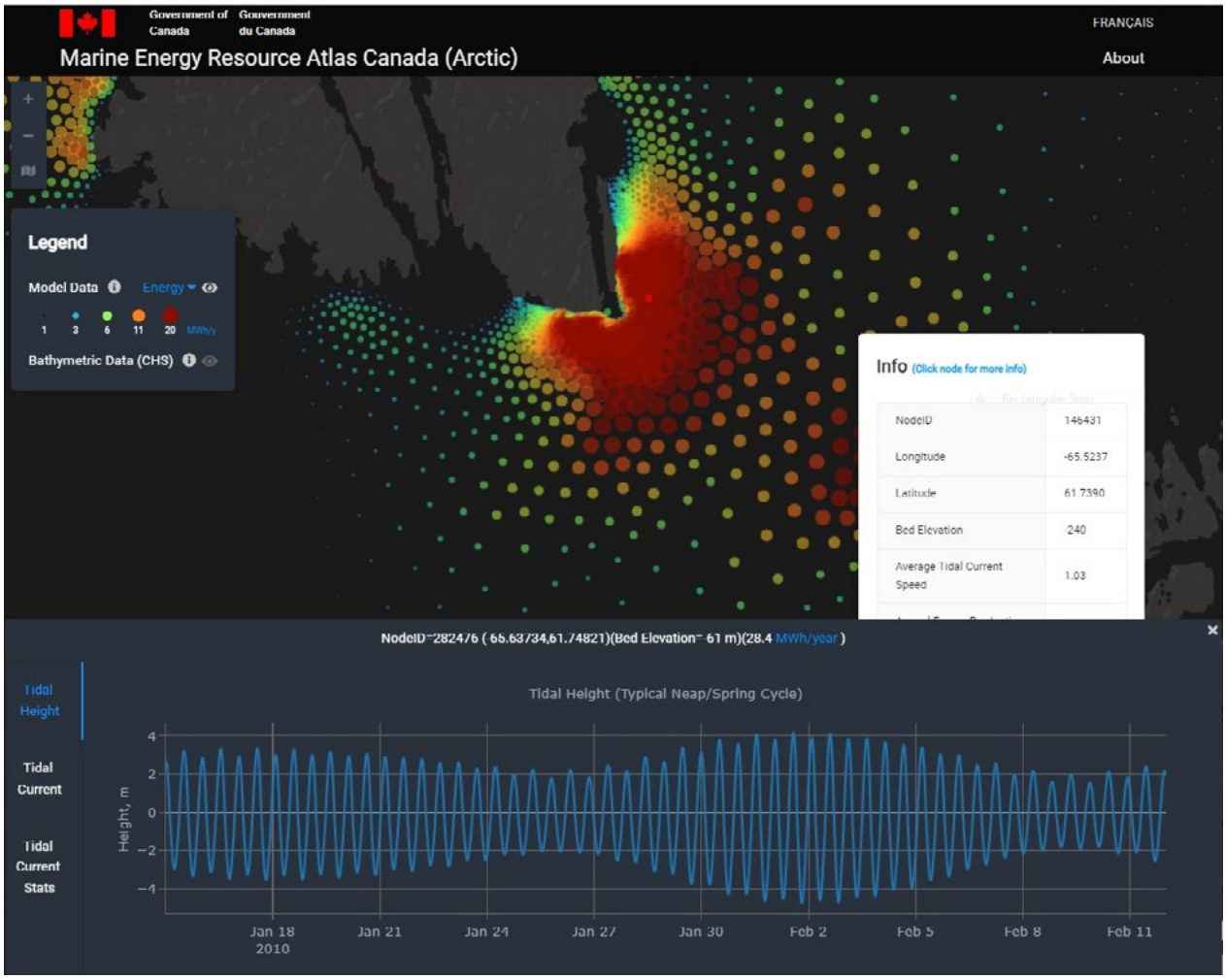
FORCE is Canada's primary centre for the demonstration of in-stream tidal energy technologies and continues to lead various research and initiatives to gather knowledge about tidal energy and support technology and project demonstration.

- In 2021, FORCE, Mi'kmaw Conservation Group, and the Ocean Tracking Network began building the largest fish data set ever collected in the Bay of Fundy, as part of a research program to reduce uncertainty around potential marine life impacts.
- FORCE also worked with the Fishermen & Scientists Research Society and a local fisher to complete a baseline lobster study to assess catchability in Minas Passage.
- Tidal energy projects led by Sustainable Marine, BigMoon Power, and DP Energy also continued to advance, achieving key project development milestones.

National Research Council (NRC)

The National Research Council Canada (NRC) has developed a Marine Energy Resources Atlas Canada (MERACAN) application to map, retrieve and view marine renewable energy resource data stored online. The graphical interface of the application makes for an easy, efficient way for researchers, students, and stakeholders, as well as developers of marine energy projects, to access or analyze marine resource data, which is both temporally and spatially resolved - this avoids specialized tools that would otherwise be needed to query and visualize. The data is stored and delivered using Amazon Web Service (AWS) technologies. An Application Programming Interface (API) using AWS Lambda is part of the toolset needed to facilitate querying the data, and includes scripts to download the specific spatial and temporal marine datasets stored on AWS S3 onto the Atlas. The Atlas app can then run data processing algorithms in JavaScript to generate plots for different marine energy statistics. The application is hosted at (https://arctic.meracan.ca). NRC is planning to incorporate new datasets and tool functionalities to the Atlas app and will continue to collaborate with the University of Victoria, University of Ottawa, University of Dalhousie, University of Laval, Polar Knowledge Canada, and Natural Resources Canada.

CPOD deployment in the Minas Passage as part of FORCE's marine mammal monitoring program.



Marine Energy Resources Atlas Canada (Arctic) application showing tidal flows and hydrokinetic energy near communities in northern Canada.

Natural Resources Canada – CanmetENERGY-Ottawa

NRCan/CanmetENERGY-Ottawa (CE-O) is continuing collaborative research projects in advancing river hydrokinetic energy with National Research Council (NRC), academia, industry and CHTTC. Demonstration of tidal and river hydrokinetic energy systems (RHE) will support technology and project developers to demonstrate tidal energy and RHE systems, resulting in two to five systems deployed by 2025.

A pre-feasibility level study of a potential RHE project in a community in the Northwest Territories (NWT) was carried out to assess the techno-economic feasibility of deploying RHE turbines based on the community demand. A high-level installation plan was developed with the potential turbine deployment locations, the number of turbines in an array layout, and the path of transmission lines to the nearest interconnection point, as well as an overview of the turbine technologies suitable for the site. A high-level project lifecycle cost analysis including the levelized cost of energy (LCOE) analysis was also performed for leading technologies showing that the RHE is competitive with the current cost of diesel-generated electricity.

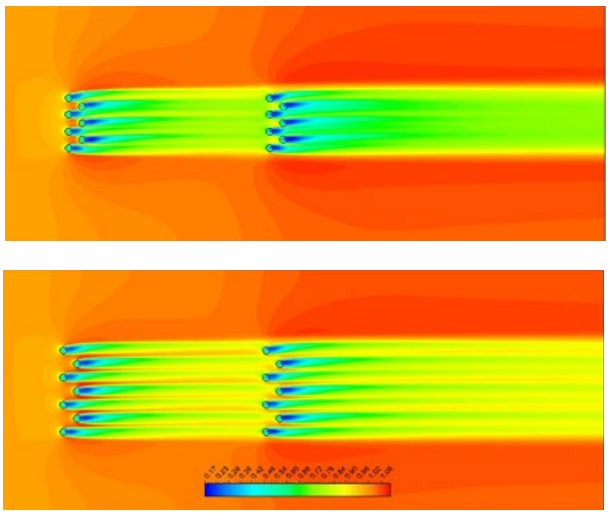
Preliminary site layout with 2 rows of 4 turbines (rated at 50kW with a flow velocity of 3m/s)

CE-O has initiated a feasibility level tidal energy project to assess the resource, electrical load, and energy production for establishing a potential demonstration

electricity into a micro-grid with other renewables and energy storage.

In order to effectively model RHE turbines in arrays, simplified models of an RHE turbine have been developed and implemented in various CFD packages, and numerically validated with high-resolution full CFD simulations in collaboration with Laval University and NRC. Based on the simplified models, preliminary RHE turbine array guidelines have been developed for deploying RHE turbines in rivers and channels with low and high blockage ratios and in various layouts including online, tandem and staggered configurations. Validations of the numerical models through field-testing is planned.

CE-O initiated a project to develop a methodology to identify and locate river hydrokinetic resources with significant RHE potential along river stretches through the optical and RADARSAT Constellation Mission (RCM) satellite image processing. Hydrokinetic Resource Assessment using SAR Satellites (HyRASS) methodology has been developed in collaboration with the University of Manitoba and NRCan's Canada Centre for Remote Sensing. Based on HyRASS methodology, a database of attractive river hydrokinetic sites is being created enabling project developers to better identify, plan and implement river hydrokinetic projects in Canada.



Normalized streamwise velocity contours showing turbines wakes on the mid-span horizontal plane for a fixed inter-row spacing and two different lateral inter-turbine spacing

Offshore Energy Research Association (OERA)

The Offshore Energy Research Association (OERA) continued to make progress with the Pathway Program over the course of 2021. The Pathway Program is a $2 million collaborative environmental effects monitoring research program aimed at reducing regulatory uncertainty and compliance costs for tidal energy projects. This project is supported by the Government of Canada and the Province of Nova Scotia. In 2021, a software tool that uses machine learning algorithms to analyze post-processed hydroacoustic data collected by echo sounders was developed as part of the project. The tool can be used to analyze echosounder data collected near instream tidal turbines and to automatically populate tables and figures that can demonstrate frequency, abundance, and distribution of fish in a standardized format to regulators. The Pathway Program's subsea monitoring platform was also successfully redeployed at the Minas Passage testing site. The various sensors on the platform – including imaging sonar and echosounder devices – will be used to collect data that will be sent to shore through the subsea cable and monitored in real-time.

Sustainable Oceans Applied Research (SOAR)

Sustainable Oceans Applied Research (SOAR) focused on advancing methods for working with remote Indigenous communities to conduct tidal energy site assessments and developing effective methods for evaluating interactions between tidal devices and marine animals. This work was supported by Natural Resources Canada's (NRCan) Clean Growth project (in partnership with the CHTTC) and the Pathway Program (supported by NRCan and led by OERA).

SOAR's research with remote Indigenous communities was conducted on the Pacific coast of Canada in collaboration with the University of Victoria, Northern Labrador in collaboration with the Nunatsiavut Government, and Nunavut in collaboration with Ocean Renewable Power Company (ORPC). SOAR's primary focus has been on providing cost-effective, reliable, and user-friendly tools for oceanographic data collection to local knowledge holders for direct participation in site assessment as needed to evaluate resources and inform Community Energy Plans at diesel reliant communities.

Research on environmental monitoring led by SOAR focused on the use of multibeam imaging sonars and has demonstrated the Tritech Gemini to be effective for target detection and tracking in the Grand Passage and Minas Passage (FORCE site) environments. Experiments have been conducted with artificial (controlled) targets, as well as data collection around several species of marine animals including white sharks, humpback whales, dolphins, mackerel, herring, mola mola, and cod. Ongoing work is focused on the automation of target detections in collaboration with MarineSitu and North Highland College.

University of Victoria (UVic)

The University of Victoria (UVic) made progress leading several projects and initiatives focused on wave energy and clean energy for remote community development working with local suppliers, industry, researchers, and Indigenous communities. UVic continues to lead this work through its established Pacific Regional Institute for Marine Energy Discovery (PRIMED), which is aimed at eliminating the uncertainty and risk for "first-of-a-kind" community-based marine renewable energy projects.

Key projects and activities over 2021 included:

- Progress on FEED study to examine the feasibility of wave energy devices to power Yuquot and facilitate Mowachaht Muchalaht First Nations (MMFN) desire for a community resurgence.
- Tidal energy resource assessment and electricity demand side analysis for potential future Blind Channel Tidal Test Centre.
- Building and testing of a standardized smart grid integration solution for marine renewable energy generators.
- Testing and validation of a novel Floating Light Detection and Ranging platform for collecting wind, atmospheric data, and current speeds.

Deployment of one of two wave buoys near the Yuquot site in British Columbia

Sustainable Marine's PLAT-I 6.43 in Grand Passage, Nova Scotia

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Sustainable Marine

As part of its project at FORCE, Sustainable Marine launched its second-generation platform, the PLAT-I 6.43, in Grand Passage, Nova Scotia. The platform features a 50% increase in power output over the first-generation prototype. Construction of a substation for Sustainable Marine's Grand Passage site was completed and its Supervisory Control & Data Acquisition System was also installed. This will enable all aspects of the system (both onshore and offshore) to be tested prior to deployment at the FORCE site.

PLANNED DEPLOYMENTS

Big Moon Power

Big Moon Power announced that it had begun assembly of its first device – one of its eighteen devices planned to be deployed at FORCE. Each will generate roughly 500 kW of electricity.

DP Energy

DP Energy developed a monitoring platform to demonstrate an environmental monitoring platform as a part of OERA's Pathway Program. The platform was designed and underwent harbour testing during 2020. It was further tested and deployed at the FORCE site in 2021. Sensor characterization work continues and will carry into early 2022. In August 2021, DP Energy signed a Joint Development Agreement with Chubu and K-Line to bring Phase 1 of the 9 MW Uisce Tapa project through the final stages of initial planning. The project has completed final site characterization and final engineering activities are expected to complete in the first half of 2022. Permitting activities are ongoing. The project plans turbine installation in the fall of 2023.

Jupiter Hydro

Jupiter Hydro has continued planning for the development of its project in the Bay of Fundy which is in two phases: the testing of a non-grid connected 1 MW prototype and the other for 2 MW demonstration.

NewEast Energy

NewEast Energy has been working towards the deployment of its 800 kW project in the Bay of Fundy's Minas Passage. Four of New Energy's EnviroGenTM Power generators will be installed as part of a floating grid-connected array.

Nova Innovation

Nova Innovation continued the development of its 1.5 MW tidal energy project in Petit Passage, Nova Scotia. The "Nova Tidal Array" will be developed in three separate 500 kW phases, allowing any environmental effects to be carefully monitored and managed. Nova received authorization from the Department of Fisheries and Oceans Canada (DFO) for Phase 1 of the project which will see five 100 kW in-stream tidal turbines installed, beginning with a single turbine. In early 2022, Nova plans to install a Remote Observation Platform (ROP) and instruments for monitoring in advance of first turbine deployment.

Ocean Renewable Power Company (ORPC) Canada

ORPC Canada has been working with the Canadian Hydrokinetic Turbine Test Centre (CHTTC) to plan the deployment of an ORPC RivGen® power system. In September 2021, ORPC Canada and Canadian engineering firm CIMA+ were honored with the Association of Consulting Engineers Quebec International Project Award for their collaborative work with the Indigenous community of Igiugig, Alaska, on a marine energy project which features ORPC's RivGen power system, the longest operating marine energy device in all of the Americas. In August 2021, ORPC Canada conducted field work including site resource assessments in Nunavut.

Sustainable Marine

Sustainable Marine continues to work towards the development of its 9MW Pempa'q project at FORCE. As part of this project, the construction of the first PLAT-I 6.43 platform was completed and launched in Grand Passage for testing and conditioning before it is deployed at FORCE. Sustainable Marine has also been developing an advanced environmental monitoring system, completed the manufacture of the first rock anchors that will be used to secure the PLAT-I 6.43 at the FORCE site, and commissioned the construction of the Tidal Pioneer, an advanced inshore construction vessel that will perform complex tasks safely in the high-flow project site.

Waterotor Energy Technologies (Waterotor)

Waterotor deployed 5 kW and 4 x 1 kW systems at the CHTTC in summer and fall. The systems will endure long life testing through ice conditions and through all seasons on the Winnipeg River near Seven Sister Falls, Manitoba. The Waterotor technology is designed to operate for up to 20 years and will collect data while being demonstrated at CHTTC.

Yourbrook Energy Systems (Yourbrook)

Yourbrook Energy Systems, a British Columbia based tidal energy technology developer, continues to work on its 500 kW Kamdis Tidal Power Demonstration Project in Masset Inlet, Haida Gwaii. Yourbrook gathered data at the site over the course of four months and worked towards refining technical aspects of the project including modelling of dynamic blades and platform design for testing and third-party validation.

RELEVANT NATIONAL EVENTS

- **Marine Renewables Canada 2022 Annual Conference** - November 22-24, 2022 Halifax, Nova Scotia

3.4 CHINA

AUTHORS
Peng Wei, National Ocean Technology Center

OVERVIEW

China attaches great importance to tackling climate change. In order to achieve the goal of "carbon peak and carbon neutral", China released and implemented a series of plans and measures to support the development of renewable energy, including ocean energy. China will actively promote the large-scale utilization of ocean energy and demonstration projects for wave energy and tidal current energy.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

In 2021, China has implemented a series of climate change strategies, measures and actions to support the development of renewable energy, including ocean energy, and will release implementation plans and supporting measures in relevant sectors and industries in the next stage, with a view to building a "1+N" policy system of carbon peak and carbon neutral.

In 2021, promoting the large-scale development of ocean energy has been set out in the 'The Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035'.

MARKET INCENTIVES

In 2021, China issued some policies and measures to promote the development of renewable energy industries such as wind power and photovoltaic power in terms of preferential loan, green power certificates and feed-in tariffs, providing a reference basis for further research and development of ocean energy industry policies.

PUBLIC FUNDING PROGRAMMES

In order to promote renewable energy technological innovation and development, the Ministry of Science and Technology (MOST) released the National Key Research and Development Program (NKRDP) of 'Renewable Energy and Hydrogen Energy Technology' to support research on the efficient conversion mechanism, key technologies and equipment of ocean energy. The application of projects was started in 2018.

RESEARCH & DEVELOPMENT

In the field of fundamental research of ocean energy, the research team led by Ocean University of China is researching on the efficient conversion mechanism of tidal range, tidal current and wave energy. In OTEC technology research, the Southeast University is conducting research on key techniques of OTEC. The project group organized by CSG is carrying out research on MWs wave energy conversion, the design and model test of the 1 MW WEC have been completed.

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Wanshan 1 MW (2×500 kW) Wave Energy Demonstration Project

The demonstration project is carried out jointly by GIEC, China Southern Power Grid, China Merchants Heavy Industry Co. and other units. The first 500 kW WEC “Zhoushan”has completed its first round of open sea testing, and is undergoing maintenance. The second 500 kW WEC“Changshan” has been completed and deployed to sea trial near Wanshan Island in April 2021.

"Zhoushan" under maintenance

Wave Energy Aquaculture Cage “Penghu”

In June 2019, the first semi-submersible aquaculture platform Penghu was deployed to sea trail. To date, Penghu has completed 28 months of demonstration operation in the aquaculture base of Zhuhai city, successfully completed multi-season breeding of various species such as golden pomfret and grouper, and achieved good demonstration effect and economic benefits. The Penghu semi-submersible aquaculture platform has provided a new form of offshore aquaculture supported by green energy. GIEC has completed the design of several models to meet different user needs and signed some commercial orders for the platform.

"Changshan" in transit

LHD Tidal Current Energy Demonstration Project

The continuous operation time of the LHD tidal current energy demonstration project has exceeded 50 months until December 2021.

LHD demonstration project in operation

PLANNED DEPLOYMENTS

LHD Tidal Current Energy Demonstration Project

The project plans to build the #2 platform and a MWs new turbine near its #1 platform. In 2021, the #2 platform has been installed, the main structure of the MWs new turbine has been completed and will be deployed in 2022.

Platform being installed

3.5
DENMARK

AUTHORS
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OVERVIEW

Wave energy in Denmark is funded mainly through the funding programme EUDP, which is a part of the Danish Energy Agency. In Denmark, there are eight active Wave Energy projects between TRL 3-6. The developers are united in the Danish Partnership for Wave Energy – and propose a new strategy for the development of wave power in Denmark. A small delegation presented the perspectives of combining wave energy with offshore wind energy at the energy islands in the North Sea to the Danish Parliament in November 2021. In addition, perspectives were presented on Wave Power to become a part of the renewable energy mix from the North Sea in 2030.

Crestwing has during 2021 worked on the further development of their hinged raft based on results from half-scale testing in Kattegat with an installed power of about 20 kW. Lots of effort has also been invested in seeking funding to support this development and demonstration opportunity.

Wavepiston is testing at the test site PLOCAN at Gran Canaria where several power modules will pump seawater to the Plocan platform for further processing. Initial testing had been carried out at the Danish test site DanWEC during 2017 – 2019.

EXOWAVE is based on the principle of the bottom-mounted oscillating wave surge converter. In 2021, the prototype has been designed and built and is being deployed offshore in Q2 2022, at DanWEC.

Floating Power Plant is combining wave and wind power on a common floating platform and is involved in several development tracks including Power-to-X. The small start-up company has now fifteen employees and targets a prototype installation at PLOCAN in Gran Canaria.

Resen Waves continues work on entering the commercial market providing small-scale Smart Power Buoys for autonomous power, i.e. for tsunami warning systems and data communication.

WaveDragon is an overtopping WEC technology ready for prototype testing at a larger scale. In 2021, WaveDragon has been focusing on finding the funding to support development and demonstration.

KNSwing is a floating ship-shaped WEC with multiple Oscillating Water Columns and in 2021, it has been further optimised and developed with support from the Marine Energy Alliance (MEA) project.

WaveStar completed a half-scale test at the Danish test site DanWEC in 2013, where performance and availability data were collected. WaveStar is ready to build and test a full-scale 6 MW converter.

Aalborg University and the Danish test site **DanWEC** are both engaged in the Ocean Energy Scale-Up Alliance (OESA) project and developing new activities to broaden the spectrum of clients that can benefit from testing in relation to the extended Port of Hanstholm.

DTU is involved in numerical modelling under OES Task 10 but is also supporting several of the Danish WEC system with development of numerical tools.

Picture of the Hanstholm harbour and the location of the DanWEC test site

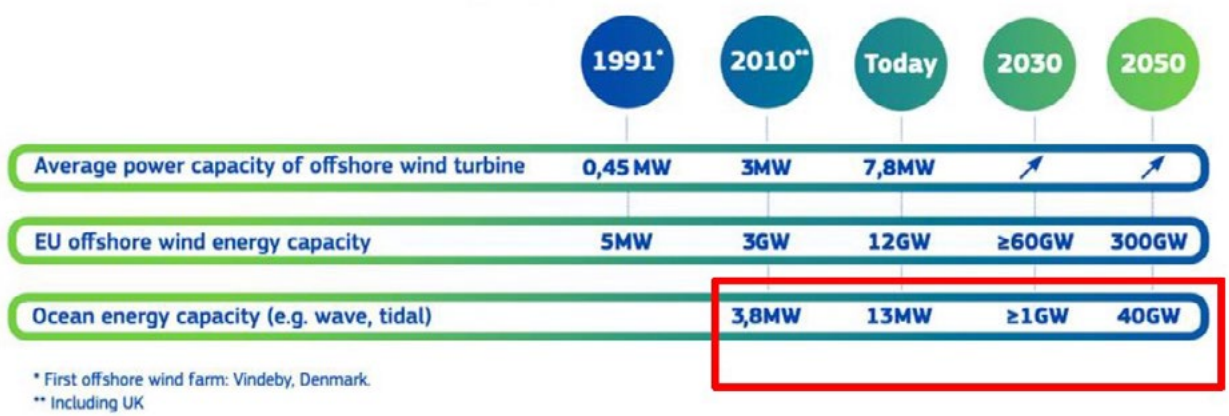
SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Denmark has no national strategy on wave energy. Supported by EUDP and *Energinet.DK* a strategy for the development of wave power through industrial partnerships was presented in 2012 followed by Roadmaps in 2015.

Similar to concrete targets for deployment established in Canada, China, France, Ireland, Italy, Portugal, South Korea, Spain, the UK and in particular the EU policy, the **Wave Power Partnership** sets out three ways of promotion of wave energy in Denmark. The perspectives from the Wave Power Partnership are as follows:

- **SET A POLITICAL GOAL** that 4 GW of wave energy should be included in the Danish energy mix by 2050, corresponding to 10% of the pan-European objective in the EU.
- **ACCELERATE** the development of wave energy by integrating demonstration and development projects in the future energy islands as well as other offshore projects in Danish waters.
- **EAR-TAG SUPPORT** for the development of wave energy and support the development of the Danish wave energy sector through education and research, proactive export policy as well as business promotion through, for example, the State's green investment funds and co-ownership.

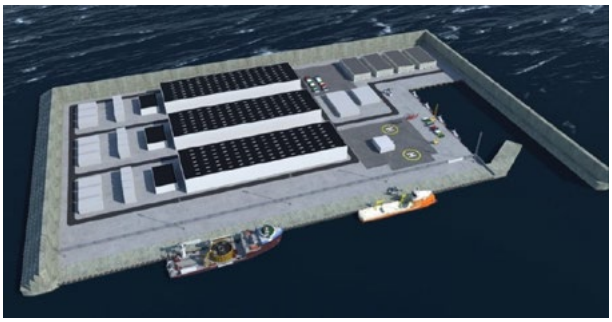


Targets for the deployment of offshore wind and Ocean Energy set by the EU 2020

MARKET INCENTIVES

Earmarked pools for the development of wind energy have been a great success. In a similar way, significant amounts of earmarked funding for wave energy under the State's Green Development and Demonstration Programmes such as (EUDP) can facilitate the development to avoid competition with well-established technologies for the same money. Although for now, this is not in the pipeline.

The North Sea has been identified as a strategic hot spot for offshore technology development in the EU Commission's offshore strategy. The future Energy Islands in Denmark provides a unique opportunity to integrate Wave Energy into the innovation environment around the islands for research, development and testing of wave energy solutions; in combination with future offshore wind farms and Power2X technologies.



Artist impression of the future energy island in the North Sea

Denmark can make use of the infrastructure and the knowledge, from wind energy and test the combination of wind + wave, which will be around the energy islands and thereby strengthen Danish competitiveness in offshore energy.

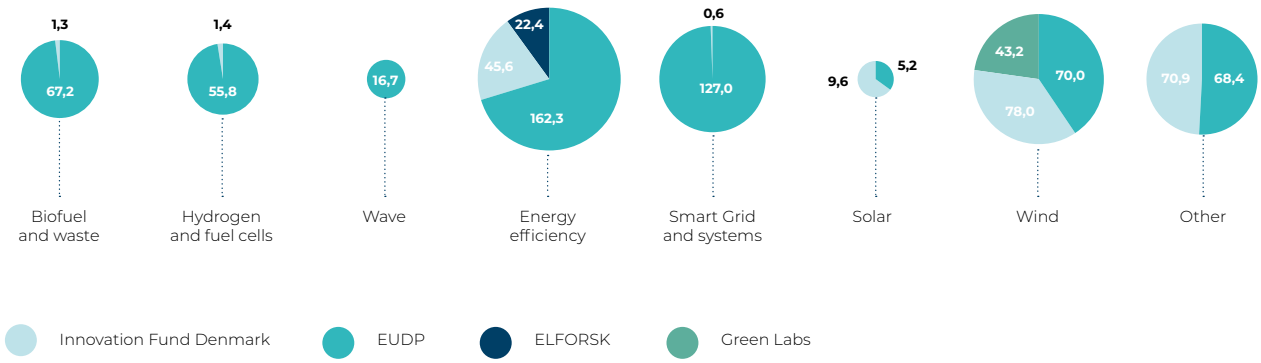
PUBLIC FUNDING PROGRAMMES

There are three national funding programmes that supports ocean energy, including:

- Energy Technology Development and Demonstration Program – EUDP
- Innovation Fund Denmark
- ELFORSK

Each of these funding programmes supports a wide range of renewable and clean energy activities, and therefore ocean energy initiatives and proposals are competing with other technologies as for example wind energy for funding. Wind Energy is big in Denmark and even after more than 40 years of development, it still requires a large amount of funding for further development. Figure shows that wave energy was granted almost 17 million DKK (2.5 M€) from EUDP alone in 2020.

Research and development initiatives and proposals within ocean energy are mainly supported by EUDP and private companies. Examples of projects supported are given in the next section.



The category "Other" includes: sustainable transport projects, geothermal energy, administrative and social analyses.

Grants from EUDP, Innovation Fund Denmark and ELFORSK in 2020.

RESEARCH & DEVELOPMENT

Aalborg University (AAU) is engaged in the measurement and analysis of the waves at the DanWEC test site close to Hanstholm. AAU is involved in the IEC TC 164 standardization effort, and partner in several European projects such as *LIFTWEC, OESA, VALID*. AAU is also performing a 'proof-of-concept' analysis/ testing of new concepts. In 2021, AAU was contacted by four inventors, of which two new ideas were tested in the laboratory.

Tank testing of existing WEC concepts (FFP, NEMOS, EXOWave) has also been conducted at AAU during 2021– as well as dedicated experiments for comparison with numerical models, OES task 10.

The **Danish Technical University DTU** department of Mechanics is supporting several Danish developers with the development of numerical models such as KNSwing, WavePiston and Resen Energy. Furthermore, DTU is a partner in the OES Task 10 project, coordinating the latest test case of the fixed wave energy device of the Oscillating Water Column (OWC) type.

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Wavepiston is testing at the test site PLOCAN at Gran Canaria where several power modules will pump seawater to the Plocan platform for further processing. Initial testing has been carried out at the Danish test site DanWEC during 2017 – 2019.

Aalborg University and the Danish test site **DanWEC** are both engaged in the OESA project and developing new activities to broaden the spectrum of clients that can benefit from testing in relation to the extended Port of Hanstholm.

Wavepiston testing at Plocan Gran Canaria

PLANNED DEPLOYMENTS

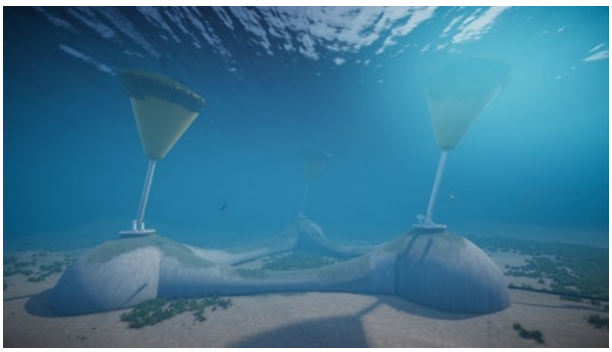
EXOWAVE is based on the principle of bottom-mounted oscillating wave surge converter. During 2021, Exowave has completed the engineering and manufacturing of the prototype that will be tested at DanWEC during 2022. Specifically, Exowave will test wave energy converters to be used for electrical power production, desalination of seawater into fresh water and technical clean water for electrolysis (PtX). Exowave has together with a major offshore wind turbine manufacturer prepared a feasibility study combining 600 MW of offshore wind and 250 MW of wave power, with extremely positive results. The concept is explained in this video.

Wavepiston will in 2022 install their first full-scale system at PLOCAN, Gran Canaria, for both power production and desalination, co-funded by the Horizon 2020 Fast Track to Innovation programme.

Floating Power Plant (FPP) is combining combining wave and wind power on a common floating platform and is involved in several development tracks including Power-to-X. The small start-up company have been expanded from 9 to 15 employees, three of whom are in the newly opened office in Gran Canaria. This office has been set up to help launch the world's first combined floating wind and wave power plants, which is expected to be ready in 2024. In 2021, FPP managed to sign a contract with the test site PLOCAN, ensuring access to the area and conditions.

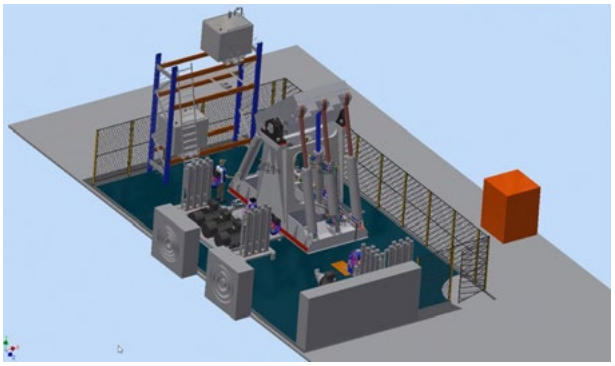
In 2021, in collaboration with Fritz Schur Energy, Seasystems and Aalborg University, FPP has designed the world's largest dry test plant for wave power in the form of an over 30-ton Power Take-Off test bench, which will be ready in Nakskov Harbour as early as 2022.

Finally, 2021 has featured basin tests in IH Cantabria, where in addition to confirming the model data, there were also conducted survival tests to see how the platform would handle the worst storms in the North Sea – and the model was impressively stable.

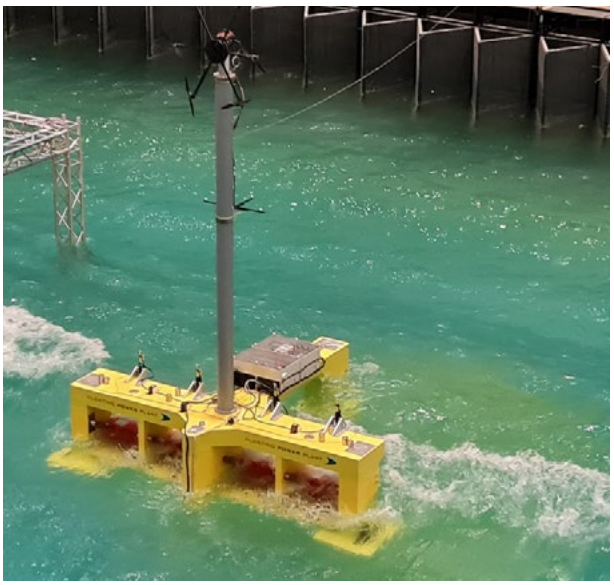


Artist impression of the EXOWAVE system

Wavepiston will continue and expand their installed system at PLOCAN



The full-scale test-bench for the PTO system of Floating Power Plant



Tank testing of the combined wind and wave energy system Floating Power Plant

3.6 EUROPEAN COMMISSION

AUTHORS
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OVERVIEW

The European Commission is supporting the development of the ocean energy sector through an array of activities: the Green Deal, the Energy Union and the SET-Plan in particular, and the new approach for a sustainable blue economy in the EU[1].

In November 2020 the European Commission launched the Offshore Renewable Energy Strategy, highlighting the role that offshore wind and ocean energy technologies are expected to play to contribute to the EU's goal of climate neutrality by 2050. The Strategy proposes to increase Europe's offshore wind capacity, including floating wind, from its current level of 12 GW to at least 60 GW by 2030 and to 300 GW by 2050. The strategy foresees avenues for the creation of an ocean energy industry in the EU, targeting 100 MW installed by 2025, 1 GW by 2030 and 40 GW by 2050.

The European Commission cooperates closely with its Member States to increase support for ocean energy and to encourage them to include trajectories for marine renewable energies in their 2030 National Energy and Climate Plans.

The European Commission continued to support ocean energy development via their funding programmes. The new Horizon Europe programme for Research, Demonstration and Innovation has been launched in 2021.

The new Innovation Fund support programme has been launched in 2020 and published its first calls with deadlines in 2021. The first calls were calling for projects on demonstrating wave energy devices to increase experience in real sea conditions, on the demonstration of innovative rotors, blades and control systems for tidal energy devices and on innovative foundations, floating substructures and connections systems[2]. First results of the new programmes are expected in 2022.

1 https://ec.europa.eu/oceans-and-fisheries/ocean/blue-economy/sustainable-blue-economy_en
2 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities

EUROPEAN STRATEGY

The European Commission presented the European Green Deal[3] in 2019. It will be the most ambitious package of measures that should enable European citizens and businesses to benefit from sustainable green transition. In follow up of this package the Commission presented in 2020 an EU strategy on energy system integration, an Industrial Strategy for a green and digital Europe, and the offshore renewable energy strategy. The Offshore Renewable Energy Strategy is the key policy initiative released in 2020 to support the development of ocean energy in the EU. The strategy was released in the context of the European Green Deal and its ambition to drive the EU towards climate neutrality by 2050. The strategy recognises the role of ocean energy to contribute to the decarbonisation goal. The expectation is that by 2030 ocean technologies could make a significant contribution to Europe's energy system and industry, particularly supporting grid stability and playing a crucial role in decarbonising islands in the EU. The Offshore Renewable Energy Strategy places significantly emphasis on the need to continue the cost-reduction of ocean energy technologies to enable for the uptake of wave and tidal energy technologies in the EU energy system. As foreseen by the strategy a crucial but feasible step to reach commercial size by 2030 would be implementing the existing pipeline of 100 MW pilot-farms projects by 2025.

It is expected that EU Islands can play a key role in the development of ocean energy technologies in the EU. EU Islands in fact provide attractive testing and demonstration grounds for innovative offshore electricity generation technologies. The Clean Energy for EU Islands Initiative provides a long-term cooperation framework to promote replicable and scalable projects with funding from private sector investors, relevant EU support instruments, and technical assistance, in order to accelerate clean energy transition on all EU islands.

The offshore renewable energy strategy places a strong emphasis on the importance of integrating ocean energy technologies safely in the environment. As such, to facilitate dialogue on the environmental, economic and social sustainability of offshore renewable energy, the Commission is ready to facilitate and promote a 'community of practice' where all stakeholders, industry, social partners, NGOs and scientists can exchange views, share experience and work on joint projects.

To meet the EU's energy and climate targets for 2030, EU Member States need to establish a 10-year integrated national energy and climate plan (NECP) for the period from 2021 to 2030 (See annual report 2020). The national plans outline how the EU Member States intend to address energy efficiency, renewables, emissions reductions, interconnections, and research and innovation and have been submitted in 2020.

The European Commission evaluated its Blue Energy Communication in 2020-2021. The main conclusions from this evaluation are the following: The EU successfully implemented the actions included under Phase 1 of the Communication, by setting up the Ocean Energy Forum and supporting the adoption of the Ocean Energy Strategic Roadmap. For what concerns the actions under Phase 2, some progress has been made in the development of sector-specific guidelines for the implementation of relevant legislation, in relations to the EU Nature legislation and to the MSP Directive, but no European Industrial Initiative was set up by 2020. The Ocean SET-Plan adopted in 2018, however addresses, at least partially, the needs identified in the impact assessment. In addition, while outside of the scope of this evaluation, it must be noted that the Clean Energy Industrial Forum announced for 2021 in the EU offshore renewable energy strategy will also cover the ocean energy sector and therefore partially addresses the need for a European Industrial Initiative.

The European Commission has also included an analysis of the role of Ocean Energy in the first report on the progress of clean energy competitiveness, with recommendations on exploring specific business cases for ocean energy such as it value in the grid (beyond the LCOE) and its potential for decarbonising small communities and EU islands.

3 https://ec.europa.eu/info/publications/communication-european-green-deal_en

MARKET INCENTIVES

In 2020 the European Commission Launched the Innovation Fund succeeding the NER 300. The NER300 programme was the main market incentive scheme supporting first-of-a-kind commercial-scale renewable energy projects in previous years. Information about projects awarded can be found in previous annual reports.

The Innovation Fund is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies and it will provide around EUR 10 billion of support over 2020-2030 for the commercial demonstration of innovative low-carbon technologies, aiming to bring to the market industrial solutions to decarbonise Europe and support its transition to climate neutrality. The Innovation Fund improves the risk-sharing for projects by giving more funding in a more flexible way through a simpler selection process and is also open to projects from energy-intensive industries. The Innovation Fund focuses on highly innovative technologies, such as ocean energy, and big flagship projects within Europe that can bring on significant emission reductions. It is about sharing the risk with project promoters to help with the demonstration of first-of-a-kind highly innovative projects. The first call for large-scale project proposals (capital costs >7.5 million EUR) was open in 2020. The first call for small scale projects (capital costs between EUR 2.5 and 7.5 million) was launched at the end of 2020 and will close in March 2021.

The Commission supports the ocean energy sector via BlueInvest. This programme aims to boost innovation and investment in sustainable technologies for the blue economy, by supporting readiness and access to finance for early-stage businesses, SMEs and scale-ups. The BlueInvest pilot initiative managed by the European Investment Fund, provides financing to underlying equity funds that strategically target and support the innovative blue economy. This sector can play an important role in the transformation to a carbon-neutral economy by 2050, an ambition announced in the European Green Deal. The programme is backed by the European Fund for Strategic Investments, the financial pillar of the Investment Plan for Europe.

PUBLIC FUNDING PROGRAMMES

2020 was the last year for Horizon 2020 to publish calls for R&I projects. The last call was to support Green Deal and included a specific topic asking for projects demonstrating at sea critical offshore renewable energy innovations. Two ocean energy projects have been selected in this call: EU-SCORES and Forward 2030.

Horizon Europe will be the successor of Horizon 2020 and the budget proposal for Research and Innovation is 95.5 billion EUR. After adoption the programme will commence in 2021 and will include topics on ocean energy development under the Climate, Energy and Mobility subprogramme.

The European Investment Bank (EIB) together with the European Commission is implementing the InnovFin Energy Demo Projects (EDP) scheme which provides support in the form of loans for first-of-a kind projects. InnovFin aims to facilitate and accelerate access to finance for innovative businesses and projects in unproven markets in Europe. The scheme helps reducing the financial risk of demonstration projects, offering equity and debts tailored to the need of the project.

From The InvestEU Programme will bring together under one roof the multitude of EU financial instruments currently available and expand the successful model of the Investment Plan for Europe, the Juncker Plan. With InvestEU, the Commission will further boost investment, innovation and job creation.

RESEARCH & DEVELOPMENT

The European Commission supports different activities addressing the development of ocean energy technologies. In particular, since 2014, the year when the Horizon 2020 (H2020) Framework Programme was launched, the EC has supported 47 projects addressing different technologies at various stages of the development. Currently 12 projects are still active.

EU support is fundamental for ocean energy R&D, supporting a wide range of tidal and wave energy technologies. EU projects aimed at the development of tidal technology have contributed to the progression of technology to higher TRL. The R&D undertaken has lead to the development of new components, namely PTO, umbilical and tethers that can assist the cost-reduction of tidal energy technology and drive it towards the targets of the SET Plan.

In terms of wave energy, most projects put significant emphasis on the development of reliable PTO. Results from EU funded TRL 5 experiments indicate that performances are on par or even better than expectation, providing a positive outlook for the development of wave energy technology and their progression to higher TRL.

An overview of awarded H2020 R&D projects in the last four years and which are still ongoing or just finished in 2021, is presented in the table below, focusing on the objective of the newly announced projects. Information about projects in previous years can be found in earlier IEA-OES annual reports or in the CORDIS database https://cordis.europa.eu/projects.

Ocean Energy R&D H2020 projects awarded since 2018

More information about the projects and results can be found via the CORDIS project database https://cordis.europa.eu/projects/en

Year	Acronym	Title	Technology developer	Focus
2021	EU-SCORES	European Scalable Complementary Offshore Renewable Energy Sources	Corpower	This project will present the benefits of continuous energy production with small space requirements via complementary energy sources (wind, sun and waves). An offshore photovoltaic system will be installed in Belgium co-located with a bottom-fixed wind farm, and a wave energy array in Portugal co-located with a floating wind farm.
2021	FORWARD -2030	Fast-tracking Offshore Renewable energy With Advanced Research to Deploy 2030MW of tidal energy before 2030	Orbital Marine Power	This project will develop a multi-vector energy system that will combine predictable floating tidal energy, wind generation, grid export, battery storage and green hydrogen production.
2021	EuropeWave	Bridging the gap to commercialisation of wave energy technology using pre-commercial procurement	Several wave energy developers	The project will build on the work of Wave Energy Scotland to help Europe's wave energy innovation community transition to commercial viability. To do this, the project uses an innovative 'pre-commercial procurement' approach to identify and fund the most promising wave energy.

2020	Valid	Verification through Accelerated testing Leading to Improved wave energy Designs	Corpower	Development and validation of a new test rig platform and procedures for accelerated hybrid testing to improve the reliability and survivability of the components and subsystems that form Wave Energy Converters.
2020	Impact	Innovative Methods for wave energy Pathways Acceleration through novel Criteria and Test rigs		To develop and demonstrate a next-generation 250kW Dual Hardware-In-the-Loop (DHIL) testing platform for Wave Energy Converters (WECs).
2020	MUSICA	Combined RES systems to optimise space on small islands	SINN Power GmbH	MUSICA project has developed a replicable smart multi-usage of space (MUS) platform for the concurrent use of three types of renewable energy – wind, PV and wave – at small islands and so-called green services to support aquaculture.
2019	LiftWEC	Development of a novel wave energy converter based on hydrodynamic lift forces		Development of LiftWEC, a novel type of wave energy converter, based on the exploitation of lift forces generated by wave-induced water velocities.
2019	Element	Effective Lifetime Extension in the Marine Environment for Tidal Energy	Nova Innovation	Focus on the development of blades for tidal turbines.
2019	NEMMO	Next Evolution in Materials and Models for Ocean energy		The project aims to drive down costs by designing larger, lighter and more durable composite turbine blades.
2018	The Blue Growth Farm	Development and demonstration of an automated, modular and environmentally friendly multi-functional platform for open sea farm installations of the Blue Growth Industry	WAVENERGY. IT SRL	To produce advanced industrial knowledge with a fully integrated & efficient offshore multipurpose floating platform hosting a commercial 10 MW wind turbine and a number of wave energy converters (WEC).
2018	RealTide	Advanced monitoring, simulation and control of tidal devices in unsteady, highly turbulent realistic tide environments	Sabella, EnerOcean	The projects aims to identify failure caused o tidal turbines at sea whilst providing a step-change in the design of key components such as blades and PTO.
2018	Imagine	Innovative Method for Affordable Generation IN ocean Energy	Innovative Method for Affordable Generation IN ocean Energy	The Imagine project aims at developing a new Electro-Mechanical Generator (EMG).
2018	MegaRoller	Developing the PTO of the first MW-level Oscillating Wave Surge Converter	AW-Energy	The MegaRoller project aims to develop and demonstrate a next-generation Power Take-Off (PTO) solution for wave energy converters.

2018	Sea-titan	SEA-TITAN: Surging Energy Absorption Through Increasing Thrust And efficiency	Wedge, Corpower	The SEA-TITAN project aims at designing, building, testing and validating a direct drive PTO solution to be used with multiple types of wave energy converter.
2018	DTOceanPlus	Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment	Corpower, EDF, Enel Green Power, Naval Energies, Nova Innovation, OceanTEC	Development of second generation open source design tool for ocean energy technologies including sub-systems, energy capture devices and arrays from concept, through development, to deployment.

The European Maritime and Fisheries Fund (2014-2020) seek to promote a growth and job based recovery in Europe in the Blue Economy. The fund supports coastal communities in diversifying their economies, finances projects that create new jobs and improve quality of life along European coasts and makes it easier for applicants to access financing. The fund has financed some smaller projects in the past years focussing on environmental aspects supporting ocean energy technology development.

Ocean Energy EMFF projects awarded since 2018

More information about the projects and results can be found via the EMFF datahub
https://ec.europa.eu/easme/en/european-maritime-and-fisheries-fund-0

Year	Acronym	Title	Technology developer	Focus
2018	WESE	Wave Energy in Southern Europe	AW-energy	To contribute to increase the current knowledge on environmental impacts of Wave Energy (WE).
2018	SEA wave	Strategic Environmental Assessment of Wave energy technologies	CorPower Laminaria, Wello Oy, New Wave Technologies	To address the long-term environmental concerns around the development of wave energy technology.
2019	VPSTTG	VPSTTG: VPS for Tidal Turbine Generators	Atlantis	To manufacture and test an improved tidal turbine's pitch system – an important component enabling technology for more cost-effective tidal energy turbines.
2019	SIMBIOSE	Sustainable Innovation in la Martinique: BIOfouling Solution for clean Energy	Naval Energies	To find solutions for biofouling which will contribute to maintain heat exchangers' energy performance (OTEC).
2020	Wavefarm	WaveRoller Wave Farm Scale-Up - Preparing to deploy the world's first commercial wave energy farm	AW-Energy (Finland)	To prepare AW-Energy to deliver the world's first large-scale WaveFarm, with up to 24 integrated WaveRoller units.
2020	SafeWave	Streamlining the Assessment of environmental efFEcts of WAVE energy	CorPower GEPS Wello Oy	Improvement of the current knowledge on the environmental effects and risks of wave energy and modelling of cumulative impacts of future larger scale WE deployments.

REGIONAL COOPERATION PROGRAMMES

Interreg projects aim at fostering transnational cooperation among neighbouring countries, encouraging collaboration to improve economic, social and territorial development of European regions. Since 2016, 16 Interreg projects have supported exclusively or partly ocean energy development for a total of EUR 132 million.

List of Interreg projects supporting ocean energy development and demonstrations in Europe

Project Name	Sea Basin	Specific to ocean energy	Total project cost	Start Year
Renewable energy projects in the countries of north-west Europe	North West Europe	No	€5,000,000	2018
Blue-GIFT (Blue Growth and Innovation Fast Tracked)	Atlantic	No	€2,500,000	2018
Marine Energy Alliance	North West Europe	Yes	€6,000,000	2018
OPIN (Ocean Power Innovation Network)	North West Europe	Yes	€2,570,000	2018
Tiger (Tidal Stream Industry Energiser Project)	Channel Manche	Yes	€46,800,000	2019
OceanDEMO (Demonstraton Programme for Ocean Energy)	North West Europe	Yes	€12,850,000	2019
OESA (Ocean Energy Scale-Up Alliance)	North Sea	Yes	€6,200,000	2019

RELEVANT PUBLICATIONS

Report on Progress of clean energy competitiveness
https://ec.europa.eu/energy/sites/ener/files/report_on_clean_energy_competitiveness_com_2020_953.pdf
EU strategy on energy system integration
https://ec.europa.eu/energy/topics/energy-system-integration/eu-strategy-energy-system-integration_en
A new Industrial Strategy for a green and digital Europe
https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en
An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future
https://ec.europa.eu/energy/sites/ener/files/offshore_renewable_energy_strategy.pdf
COMMISSION STAFF WORKING DOCUMENT EVALUATION Support instruments for the development of ocean energy policy 2014
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2021%3A433%3AFIN&qid=1640286227249
Support study for the evaluation of the development of ocean energy policies
https://op.europa.eu/en/publication-detail/-/publication/5bb8a1f6-0ace-11ec-adb1-01aa75ed71a1/language-en
Clean Energy Transition –Technologies and Innovations Report
https://ec.europa.eu/energy/sites/ener/files/documents/swd2020_953_-_1_en_autre_document_travail_service_part2_v2.pdf
Promising new technologies to help Europe achieve its ambitious climate goals - Results Pack on ocean energy
https://ec.europa.eu/inea/sites/inea/files/innovationfunds/cordis_rp_oceanenergy_brochureen_v1.pdf
National energy and climate plans (NECPs)
https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en
JRC Ocean Energy Technology Development 2020 Update Report
https://setis.ec.europa.eu/ocean-energy-technology-development-report-2020_en
EU programmes; Funding & tender opportunities
https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities

3.7
FRANCE

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OVERVIEW

In 2021, French activity in Ocean Energy was mainly supported through publicly funded projects at the European, national or regional levels. Even if the national Pluri-annual Energy Policy does not set targets for ocean energy technologies as it does for offshore wind, new estimates in the view of a full decarbonisation of the energy mix in 2050 now take a minimum installation of 3 GW of ocean energies into account. Meanwhile, long-lasting experiments (> 1 year) reveal ambitions for grid-connected tidal electricity generation, with the two pilot projects of tidal stream energy (subject to the confirmation of French state aid) in the Raz Blanchard which is one of the most significant potential tidal energy sites in the world. At the same time, testing continues for specific turbines, wave energy converters and hybrid systems designed for non-interconnected sites or for alternative usage. Many R&D projects for Offshore Renewable Energies are addressing technological issues that will be immediately useful for offshore wind, with a strong focus on floating technologies. Many of these coming advances have potential applications for ocean energy technologies, therefore no time will be lost! The lasting pandemic has not diminished the fast growing community of engineers, researchers and skilled professionals that firmly supports the deployment of ORE in the country.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

In France, the Energy Act (*Loi de Transition Energétique pour la Croissance Verte*), adopted in August 2015, defines an aim of 40% renewable energy in the electricity mix by 2030. The application decree called "Pluri-annual Energy Policy", which sets 10-year targets for installed capacity for all types of energy used in electricity production was updated in 2020 and will be next time updated in 2024. Separate but comparable documents are defined for the mainland as well as overseas regions and territories. In the present document, distinct and ambitious figures of installed capacities and timing for calls for tenders are given for both bottom-fixed and floating offshore wind energy. However, for ocean energies, objectives remain limited to the availability of public incentives for prototypes and pilot farms of converters until the LCOE of these technologies is demonstrated to be commercially competitive with respect to other renewable sources of energy.

However, new thinking has emerged on the urgent need to accelerate the achievement of one of the main objectives of the Paris Climate Agreement, namely carbon neutrality by 2050. The French TSO has issued in October 2021 a wide-ranging study on the evolution of the power system called "Energy Pathways 2050." 8 scenarios are proposed that all achieve the balance between a growing electricity demand (mobility, industry, households) and a fully decarbonated production. In all scenarios, Offshore Renewable Energies are considered as a key asset to succeed in this challenge, and Ocean Energies are cited with a contribution to the energy mix of up to 3 GW, especially in the fully renewable scenario (as opposed to all others that vary the share of the nuclear generation). This can indeed be considered as a step forward in comparison with the present shorter term Pluri-annual Energy Policy.

Although the policies, permitting and incentives for offshore energies depend on the Ministry of Ecological Transition, the Ocean Ministry provides a good impetus to their deployment by prioritizing a fair and efficient marine spatial planning with a planning guideline called the Strategic Seaboard Document (DSF), also to be periodically revised, as well as promoting an enlightened public debate in the consenting process involving fisheries and other stakeholders. As a reminder, a set of laws and decrees in recent years (2018, 2019, 2020, 2021) have been enacted supporting offshore renewable energies by simplifying their deployment, namely:

- most of the legal obligations (preliminary technical studies, initial environmental assessment, public participation) are performed upstream of the actual permit issuance, by the State, thereby considerably reducing the risk for project developers;
- a permit with variable characteristics can be issued allowing for technological flexibility if developers have provided an impact study assessing the maximum negative effect for each variable characteristic;
- for commercial farms, the cost of the export cable is to be supported by the French Transmission System Operator, which also shoulders more legal and financial responsibilities with respect to the availability of electricity exportation;
- for future implementation of ORE farms on the EEZ, a regulatory framework has been set up on 31/12/2021, which is a specific update for ORE from generic previous regulations applying to industrial activities in the EEZ.

MARKET INCENTIVES

In 2019, the Energy and Climate law created the « experimentation contract » to support innovation in renewable energies, especially ocean energies and floating offshore wind. This mechanism enables the administrative authority to launch calls for projects to select innovative projects and decide at a later date the conditions and characteristics of the feed-in-tariff scheme. The goal of this measure is to simplify and accelerate the attribution of a feed-in-tariff for small projects.

In compliance with EU regulations on competitiveness, in the case of a call for tenders at a commercial scale, as is potentially foreseen for two high-energy tidal zones which have already been identified (Alderney Race and the Fromveur Strait in Brittany), a major part of the selection criteria will rely on the assessed electricity price per MWh. However, the present LCOE of tidal energy is considered too high to enable such a call, and present projects are supported by regional and European funds.

PUBLIC FUNDING PROGRAMMES

The "Investment for the Future" program managed by the Prime Minister and, on energy topics, by the Ministry for the Ecological and Solidary Transition, is the major provider of the above mentioned incentives through grants and loans, with the selective help of three main agencies, depending on the TRL of the project (from higher to lower): Public Investment Bank (BPI), Environment and Energy Agency (ADEME), National Research Agency (ANR). Regional local authorities also provide substantial support for prototypes and pilot projects. Since 2020, a labelling process involves the maritime industrial sector in order to identify projects that might have a significant economic impact thanks to innovation breakthroughs: ocean energy projects are included in a "smart offshore

industry" subset, and one project has already been promoted: the DeMHy project which is devoted to precise resource assessment of tidal energy in marine and estuarine environments.

At the time being, this support begins with the ADEME which has an estimated cumulative budget for ocean energy projects (any type of offshore wind excluded) awarded in or before 2020 of 73M€, which includes 6 large completed or ongoing projects. These projects involve the development of technological bricks for tidal energy, the development of tidal energy converters, wave energy converters, salinity gradient and hybrid systems for insular applications (combined renewable energies and storage systems). Ongoing projects issued from calls for tenders of previous years also involve ocean thermal energy converters, prototypes for all ocean energy technology types and technological bricks like subsea connectors or hubs, foundation concepts, specific dredging or installation tools, etc.

In 2020, the ANR officially awarded France Energies Marines (FEM), one of the seven "Institutes for the Energy Transition" and dedicated to offshore renewable energies, with 16 M€ over the period 2019-2024, for innovative research and development projects. Since this support is meant for public-private collaborative R&D projects, a 1€ public for 1€ private rule implies that more than 30 M€ is thus devoted to this large sector, helping tackle technological bottlenecks and environmental issues.

All along the French coastline, at the regional level, local authorities also support the endeavours of the MRE sector. In addition to grants allocated to R&D federative programmes like the national institute France Energies Marines, or to local initiatives like WEAMEC (Pays de la Loire region), they invest in harbour facilities in order to enable the development of offshore wind and tidal industries, thus providing enough space to build plants along new quays, e.g. in Cherbourg, Brest and St-Nazaire.

The two French competitive Sea Clusters, Pôle Mer Bretagne-Atlantique and Pôle Mer Méditerranée, have MRE in their roadmaps. Through a labelling process, they foster interest in collaborative projects that can apply for national funding, as long as the expected results of those projects can quickly be brought to market.

RESEARCH & DEVELOPMENT

Collaborative projects of the Institute for the Energy Transition FEM

As a national public-private research centre (teams in Brest, Nantes and Marseille) France Energies Marines initiates collaborative ORE R&D projects with the support of the ANR. Following is a list of selected projects running in 2021, producing data, software and publications useful for the development of ocean energy systems (offshore wind projects are not mentioned here):

DIMPACT – Design of floating platforms for ORE and impacts of energetic steep and breaking waves

RESCORE – Resources centre for offshore renewable energies

MONAMOOR – Monitoring of polyamide mooring lines (for ORE platforms)

DYNAMO – Dynamic cable monitoring (export cable for ORE platforms)

COME3T – Committee of experts for offshore renewable energies environmental issues

SPECIES – A recommendation report was issued in 2021 on the characterisation of the potential impacts of subsea power cables associated with offshore renewable energy projects: mechanical, thermal, electromagnetic field

France Energies Marines is also partner of several European projects, that are even more focused on Ocean Energies, namely:

DTOcean+ – 2nd generation advanced design tools for the selection, development and deployment of OES (also with Sabella as end-user beta-testing the tools), successfully terminated in 2021

OCEANSET – support implementation of the OE component of the SET-Plan

WEAMEC (West Atlantic Marine Energy Community) federating the ORE ecosystem of Pays de la Loire Region

In the field of Research, Education and Innovation activities, WEAMEC brings together around 30 institutions and research laboratories (such as Centrale Nantes, University of Nantes, Jules Verne Technological Research Institute, Sea cluster…) and more than 90 partner companies and SMEs at the regional level. More than 400 companies at the French and international level collaborate with the academic and industrial stakeholders of WEAMEC. Since 2016, this program has cumulated 7.5M€ of awarded funding for projects dedicated to local academic teams in conjunction with industrial stakeholders. More than 20 projects cover a broad range of topics, with the following applicable to OES:

ECOSFARM – Generic control-command tool for testing operating strategies of tidal farms

FRYDOM – Flexible and rigid bodies dynamic modelling for marine operations

LEHERO, TOCCME, BIODYTHERM, BIODYTHERM_8, BIOROV_GPS – Marine growth

FIRMAIN, CEAUCOMP – Composite aging

OMCEND, BRAGGMETER – Structural health monitoring

ORIGAMI, QR CONNECT – Electrical connection

REDENVEOL, ANCRE-EMR, MONAMOOR – Mooring

AUTOFLEET Y1, AUTOFLEET PLUS, AUTOFLEET Platform - Autonomous sailing ship producing electricity through hydrokinetic turbines attached to the hull

Easing access to test sites and tanks – TheoRem

The French Ministry for Higher Education, Research and Innovation (MESRI) has announced on October 2021 the inclusion of THeoREM in the National Roadmap for Research Infrastructures (next update in 2025). This confirms the relevance of its established objectives:

- Unite research infrastructures (test tanks, test sites, test benches, centrifuge) from the Ecole Centrale de Nantes (ECN), Ifremer, and Université Gustave Eiffel for first-class recognition at French, European and international levels for all sectors concerned by the interactions between man-made constructions and the ocean environment, including marine renewable energies,
- Pool efforts to validate the potential of their test facilities,
- Encourage greater awareness of local authorities in Marine Renewable Energies through the network of test facilities,
- Coordinate the scientific and industrial facility users,
- Encourage and accommodate international MRE stakeholders,
- Open the infrastructure to training,
- Put THeoREM on the ESFRI roadmap, (European Strategy Forum on Research Infrastructures).

Indeed, a clearly established objective of THeoREM is to be part of the European Research Infrastructures landscape, as the French node of the future ERIC Marinerg-i. The Marinerg-i RI will be an independent legal entity of distributed Offshore Renewable Energy testing infrastructures. It was included in the 2021 ESFRI Roadmap and THeoREM and the Marinerg-i consortium partners are now applying to enter the preparatory phase, aiming at establishing the legal, governance, scientific and business components required to implement the Marinerg-i research.

Since 2016, the **SEM-REV wave and floating wind test site of ECN** is involved in the Interreg projects Foresea, OceanDemo and BlueGift which aim to help bring ocean energy technologies to market by providing access to Europe's world-leading network of test centres. Through these projects, the performance of innovative ocean renewable energy technologies are demonstrated in real sea conditions, helping to leverage the investment needed to take new products to market.

SEENEOH, the estuarine tidal test site running in Bordeaux, also belongs to the set of test sites, access to which is facilitated for SMEs thanks to the OceanDemo and BlueGift Interreg projects.

Renovation of the Ifremer wave basins in Brest

This renovation program IjinMor granted by the Britany Region refits the Brest deep wave basin and canal with new wavemakers, respectively 25 and 8 articulated panels for the deep basin and the tow canal. The wave max height is increased to 80cm in the deep basin, allowing the test of the floating converter from the standard wave conditions to the severe cases. The directionality of the wave is a new feature allowing a more realistic representation of the sea states and so the loading conditions meet at sea. The canal offers the possibility of waves up to 1m height and adjustable depth from 1 to 3m. Both basins are dedicated to research program with model test at sea and open to internal and academic partners' projects as well as industrial R&D projects.

Wave maker at IFREMER Brest wave Canal © Ifremer

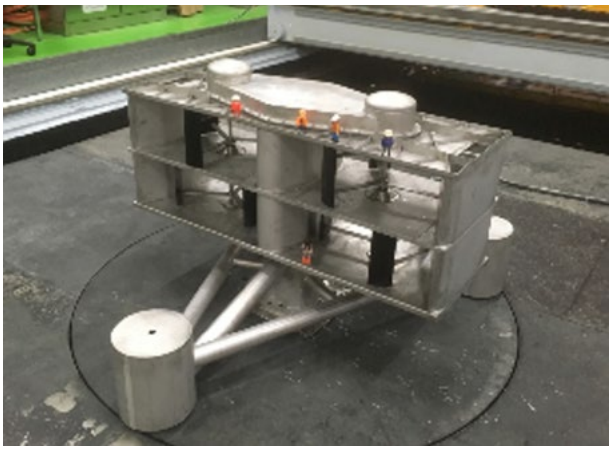
Wave maker at IFREMER Brest deep basin © Ifremer

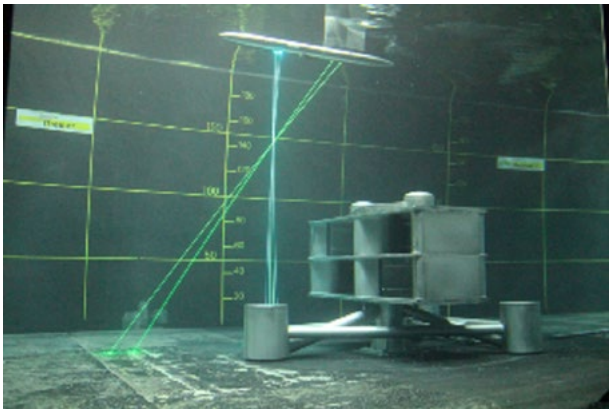
Tidal demonstrations across the Channel - TIGER project

The Tidal Stream Industry Energiser Project, known as TIGER, is the biggest ever Interreg project (46M€) that will prove game-changing for the European tidal stream energy sector. The TIGER project will drive the growth of tidal stream energy in France and the UK (Channel Manche region) with significant economic benefits for coastal communities. On the French side, three sites are involved:

- Raz Blanchard in Normandy, on the very place where 2 pilot projects were already planned, Hydroquest and SIMEC prepare new multi-MW deployments, manage an updated consenting process and expect the agreement of a specific feed-in tariff;
- Paimpol-Bréhat (North of Brittany), whose transition towards an open test site for different tidal turbine technologies is managed by EDF, BDI and SEENEOH, will host MINESTO for demonstration in 2022;
- Morbihan Gulf (South of Brittany), on a site consented in 2020, where Sabella will deploy two 250 kW turbines.

Two reports have been published which are aimed to a broad diffusion, namely: Guidelines for Tidal Energy Project development – A methodology for Site Selection; Guidelines for Tidal Energy Project development – Consenting processes in France and in the UK.





HydroQuest 1 MW prototype at 1/20 scale © Ifremer

Physical simulations in tank tests for tidal energy converters

Ifremer, the national research centre for the sustainable exploitation of the seas, performs studies and experiments in close collaborations with many OE developers. Numerical and physical simulations

complement each other, before scaled or real-size demonstration at sea. At the Boulogne test tank, a generic study has been undertaken to quantify the impact of vertical velocity profiles on bottom-mounted obstacles in terms of load variations. This case study is also useful to better understand the energetic exchanges in the wake of large obstacles in a tidal stream.

A 1/20 scale model of the HydroQuest 1 MW turbine was specifically designed to study the behaviour in a controlled environment where the site conditions can be partly reproduced. Thus, the behaviour of the machine is studied for different types of operating conditions encountered on site (swell, turbulence, angle of incidence, etc.). The results obtained make it possible to quantify the influence of each parameters on the operation of the tidal turbine. The wake of the tidal turbine was also determined from LDV 3C (Laser Doppler Velocimetry) measurements. The comparison of the results obtained on a 1/20 scale with those obtained on site (see below, analysis of data recorded at the Paimpol-Brehat test-site) will make it possible to evaluate the effects of similarity and scales and to validate the different design choices.

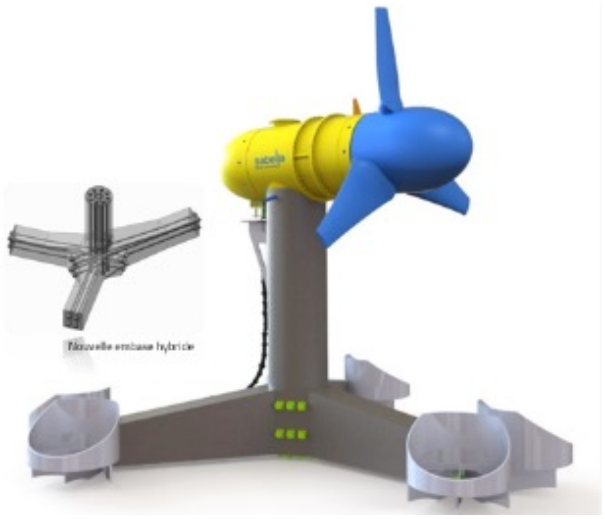
Progress in competitive tidal foundations for gravity based tidal turbines

SABELLA has finalized the design of its hybrid concrete/steel foundation project, in partnership with SAITEC, ALLIA, RISE and Alkit Communication, within the framework of the CF2T project financed by the European OCEAN-ERA Net cofund programme.

The objective of the project was to design and develop a competitive foundation for tidal turbines by combining concrete and steel in order to reduce manufacturing costs and increase the life span of the supporting structure. The work carried out has also made it possible to make the foundation modular, allowing it to be installed in several packages in order to limit the lifting capacity required for the installation vessel and reduce the costs of offshore operations.

This modularity also makes it possible to reduce by 22% the CO_2 emissions associated with the manufacture and installation of this hybrid structure compared to the previous steel structure.

Finally, an adapted monitoring system has been developed to improve knowledge of the loads applied to the foundation and to monitor its health to improve its reliability.



Design of the optimized cost effective hybrid foundation issued from the CF2T project

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Test sites: 4 grid-connected test sites for ORE are operational in France for validating prototypes and subsystems.

Paimpol-Bréhat

HydroQuest's 1MW tidal stream turbine demonstrator, installed at the EDF test site in Paimpol-Bréhat in April 2019, was disconnected in April 2021 and taken out of the water for expertise as scheduled in September 2021. These two years of tests in real conditions on a very demanding site have enabled, in addition to the certification of the power curve by Bureau Veritas, to prove its robustness with thousands of hours of operation and a total availability. The expertise of the machine demonstrated in particular the mint condition of the generators and the subsea converter.

HydroQuest turbine after more than 2 years in operation © HydroQuest

Inside the HydroQuest turbine © HydroQuest

SEM-REV test site

On the Atlantic coast offshore Le Croisic, run by Centrale Nantes, this test site is dedicated to wave and floating offshore wind.

The Wavegem platform is a hybrid (wave, solar) autonomous energy production platform which is designed to supply marine or island installations without access to the electricity grid. Wavegem is designed by GEPS Techno. The 21m x 14m and 7m high platform derives its energy from waves by converting the movements of the float into electrical energy through a closed loop circulation of seawater employing a low speed turbine. PV solar panels also cover the platform. The overall installed capacity reaches 150 kW. The platform is secured with a four-point synthetic mooring system. Offshore testing began in August 2019 and ended in November 2021, towed back to St-Nazaire harbor. This platform is now waiting for a new load on board: a sea-water hydrogen electrolyser for a direct conversion (summer 2022). GEPS Techno Other also aims at powering the blue economy, for instance telecommunication cables, with this technology.

GUINARD Energies Nouvelles is pursuing a policy of developing their 3.5 kW tidal energy technology POSEIDE 66 in isolated community markets, and particularly along rivers and estuaries: in 2021, it succeeded to deploy it in France and Togo.

Wavegem hybrid wave-solar platform back to St-Nazaire harbour © Dr. M. Huguet

PLANNED DEPLOYMENTS

HydroQuest and the independent power producer Qair are ready to develop the world's most powerful and innovative pilot project of tidal stream energy, FloWatt, at the Raz Blanchard in Normandy. FloWatt will consist of 7 HydroQuest turbines with a unit power of 2.5 MW, for a total project power of 17.5 MW. Subject to the confirmation of French state aid, FloWatt could be commissioned for 2025, with the construction of the tidal turbines starting in 2023. The pilot project will then be operated for a period of 20 years and produce 40 million kWh/year, equivalent to the consumption of 20,000 inhabitants.

Nearby, the **Nepthyd project**, partnering SIMEC Atlantis and the independent power producer Akuo, also plans to develop a pilot project of tidal stream energy. The installed capacity will be 12 MW, on a site that has been consented in 2014.

In terms of location, the Raz Blanchard / Alderney Race, located between the Cap de la Hague and the Channel Island of Alderney, is the ideal place for this type of project because its marine current is one of the most powerful in the world and represents a potential for tidal energy of 3 GW out of the 3.5-5 GW of potential identified in France.

In the Fromveur passage, the second French hotspot for tidal resource off the Western coast of Britany nearby Ushent island, **SABELLA** is planning to redeploy its grid-connected D10-1000 tidal energy converter in the summer of 2022, starting its 3rd testing campaign. It should mark a step forward towards creating a sustainable energy model for isolated communities in off-grid locations with tidal energy resources, in the framework of the PHARE project.

RELEVANT NATIONAL EVENTS

A yearly survey of the sector

The assessment of jobs and business data for the entire ORE sector is performed yearly by the Observatoire des Energies de la Mer, through a questionnaire issued at the end of the year. Hence, at this date, only 2020 figures are available. The main results focusing on ocean energies are:

- 324 full-time equivalents (11% of the ORE sector);
- 12 M€ of turn-over (4% of the ORE sector);

Tidal remains the most significant technology for the economic development of the sector in France, followed by wave, OTEC and a number of emerging activities in salinity gradient.

A yearly forum for the sector

SEANERGY, the international forum dedicated to Offshore Renewable Energy, is the largest of the sector in France covering all ORE technologies. The event gathers each year more than 3,500 international players (politicians, contractors (energy operators and industrials), technological experts, NGOs, researchers, investors and subcontractors) - around an exhibition space with 250 exhibitors, industrial and technical conferences, B2B meetings, job-dating sessions, pitches, an interview stage, research area and local technical visits. The 5th edition of SEANERGY has taken place from September 21 to 24 2021, in Nantes and Saint-Nazaire. Next edition will take place in Le Havre, 15-17 June 2022.

3.8
GERMANY

AUTHOR
Fabian Thalemann, Fraunhofer IEE

RESEARCH & DEVELOPMENT

In the public sector, around 15 R&D institutes and universities have been involved into developing wave, tidal current and osmotic power mainly in the framework of national and European research projects over the last decade.

SCHOTTEL HYDRO

Tidal power developer SCHOTTEL HYDRO with its partner Sustainable Marine have launched the second generation of the PLAT-I platform in Grand Passage in the Bay of Fundy, Canada. The floating trimaran platform is rated at 420 kW and carries six next-generation SCHOTTEL Instream Turbines "SIT". A substation has been constructed and commissioned to connect the platform to the Nova Scotian grid in early 2022 for initial sea trials. Later in the year, it will be moved to the Fundy Ocean Research Center for Energy (FORCE) in Nova Scotia, Canada, as the first unit of a 1.26 MW floating array project. This will be the first phase of the 9 MW "Pempa'q" Tidal Energy project at FORCE.

In 2021 SCHOTTEL HYDRO has concluded a research project called "Optimization of a Floating Turbine System for Harnessing Tidal Energy (OST)". Partners had been Potsdam Model Basin, Fraunhofer IEE, the Institute of Fluid Mechanics and Hydraulic Machinery at the University of Stuttgart and the Center for Wind Power Drives at RWTH Aachen University. As part of this project, a process to test critical subsystems (such as foils, drivetrains and power conversion equipment including software) onshore prior to deployment in the field has been established. As part of the OST project, SCHOTTEL HYDRO has collaborated with the world-renowned Center of Wind Power Drives (CWD) at RWTH Aachen University to test its latest generation SIT250 drivetrain. A unique, tailor-made test rig was built within CWD, and 'accelerated lifetime testing' was successfully completed in a six-month period, replicating five years of operation in the Minas Passage, Bay of Fundy, Nova Scotia, Canada.

PLAT-I deployed at Grand Passage, Bay of Fundy, Canada

Next generation SITs as deployed on PLAT-I

As part of the OST project und supported by the MARINET2, SCHOTTEL HYDRO also concluded the development of the next generation rotor, including model scale testing with CNR INM in Rome, Italy, as well as a complete analysis in the MaREI Centre at NUI Galway concerning the full-scale structural rotor behaviour under fatigue loading, reviewing aspects such as torsional deflection and overall performance of its passive-adaptive pitch behaviour. Further in-house testing of the foil as carried out by SCHOTTEL HYDRO involved ultimate loading and testing the integrity of the blade until failure.

SCHOTTEL HYDRO is currently conducting two further scientific projects in Germany: The aim of the EvoFoil project together with partners M&D Composites and Leibniz University Hannover is to develop a new generation of robust and economic rotor blades for tidal turbines. In the second project AutoBLADE also with Leibniz University Hannover, an automated draping system for dry fiber layup is being proved.

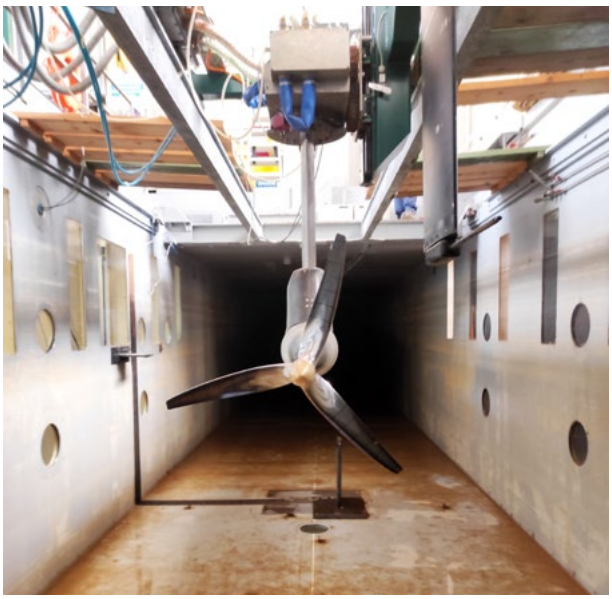
SKF, bearing specialist

Bearing specialist SKF won the sought-after „Best of Industry Award 2021“, following the success of providing two complete and fully integrated 1 MW drive trains for Orbital Marine Power's O2 tidal energy converter. The device started grid-connected operation at EMEC in June of 2021. SKF is furthermore engaged in the EnFAIT project with tidal turbine developer Nova Innovation, aiming to demonstrate the development, operation and decommissioning of a tidal power array of six turbines. As a member of the consortium, SKF provides bearing and seal solutions for the tidal turbines, including optimised programmes, condition monitoring systems and post-decommissioning forensic analysis. On a third track, SKF cooperates with Swedish wave power developer CorPower, assisting with bearing solutions, but also lubrication and monitoring expertise.

SINN Power GmbH

German leading developer SINN Power GmbH is now ready for a go-to-market with their SOcean hybrid platform. After finalizing the project „Testing of a Modular Concept for the Generation of Grid Conform Electricity from Irregular Ocean Waves in a Generator Array“ and a test phase in the Greek port of Heraklion, the lead pipeline is now filled with international pilot project inquiries and field evaluations are running. Based on SINN Power's wave energy power converters, the SOcean hybrid platform could be also equipped with photovoltaic panels and additional small wind turbines for an extensive renewable energy output

Drivetrain test rig at Center of Wind Power Drives, RWTH Aachen University



Model test at CNR INM, Rome, Italy

at any weather conditions. The robust aluminum structure of SOcean is designed for harsh maritime environments and could be easily transported worldwide due to its wave energy converter segments in standard 40' containers. Besides the smooth transport, a space saving and intuitive mounting makes SOcean a unique wave power product.

SINN Power also upgraded its in-house developed SGrid IP68 rated smart-grid electronics. The modular SGrid elements are flexible and plug-and-play for the entire path from power generation to grid feed-in. Inspired by customer feedback SINN Power is now entering in advanced applications like aquaculture farms, offshore wind farms, harbours and nearshore applications. Wave energy accompanied with wind and solar pushes wave energy generation from early-stage technology to stable power supply.

Power train for Orbital Marine Power's O2-2000, developed and manufactured by SKF

NEMOS GmbH

German wave power technology developer NEMOS GmbH published the results of their latest research project "NEMOS – Design, Manufacturing, Installation and Commissioning of a NEMOS Wave Power Plant Model at 1:1 Scale" in March of 2021. The conclusion of the project also saw the decommissioning of the floater part of NEMOS' wave power prototype that had been installed in the Belgian North Sea in 2019. The remaining research tower is being used by various research institutions and companies to test novel offshore technologies. Since then, the company has focussed on further development of flexible tension cablings, the key sub-technology of their wave power technology. More information: Final report available in German language

Current build-out of SINN Power's SOcean hybrid platform at the port of Heraklion

3.9
INDIA

AUTHOR
Purnima Jalihal, National Institute of Ocean Technology (NIOT)

OVERVIEW

India has a long coastline of about 7500 km with many estuaries and gulfs, and ocean energy can be extracted for both grid and off-grid applications from various resources such as waves, tidal currents and ocean thermal gradient. National Institute of Ocean Technology (NIOT), an institute under the Ministry of Earth Sciences (MoES) has been entrusted to develop technologies pertaining to ocean energy. Ocean Energy and fresh water initiative as part of the recently launched Deep Ocean Mission and an OTEC powered desalination plant are under execution currently by NIOT.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

The Ministry of New and Renewable Energy (MNRE) is the nodal Ministry of the Government of India for all matters including tariff fixation and policy formulation relating to new and renewable energy. MoES works towards the technology development of ocean energy devices.

MARKET INCENTIVES

Currently, MNRE is considering floating calls to fund various proposals related to ocean energy.

PUBLIC FUNDING PROGRAMMES

The Cabinet Committee on Economic Affairs chaired by the Prime Minister of India, approved the proposal of MoES on "Deep Ocean Mission", with a view to explore the deep ocean for resources and develop deep sea technologies for sustainable use of ocean resources. Deep Ocean Mission is a mission mode programme to support the Blue Economy Initiatives of the Government of India. MoES will be the nodal Ministry implementing this multi-institutional ambitious mission. Energy and fresh water from the ocean is one of the components in this mission. As part of this, studies and detailed engineering design for offshore Ocean Thermal Energy Conversion (OTEC) powered desalination plant are planned.

NIOT under MoES has commenced the execution of an OTEC powered desalination plant of 100 m3/day capacity in Kavaratti, UT Lakshadweep. Detailed engineering of the plant including cold water conduit is being finalized for fabrication.

RESEARCH & DEVELOPMENT

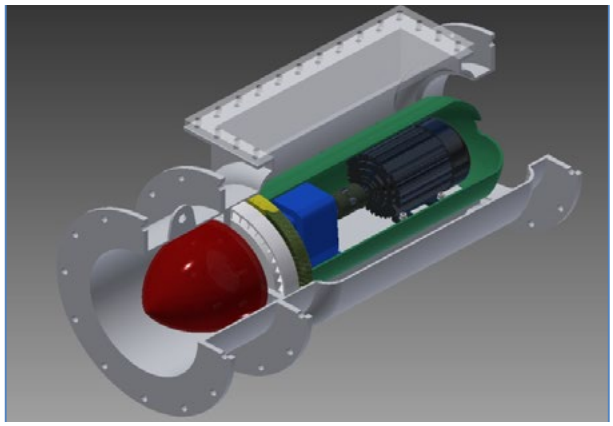
Energy from ocean thermal gradient

The studies in Open Cycle OTEC and Low-Temperature Thermal Desalination (LTTD) laboratory at NIOT were continued to assess and improve performance of various components for OTEC and LTTD cycle including turbines. These studies will help understand the performance of the large capacity OTEC and Desalination plant at Lakshadweep. Studies on cold water conduits, including vortex induced vibrations studies, have been undertaken towards the design of a large-scale OTEC plant.

Wave Energy

Wave energy potential assessment was carried out by NIOT for the state of Andhra Pradesh on the east coast of India as per request from New and Renewable Development Corporation of Andhra Pradesh (NRDCAP).

OTEC-LTTD laboratory set-up at NIOT



New open-cycle OTEC power module for laboratory

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Two Startup firms are now working in the area of wave energy and hydrokinetic devices towards development and demonstration in Indian waters.

3.10
IRELAND

AUTHOR
Shadi Kalash, Sustainable Energy Authority of Ireland

OVERVIEW

Ireland has one of the best offshore renewable energy resources in the world with a sea area of 490,000 square kilometres which is approximately seven times the size of our landmass[1]. Because of Ireland's location at the Atlantic edge of the EU, we have more offshore energy potential than most other countries in Europe, with an estimated long-term potential of 70 GW of Ocean Energy opportunity (wind, wave and tidal) within 100 km of the coastline[2].

In 2021, Ireland launched an updated and amended version of the of the Climate Action Plan that was initially published in 2019. The Climate Action Plan 2021 represent the path to achieve the national commitments of halving greenhouse gas emissions by 2030 and reaching net zero by 2050 at the latest. It provides a detailed plan for taking decisive action to achieve a 51% reduction in overall greenhouse gas emissions by 2030 and setting us on a path to reach net-zero emissions by no later than 2050, as committed to in the Programme for Government and set out in the Climate Act 2021[3]. The Plan lists the actions needed to deliver on our climate targets and sets indicative ranges of emissions reductions for each sector of the economy. It reflects the ambitious targets set in 2020 through the Programme for Government[4] to progress offshore energy in Ireland including a target to achieve 5 GW of offshore wind by 2030 and achieving 80% renewable electricity by 2030. There is a further commitment in the Programme for Government to develop a longer-term plan to utilise the potential 30 GW of offshore floating wind power in our Atlantic waters.

There are four actions that are specifically relevant to the development of offshore renewables and require Ireland to develop legislation, a new consenting system, a dedicated offshore Renewable Energy Supporting Scheme (RESS) auction, and support Ocean Energy research and development infrastructure[5].

1 https://www.gov.ie/en/press-release/07331-transition-of-offshore-renewable-projects-announced/
2 https://www.gov.ie/en/publication/e13f49-offshore-renewable-energy-development-plan/
3 https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/
4 https://www.gov.ie/en/publication/7e05d-programme-for-government-our-shared-future/
5 https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

The Offshore Renewable Energy Development Plan (OREDP)

Ireland's Offshore Renewable Energy Development Plan (OREDP) published in 2014 highlights Ireland's focus on stimulating industry-led projects for the development and deployment of Ocean Energy devices and systems. The OREDP identifies resources for increasing indigenous production of renewable electricity, contributing to reductions in greenhouse gas emissions, improving the security of energy supply and creating jobs in the green economy in Ireland. The OREDP sets out key principles, policy actions and enablers for the delivery of Ireland's significant potential in this area. In 2021, the new OREDP development is commenced where OREDP II will be completed to quantify the offshore renewable energy potential in Ireland's maritime area. The availability of more marine data, and the development in Ocean Energy technologies including floating offshore wind are among the key drivers for an updated OREDP. The OREDP II will also provide an evidence base for the assessment of areas suitable for deployment of offshore renewable energy. The OREDP II will be an important planning tool as Ireland transitions to a plan-led regulatory regime for the future development of offshore renewable energy underpinned by the National Marine Planning Framework (NMPF). As indicated in the Climate Action Plan 2021; Action 116; the new OREDP will be completed by the end of 2022[6].

Policy development for Marine Consenting

Over the course of 2021, there has been significant progress made in relation to policy for offshore renewable development. Ireland's ambitions for the offshore renewable energy sector are contingent on delivering and effective and efficient licensing and regulatory regime for offshore renewable energy. This will provide certainty to project promoters and provide a pathway to realising the necessary investment in offshore renewable energy.

The NMPF is Ireland's first comprehensive marine spatial planning framework which was formally established by the Irish Government in July 2021. The NMPF brings together all marine-based human activities for the first time, outlining the Government's vision, objectives and marine planning policies for each marine activity. The NMPF sets out the Irish Government's long-term planning objectives and priorities for the management of our seas over a 20-year time frame. It also sets out specific objectives and marine planning policies for all the activities taking place in Ireland's seas, from aquaculture to wastewater treatment. All these activities are contextualised within the pillars of their economic, environmental and social considerations. The NMPF sets out the proposed future approach to the adoption of spatial designations for marine activities including offshore renewable energy development, development,whilst taking account of the existing network of designated European sites under the Birds and Habitats Directives[7].

The Marine Area Planning Act

The Department of Housing, Local Government & Heritage have prepared the Marine Area Planning (MAP) Act; formally known as the Marine Planning and Development Management (MPDM) Bill. The MAP Act is enacted as a new law in December 2021 in lieu of the foreshore act. The MAP Act establishes into law a new marine planning system, which is underpinned by a statutory Marine Planning Statement, and guided by the NMPF. It consists of a development management regime from the high-water mark to the outer limit of the State's continental shelf administered by An Bord Pleanála and the coastal local authorities. It will provide a modern, up-to-date regulatory and marine planning framework for offshore renewable energy developments beyond the limits of the foreshore (12 nautical miles). This will be an important foundation for investment in the offshore renewable energy sector as well as providing a more transparent, participative system for all marine stakeholders. The MAP Act streamlines

6 https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/
7 https://www.gov.ie/en/publication/a4a9a-national-marine-planning-framework/

procedures using a single consent principle: one State consent known as a Maritime Area Consent (MAC), that enables occupation of the Maritime Area and one development consent (roughly similar to planning permission), with a single environmental assessment. The Act will enable the establishment of a new independent agency, the Maritime Area Regulatory Authority (MARA). When established MARA will focus solely on the regulation of Ireland's maritime area and will grant MACs, licence specified maritime usages, ensure compliance with MACs, and licences and offshore planning permissions. The new State Agency; MARA; is expected to be operational by Q1, 2023 and it will be based in Wexford[8]. The passage of the legislation has been prioritised in 2021 to ensure that the new consenting model, as well as implementation of a new offshore grid connection policy that lines up with the RESS auction timeframes will ultimately deliver Ireland's 2030 targets.

MARKET INCENTIVES

The Renewable Electricity Support Scheme (RESS) provides support to renewable electricity projects in Ireland. With a primary focus on cost effectiveness, the RESS delivers a broader range of policy objectives, including:

- Providing an Enabling Framework for Community Participation through the provision of pathways and supports for communities to participate in renewable energy projects.
- Increasing technology diversity by broadening the renewable electricity technology mix.
- Delivering an ambitious renewable electricity policy to 2030.
- Increasing energy security, energy sustainability and ensuring the cost effectiveness of energy policy

The final results of the first RESS auction (RESS-1) were approved by Government in September 2020. The overall successful volume in RESS-1 is 2,237GWh of shovel ready renewable electricity projects. This equates to 479 MW of onshore wind and 796 MW of solar. A considerable saving on the previous REFIT scheme has been achieved. Solar energy accounted for approximately 34% of the overall auction energy volume. Seven out of eight qualified community projects were successful. These projects are required to commence operation before 2023 at the latest[9].

In Q4 2021, the Department of the Environment, Climate and Communications (DECC) has opened a consultation on the first auction to supply electricity from offshore wind under the Renewable Electricity Support Scheme (ORESS 1). The first offshore auction will be a major step towards meeting the Irish Government's goals of up to 80% renewable electricity by 2030, with 5GW coming from offshore wind. It will also support the achievement of the objectives set out under the Climate Action Bill and the measures set out in the Climate Action Plan 2021. At least three offshore auctions are currently planned. Due to the relatively long development timelines of offshore wind projects, only the first two of these auctions can be expected to contribute towards Ireland's 2030 5GW installed capacity target[10].

The table below sets out an indicative forward schedule of RESS auctions for the next three years. The indicative volumes are based on estimated renewable generation volumes required to meet Ireland's target of up to 80% RES-E by 2030[11].

8 https://www.gov.ie/en/press-release/d13b0-maritime-area-planning-bill-2021-passes-through-all-stages-of-the-oireachtas/
9 https://www.eirgridgroup.com/site-files/library/EirGrid/207158-EirGrid-Renewable-Energy-Scheme-LR5.pdf
10 https://www.gov.ie/en/press-release/f6070-consultation-opens-on-first-auction-to-supply-electricity-from-offshore-wind-under-the-renewable-electricity-support-scheme-oress-1/
11 https://assets.gov.ie/212080/be6fa505-d4e7-4634-80d9-64fd9d1a0800.pdf

Auction Type	Indicative Auction Volume (GWh)	Indicative Auction Dates	Indicative Auction Commercial
Onshore RESS 2	1,000-3,500	Q2 2022	2024
Offshore RESS 1	7,500-10,000	Q4 2022	2027
Onshore RESS 3	2,000-5,500	Q2 2023	2025
Offshore RESS 2	15,000-25,000	2024-2025	2029
Onshore RESS 4	1,000-5,000	2024	2026

PUBLIC FUNDING PROGRAMMES

SEAI Prototype Development Fund

The prototype development fund (PDF) was developed by SEAI in order to provide funding specific to Ocean Energy developers. The programme operated from 2009 to 2019 and during this time supported over 125 projects with +€21m grant funding. Many projects supported through the programme have utilised Ireland's suite of test facilities, particularly development of small-scale physical models in the wave basins at the National Ocean Test Facility at University College Cork and sea trials in Galway Bay. Since the PDF closed, opportunities to fund Ocean Energy technologies has been maintained via the SEAI Research, Development and Demonstration fund.

SEAI Research, Development and Demonstration Fund

The SEAI National Energy Research Development and Demonstration (RD&D) Funding Programme invests in innovative energy RD&D projects which contributes to Ireland's transition to a clean and secure energy future. The key programme objectives include the following:

- Accelerate the development and deployment in the Irish marketplace of competitive energy-related products, processes and systems
- Support solutions that enable technical and other barriers to market uptake to be overcome
- Grow Ireland's national capacity to access, develop and apply international class RD&D
- Provide guidance and support to policy makers and public bodies through results, outcomes and learning from supported energy projects

In 2021, there were sixteen offshore energy projects granted funding under the RD&D with an approximate budget of €7M. A new call is planned to open in Q1, 2022 where applicants can submit their applications under one of the different categories of the call[12].

OCEANERA-NET Cofund

The Ocean Energy ERA-NET Cofund (OCEANERA-NET COFUND) project is a five-year action that secured support through the European Union's Horizon 2020 Programme for Research and Innovation in 2016. This programme has built on the work of OCEANERA-NET and with an increased budget and financial support from the EU Commission, the COFUND programme focuses on collaborative projects that demonstrate and validate innovative technologies for Ocean Energy[13].

The first joint call was launched in 2017 and was open to applicants from three European countries (Ireland, Spain, Sweden) and four regions (Brittany, Pays de la Loire, the Basque Country, and Scotland). Three projects, with four Irish partners, were awarded grants in the COFUND joint call. A second call was issued in 2019 and contracts for projects were awarded in 2020. Three projects with Irish partners were awarded funding under this final call. All projects commenced operation in 2020 and it is anticipated that projects will run to 2022.

12 https://www.seai.ie/grants/research-funding/research-development-and-demonstration-fund/
13 https://www.oceancofund.eu/

SEAI/LIR NOTF Industry access programme

Similar to the EU funded MaRINET2 project, SEAI and LIR National Ocean Test Facility (NOTF) in UCC have designed and funded a pilot programme to enable the testing and progression of ORE technologies through the early development stages in advance of open sea testing. It is supported by SEAI and is open to any type of ORE technology (wave, wind, tidal, floating solar) that can be tested at the Lir NOTF. The first call was run successfully in Q4 2021 and the testing of 6 different Ocean Energy technologies is expected to be completed in Q1 2022. This programme will run again in Q3 2022 and further information can be found on LIR website[14].

RESEARCH & DEVELOPMENT

The Irish government is taking major steps towards making Ireland carbon neutral by 2050. One of the key steps that have been taken since 2003 is the continuous support for the development of the national testing facilities, and funding the research and development for Ocean Energy.

KEY NATIONAL RESEARCH ACTIVITIES

SEAI has supported many Ocean Energy projects through Government funded grant support to Irish research institutions and Enterprises. The following list is providing examples of the projects that have been awarded under SEAI RD&D fund in 2021. For further details about funded projects, you may refer to SEAI national energy research database[15]:

- **New power take-off (PTO) and control system for DUO wave energy technology to enable access to emerging markets**

  Pure Marine Gen Ltd. has developed the DUO wave energy convertor (WEC) concept. The DUO is a floating, self-reacting device, which allows power to be captured from both heave and pitch/surge motions. During this project, numerical modelling and tank testing will act as a stepping stone to utility-scale deployments in the longer term.

- **Wave Goodbye to Diesel (WGtD)**

  This project is led by Technology From Ideas Ltd. in order to decarbonise the aquaculture sector using renewable energy. This project aims to integrate into the existing mooring lines of the feed barge a novel, innovative, polymer spring that pumps pressurised seawater through a conventional hydro-electric turbine, producing electricity which is stored and distributed through an onboard micro-grid battery storage unit.

- **BlueBox - Edge computing for ocean data science**

  Ocean Wave Venture Ltd. is leading the project which aims to reduce costs and enhance the value of data collected by long-endurance ocean observation systems. The data analytics in ocean observation applications will be enhanced and a dedicated offshore Internet of Things platform will be developed.

- **CETUS – Cetacean, Elasmobranch, Turtle and Seabird distributional modelling platform supporting the sustainable development of offshore renewable energy**

  To understand the potential interactions between megafauna (e.g.,cetaceans, seabirds, and elasmobranchs) and Ocean Energy Renewable (ORE) devices. CETUS aims to find and compile all available datasets on sensitive megafauna species and build a nationally standardised database that can support the visualisation and mapping of species distributions. The project is led by University College Cork in Ireland.

14 http://www.lir-notf.com/
15 https://www.seai.ie/data-and-insights/seai-research/research-database/

Besides, many other research and development projects commenced before 2021 and continue to support the Ocean Energy sector such as MaREI which is another example of the Irish state's investment in the research community. MaREI is the Science Foundation Ireland Research Centre for energy, climate and marine, coordinated by the Environmental Research Institute (ERI) at University College Cork. MaREI has over 200 researchers across 13 partner institutes in Ireland working with over 75 industry partners focussing on the energy transition, climate action and the blue economy. MaREI's research capabilities cover a wide range of cross-cutting topics in marine renewable energy technologies, materials and structures, observation and operations, coastal and marine systems, bioenergy, energy policy and modelling, and energy management. MaREI researchers work with collaborators in more than 36 countries and this research increasingly underpins energy and climate policies of the Irish Government and the European Union. Through engaged research and dialogue with stakeholders and communities, MaREI also supports the human and societal dimensions of climate action and marine conservation. More information can be found on MaREI website[16].

NATIONAL TESTING FACILITIES

Ireland provides test sites that facilitate the testing and development of wave, tidal and offshore wind energy technology at all technology readiness levels (TRL). Ongoing improvement and expansion of Ireland's test and demonstration facilities are key to the Ocean Energy goals in Ireland. Current facilities cover all Technology Readiness Levels (TRLs) from 1 – 9 and are detailed below:

Lir National Ocean Test Facility

The Lir National Ocean Test Facility (NOTF) is a world-class centre for renewable energy and marine research, located in the UCC Beaufort Building in Ringaskiddy, Co. Cork. Lir is a custom-designed test facility that features upgraded and expanded tanks and equipment for the testing of small-scale Ocean Energy renewable devices with TRL ranging from 1 to 4. Lir is an essential part of Ireland's Ocean Energy research and testing infrastructure and provides a significant launch pad for both national and international marine renewable energy developers. Testing infrastructure includes:

- A Deep Ocean Wave Basin (circa 1:15 scale testing).
- The Open Ocean Emulator, an ocean wave basin with a sophisticated 2-sided paddle system and a two-sided absorption system (circa 1:50 scale testing).
- A wave and current flume with coastal/tidal testing capabilities (circa 1:50 scale testing) and a wave demonstration flume.
- Mechanical and electrical workshops.
- Electrical testing infrastructure, including a smart grid and a series of linear and rotary rigs used to test power take-off and energy storage.

Galway Bay Test Site

The Galway bay Test Site is located on the north side of Galway Bay, 2.4km southeast of Spiddal village, which is located 19km west of Galway city. The area of the site is 37 hectares and it has water depths of 21-24 metres. The test site area is demarcated by four cardinal marks, one at each corner. The test site facilitates the open sea deployment of a quarter to half scaled prototypes of Wave Energy Converters (WEC's) with TRL ranging from 4 to 6. The Marine Institute (MI) with support from SEAI has been developing the Ocean Energy Test Site since 2006. Real-time oceanographic data, time-series data and full spectral data are available on the Galway Bay dashboard and the Marine Institute's Data Request service[17].

Atlantic Marine Renewable Energy Test Site (AMETS)

The Atlantic Marine Energy Test site in Belmullet Co. Mayo is being developed by SEAI in order to test full-scale pre-commercial offshore energy technologies with TRL ranging from 7 to 9. The development of the AMETS has progressed steadily over the last decade.

16 https://www.marei.ie/
17 https://www.marine.ie/Home/site-area/infrastructure-facilities/ocean-energy/galway-bay-test-site-0

The following consents and planning permissions have been put in place for the site:

- The ESB connection agreement is in place since 2011.
- The foreshore lease for the AMETS and deployment of the offshore cable; awarded in 2015 for wave energy devices.
- Planning permission the electrical substation, awarded in April 2017.

Since 2018 the main focus for the site has been the INTERREG NWE funded AFLOWT project (Accelerating market uptake of Floating Offshore Wind Technology). The project will support site development includes onshore civil works for substation build and grid reinforcements and offshore works for electricity export cable deployment. AMETS is to be ready for offshore energy technology deployment by the end of the AFLOWT project in 2023.

EU PROJECTS

Ocean Energy projects that Irish partners are participating in through European-funded programmes include:

- **H2020 INFRARIA MaRINET2** project will provide and co-ordinate free access to Ocean Energy developers to test infrastructure throughout Europe. MaRINET2 has built upon the previously successful MaRINET programme. UCC are project co-ordinators. Facilities at NUI Galway and the University of Limerick are also included, as well as the Galway Bay Marine and Renewable Energy Test Site.
- **H2020 TAOIDE** proposal is to develop a fully-integrated generator to grid energy delivery system with high reliability and availability, suitable for use in multiple architectures of marine renewable energy systems. This work will provide the basis for development of a power production system certified for use in marine renewable energy applications – a system designed for the specific environments and regulations of the European Union market, utilising skills, expertise and capabilities of European partners. The Irish partners in these projects are ORPC Ireland, UCC, and Letterkenny Institute of Technology.
- **H2020 FloTEC** Project (Floating Tidal Energy Commercialisation): The FloTEC project will demonstrate the potential for floating tidal stream turbines to provide low-cost, high-value energy to the European grid mix. The project will entail the construction of a turbine device that will be deployed alongside an existing floating tidal array which will serve as a demonstration platform for commercially viable tidal stream energy. Irish partners include UCC/MaREI and Eirecomposites.
- **H2020 LiftWEC** has the objective of developing a new type of wave energy convertor. Irish Partners are MaREI-UCC and MaREI- MU (led by QUB).
- **H2020 MUSICA** project involves the deployment of a multi-purpose renewable energy platform in the Mediterranean. Irish Partner is MaREI-UCC.
- **H2020 OceanSET** (Support to the Realisation of the Ocean Energy Implementation Plan of the SET-Plan) project will run from February 2019 to December 2021. The project was developed to support the Implementation of the European Strategic Energy Technology Plan (SET Plan) for Ocean Energy. The Implementation Plan focuses on the key challenges for wave and tidal energy technologies. Its ambition is to outline a structured approach that will enable wave and tidal technologies to follow a credible development path, with the ultimate destination of a commercially viable wave and tidal industry. SEAI is the lead partner in this project.
- **H2020 IMPACT** Development of new test rigs for the development of wave energy convertors. Irish Partner is MaREI-UCC.
- **H2020 Saturn** Testing of innovative solutions for reducing the most harmful effects of underwater noise. Irish Partner is MaREI-UCC.
- **Interreg ProtoAtlantic** Innovation in the marine environment including testing of various offshore renewable energy technologies. Irish Partner is MaREI-UCC.
- **INTERREG NWE MEA** project (Marine Energy Alliance) is a 4 year project running from May 2018 to May 2022. The aim of MEA is to progress the technical and commercial maturity level of early-stage (TRL 3 – 4) marine energy technology companies with the overall goal of reducing the risk of device failure in subsequent demonstration phases. Irish Partners include Exceedence Ltd and MaREI-UCC.

- **INTERREG AA PORTOS** project works on developing offshore renewable energy solutions (wave and tidal) for European ports. Irish Partners are MaREI-UCC and Shannon Foynes Port.
- **INTERREG Ireland-Wales Selkie** Project addresses identified gaps that are slowing the progression of the wave and tidal energy sectors. Irish Partners are MaREI-UCC, GDG ltd and DP Energy.
- **Interreg EERES4WATER** Development and promotion of energy-water nexus resource efficiency through renewable energy and energy efficiency. Irish Partner is MaREI-UCC.
- **INTERREG Northern Ireland, Ireland and Scotland BRYDEN PHD Programme.** This programme offers fully funded PhD Studentships in Marine renewable energy and Bio-energy. Using a Doctoral Training Centre model, the BRYDEN CENTRE project will recruit 34 PhD students and 6 PDRAs; each of whom will work with industry to produce industrially relevant research with the potential for commercial exploitation and resulting economic growth within the region. Letterkenny IT are the Irish Partners in this project.
- **INTERREG NWE OPIN** project (Ocean Power Innovation Network) is a three-year project running from October 2018 to December 2021. OPIN will design, test and deliver an innovation model to build cross-sectoral collaboration, to accelerate growth of the Ocean Energy sector and its supply chains. Irish partners include SEAI, as lead partner, with MRIA, ESB and Enterprise Ireland as associate partners.
- **INTERREG AA Blue-GIFT Project:** The €2.5 million Blue-GIFT (Blue Growth and Innovation Fast Tracked) project kicked off in 2019 and announced its third call for applications in December 2020. Funded by Interreg Atlantic Area, the Blue-GIFT project is a coordinated Ocean Energy technology demonstration programme encouraging longer-term demonstration and technology de-risking across the Atlantic Area regions. The calls offer support package vouchers to Ocean Energy companies for access to demonstration sites across the Atlantic Area, lowering costs for testing and validating technologies in real sea environments. The project aims to support a minimum of eight floating wind, wave or tidal demonstration related projects across the Atlantic Area region. BlueWise Marine's (formerly SmartBay Ireland) role in the project is to transfer know-how gained from the very successful FORESEA project and to coordinate and administer the applications and call procedure in the project. The access to the test sites is only available for the southern test site in PLOCAN, WaveEC, Bi-MEP and Seeneoh.
- **INTERREG NWE OceanDemo:** This is a follow on project from the successful FORESEA project, which targets multi-machine Ocean Energy demonstrations. OceanDEMO recognises that the transition from single machine to pilot farm scale is critical for the future of the Ocean Energy sector. The project aims to ease the transition towards pilot farms by providing free access to Europe's network of open sea test centres: EMEC – European Marine Energy Centre, UK; DMEC– Dutch Marine Energy Centre, Netherlands; Centrale Nantes/SEM-REV – Site d'Expérimentation en Mer pour la Récupération de l'Énergie des Vagues, France; and the SmartBay Marine and Renewable Energy Test Site in Ireland. The project released its fourth call for applications in June 2021 and focused on devices that will be installed in 2021 or early 2022[18].
- **INTERREG NWE AFLOWT:** Accelerating market uptake of Floating Offshore Wind Technology (AFLOWT) is a five-year project (2019 – 2023) aiming to demonstrate the survivability and cost-competitiveness of a floating offshore wind technology. The ambitious €31 million floating offshore wind project also support the development of an active supply chain in North West Europe which has some of the strongest wind and ocean resources in the world. Three of the nine partners are from Ireland: Sustainable Energy Authority of Ireland (SEAI), University College Cork (UCC), and Electricity Supply Board (ESB). Meanwhile, SEAI continue site development at the Atlantic Marine Energy Test Site (AMETS) in Co. Mayo, Ireland. Site development includes onshore civil works for substation build and grid reinforcements and offshore works for electricity export cable deployment. AMETS is to be ready for offshore energy technology deployment by the end of the AFLOWT project in 2023[19].

18 https://www.nweurope.eu/projects/project-search/oceandemo-demonstration-programme-for-ocean-energy-pilot-farms-and-supporting-technologies/#tab-6
19 https://www.nweurope.eu/projects/project-search/aflowt-accelerating-market-uptake-of-floating-offshore-wind-technology/news/aflowt-project-update/

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

No Ocean Energy technology has been deployed in the Irish water in 2021.

PLANNED DEPLOYMENTS

New Wave Technology trading as Ocean Energy plan to deploy a near full-scale model to test in US Navy WETS facility in Hawaii in 2022. The project is co-funded by both SEAI and DOE in the US. The project has been in place since 2016 and up to now has focussed on, build, transport and access to the site. The technology was transported from Oregon to Hawaii in November 2019 and in now awaiting access to the test site. It is anticipated that a year testing regime will follow. This project is stage/phase 4 of the Development & Evaluation Protocol for Ocean Energy technology, the prior stages having been completed with financial assistance from SEAI, the Marine Institute, Enterprise Ireland and EU funding. The prior stage included several deployments at the Galway Bay Quarter Scale test site – during which the device accumulated over 24,000 hours of open water testing.

OE Bouy during construction in Oregon

RELEVANT NATIONAL EVENTS

1. **The National Energy Research and Policy Conference:** This is an annual conference that aims to facilitate discussion on the role of energy research and policy in achieving Ireland's long term clean energy goals. In 2021, this conference focused on how to decarbonise the transportation sector in Ireland using renewable energy including Ocean Energy technologies. It is planned that this conference will be conducted again in Q4 2022[20].
2. **The Irish Wind Energy Research Network:** SEAI organised the 10th meeting of the Irish Wind Energy Research Network (IWERN) on Wednesday 8th December 2021. In 2017, SEAI initiated the network to bring together Irish academic researchers and industry experts, who engage in onshore and offshore wind energy research, both nationally and internationally. The network provides an opportunity for those involved in wind energy research to regularly meet and share experiences.
3. **OPIN network:** Many webinars have been organised during 2021 under the umbrella of the Ocean Power Innovation Network (OPIN) which is led by SEAI. OPIN is an NWE Interreg co-funded project that provides practical supports to ocean developers such as free access to technical workshops and events, networking opportunities and technical assessments. Many webinars are expected to be organised during the course of 2022[21].
4. **SEAI Energy Show 2022:** The SEAI Energy Show is a business to business event, focused on sustainable energy solutions. It is an exhibition offering expert seminars, technology demonstrations and multiple networking opportunities for visitors. It is set to take place in March, 2022 in Dublin[22].

20 https://www.seai.ie/events/research-conference/
21 https://www.nweurope.eu/projects/project-search/opin-ocean-power-innovation-network/#tab-3
22 https://www.seai.ie/events/seai-energy-show

3.11
ITALY

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OVERVIEW

In the wake of the slowdown already observed in 2020 after the outbreak of the Coronavirus pandemic, 2021 was also characterized by a reduced rhythm of marine projects development. Nevertheless, some relevant advances concerning ocean energy occurred, both regarding technological innovations and research infrastructures. Some considerable activities were also planned for the coming years. These changes are described in the report, together with the annotation of the most relevant 2021 events.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

In 2020 Italy issued the National Integrated Energy and Climate Plan (NECP), setting challenging energy and environmental targets for 2030. NECP was presented by the Ministry of Economic Development, the Ministry of Environment and the Ministry of Transport and Infrastructures, but it was prepared with the collaboration of various high-level technical and research bodies.

Renewables are expected to grow remarkably, getting to very high levels of penetration in the electricity sector, around 55%. A key role will be played by mature technologies such as photovoltaic and wind plants, which will be promoted through competitive mechanisms and regulatory actions, however innovative and promising technologies, including marine, are also encouraged to give a contribution to 2030 targets. In that context the NECP announced that *ad hoc* measurements will be put in force for such innovative technologies, evaluating different supporting schemes. Such provision was also confirmed by the Legislative Decree no. 199/2021 issued on December 15, 2021, concerning the "Implementation of Directive 2018/2001/EU on the promotion of the use of energy from renewable sources". This decree contains provisions on energy from renewable sources and defines the necessary framework to achieve 2030 targets on RES share and the expected enhancement related to the implementation of the new “Fit for 55” package recently promoted by the European Commission, which aims at reducing the greenhouse gas emissions by at least 55% within 2030 compared to 1990. In particular, the Decree envisages the definition of tenders for innovative technologies.

The National Recovery and Resilience Plan (NRRP), the national plan functional to access the funds allocated in the Next Generation EU area, aims at giving a strong

impulse for a rapid restart after the pandemic impact on country society and economy. It is divided into 6 Missions or main thematic areas on which to intervene, identified in full coherence with the 6 pillars of the Next Generation EU. The mission with the greatest allocation of resources is that relating to the Green Revolution and the Ecological Transition, to which over 31% of the total amount of the Plan will be allocated, or 69.8 billion euros of the 210 overall. Its goal is to intensify Italy's commitment to the ambitious objectives of the European Green Deal and create new opportunities for growth and development for our country. In particular, the investment 1.3 of Mission 2C2 is concerned with the promotion of innovative plants, including marine energy converters, to which 680 million euros are allocated.

Finally, the cluster "Blue Italian Growth" (BIG), led by the Italian National Research Council (*Consiglio Nazionale delle Ricerche – CNR*), has continued its progress towards the establishment of an open structure for the aggregation of all the national actors involved in all the different sectors of the Blue Economy, including Marine Renewables. Sectoral Action Plans have been developed.

MARKET INCENTIVES

The Ministerial Decree 04/07/2019 is the latest issued support scheme, with the aim of promoting, through financial support, the diffusion of plants for the production of electricity from small, medium and large size renewable sources. In continuity with the D.M. 06/07/2012 and the D.M. 23/06/2016, registries and auctions are available to access incentives, which are dedicated to newly built photovoltaic plants, onshore wind turbines, hydroelectric plants and those with purification gas; according to NECP and Decree 199/2021, support for innovative technologies will be provided through following *ad-hoc* schemes, which will evaluate several kinds of promotion, depending on the maturity level of technologies.

D.M. 23/06/2016 was the latest scheme providing support for ocean energy. The Decree identifies four different ways of access to incentives: direct access, bid auctions (Dutch Auctions), registries for new power plants, for fully reconstructed power plants, for reactivated, empowered and hybrid power plants and registries for rebuilding intervention.

All the support schemes are managed by the Italian Energy Service Operator (*Gestore Servizi Energetici* - GSE), the body in charge of managing incentives to renewable energy.

New, fully reconstructed, reactivated or empowered wave and tidal energy power plants can access directly to incentives if their capacity is not greater than 60 kW, otherwise they must apply for access to registries.

The Directive 2014/89/EU on Marine Spatial Planning is also relevant for the specific Blue Energy Sector, as it establishes a framework for the implementation of maritime spatial planning and integrated coastal management by Member States, aimed at promoting the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources. The Directive has been transposed into the Italian legislation via the D. Lgs 201/2016.

PUBLIC FUNDING PROGRAMMES

In the National Recovery and Resilience Plan (NRRP), the investment 1.3 o Mission 2C2 is concerned with the promotion of innovative plants, including marine energy converters, to which 680 million euros are allocated.

The rationale is that achieving the 2030 and 2050 renewable energy targets implies a great deal of investment in the search for innovative energy production solutions, in terms of both technologies and plant configurations.

The project aims to support the construction of energy generation systems offshore renewable, which combine technologies with high development potential with multiple technologies experimental systems (such as systems that exploit wave motion), in innovative structures, also integrating storage. The

intervention, therefore, aims to build plants with a total capacity of 200 MW from RES in the coming years. The implementation of these interventions, considering the different technologies used, would make it possible to produce around 490 GWh per year, leading to an estimated reduction in greenhouse gas emissions of 286,000 tons of CO_2.

According to data from the 2021 OceanSET report, in 2019 in Europe, energy from the sea received 42.7 million euros in funding from regional and national research and development programs. The United Kingdom allocated the highest budget for Ocean Energy with 22 million euros, while France was the second with 5.8 million euros. Funds from Italy, Spain, Sweden and Ireland are between € 2 million and € 4.7 million;

Thanks to two innovative models developed by ENEA from 2020 it is possible to estimate the production of energy from the sea thanks to high-resolution forecasts of waves and tidal currents in the Mediterranean:

- **MITO:** capable of providing forecasts on the temperature, salinity and speed of sea currents with spatial detail ranging from 2 km up to a few hundred meters as in the case of Straits of Gibraltar, the Dardanelles and the Bosphorus;
- **WAVES:** the wave prediction system that guarantees resolution up to 800 meters in marine and coastal areas with high energy potential. Both models use the ENEA super computer "CRESCO6" with 1.4 million billion mathematical operations per second.

In the Mediterranean, the areas with the highest potential for wave energy are the western coasts of Sardinia and Corsica, but also the Strait of Sicily and the coastal areas of Algeria and Tunisia, where the average energy flow fluctuates between 10 and 13 kW/m. In addition to the waves, a novelty has been introduced in the model: local tides and those transmitted from the Atlantic through the Strait of Gibraltar have been included.

In Italy, tidal energy can be extracted mainly in the Strait of Messina. Together with the Strait of Gibraltar, this area shares the record as the most promising site in the Mediterranean: in fact, thanks to the exploitation of its currents that reach speeds of over 2 meters per second, the production of energy could reach 125 GWh per year, an amount sufficient to meet the energy needs of cities like Messina itself.

In our country, attention is growing for the exploitation of energy from the sea, in particular from waves since the extraction of energy from the tides is limited to a single geographical area and technology has a higher level of maturity. Initiatives in this sector are multiplying, but the most significant at public level concern the Research of the Electricity System and the recent establishment of the Blue Italian Growth National Technology Cluster (BIG) which sees in the development of marine renewable energies a driving force for economic growth and for the relaunch of the shipbuilding industry in our country. ENEA, together with the Polytechnic of Turin, is responsible for the activities related to marine renewable energy at the Technical Scientific Council of the Cluster-BIG. In February 2022 a collaborative workshop will be held to update the national action plan that will facilitate the achievement of marine energy objectives.

The Committee of Research Experts for the Electricity Sector (*Comitato di Esperti di Ricerca per il Settore Elettrico - CERSE*) plays a strategic role in orienteering R&D activities towards innovation of the electrical system, through funding under the EU principles that regulate State aid for Research and Development and Innovation. (Communication from the Commission 2014/C 198/01). The CERSE is composed of five members, appointed by the Minister of Economic Development, and is responsible for regulating public funding for research projects of general interest in the electricity sector.

RESEARCH & DEVELOPMENT

RESEARCH INFRASTRUCTURES

Marine Offshore Renewable Energy Lab (MORE Lab)

ENI's inaugurated a joint research laboratory with the Polytechnic of Turin, named Marine Offshore Renewable Energy (MORE) Lab. The MORE laboratory allows to deepen the study of all marine energy sources, investigating not only wave motion but also offshore wind and offshore solar. The MORE Lab is based at the Polytechnic of Turin but triangulates with two important Eni structures: the Marine Virtual

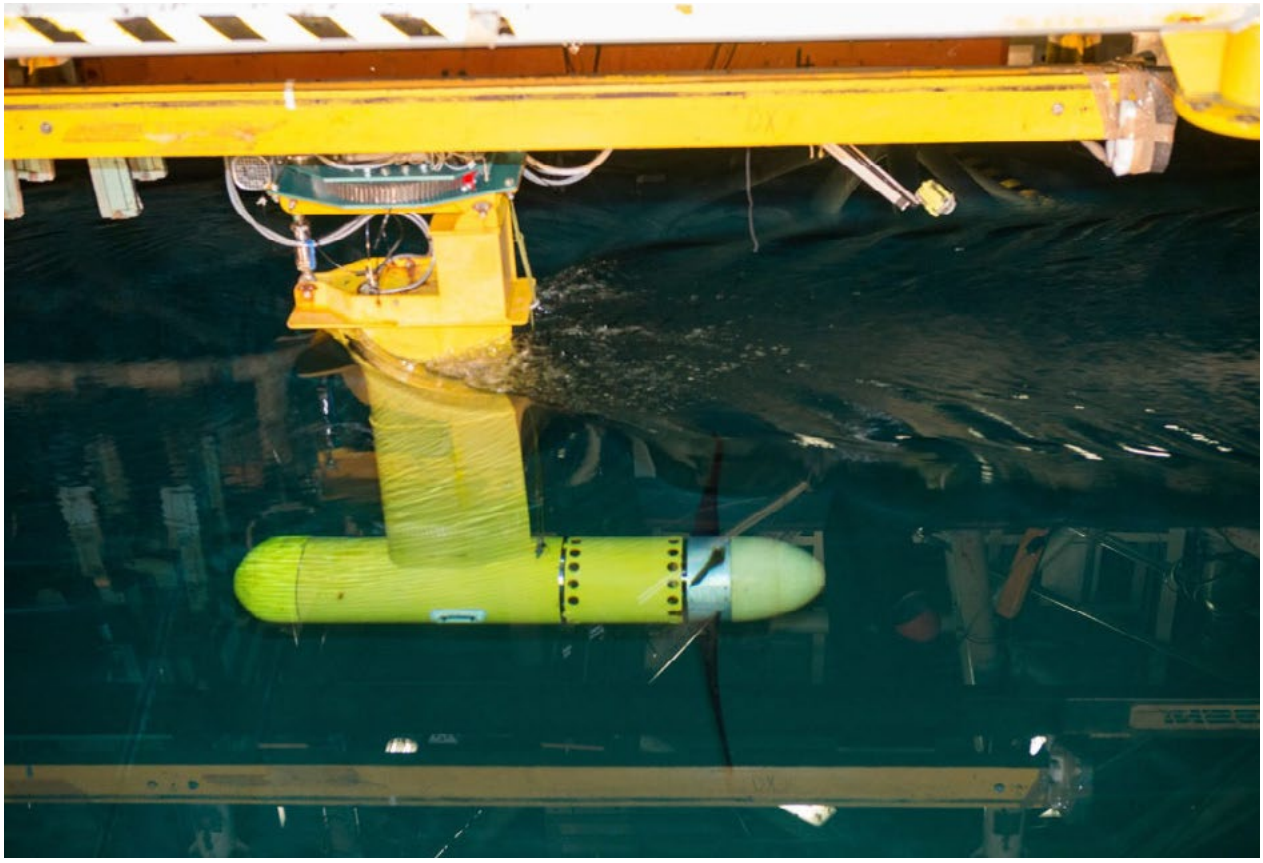
Lab (at the HPC5 supercomputing center in Ferrera Erbognone) and the offshore test area in Ravenna, where the pre-prototype phase of the ISWEC wave converter (the world's first hybrid and distributed wave and photovoltaic power generation plant). In addition to Piedmont, Lombardy, Emilia Romagna also in Sicily, the laboratory collaborates with the Polytechnic site in Pantelleria, where other aspects of this technology are tested in an ecosystem, the insular one, which aims at energy autonomy and zeroing of the landscape impact. Within Pantelleria, the MORE Lab has a sea area in permission for experimental testing; moreover, being the regional partner of the Clean energy for EU islands secretariat, the MORE lab has redacted the Energy Transition agenda for the decarbonization of the Island, currently in its second phase of implementation.

TOWING TANKS

Small and medium scale prototypes are tested in wave flumes and wave tanks where a specific sea state can be artificially created, and power production and device survival assessed:

CNR-INSEAN towing tank: In particular, the CNR-INSEAN offers the Umberto Pugliese towing tank, one of the largest worldwide. It is 470 m long, 13.5 m wide and has a depth of 6.5 m. It is equipped with a towing carriage that can achieve a maximum speed of 15 m/s. These infrastructures are used to test large-scale models of concepts with TRL up to 5 and allow the simulation of real operating conditions at sea, accounting for the combined effects of winds, currents and waves. The facilities are equipped with advanced measuring systems to provide the complete characterization of device performance and response to simulated operating conditions, including extreme events. Testing activity is supported by in-house laboratories for the design, manufacturing and maintenance of test models. A moving laboratory for field measurements is being developed to support on-site characterization and prototype operation activities. The CNR facilities have been included in the leading internationally distributed infrastructure MARINERG-I (a Horizon 2020 Project covering years 2017-2019), designed to accelerate the research development and deployment of offshore renewable energy (ORE). Similar initiatives are being promoted by CNR in the framework of the H2020 project “MARINERG-I” (2017-19).

University of Naples Naval Tank: The Naval Tank of the Department of Industrial Engineering - Section Naval of the University of Naples Federico II consists

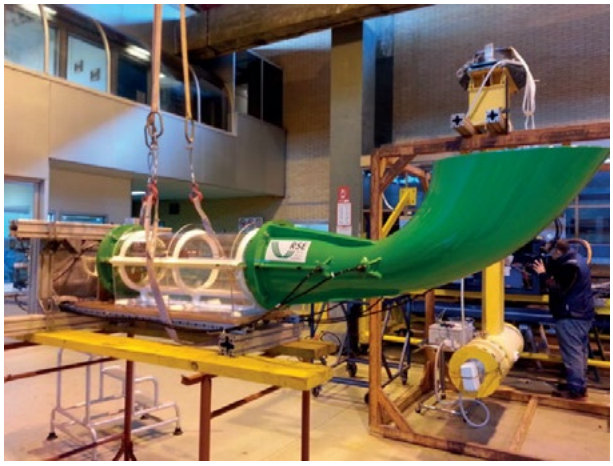


Examples of vertical-axis marine current turbines (VACT) models tested in the CNR-INSEAN towing tank (Kobold turbine)

of a straight basin, a dynamometric wagon and a wave generator. The laboratory of electronic measurements and instruments, the workshops for wood and iron processing, the laboratory for photographic surveys and television shooting are also annexed to the naval tank. The actual tank, having an overall size of 140.20x13.16x5.55 m is all enclosed in a casing, statically independent of it, which at a lower level allows to complete inspection and, at an upper level, delimits the working and running environment of the dynamometric wagon on rails arranged on the edges of the basin.

The Naval tank of University of Naples Federico II

Waves4water project: In March 2020, an open procedure was published for the award of research services for the development of new technologies to improve the energy and water supply system within the Porto Conte Regional Natural Park. The "Waves4water" project involves the implementation of technology for producing electricity from sea waves and for desalination. Through an activity of experimental research and development (R&D), the project will arrive at the prototyping, and the subsequent experimentation, of a system that will integrate a marine wave energy converter and a desalinator with which freshwater will be produced for self-consumption and agricultural uses within the Regional Park. The Waves4water project has the goal of producing renewable energy quantities per day on an annual average of at least 30 kWh/day, producing at least 2000 m^3 of desalinated water per year.



INNOVATIVE CONVERTERS

WAVESAX

RSE S.P.A. (*Ricerca sul Sistema Energetico* - Research on the Energy System), in collaboration with Tuscia University, developed **WAVESAX** (TRL 5/6), an innovative wave converter within the OWC category, registered by the European Patent Office (Patent Document N. 2 848 802 B1, European Patent Bulletin 2016/23). This device has been conceived for its integration in coastal structures (e.g. harbours and ports). It consists of a vertical pipe in which water moves upward and downward, following the wave motion. Inside the pipe a hydraulic turbine is positioned, which transforms the energy of the moving water into electricity. The turbine is of a bi-directional type (i.e. the rotor rotates in the same direction during both the ascending and the descending phase of water motion).

The WAVESAX 1:5 scale prototype and installation in the port of Civitavecchia

The main advantages of the device are its low cost and its modularity, as it can be installed individually or in batteries of several elements. Laboratory test studies have been performed on a scale model (1:20) in the ocean wave basin of the HMRC - Hydraulic Marine Research Centre (Cork, Ireland).

A second 1:5 scale prototype has been tested at the ECN Hydrodynamic and Ocean Engineering Tank (Nantes, France). In December 2020, a 1:5 prototype was installed in the port of Civitavecchia, with 15 kW nominal power. In the first months of operation, the relation between hydraulic power, turbine power and electricity generation were studied, leading to satisfying results.

PeWEC 2.0

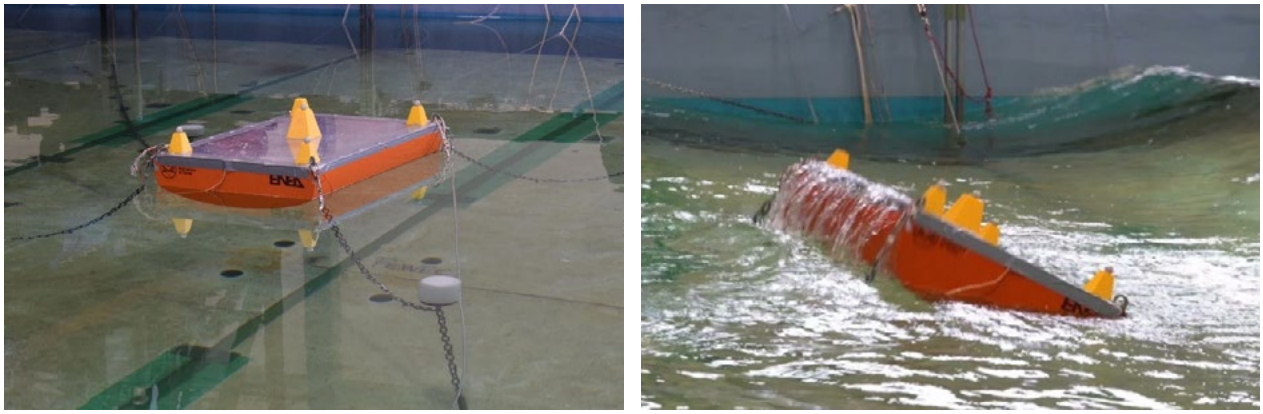
The Pendulum Wave Energy Converter (PeWEC) is, according to usual classifications, an offshore, floating, single-body, point-absorber, pendulum-based device. The PeWEC is mainly composed of a floating hull moored on the seabed and a pendulum connected to the shaft of an electrical generator, which is integral with the hull structure. In other words, the generator shaft constitutes the pendulum hinge. The pendulum, the electrical generator and all the other equipment necessary for the device functioning are enclosed in the hull and protected against the corrosive action of seawater.

The PeWEC project, born in 2014 from the collaboration between ENEA (the Italian National agency for new technologies, energy and sustainable economic development) and the Politecnico di Torino, was initially financed by the Italian Government through the grant Accordo di Programma ENEA-MISE 20155. A 1:12 scaled prototype was designed and widely tested at the INSEAN wave basin. Under the ongoing grant Accordo di Programma ENEA-MISE 2019-2021, several technical improvements took place, with a testing phase in naval tank in Federico II (Naples) carried out in 2021.

The two research partners are now working on the realization of the preliminary 1:1 scale PeWEC project to be installed along the “most energetic” coasts of the Mediterranean, such as the west coast of Sardinia and the Strait of Sicily. The 525 kW device will be 15 meters long, 23 meters wide and 7.5 meters high for a weight, including ballast, of over 1,000 tons.

W.e.l.s.

The technology is called W.e.l.s. (Wave energy light system), and is the result of long studies that start from the first turbine created in order to exploit the wave energy. Two turbines were installed in Lipari island (150 Watt and 1.3 kW) to properly prove that these turbines can start to produce electricity with a minimum wave. These are particular turbines unique in the panorama of the reference market, able to produce electricity using very low waves and with application in port docks and breakwaters. Currently, 5 and 7 kW turbines are under construction and a project of 10 kW turbines will be tested in one of the large OWC rooms in the Civitavecchia harbour. The project was born from the collaboration between CNR, Fimeco ltd (Messina company that deals with mechanical processing and hydroelectric turbines) and Enermedesea ltd (an innovative start-up specialized in the renewable energy sector). In Lipari, the turbines have been placed for demonstration purposes and have already been dismantled. Enermedsea intends to submit to the Lipari municipality a partnership proposal for the construction of a 300 kW power plant.

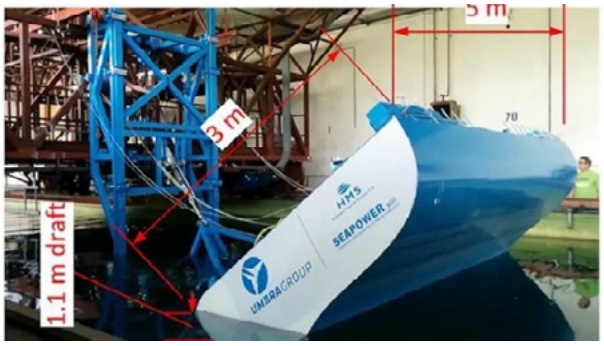


Testing phase of the 1:12 prototype at the University of Naples naval tank

The turbine developed by Fimeco and Enermedsea installed in Lipari island breakwater barrier

PIVOT Wave Converter

The PIVOT system consists of a hinged floating body oscillating under the effect of wave motion and an electric generator, connected via hi-tech components. It has been developed from the GEL prototype by SeaPower s.c.r.l.in collaboration with the University of Naples "Federico II". The conversion of mechanical energy can be achieved through a variety of technical solutions. The PTO currently consists of an electric generator coupled to a recirculating-ball screw that was designed in collaboration with the manufacturer, Umbra Group Spa.



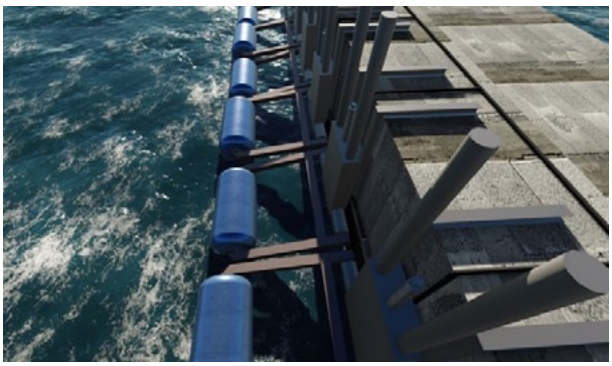
Wave tank experimental test on large scale model of Pivot

The PIVOT concept can be exploited in different configurations, by using alternative PTOs or by adapting the mobile and fixed structures to specific requirements. In particular, a system based on an oscillating floating body is currently under development, in which the mechanical transmission of motion to the generator is achieved via an innovative system that reduces the criticalities deriving from the alternating wave-induced motion. The new configuration will be designed for both offshore and onshore installation.

The ECOMar 100 wave energy converter for near-shore installation (TRL 4)

The ECOMar system by Kuma Energy is a Wave Energy Converter that can be integrated into any vertical structure and installed on any seabed. ECOMar is a versatile hybrid system that combines a hydraulic and an electromagnetic converter, allowing energy production at both low and high frequencies and for different wavelengths. It integrates a system for environmental monitoring, in order to automatically be switched off in case of extreme sea conditions, and is designed to be completely harmless for vessels adrift, as its floating body acts as a robust fender. ECOMar can be easily equipped with a system for the collection of plastic or other floating waste.

A 1:8 prototype has been tank tested while a pilot plant is under development. In December 2019, the Apulia Region Economic Development Department and the company Kuma Energy signed a contract for the construction of a pilot plant for the measurement of wave motion in the harbour of Taranto, preparatory to the construction of future plants. In March 2020, the Port System Authority of the Southern Adriatic Sea and Kuma Energy srl, have signed a memorandum of understanding aimed at starting the first pilot plant of the ECOMar system.



The ECOMar 100 wave prototype

TECHNOLOGY DEMONSTRATION

In Italy, there is an increasing interest in the exploitation of wave and tidal energy converters. In particular, wave converters integrated into conventional breakwaters have gained more and more interest among the port managers, as they offer the opportunity of energy self-sufficiency for the infrastructures in conjunction with a limited increase in costs and with ease of maintenance. Italian companies engaged in the supply chain for wave and tidal energy converters detain long-term experience and innovation capacity, which can support all the specific, high-tech steps of the design and production process. The most promising devices that have been developed and improved in the last few years are reported below.

Table 1. Overview of the main projects in Italy to 2021

Country	Name of project	Technology Developer	Place	Project Status	Type of resource	Installed Capacity (MW)
Italy	REWEC3 @ Civitavecchia	Mediterranean University of Reggio Calabria	Civitavecchia, Tyrrhenian Sea	fully operational	Waves	0,020
Italy	Overtopping Breakwater for Energy Conversion (OBREC)	University of Campania Luigi Vanvitelli	Napoli, Thyrrenian Sea	fully operational	Waves	0,008
Italy	MaREnergy	ENI, Wave for Energy, Politecnico di Torino	Ravenna, Adriatic Sea	fully operational	Waves	0,050
Italy	Marina di Pisa H-WEP 1	Enel Green Power	Pisa, Thyrrenian Sea	fully operational	Waves	0,050
Italy	GEMSTAR Demonstration II	Seapower Scrl	Messina, Thyrrenian Sea	early planning	Tidal Currents	0,300
Italy	ISWEC revamp	ENI, Wave for Energy, Politecnico di Torino	Pantelleria, Mediterranean Sea	Planned to be fully installed by mid 2022	Waves	0,250
Italy	ISWEC MED	ENI, Wave for Energy, Politecnico di Torino	Pantelleria Island, Mediterranean Sea	Planned for 2024	Waves	1

REWEC3

The Mediterranean University of Reggio Calabria has been developing the REsonant Wave Energy Converter (REWEC3), which is a particular type of Oscillating Water Column (OWC) incorporated into a traditional vertical breakwater of monolithic reinforced concrete structure type. This activity is being carried out in cooperation with Wavenergy.it – an Academic Spin-Off of the Mediterranean University. It consists of a vertical pneumatic chamber connected to the open wave field by a U-duct.

A small-scale device has been installed at the Natural Laboratory of the University in 2005. The REWEC3 has already been installed in the port of Civitavecchia (Rome) and the famous architect Renzo Piano plans to insert it in the new port of Genoa. It will soon also be built in the Port of Salerno and Roccella Ionica (Reggio Calabria) and its installation will be evaluated both in the Principality of Monaco and in Belgium to defend the artificial islands. About the first full-scale prototype built in the port of Civitavecchia, the Port Authority of Civitavecchia decided to upgrade its infrastructure and adopted the REWEC3 technology for the realization of 17 new caisson breakwaters. Each REWEC3 caisson is 33.94 m long and includes 6-8 independent chambers. The total length of REWEC3 caissons is 578 m. A first Wells turbine of 20 kW has been installed. With all the caissons equipped with turbines, the total capacity would be 2.5 MW.

Overtopping Breakwater for Energy Conversion (OBREC)

The University of Campania Luigi Vanvitelli has developed a wave energy device denominated OBREC, embedded into a breakwater and based on the wave overtopping process. A 1:30 scale prototype was tested at Aalborg University (Denmark) during two complementary experimental test campaigns in 2012 and 2014. Tests have shown that the integration of an OBREC into a breakwater improves its overall performance. A full-scale, 6 m long prototype has been installed in the port of Naples in 2015, along the San Vincenzo rubble mound breakwater, where sea depth is about 25 m and available wave power is estimated to be around 2.5 kW/m. The overall performance of the device is being monitored.

Breakwater equipped with the OBREC prototype in the Naples harbour

Inertial Sea Wave Energy Converter (ISWEC)

The Polytechnic of Turin developed ISWEC (TRL 7), a pitching point-absorber wave energy converter suitable for mild climate seas such as the Mediterranean. It is based on the gyroscopic technology already used in marine applications for roll stabilization, except that the direction of energy transfer is reversed, with the gyroscopic torque induced by the incoming waves being exploited by the electrical PTO. Research activities started 15 years ago and led to the development of the technology industrialized by Wave for Energy, a spin-off of the Polytechnic of Turin.

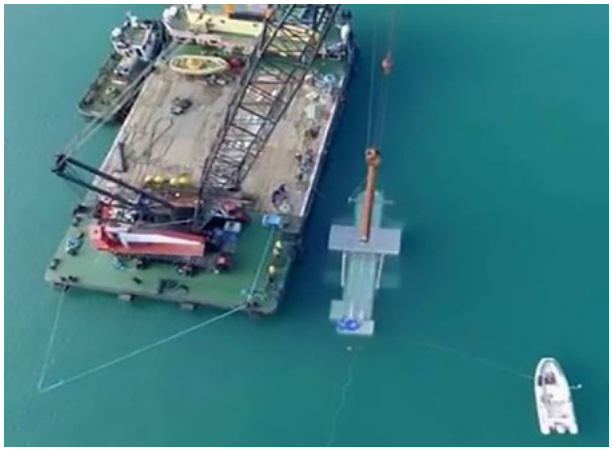
In August 2016, the first full-scale ISWEC prototype, with a nominal power of 100 kW, was moored 800 m from the coast of Pantelleria. In March 2019, another ISWEC pilot project has been put into operation, with a nominal capacity of 50 kW, in the Adriatic Sea off the coast of Ravenna. In October 2019, Fincantieri, Cassa Depositi e Prestiti, ENI and Terna agreed to launch the first phase of a joint project to convert ISWEC into an industrial-scale power station.

ISWEC installation

PowerBuoy

Ocean Power Technologies (OPT) PowerBuoy has been deployed in the Adriatic Sea since November 2018 by the Oil&Gas company Eni in a project aiming to demonstrate the suitability of wave energy technologies in oil and gas operations. Operating continuously and error-free for six months, as part of Eni's MaREnergy project, PB3 PowerBuoy has produced more than 1 MWh cumulative energy. The OPT PowerBuoy will be used to advance Eni's research and development of proprietary integrated subsea technology systems to allow future applications for

Deployment of OPT PowerBuoy in the Adriatic Sea



The installation in Marina di Pisa

remotely controlled field developments powered by wave energy, environmental monitoring and offshore asset inspection using autonomous underwater vehicles (AUVs).

H-WEP 1

H-WEP 1 wave energy converter was first deployed off the coast of Marina di Pisa (Tuscany) by 40South Energy in September 2018 and it is operated and managed by Enel Green Power. The H24-50 kW is a sort of large mobile body that runs on a horizontal guide that collects the energy of the waves and puts it directly into the grid. H24 has the shape of a large table about 2 m high and 20 m long. It also has an electromechanical system which, by exploiting the wave movement, generates energy. In grid-connected situations these machines are being used in Wave and Tidal Energy Parks consisting of several units in arrays, typically disposed parallel to the shore. The ideal situation is when coastal protection structures are already present or in need, like when there are harbours or airports.

Tidal turbines - GEM and GEMSTAR

ADAG and SeaPower s.c.r.l., in cooperation with Ing. Morrone, designed **GEM**, the Ocean's Kite (TRL 7), an ocean current energy conversion system that consists of a submerged body with two horizontal axis hydro turbines. It is tethered to the seabed and free to self-orienting to the current. The device is placed at the desired depth thanks to its self-towing winch and is easily recovered to the surface for maintenance. A first full-scale 100 kW prototype has been deployed in Venice lagoon. A full-scale prototype of 300 kW will be installed in the Strait of Messina.

Illustration of the deployed GEMSTAR system.

GEMSTAR is a submerged floating tidal current hydrokinetic turbine system (an evolution of GEM turbine), consisting of two counter-rotating turbines, mounted on the sides of a submerged structure that contains the electronic components. During operation, GEMSTAR behaves like a sort of submarine kite that remains fixed thanks to the balance between the thrust acting on the turbine and the structure, and the buoyancy force of the hollow part of the structure. For maintenance, GEMSTAR can be brought to the surface releasing the tension of the mooring line; also, an heading direction control system avoids the uncontrolled rotation around the vertical axis and the related possible excessive twisting of the mooring and power cables.

RELEVANT NATIONAL EVENTS

- **2-4 June 2021** - Marine 2021, Virtual IX International Conference on computational methods in marine engineering. Machine learning and artificial intelligence in marine engineering
- **30 June 2021** - Chamber of Commerce Chieti Pescara, meeting, as part of the Interreg Italy-Croatia Coastenergy Project, "Blue Energy and local hub to promote marine renewable sources"
- **22 July 2021** - A Sea of Energy, Municipality of Noli (Savona, Liguria Region)
- **4-6 October 2021** - IEEE International Workshop on METROLOGY FOR THE SEA, Reggio Calabria, Italy
- **21 September 2021** - Towards the States General of the Blue Economy in the Mediterranean: a roadmap between Italy and Tunisia

3.12
MEXICO

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OVERVIEW

The programme for the implementation of Technological Roadmaps for ocean energies, published in 2017 by the Ministry of Energy, is being continually updated as technological developments take place and public policies are altered. At national and local (potential sites) scale, theoretical assessment of wave, current, saline gradient and thermal gradient energy resources in Mexico has been completed by CEMIE-Océano. Progress has been made in the instrumentation of two natural laboratories and in the CEMIE-Océano wave tank testing activities have begun. Comprehensive studies for energy extraction viability were conducted, incorporating technical, environmental and social aspects. Joint projects were carried out to develop marine current turbines. Mexico has been developing and testing superhydrophobic, nanostructured ceramic and polymeric coatings for marine environments. CEMIE-Océano, A.C. initiated activities, and the CEMIE-Océano Project and CEMIE-Océano, A.C. organized the 1st CEMIE-Océano International Conference (virtual).

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Short and medium-term goals have been set for the generation of electricity from clean energy sources. The Energy Transition Law (LTE) (2015) establishes a minimum share of clean energy electricity generation of 25% by 2018, 30% by 2021 and 35% by 2024. This 2024 goal is the commitment of Mexico as part of the Paris Agreement. In particular, the Technological Roadmap (TRM) for ocean energy is focused on strengthening the technological capabilities required, including infrastructure, specialized human resources and technological services. It also prioritizes the actions required to reach the 2030 goals for installed capacity, as well as detailed activities, identification of stakeholders, targets and milestones in a specific timeframe. It is therefore estimated now that ocean energy could contribute 500 to 1000 MW of installed capacity by 2030.

In 2021, a constitutional energy reform was proposed by Mexico's President with the aim of putting the Comisión Federal de Electricidad (CFE) in charge of setting terms for private generators. This reform would decrease interest in the use of renewable energies and therefore the possibility of more private investment in renewables in Mexico would be affected. This reform will be debated in Congress in 2022.

PUBLIC FUNDING PROGRAMMES

The Fund for Energy Transition and the Sustainable Use of Energy was created by the Ministry of Energy (SENER) and the National Science and Technology Council (CONACYT) to promote and support projects and initiatives which contribute to the fulfilment of the National Strategy for Energy Transition and the Sustainable Use of Energy. In 2017, CEMIE-Océano was created through this fund; the approximate budget of the CEMIE-Océano for 2021 was around 1.5 million Euros. This fund was closed in 2021 in line with national policies. Currently, there are no public funding programmes for marine energy research and development.

RESEARCH & DEVELOPMENT

CEMIE-Océano

Progress was made on the CEMIE-Océano developed project into a vertical axis helical turbine for low-speed marine currents. The main difficulty, inherent in developing turbines, is achieving dynamic similarity. When scaling the device from laboratory size to real size machinery, the process is more complex than a geometrical enlargement. For adequate scaling, the first laboratory-sized prototype featuring the final geometric parameters was 3D-printed (16 cm in diameter, 16 cm in height) using the capabilities and characteristics of the flume at the Instituto de Ingeniería, UNAM, Mexico. Experiments were carried out changing flow velocity and turbine load. For the characterization of the turbine, procedures were designed and a torque measurement technique developed, thus providing power coefficient values for each test. At the same time, numerical simulations were performed to compare torque predictions.

These results allowed the design and building of a larger turbine prototype, as well as the definition of the procedure to attain dynamic similarity for these velocities and dimensions. Considering a flow velocity of 1.2 m/s for regular operating conditions, the estimated mechanical power output is 300 W and the turbine rotation startup is at 0.8 m/s. This prototype was manufactured in glass fiber (100 cm in diameter, 86 cm in height) with an internal structure made of iron. The latter was sent to the towing tank in the Kelvin Hydrodynamics Laboratory at the University of Strathclyde, UK. The instrumentation required for the tests and sent along with the turbine. Experiments were carried out in late 2021. The latest results indicate a rotation startup point of 0.4 m/s. Analysis of the experimental results will be completed in early 2022, with the idea of performing design improvements and installing the device in the Cozumel Channel, in SE Mexico.

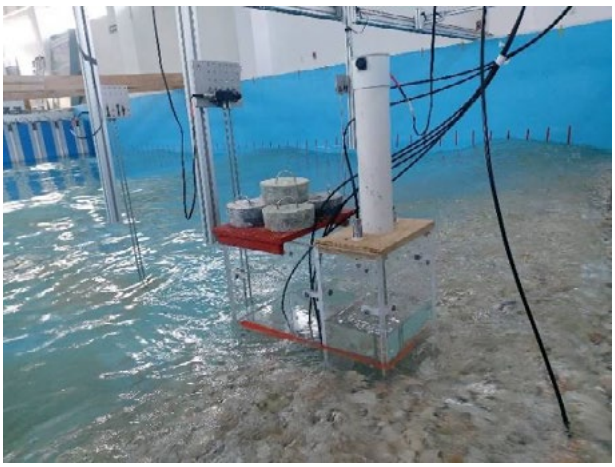
Large scale prototype of the vertical axis helical turbine for low-speed marine currents

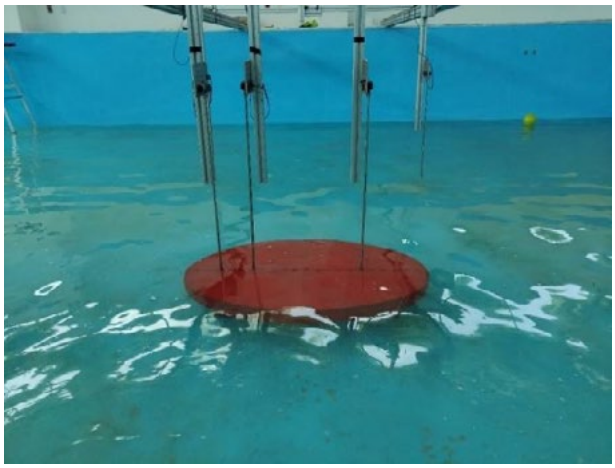
The CEMIE-Océano wave tank was inaugurated, located at the Instituto EPOMEX of the Universidad Autónoma de Campeche. In this laboratory, the operation of an Ocean Wave Chamber (OWC) was characterized under different conditions of height, period and wave direction. The objective is to evaluate its efficiency for Mexican wave conditions. Likewise, work was carried out on the study of a wave concentrator lens through physical and numerical simulation.

Successful laboratory-scale tests have been carried out in a wave tank in the Universidad de Colima, where a Wave Energy Converter, based on the Stewart-Gough Platform (CICESE-SGP-WEC) concept was used. The main results are being analysed and the principal focus is the use of six linear generators as the legs of the floating component of the device. Efficient conversion is the greatest challenge while the arrangement and geometry of six linear generators will benefit energy harvesting, regardless of the relative wave direction and wave field directionality.

The resource evaluation for oceanic currents in the Mexican Caribbean, with an emphasis on the region of Cozumel Island, was concluded in 2021. This evaluation was performed at different spatial scales, assessing the oceanic currents in deep waters with ADCP measurements, using a validated and adjusted medium-scale numerical model (HYCOM), with measurements at shallower depths (20 m), where the combined effects of waves and turbulence are being assessed, and with a nested numerical model (ROMS) that includes turbine-scale resolutions and effects. We have also advanced considerably on the evaluation of the environmental impacts at this sensitive location, including the probability of collision for marine mammals and large fish, noise propagation, alteration in larval dispersion patterns, alteration in coastal morphology and sedimentation patterns, and effects on large scale oceanographic processes (i.e. upwelling and mixing). The results of these achievements give us confidence that energy extraction at the site is a possibility that would not produce adverse effects to the environment. At national scale, the Atlas of Available Tidal and Oceanic Current Energy, and a comprehensive evaluation of the tidal energy resource in the Gulf of California, were concluded.

The OTEC-CC-MX-1kWe prototype is currently being laboratory tested and the results are promising. OTEC-CC-MX-1kWe is the first OTEC power plant prototype designed and installed in Latin America. The objective is to develop and test an OTEC system that will encourage thermal energy use in Mexico. This closed-





Ocean Wave Chamber (OWC) tested in the CEMIE-Océano wave tank

OTEC-CC-MX-1kWe prototype in the Universidad del Caribe

One of the RED salinity gradient energy laboratory prototypes developed by CEMIE-Océano

Nanostructured and superhydrophobic materials tests in the Mexican Caribbean

cycle OTEC prototype has been being developed since 2018 at the Universidad del Caribe. It uses R-152a as a working fluid and it is hoped it will produce 1 kW gross of electric energy.

In salinity gradient energy, substantial advances were made in understanding three main aspects:

1) The natural energy resource in Mexico (river mouths, hypersaline coastal lagoons, other saline water bodies resulting from industrial activities). Through field campaigns to measure the physical and ecological characteristics of the systems, a sound idea of the theoretical energy potential and the factors that must be carefully considered to minimize, and if possible, avoid negative impacts to both the biota and the physical function of each particular system.

2) The technology for energy acquisition, mainly through studying the RED technique, experimenting with membranes (made of graphene), with the electrodes, and with the fluxes within the membranes, with the collaboration of CEMIE-Océano members from various institutions, currently working on RED prototypes.

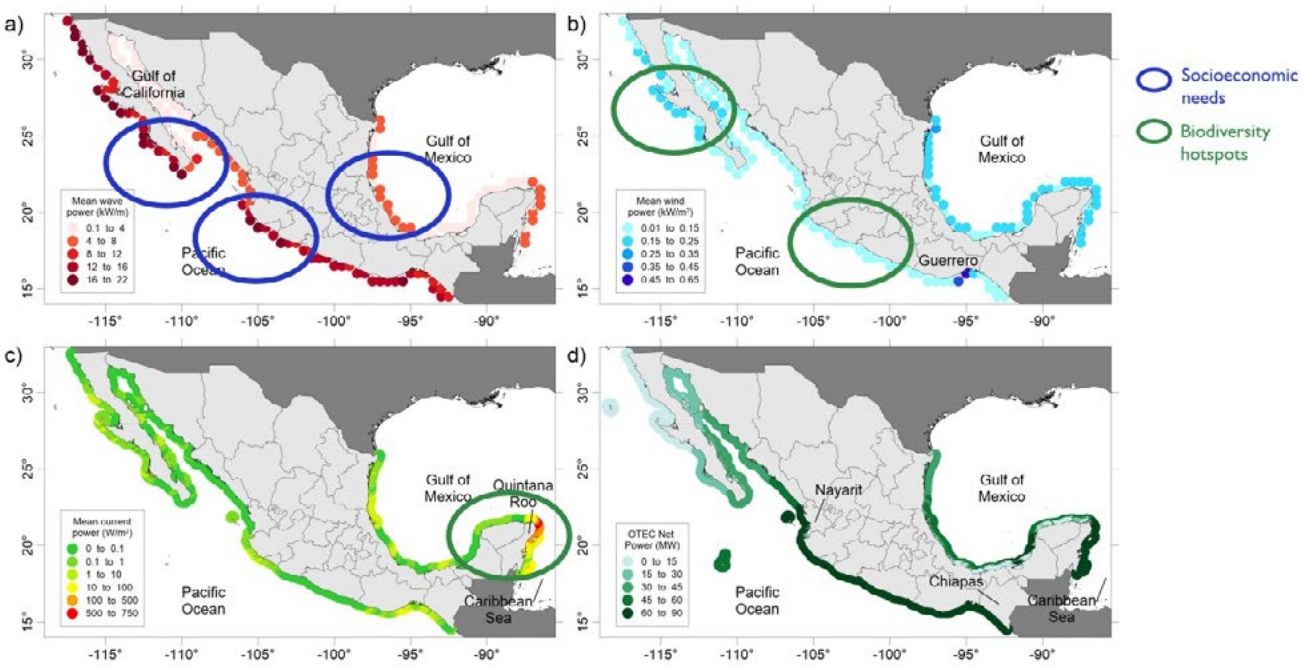
3) A large database is being organized of all the field data gathered and information acquired. This will soon be publicly available through an online Atlas that contains the thermohaline characteristics of the sites studied and their environmental variables.

Mexico is currently developing nanostructured and superhydrophobic ceramic, polymeric and metallic materials, capable of withstanding the harsh, corrosive marine environment. These materials are being tested in the Mexican Caribbean to validate their performance and study how their microstructure and composition can affect or inhibit the growth of different biofilms. This work is currently being expanded with the use of machine learning and artificial intelligence in order to accelerate the discovery of new compositions and microstructures.

Advances have been made in the socio-environmental impact assessment:

a) a diagnosis of zones with potential for ocean power generation, based on technical potential, the geomorphological characteristics of the coast, the socioeconomic needs and environmental restrictions (presence of protected natural areas with fragile ecosystems such as mangroves and coral reef);

b) generation of information on the structure, composition and functioning of coastal and marine



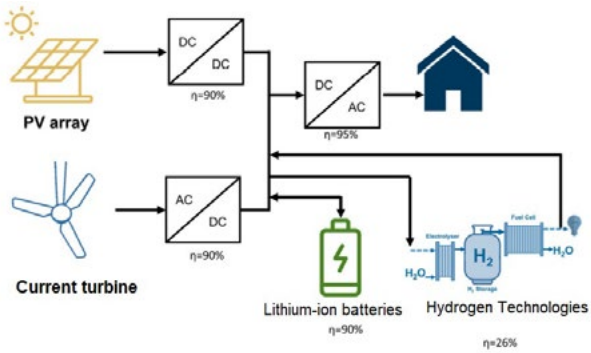
Assessment of potential marine renewable energy, socioeconomic needs, and biodiversity hotspots: a) waves, b) offshore wind, c) ocean currents, d) thermal gradient (OTEC)

ecosystems and species, to determine the potential socio-environmental impact of the installation of new energy generating devices. This group has made inventories of flora and fauna at potential sites for ocean power generation. Keystone species considered in these analyses include marine mammals, endemic, and invasive species, which largely affect the functioning of the natural ecosystems.

c) the Ecology Group has also made life cycle assessments and evaluated the efficient use of energy in human settlements on the coasts.

The combination of these approaches yielded a National assessment of potential sites for ocean energy production considering a multidisciplinary perspective.

CEMIE-Océano is developing stand-alone systems in remote regions using renewable resources (e.g. solar and marine), which require energy-storage systems that permit continuous power to be supplied, despite the natural intermittence of the resources. Hybrid storage systems are needed in stand-alone systems since, for daily storage, lithium-ion batteries are better suited, while for seasonal storage, hydrogen-producing systems are more suitable to manage the amount of energy and the length of storage needed because of the high variation in seasonal renewable-energy.



Hybrid storage systems for including marine renewable energy

Science dissemination and communication activities of the CEMIE-Océano included the publishing of 3 books in Spanish: "Devices for Obtaining Power by Currents: Present Situation"; "Climatology of Tropical Cyclones in Mexico", and "A Business Plan Focused on Research and Development Projects", and also, the biannual publication of the CEMIE-Océano bulletin, which is the main form of disseminating information on the activities of participants in CEMIE-Océano. This is complemented by publications on the website (www.cemieoceano.mx) and social networks, which, together had an annual increase in consultations 50% higher than 2020.

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

A Natural Laboratory for Scientific Research and Development of Marine Energy is being installed in waters off Todos Santos Bay, near Ensenada, Baja California. An HF radar system is included in the site, as well as a Marine Radar and several wave and current sensors, anchored to fixed bottom structures and also deployed in surface, oceanographic buoys. The goal is to gather detailed information regarding the environmental variables of this site, as well as comprehensive data on the prevailing wave regime and its spatial and temporal variability.

Following numerical and laboratory tests, a hydrogenerator has been upscaled for tests in the field. The hydrogenerator HIPA is a floating device with combined vertical and horizontal blades, and a structure to concentrate currents in order to increase velocities. The device is instrumented with torque measurements and rpm estimations, apart from cameras and velocity measurements (acoustic and electromagnetic velocimeters). Preliminary tests show better anchoring systems are needed and the possibility of fully submerging the blades to improve performance seems desirable.

HIPA hydrogenerator testing in the field

PLANNED DEPLOYMENTS

CEMIE-Océano is planning further installations soon:

- A wave energy device - Baja California
- An ocean current turbine - Cozumel Channel

RELEVANT NATIONAL EVENTS

- In June 2021, the "Virtual workshop on ocean energy sources" was organized by CEMIE-Océano. This had 9 modules, with a total of 42 hours of pre-recorded lectures and 18 hours of face-to-face sessions. More than 150 attendees participated in the workshop.
- In August 2021, the 1st CEMIE-Océano International Conference (virtual) was held, organized by the CEMIE-Océano Project and CEMIE-Océano, A.C. The event consisted of 89 oral presentations, 27 posters and 12 keynote speeches. The participants included experts and students from Mexico, Colombia, Spain, the United Kingdom and Uruguay.
- CEMIE-Océano, A.C. (https://cemieoceano.mx/CEMIEOAC/) was established in 2020 to give continuity to the research that has been developed within the CEMIE-Ocean Project of the SENER-CONACYT Sector Fund. It began its activities with the 1st General Assembly in November 2021 (virtual).
- The Pan-American Marine Energy organization will have its bi-annual meeting, PAMEC 2022, at CICESE and UABC in Ensenada, Baja California, Mexico, 15-18 May. CEMIE-Océano will be one of the main pillars in the organization, as well as in the promotion of the meeting.

3.13
MONACO

AUTHOR
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SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

On the instigation of H.S.H. Prince Albert II, the environment and subjects related to sustainable development are among the most important political priorities in the State of Monaco, on both a national and international level. The actions of the Princely Government take into account the topics of biodiversity, preservation & management of natural resources and the reduction of greenhouse gases and also a specific policy towards the establishment of a sustainable city.

The Principality of Monaco joined the OES in June 2013. This action was part of the Government targets for combating climate change and recognizing the relevance of international cooperation.

Monaco is a coastal country with 2,08 km² of area, bordered by the Mediterranean Sea, with a coast length of 3829 m.

The Government pursues a sustainable development policy aimed at achieving full compliance with the Principality's undertakings.

According to the National Determined Contribution, in line with the provisions of the United Nations Framework Convention on Climate Change and the Paris Agreement, Monaco is committed to reducing greenhouse gas emissions by 55% in 2030 compared to the reference date of 1990 and to achieving carbon neutrality in 2050.

PUBLIC FUNDING PROGRAMMES

Within the framework of the Paris Agreement, a National Green Fund has been created and is financed by:

- a contribution generated through the sale of electricity;
- the Government budget.

This fund is dedicated to financing actions in favour of the reduction of GHG emissions and the energy efficiency and the development of renewable energies. Furthermore, the Government holds 100% of the shares of a venture capital firm, known as "*Société d'Aide à la Création et au Développement d'Entreprise*" (SACDE), the aim of which is to support innovative Monegasque companies.

RESEARCH & DEVELOPMENT

A prototype of the society SBM Offshore of a wave-powered machine should be set up in the Monaco territorial waters in partnership with the Government Services in 2022-2023. The project initially planned for 2021 has been postponed.

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

In Monaco, the sea is used as a renewable energy source for the development of a heat pump system. The first seawater heat pump in Monaco dates back to 1963. 80 seawater heat pumps produce 17% of the energy consumed in the Principality (about 191 GWh/year).

Many buildings located on the coast benefit from this reversible system, for heating in winter and air-conditioning in summer.

PLANNED DEPLOYMENTS

Two new thalossothermal loops connected to seawater heat pumps are under construction. They should supply 3500 homes and eliminate 6 kt of CO_2 equivalent of GHG emissions (approx. 8% of the total emissions of Monaco).

RELEVANT NATIONAL EVENTS

5 - 7 April 2022: EVER Monaco (Ecologic Vehicles/Renewable Energies)

3.14
NETHERLANDS

AUTHOR
Jos Reijnders, Netherlands Enterprise Agency

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

The Netherlands has a national target of 16% renewables in 2023 and follows the EU targets for 2030. There is no specific target for ocean energy. The marine spatial planning is focused on offshore wind, special areas have been appointed for offshore wind (3500 MW).

The reconnaissance study conducted by TNO gave no reason to revise the innovation agenda for ocean energy. An additional study is now being started to address possible knowledge gaps.

MARKET INCENTIVES

The generic national subsidy scheme (SDE++, stimulating renewable energy) for 2022 is not yet open. In 2021, the subsidy for the ocean energy options varied from 0.0579 €/kWh to 0.1097 €/kWh, divided into 4 phases. The project probabilities in lower subsidized phases are higher. The maximum subsidy for renewables is limited to 300 €/ton avoided CO_2. In general, subsidies decrease every year, due to the decreased costs of offshore wind, which is considered the benchmark. Other techniques are also experiencing a drop in price.

PUBLIC FUNDING PROGRAMMES

In addition to the feed-in tariff (OPEX subsidy) mentioned above, there are generic funding programmes (CAPEX subsidy) for all relevant types of renewable energy. The Ministry of Economic Affairs and Climate initiated a number of grants via generic R&D instruments, these are also available for ocean energy research. These programmes have a tender system in which projects compete with each other, and have a general condition that a cost reduction must be achieved by innovation.

RESEARCH & DEVELOPMENT

In 2021 there were no new projects, the following projects are still running:

OceanDEMO is a 4-year Interreg North West Europe project running from 2019 to 2022. Ocean DEMO specifically targets multi-device ocean energy installations to prove their technology at full commercial scale. By the end of 2021, Dutch Wave Power started their deployment off the coast of The Hague in 2022. Dutch developers SeaQurrent and Oceans of Energy were already demonstrating their scaled systems.

VALID is a 3-year H2020 project. It will develop and validate a new test rig platform and procedures for accelerated hybrid testing that can be used across the wave energy sector to improve the reliability and survivability of the components and subsystems that form Wave Energy Converters (WECs). The methodology for accelerated hybrid testing combines both physical testing (physical test rigs) and virtual testing (simulated environment, numerical models and data). The VALID Hybrid Test Platform (VHTP) will become the interface that allows for seamless accelerated hybrid testing. With the long-term goal of establishing a standard for future use and making a step-change impact on the sector, the new test rig platform and methodology will be validated for a variety of WECs, critical components and subsystems through three different user cases. TU Delft is one of the academic partners contributing to the development of the new hybrid testing platform with open access for models, testbeds and improved data management to lower the cost on future technologies.

TECHNOLOGY DEMONSTRATION

OPEN SEA TEST SITES

Main developments in test sites during 2021:

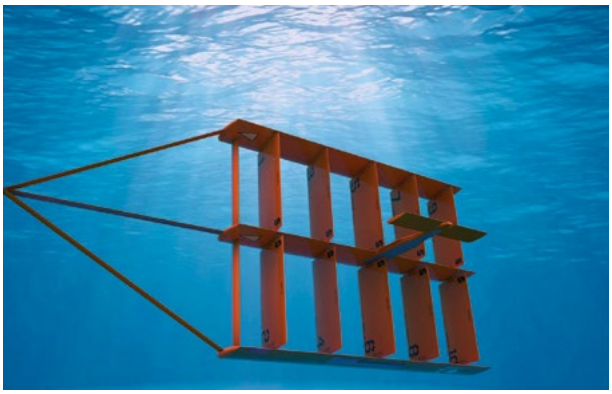
Test Site Name	Location	Promoter/ manager	Grid Connection (Y/N)	Status
REDstack	Afsluitdijk	REDstack	Y, 4-50 kW	Operational
Tidal test site Ameland	Ameland	SeaQurrent	Y, 500 kW	Planned 2022
Wave test site Texel	Texel	Slow Mill	N, 40 kW	Operational
Tidal Test Centre (TTC)	Grevelingen barrier	BT Projects	N	Stopped

OPERATIONAL PROJECTS

Tocardo's Oosterschelde Tidal Powerplant (OTP), made up of a platform of 5 x T-2, 250kW Tocardo tidal turbines, resumed full continuous operations again on 1 February 2021. At the end of the year, Tocardo shipped 3 x T-1, 40-100 kW tidal turbines to Pembroke, UK. This community-scale turbine cut down the LCOE by simplifying the logistical operations and by improving its reliability and applicability.

Slow Mill has commissioned their 40 kW wave energy installation at the Port of Den Helder. The company designed a novel wave energy device for the moderate wave climate of the North Sea and tested a prototype 4 km of the coast of Texel island. In the summer of 2021, Slow Mill completed inspection and sampling at sea for deploying, providing the island of Texel with clean renewable energy next year. Each full-scale wave energy converter is projected to harness 400 kW from North Sea waves.

SeaQurrent has completed the grid-connected test site offshore the island of Ameland in the Wadden Sea ahead of the upcoming demonstration of its full-scale TidalKite device. The TidalKite is anchored to a monopile in the seabed with a high-tech tether and flies underwater across the current. The traction force generated by the kite drives a hydromotor, which in turn drives a generator, generating green electricity. Demonstration is planned for 2022, following the completion of preparatory works on the test site. The 1:10 scale TidalKite, rated at 50 kW, has already been tested in the Dutch Wadden Sea.



Dutch Wave Power will test its device in 2022 at a testing site 12 km off the coast of The Hague. In the summer of 2021, Dutch Wave Power completed a series of tests on its wave energy technology at Maritime Research Institute Netherlands (MARIN). This followed a series of prototype testing in the Delta Flume at knowledge institute Deltares. The device consists of a floating body containing all the energy conversion components, completely sealed off from the seawater. The floating body moves along with the rotating movement of the waves. This rotation is used to generate renewable energy, 0,25 MW at full-scale.

REDstack is generating Blue Energy from the difference in salinity between river water and sea water at the Afsluitdijk. This is the first RED technology installation in the world which has been operating continuously since its beginnings in 2014, with a blue energy production capacity of max 50 kW. Other potential applications include wherever a river naturally empties into the sea or within the desalination process. To further this latter application, REDstack joined the Hyreward project at the end of 2021. In the same year, REDstack also developed two successful chemical approaches that modify the membrane surface, to make it more resistant to fouling. This will prevent components to accumulate on and in the membrane, thus reducing the electrical power output of the cell.

PLANNED DEPLOYMENTS

- SeaQurrent kite demonstrator (500 kW) at the Wadden Islands (2022)
- Slow Mill wave demonstrator (40 kW) off the coast of Texel (2022)
- Dutch Wave Power off the coast of The Hague (2022)
- REDstack demo plant (0.5-1 MW, further future)
- Tocardo in Eastern Scheldt (further future)
- Several arrays in Afsluitdijk discharge gates (further future)

RELEVANT NATIONAL EVENTS

Offshore Energy Exhibition & Conference (OEEC)

On 26 & 27 October 2021, the Offshore Energy Exhibition & Conference (OEEC) took place in Amsterdam. The OEEC is Europe's leading event for the entire offshore energy industry, connecting the maritime and offshore world for sustainable solutions. This year, DMEC collaborated with IRO, NWEA and the North Sea Energy Gateway to organize a program full of Marine Energy content. Next to the session: *Marine Energy: Joining forces to reach the European Targets for Offshore Renewable Energy*, ocean energy companies contributed within several Talkshows, Offshore Energy Talks and Round Tables.

Dutch Marine Energy Community Strategic Session

On 23 December 2021, DMEC organized a strategic session for the Dutch Marine Energy Community, which includes over 140 developers, researchers and other professionals working in affiliated public and private sectors. The goal of the session was to establish a shared vision for the public affairs strategy for the Dutch Marine Energy sector in 2022 and beyond.

NVDE Open Duurzame Energiedag

On 11 September 2021, the Dutch Renewable Energy Association NVDE organized the 'Open Duurzame Energie Dag'. On this day, sustainable energy projects in the Netherlands opened their doors to the public. DMEC showcased marine energy solutions at its new offices in Scheveningen harbour. Dutch marine energy technology developers were present to showcase their innovations and marine energy solutions could be experienced in virtual reality.

IRO X DMEC event 'The Potential of Marine Energy'

On 11 March 2021, IRO (Association of Dutch Suppliers in the Offshore Energy Industry) and DMEC together organized the online event 'The potential of Marine Energy". The goal of the session was to introduce marine energy and its potential to the offshore and maritime industry and to further explore collaboration opportunities.

European Maritime Day (EMD)

The European Maritime Day (EMD) is the annual two-day event during which Europe's maritime community meets to network, discuss and forge joint action on maritime affairs and sustainable blue economy. During the EMD on 20-21 May 2021, a workshop was held on the benefits that ocean energy can bring to all European sea basins and on how getting these devices in the water is a pan-European effort. Leading European manufacturers presented the latest news from their projects under construction and showcased the economic success stories behind them.

3.15
NEW ZEALAND

AUTHOR
Vladislav Sorokin, The University of Auckland

OVERVIEW

The key achievements in 2021 include:

- holding the Offshore Future Energy Forum, 25-26 November 2021, organised by New Zealand's national new energy development centre Ara Ake.
- holding a Workshop on Blue Ocean Economy and Marine Energy, 17th of June 2021, organised by Aotearoa Wave and Tidal Energy Association AWATEA with the participation of the Minister of Energy and Resources, Hon Dr Megan Woods.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

There is a Renewable Energy Strategy launched by The Ministry of Business, Innovation and Employment.
No significant market incentives for ocean energy.
No Funding Agencies and national funding programmes specific for ocean energy.

RESEARCH & DEVELOPMENT

Key R&D activities:

- Azura Wave Power, conducting wave tank testing and detail design for 500 kW device.
- The University of Auckland, developing an environmental monitoring buoy powered by wave energy.

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Azura Wave Power has a 20 kW device deployed for 18 months of grid-connected trials at Wave Energy Test Site (WETS) in Hawaii.

PLANNED DEPLOYMENTS

Azura Wave Power has a 500 kW device, with deployment scheduled for Q4 2023.

Ruka Marine Turbine device developed by Environment River Patrol-Aotearoa is to be deployed in 2022.

Aquantis has a 20 MW ocean gyre current project in the US and a 30 MW tidal current project In Wales, both under development.

RELEVANT NATIONAL EVENTS

- Offshore Future Energy Forum, 25-26 November 2021
- Workshop on Blue Ocean Economy and Marine Energy, 17th of June 2021
- Blue and Green Technology Conference 2022

3.16
PORTUGAL

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OVERVIEW

Carbon neutrality is one of the country's major challenges for the coming years and marine renewable energies can make a decisive contribution to this goal. In May 2021, the Portuguese government approved the *National Ocean Strategy 2021-2030* with 10 strategic objectives for 2030. This is the instrument that will set the course for the Portuguese public policy of the Sea in the next decade. The National Energy and Climate Plan 2021 - 2030 has targets for marine renewable energies (wave and offshore wind) with key support measures and actions.

2021 saw the launch of the EU-SCORES project, a €45 million marine energy project that will pave the way for bankable hybrid offshore parks across Europe by 2025. Under the project lead of the Dutch Marine Energy Centre (DMEC), a 1.2 MW wave energy array by CorPower Ocean in Portugal co-located with a floating wind farm will be built, as well as an offshore solar PV system co-located with a bottom fixed wind farm at the Belgium coast. Both developments will showcase the benefits of harnessing complementary power sources.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Portugal's energy sector policy aims to decarbonise the energy supply and reduce energy import dependency primarily through broad electrification and a rapid expansion of renewable electricity generation, along with increased energy efficiency.

The Directorate-General for Energy and Geology (DGEG), housed within the Ministry for the Environment and Climate Action, has the main responsibility for developing and implementing Portugal's energy policy.

In 2021, It was approved, by the Resolution of the Council of Ministers n.º 107/ 2019, of 1 July, the Roadmap for Carbon Neutrality 2050 (RNC 2050). In conjunction with the objectives of the RNC 2050, the National Energy and Climate Plan 2030 (PNEC 2030) was developed, which constitutes the main instrument of national energy and climate policy for the next decade towards a carbon neutral future, and which was approved by Council of Ministers Resolution No. 53/2020, of 10 July.

National Energy and Climate Plan (NECP) for 2021 to 2030

To meet the EU's energy and climate targets for 2030, EU Member States established a 10-year integrated National Energy and Climate Plan (NECP) for the period from 2021 to 2030 proposing national targets and defining the measures to support these targets. Portugal's NECP was submitted to the EC in 2019 and was approved by Cabinet Resolution No. 53/2020 in July 2020.

The 2030 national targets for renewables are 47% in gross final energy consumption and 80% in electricity (In 2020, renewables accounted for 34% of gross final energy consumption and 55% of electricity generation).

The NECP further indicates that to achieve these targets, the installed capacity of renewable electricity generation needs to grow from 14.1 GW in 2019 to 27.4 GW by 2030 (most of this growth is expected to come from solar PV, wind, hydropower and marine renewable energies).

In particular, for marine renewable energies, the NECP indicates that, by 2030, offshore wind should reach 0.3 GW and wave energy 70 MW. The targets in the NECP are intended to put Portugal on a path to achieving the economy-wide carbon-neutral goals set in the Roadmap for Carbon Neutrality 2050 (RNC2050).

Roadmap for Carbon Neutrality 2050 (RNC2050)

The Government of Portugal submitted in September 2019 its long-term strategy for low-emission development to the United Nations Framework Convention on Climate Change (UNFCCC), highlighting its intention to achieve carbon neutrality by 2050. Portugal's Roadmap for Carbon Neutrality 2050 (RCN2050) elaborates a path to carbon neutrality and identifies guidelines for policies and measures required to achieve this goal, with a focus on increasing the use of domestic renewable energy while reducing and electrifying final energy demand.

The RNC2050 sets goals for renewables to cover 71-72% of final energy consumption by 2040 and 86-88% by 2050.

Portugal's policy to achieve its renewables targets is focused on increasing renewable electricity generation while accelerating the electrification of all demand sectors and decarbonising the gas supply with biomethane and renewable hydrogen.

National Strategy for the Sea 2021-2030

In 2021, Portugal approved the 2021–2030 National Ocean Strategy. The purpose of the strategy is to enhance the contribution of the ocean to Portugal's economy and promote a healthy ocean that increases the welfare of the Portuguese people. It centres around 10 objectives, including combatting climate change, decarbonising the economy and promoting renewable energy, stimulating scientific knowledge, technological development and blue innovation. The corresponding Action Plan was published in September 2021 containing over 180 concrete measures to execute until 2030, for each area, including relevant actions for Marine Renewable Energies.

The ENM 2030 and the Action Plan can be assessed at: www.dgpm.mm.gov.pt/enm-21-30

Permits for Private Use of the National Maritime Space (TUPEM)

The right to private use of the national maritime space is granted by concession, license or authorization, formalized in the form of 'permits of private use of the maritime space', briefly TUPEM. The authority responsible for TUPEM approval is the Directorate-General for Natural Resources, Safety and Maritime Services (DGRM), which shall ensure the consultation of other public services and bodies.

Whenever TUPEM is associated with the use or activity related to geological resources, energy resources and renewable energy, including their infrastructure, the Directorate-General of Energy and Geology (DGEG) is the coordinator of the all licensing process.

The request for TUPEM is submitted online at DGRM website (https://www.dgrm.mm.gov.pt).

Technological Free Zones (ZLT)

In 2021, by decree-law 67/2021, the government created the legal framework for the constitution of Technological Free Zones ("ZLT - Zonas Livres Tecnologicas") in Portugal and announced the creation of one Technological Free Zone for marine renewable energies projects located Offshore Viana do Castelo, northern Portugal. ZLT's are physical spaces for the testing and demonstration of new technologies and innovations, in a real environment, under special legislation and permanent monitoring by regulatory entities. This approach is a coherent and aligned approach aiming to facilitate experimental and research activities with streamlining legal mechanisms. Each ZLT is managed by an entity responsible for setting the rules and conditions for its access.

More information at: https://www.ani.pt/en/knowledge-valorization/interface/free-zones-for-technology-framework-for-regulatory-sandboxes/

PUBLIC FUNDING PROGRAMMES

Foundation for Science and Technology (FCT)

The Foundation for Science and Technology (FCT) is a national funding agency under the responsibility of the Ministry for Science, Technology and Higher Education whose mission is to boost Portugal's RD&D capabilities in all scientific fields. FCT provides RD&D funding through several programmes, including tenders for RD&D projects, grants, scholarships, support of public-private RD&D collaboration and direct funding of public research institutions.

FCT participates in the Ocean Energy ERA-NET Cofund supporting transnational collaborative innovation in the ocean energy sector. The Ocean Energy ERA-NET Cofund (OCEANERA-NET COFUND) is an initiative of eight national and regional government agencies from six European countries, which has received funding from the European Union under the Horizon 2020 Programme. The aim is to coordinate support for research and development in ocean energy, to encourage collaborative projects that tackle some of the key challenges identified for the sector as it progresses towards commercialisation.

National Innovation Agency (ANI)

The National Innovation Agency (ANI) is a state-owned agency supporting technology and business innovation to strengthen Portugal's competitiveness in global markets. The ANI's responsibilities include stimulating private RD&D investment, promoting partnerships between Portugal's RD&D entities and industry, and increasing the participation of Portugal's RD&D entities and industry in international RD&D programmes.

ANI also runs the Interface Programme that certifies and funds **Technological Interface Centres** (TICs) in several areas including renewable energies, using FITEC - Innovation, Technology and Circular Economy Fund that aims to support policies to enhance scientific and technological knowledge and its transformation into innovation.

One of the key initiatives of the Interface Programme are the National Collaborative Laboratories (CoLAB), which bring together public RD&D entities, universities, companies, business associations and government organisations to co-operate on shared RD&D objectives. Tenders for CoLABs were issued in last years, resulting in the establishment of 28 CoLABs, one of which, the **Colab +ATLANTIC**, with a mission of advancing knowledge on the interactions between the Ocean, Atmosphere, Climate and Energy in the Atlantic (https://colabatlantic.com/).

Directorate-General for Maritime Policy (DGPM)

DGPM is a public administration body of the Ministry of the Sea responsible to develop, evaluate and update the National Ocean Strategy, designing and proposing the national maritime policy, developing the maritime spatial planning strategy and management, monitor and participating in the development of the Integrated Maritime Policy of the European Union and promote national and international cooperation on maritime affairs. DGPM is currently engaged in a variety of scientific marine and maritime research topics (including socio-economy sciences related to the Ocean, monitoring of the Blue Economy, and monitoring of the Portuguese contribution to the UN SDG 14 Goal), but also in Ocean Literacy and translational aspects between academia and industrial sectors.

DGPM manages "Blue Fund", an innovative public financial instrument focused on the development of the ocean economy, scientific research and protection of the sea environment. It prioritizes the development of sea biotech start-ups, underwater robotics, innovative shipbuilding, ocean energy, aquaculture technology and innovative solutions for ocean protection, safety, monitoring and surveillance. Six projects for wave energy demonstration and robotic equipment for operations in the sea, have been developed in last years using this funding scheme, led by the following Portuguese R&D institutions and SMEs: WavEC, IST, inanoEnergy (University of Porto), In2sea, Composite Solutions and Abyssal.

OTHER INITIATIVES

Portugal's Plan of Recovery and Resilience (PRR)

To respond to the crisis caused by COVID-19, the European Union came forward with a robust package of funds. In this context, Portugal announced the Plan of Recovery and Resilience 2021-2026, which allocates around 3.2 thousand million euros of direct investment to climate reforms with a focus on mobility, decarbonization, bioeconomy, energy efficiency and renewables. Marine Renewable Energies were included in the Intention Letters submitted to the government by the end of 2021.

Atlantic Strategy Committee (ASC)

Portugal, Spain, Ireland and France are represented in this committee. The ASC is the governing body of the Atlantic Strategy aiming to ensure the political and operational coordination of the Atlantic Action Plan and provide the framework for its implementation. Marine Renewables Energy is one of the four pillars of the Atlantic Action Plan, with this objective: "The promotion of carbon neutrality through marine renewable energy". In 2021 a roadmap was prepared by the working group of Pillar 3 – Renewable Energies, with the following proposed actions:

- Set specific deployment objectives for marine renewable energy
- Define best sites for marine renewable energy farms and adjacent ports across the Atlantic
- Implement incentives for deployment of innovative renewable energy installations
- Pool together different marine renewable energy initiatives covering the EU Atlantic area
- Develop public awareness using appropriate communication tools on marine renewable energy in the Atlantic
- Strengthen cooperation in the European ocean energy community
- Develop a specific ocean energy framework for EU islands in the Atlantic

More information: http://www.atlanticstrategy.eu/en/atlantic-strategy-glance/atlantic-strategy-committee

Ocean Invest Portugal

An initiative of the Ministry of the Sea of Portugal and of the Luso-American Foundation for Development; it is an online platform for the promotion of innovative products and services in the Portuguese Blue Economy, aligned with the UN Sustainable Development Goals.

More information: https://www.oceaninvest.pt/

Bluetech Accelerator

A Startup Programme inviting startups to bring innovation to the Blue Economy. The first edition of the programme was strategically focused on the Port & Shipping industry and benefits from a partnership with the Luso-American Development Foundation (FLAD). Within the Bluetech Accelerator program, startups and partners engaged in 18 pilot projects during a period of five months, one of which was on wave energy (Eco Wave Power). https://bluetechaccelerator.com/

Portugal Blue

A new initiative for blue economy investments launched in 2020 by the European Investment Fund (EIF) and the Portuguese national promotional institution, Instituição Financeira de Desenvolvimento (IFD), co-financed by the Portuguese Ministry of Sea with resources from Fundo Azul (Blue Fund). The EIF and IFD each contribute €25 million to this joint programme to support Portuguese companies active in the area of the blue economy.

MARKET INITIATIVES

There is no FIT for renewable energy projects commissioned after November 2012.

RESEARCH & DEVELOPMENT

KEY R&D INSTITUTIONS

WavEC Offshore Renewables

WavEC is a private non-profit organization created in 2003 with a strong research and innovation component and a broad spectrum of specialized services in Marine Renewable Energies and Engineering Solutions for the ocean economy, incorporating technological, economic, environmental, social and legislative aspects.

WavEC's activities are internationally recognized through its extensive network of contacts, with a wide experience in working with international consortiums, being involved since 2003 in 60 R&D public-funded projects on marine renewable energies. WavEC is further responsible for the secretariat and communication of the IEA-OES.

IST

Two groups were active on ocean energy at Instituto Superior Técnico (IST), University of Lisbon:

- Institute of Mechanical Engineering (IDMEC) with a decades-long history in wave energy conversion studies - following previous years, the activity at IDMEC has been concentrated on wave energy conversion, especially the development of new types of oscillating water column converters (OWCs) and self-rectifying air turbines. An important area of research at IDMEC is latching control of floating and fixed-structure OWC converters, taking advantage of new types of air turbines fitted with fast valves.
- Centre for Marine Technology and Engineering (CENTEC) whose involvement in ocean energy is more recent - Ocean energy is a major area in the diversified activity of CENTEC/IST. The activities at CENTEC in ocean energy involved a wide range of topics covering waves, tidal currents and offshore wind. The characterization of the wave energy resource (and to a much lesser extent tidal and offshore wind energies) at various oceanic locations in the world has been one of the dominant topics. The study of ocean energy conversion, focused mainly on wave energy converters, with numerical theoretical/modelling and model testing of several types of devices and arrays, and also PTOs (namely hydraulic-circuit PTOs) and moorings.

FEUP – CIIMAR (Marine Energy group)

The Marine Energy (ME) team's main topics of research revolve around the development, design and optimization of technologies to harness marine renewable energy resources as well as the engineering design of coastal and maritime structures to cope with marine environmental actions, using either numerical modelling (BIEM, RANS, SPH) or physical model testing in experimental facilities (wave basin and/or wave-current flume). The ME group is strongly

committed to the research and innovation of cross-cutting, sustainable and advanced technologies or solutions to harness and withstand marine blue energy, mitigate climate change effects and support the societal transition to a low carbon sustainable economy. Current research activities focus on: the development and testing of ocean technologies, hydrodynamic modelling, dynamics of floating structures, moorings, wave energy converters, offshore wind foundations, resource assessment and characterization, risk assessment, reliability analysis, breakwater and harbour design, wave-structure interaction, coastal and offshore aquaculture, energetic sustainability, among others.

KEY R&D PROJECTS

Most Key RD&D projects in Portugal are structured around international cooperation with European funding. Below some key representative projects are presented:

Projects funded by Horizon 2020 programme:

- **EU-SCORES –** initiated in September 2021, the project aims at demonstrating and unlocking the large-scale potential of multi-source, offshore renewable energy farms across different European sea basins. This will be achieved through two demonstrations: (1) An offshore solar PV system in Belgium co-located with a bottom fixed windfarm and; (2) A wave energy array in Portugal co-located with a floating wind farm. The demonstrations in EU-SCORES aim to showcase the benefits of continuous power output by harnessing complementary power sources including wind, sun, and waves. The full-scale demonstrations are intended to prove how the increased power output and capacity installed per km^2 will reduce the amount of marine space needed, thereby leaving more space for aquaculture, fisheries, shipping routes, and environmentally protected zones. The project has 18 partners and it is led by the Dutch Marine Energy Centre (DMEC). From Portugal, WaVEC, INESC TEC and EDP Labelec are participating.
- **EVOLVE –** initiated in January 2021, this project will model future energy generation, taking in consideration supply and demand scenarios, from distribution to balancing and storage/back-up. This will allow evaluating whether, where and how ocean energy options can make a significantly positive and profitable contribution to future energy systems as secure, clean and efficient energy sources. This project will reinforce the development of marine energy while supporting emissions reduction, renewables targets and security supply requirements in a cost-effective way. WavEC will be leading the planning of energy mix scenarios, through the acquisition of metocean data, characterization of the different ocean energy resources and identification of demand and supply patterns.
- **OceanSET -** Portugal, through the Directorate General of Energy and Geology (DGEG), is participating in the OceanSET project, which has the overall goal to support the implementation of the European Strategic Energy Technology Plan (SET Plan) aiming to accelerate the development and deployment of low-carbon technologies. Partners in this project are working together to facilitate the implementation of the technology development actions of the Implementation Plan, promoting knowledge sharing across the European Commission, Member States and other stakeholders in the ocean energy sector, and investigating collaborative funding mechanisms. The Portuguese partner of this project, DGEG, is the public administration body responsible for designing, implementing and evaluating policies on energy and geological resources.
- **LIFTWEC -** coordinated by the Queen's University of Belfast, the project focus on the development of LiftWEC, a novel type of wave energy converter, based on the exploitation of lift forces generated by wave-induced water velocities. WavEC is contributing to the identification of promising configurations of the LiftWEC concept that may minimise environmental impacts and ensure social acceptance
- **ETIP OCEAN 2 -** led by Ocean Energy Europe, this project aims to define ocean energy research and innovation priorities, discuss solutions with the industry, and European and national policymakers. This project funds the *European Technology and Innovation Platform for Ocean Energy* (ETIP Ocean) which is the European Commission's advisory body for research and innovation. WavEC coordinates all

overall environmental questions and licensing tasks of the project.

- **MEGAROLLER** - aiming to develop and demonstrate a next-generation Power Take-Off (PTO) solution for oscillating wave surge converters. The project led by AW-Energy was conlcuded in 2021 with the participation of WavEC on the coordination of the environmental and socioeconomic aspects of the project.
- **SEA-TITAN** - to designing, building, testing and validating a crosscutting and innovative Direct Drive Power Take-Off (PTO) solution to be used with multiple types of wave energy converters, based on the Wedge Global W200 PTO prototype. The project concluded in 2021 was led by the Spanish company Wedge Global, and WavEC give a major contribution to the numerical modelling work.
- **MARINET2** - providing free access to a network of 57 research facilities across Europe, through a series of competitive calls open to offshore energy technology developers (offshore wind, wave and tidal energy), under the coordination of UCC. WavEC has been involved in the development of standardized procedures and metrics for the financial assessment of offshore renewable energy projects, development of physical modelling and engineering evaluation processes for eco-friendly anti-fouling coatings and coordination of the training programme comprising a set of short courses and webinars.
- **DTOceanPlus** - led by Tecnalia and comprising 18 European partners, the consortium has been developing a second-generation open-source design tool for ocean energy technologies including sub-systems, energy capture devices and arrays, concluded in 2021. WavEC coordinated the development of the modules to assess the design of each technology (sub-system, device and array), to assess the logistics and marine operations planning, as well as the system lifetime costs and the legal, institutional and political frameworks of the marine energy projects.

Projects funded by the European Maritime and Fisheries Fund (EMFF):

- **WESE** - dedicated to environmental monitoring around wave energy devices operating at sea and to develop efficient guidance for planning and consenting procedures in Spain and Portugal. It was led by the RD&I Basque center AZT. From Portugal, WavEC and the Portuguese company, Hidromod participated in this project that came to an end in 2021.
- **SAFEWAVE** – in continuation of WESE, addressing long-term environmental concerns around the deployment of wave and tidal energy converters in the marine environment. It is coordinated by EMEC, with a diverse range of project partners across six European countries. WavEC is participating through the collection, processing, analysis and sharing of environmental data around devices operating at sea.

Projects funded by the European programme INTERREG Atlantic Area:

- **Blue-GIFT** - supporting floating wind, wave or tidal demonstration projects across the Atlantic Arc region, by providing free access to key European test centres. WavEC participates in the project, offering Aguçadora test site in Portugal as an open sea testing facility. The project is coordinated by EMEC and is expected to run until end of 2022.
- **PORTOS** - aims to assess, develop and promote the integrated use of renewable energy resources in Atlantic Area ports and increase their energy efficiency, establishing a roadmap to a more competitive and sustainable sector. Additional objectives consist of disseminating the benefits of marine renewable energies and sustainability principles to the general public by organizing OpenPorts and OpenLabs events, supporting the development of novel technologies and promoting entrepreneurship. This project is coordinated by UPORTO (FEUP).

Projects with funding from the European Regional Development Fund (ERDF):

- **ATLANTIDA** – development of a platform for the monitoring of the North Atlantic Ocean and tools for the sustainable exploitation of marine resources. ATLANTIDA creates a coastal observatory and monitoring, focusing on data collection and supply, including monitoring platforms and systems, sensors, data management and information technologies, which, among other objectives, also aim to promote the development of wave energy exploitation in the North Atlantic Ocean towards its promotion as a key driver for oceans sustainability and climate change resilience. Additionally, this project also focuses on important aspects related to the quantification and study of other potentially viable ocean energy sources such as marine biomass. The project is led

by CIIMAR - Interdisciplinary Centre for Marine and Environmental Research with other Portuguese partners: UPORTO, UTAD and UMINHO.

Projects funded by "Fundo Azul" (Blue Fund) by the Portuguese Ministry of the Sea:

- **BLUECAO –** development of an offshore platform concept to supply energy and feed offshore aquaculture farms, based on a wave energy system, consisting of an aggregation of coaxial oscillating water columns (OWCs) assembled to a central food deposit conducted; this project completed in 2021 was conducted by a Portuguese consortium coordinated by WavEC with one university - Instituto Superior Técnico – and three companies - Secil, Rota Grega and Kymaner.
- **JUMP -** a pioneering initiative in Portugal to monitor underwater noise. The project coordinated by WavEC brought together 10 Portuguese partners from academia and public administration. This 2-years project was concluded in 2021, collecting and promoting information regarding noise pollution and further supporting the implementation of the Marine Strategy Framework Directive in Portugal.
- **BASEPOINT –** validation of a new water turbine PTO concept for heaving point absorbers, as part of the Symphony wave energy converter development. This project was conducted by the Portuguese SME in2sea in partnership with Sines Tecnopolo, Mecwide AS and the Dutch technology developer Teamwork Technology. Symphony is an evolution of the Archimedes Wave Swing technology invented and initially developed by Teamwork Technology, resulting in full-scale sea trials in 2004. The new turbine is key to the pressurised closed-loop water PTO with a structural membrane and an air/water spring tank, which allows putting into practice an end stop-less PTO and permanently submerged operation, both potential advantages versus other point absorbers. BASEPOINT was successfully finalised by late 2021 and development is continued with a full Symphony PTO dry test rig in the Netherlands, in the context of the ENCORE INTERREG project.

Projects funded by FCT - National Foundation for Science and Technology:

- **SAGE MIT Portugal Project –** conducted by Instituto Superior Técnico with funding from the MIT Portugal Programme through FCT, aiming to design, manufacture and assemble a new purpose-built turbine-generator set to equip wave-powered monitoring buoys. This is critical for electricity generation and storage to enable continuous data acquisition under longer-term deployment periods at the open sea. The current project aligns with the mid-term objective of deploying a fully functioning device at open sea. The project deals with important technological challenges in both mechanical and electrical engineering. On one hand, the main contribution from the scientific and design perspective is the development and validation of a multidisciplinary numerical model to couple buoys, wave energy turbines, electric generators, and batteries. On the other hand, the built prototype will enable the stakeholders of maritime industries to access a new source of electricity from renewable energy in remote maritime locations.
- **POSEIDON –** conducted by CIIMAR, the project has the overall objective of extending and validating dynamic scour protections for complex marine renewable energy foundations, with several applications, including a strong focus on wave energy converters combined with offshore wind energy infrastructures.
- **WEC4PORTS –** aiming to develop a novel hybrid wave energy converter for ports. The key components (e.g., turbines) will be built and demonstrated in Mutriku testing site, after numerical and experimental testing. Furthermore, a new material will be tested in site to assess its strength and ability to withstand harsh marine conditions. This project led by the company IMDC - International Marine & Dredging Consultants, is conducted by 4 partners, involving from Portugal INEGI and FEUP, responsible for scaled physical and numerical modelling activities, performance improvement and optimisation to reduce the LCOE.

TECHNOLOGY DEMONSTRATION

TEST SITES

Two grid-connected test sites are available offshore the Portuguese Atlantic coast:

- **Viana do Castelo test site** with ca. 100 m water depth is available for pré-commercial projects (TRL 8 - 9). At this site, Portugal's first floating offshore wind project, WindFloat Atlantic, became fully operational in July 2020, consisting of three floating turbines with a total capacity of 25 MW.
- **Aguçadora test site**, at 50 m water depth, more adequate for research and demonstration projects (TRL 6 - 8); this site has been selected by the Swedish developer Corpower for the development of their HiWave-5 flagship project consisting of a 1.2 MW first commercial-scale wave energy array.

Five Portuguese institutions – CEiiA, +ATLANTIC CoLAB, Fórum Oceano, INESC TEC, and WavEC – joined efforts to promote the testing of innovative ocean technologies in Portugal. This consortium is leading an initiative called **OceanACT- Atlantic Lab for Future Technologies** aiming to turn Portugal into a reference point for testing ocean technologies, a fundamental and decisive step in the development of scientific research infrastructures and the optimization of their performance. The initiative will allow the Aguçadoura test site and the Viana do Castelo pilot zone to be articulated to other infrastructures for testing marine robotics, telecommunications, and detection technologies for monitoring and operation activities in the ocean environment. Processes of administrative nature are underway to establish the OceanACT legal entity in 2022.

PLANNED DEPLOYMENTS

CorPower Ocean

During 2021 CorPower Ocean has expanded its operations and the team of experts within composites manufacturing and WEC operations, supporting the flagship 'HiWave-5' wave energy demonstration project of the coast of Aguçadoura in northern Portugal. The on-land operations in the port of Viana do Castelo have been expanded, where a facility for final assembly and O&M of wave energy devices became operational during 2021. A unique mobile factory cell for on-site fabrication of composite hulls has been commissioned, and the first full-scale hulls fabricated. The HiWave-5 project aims at having at least three operational devices demonstrated in a pilot farm, delivering electricity to the grid with certification of availability and performance. In 2022, the first full-scale unit 'C4' is planned to be deployed, taking the technology from TRL 6 to TRL 7.

1/4-scale Corpower's C4 wave energy converter

Manufactured process of the full-scale Corpower's C4 wave energy converter in Viana do Castelo - Commercial Harbor

RELEVANT NATIONAL EVENTS

WavEC Annual Seminar 2021 was organized on November 30th in collaboration with the Embassy of Japan to Portugal, aiming to provide its participants with a unique opportunity to explore new collaboration opportunities in business and research in marine renewable energies and other blue economy sectors.

This online event had over 250 participants - developers, researchers and other professionals working in public and private sectors.

All presentations are available at WavEC website: http://wavec.org/en/events/seminar-2021

3.17

REPUBLIC OF KOREA

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OVERVIEW

The Ministry of Oceans and Fisheries (MOF) is preparing a new long-term roadmap to contribute to the national Carbon Neutral Target by 2050 from ocean energy sectors, and this roadmap is extended from the existing 2030 commercialization plan of ocean energy systems. Many R&D projects are being carried out to support this ministry's ocean energy commercialization plan. Korea Research Institute of Ships and Ocean Engineering (KRISO) has developed a 30 kW-class wave energy converter (WEC) of the oscillating water column (OWC) type, combined with a breakwater and an energy storage system (ESS), to provide electricity to remote off-grid islands. And the demonstration plant was built at the Mook-ri small port in Chuja Island between mainland Korea and Jeju Island in 2021. Two R&D projects for developing tidal energy converters (TEC) are ongoing: (1) the development of a tidal energy converter combined with ESS to supply energy to remote off-grid islands, and (2) the development of a 1 MW class commercially available tidal energy converter by Korea Institute of Ocean Science and Technology (KIOST). The TEC-ESS combined system is being manufactured and will be installed near the existing Uldolmok Tidal Pilot Power Plant in 2022. A new project was initiated to establish the national technical standards on ocean energy systems by harmonizing the international technical specifications published by IEC.

The KRISO-Wave Energy Test Site (KRISO-WETS) was opened in September 2020 and the Yongsoo OWC Pilot Plant is being consistently upgraded using a rated power control unit and digital twin technology for the increase of capacity factor and smart operation. The Tidal Energy Converter Component Experiment Building was built in the KIOST Busan Headquarter in 2021 as an onshore facility of the Korea Tidal Current Energy Centre (KTEC).

A second-term of bilateral cooperation project (2021-2023) between South Korea and China, led by KIOST and the First Institute of Oceanography (FIO) is being conducted to exchange the technology development and the utilization of ocean energy systems, and the annual joint workshop was held in November 2021 as an in-person and remote hybrid meeting.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Within the 2030 Ocean Energy Development Plan, the ministry's action plan for developing and disseminating ocean energy systems, a strategic plan has been established in the field of tidal and wave energy development. This plan is divided into four steps: (1) the expansion of R&D in ocean energy and the establishment of open-sea test sites; (2) the construction of large-scale ocean energy farms; (3) the entrance into the global market and the expansion of domestic supply; and (4) the establishment of an ocean energy certification system and supporting policies. This plan is being revised for the Carbon Neural in 2050 and the long-term roadmap is being prepared.

MARKET INCENTIVES

The renewable portfolio standard (RPS) was established in 2012 to compel utility companies with a capacity greater than 500 MW to provide obligatory portions of their total electricity production from renewable energy, based on the Acts on the Development, Utilization, and Supply Promotion of Renewable Energy legislation. The market incentive plan, known as the tradable Renewable Energy Certificate (REC), supplements this RPS policy. The weighting value of REC is currently given as 2.0 for tidal current, 1.0 for tidal barrage with an embankment, and 2.0 for tidal barrage without embankment, while the value of REC for wave energy is expected to be set by analyzing the real power output data from the demonstration project of WEC in Mook-ri power plant and Yongsoo OWC Pilot Plant.

PUBLIC FUNDING PROGRAMMES

MOF provides public funding for ocean energy R&D programs, including demonstration projects, and 20.4 million USD was invested in the development of ocean energy systems in 2020. The main two programs will be continued by 2022, and the remaining budget for ocean energy R&D programs is about 27.3 million USD in 2021 and 2022. A new R&D program will be launched in 2022 for developing green hydrogen production technology using ocean energy with a total of 18.3 million USD.

RESEARCH & DEVELOPMENT

In 2021, a new R&D project was initiated to develop the national technical standards on ocean energy systems as a part of the project entitled "Development of standardization technologies for marine and fishery industry equipment," led by Korea Conformity Laboratories (KCL), and funded by MOF. Currently, Korean Agency for Technology and Standards (KATS) is the representative national standardization body in Korea to develop and manage technical standards. In 2021, Korea Electric Association (KEA) was designated as the cooperation organization for standards development in the field of ocean energy systems for standardization activities to setting domestic standards. KIOST and KRISO are participating in the new project to develop the national standards and have a strong collaboration with KCL, KEA, and KATS. For the national standards, it is basically intended to harmonize the technical specifications published by IEC/TC114. In addition, the project will confirm whether it is applicable in Korean and Asian environments. The standardization activities are expected that the advancement of ocean energy technology can be pursued in connection with R&D performance, and the ocean energy industry can be activated by technical standards and certification systems as well.

PROJECTS IN THE WATER

As a final accomplishment of a KRISO-led R&D project to develop 30 kW wave energy converters applicable to breakwaters in remote islands, the demonstration wave energy converter was built at Mook-ri small port in Chuja Island, and the completion ceremony was held in November 2021.

This demonstration plant adopts the OWC wave power generation method. The armor blocks on the front of the sloped breakwater in Mook-ri Port were removed, and the OWC Chamber produced by the pre-cast method was installed. This attempt, which was applied to a standalone micro-grid with the combination of the Mook-ri OWC plant and ESS system, is a very effective way to utilize ocean energy in islands with narrow land and relatively large marine space and is expected to be widely applied.

The ESS capacity of Mook-ri plant was determined in light of the power generation characteristics whose instantaneous power output was larger than average power output, and the output power of the OWC wave power is directly linked to the ESS system to minimize unnecessary power conversion steps.

As part of the project to establish a test site for tidal energy converters, an onshore tidal energy component experiment building was built in the KIOST Busan Headquarter, and a completion ceremony was held in November 2021. In this experiment building, 3 actuators for blade strength testing and non-destructive testing equipment such as ultrasonic and thermal imaging are equipped and will be operated as a KOLAS-accredited testing laboratory for blade strength testing and non-destructive testing in the near future. On the other hand, in the case of an offshore test site, construction is currently delayed due to consenting issues and others.

Overview of Mook-ri OWC Plant (Courtesy: KRISO)

Tidal energy component experiment building and actuators for testing (Courtesy: KIOST)

PLANNED DEPLOYMENTS

TEC-ESS hybrid system for remote off-grid islands is being developed utilizing dual vertical axis Darrius turbines. The generators and maintenance facilities such as an overhead crane will be equipped at the top of a steel supporting structure, and ESS will be installed on an island's landside.

The rated power of each turbine is 50 kW, and the battery charged through the dual turbine system is designed at 500 kWh to reduce the electric load in the island. This hybrid system is currently being manufactured, and KIOST plans to test its performance under open sea conditions in 2022.

RELEVANT NATIONAL EVENTS

The fifth joint workshop on ocean energy was held in November 2021 as a hybrid meeting. 8 presentations were prepared in tidal, wave, and ocean thermal energy converters and technical standardization activities.

5th Korea-China Ocean energy joint workshop (Courtesy: KIOST)

3.18

SINGAPORE

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SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Singapore is an islandic nation located in the heart of Southeast Asia with a total land area of about 729 km^2 and with a population of about 5.5 million as per data provided by Department of Statistics Singapore in 2021. In 2015, Singapore pledged to reduce its Emissions Intensity (EI, or GHG emissions per unit of GDP) by 36 per cent from 2005 levels by 2030 and stabilise emissions with the aim of peaking around 2030. The Government unveiled the Singapore Green Plan 2030, a whole-of-nation movement to advance Singapore's national agenda on sustainable development. The Green Plan charts ambitious and concrete targets over the next 10 years, strengthening Singapore's commitments under the UN's 2030 Sustainable Development Agenda and Paris Agreement, and positioning Singapore to achieve long-term net-zero emissions aspiration as soon as viable. The Green Plan has five key pillars:

a) **City in Nature:** to create a green, liveable, and sustainable home for Singaporeans.
b) **Sustainable Living:** to make reducing carbon emissions, keeping our environment clean, and saving resources and energy a way of life in Singapore.
c) **Energy Reset:** to use cleaner energy and increase our energy efficiency to lower our carbon footprint.
d) **Green Economy:** to seek green growth opportunities to create new jobs, transform our industries, and harness sustainability as a competitive advantage; and
e) **Resilient Future:** to build up Singapore's climate resilience and enhance our food security.

MARKET INCENTIVES

In Singapore, several governmental bodies provide schemes and incentives to help promote the adoption of renewables. They are the Energy Market Authority (EMA), Building and Construction Authority (BCA) and Economic Development Board (EDB). The Green-e Renewable Energy Standard for Singapore allows Green-e Energy certification of renewable energy products throughout Singapore, in order to accelerate the development of renewable generation and renewable electricity markets, and to provide consumers a meaningful mechanism through which they can express demand for renewable electricity (Green-e, 2017). Instead of subsidies, Singapore has taken proactive steps to introduce regulatory enhancements to facilitate the entry of renewable energy when such technologies become commercially viable (EMA, 2017). The Government's support for renewables mainly comes in the form of funding for Research & Development to develop capabilities within the industry. Singapore Power Group (SP) has been authorised as a local issuer of International Renewable Energy Certificates (I-RECs) or tradable certificates of energy from renewables in Singapore, the first in Asia Pacific. Each megawatt-hour of renewable energy produced is recorded as one REC and uniquely numbered and tracked. It would be used for achieving renewable energy targets and for reporting consumed energy as coming from renewable sources (SP Group, 2019). Enterprise Singapore has also formed a working committee TC114 on Marine energy, involved in the adoption of international standards to support clean marine energy initiatives of the Singapore government towards new industries such as aquaculture, desalination, electrification of marine operations, fisheries, and tidal energy-powered data centre systems, etc.

PUBLIC FUNDING PROGRAMMES

More than S$800 million public funding has been set aside by the Singapore Government for research in energy, water, green buildings and addressing land scarcity. The Ministry of National Development's SGD 50 million Research Fund for the Built Environment encourages and supports research and development for sustainability in the built environment. The NEA's Innovation for Environmental Sustainability (IES) Fund allows Singapore-registered companies undertaking environmental protection projects to apply for up to an SGD 2 million funding for the applied research, test-bedding and demonstration stages of technology developments with a maximum duration of three years.

Ocean renewable energy has been identified as one of the prominent alternative energy by ERI@N specifically towards remote coastal and islandic region as part of its strategic research interests. The government also welcomes clean technology companies to use Singapore as a 'Living Lab' to testbed and demonstrate innovative solutions before scaling up for the rest of the world. The inter-agency Energy Innovation Programme Office's SGD 195 million Energy Innovation Research Programme (EIRP), which was launched in September 2013, promoted research and development in Building Energy Efficiency for a five-year period, which ended in 2015. Of the SGD 195 million, SGD 140 million is set aside for the EIRP. The BCA Innovation Grant for Green Buildings (iGrant) co-funds up to 70% of qualifying costs or SGD 20,000, whichever is lower, at the proof-of-concept stage to allow research and development projects involving the introduction of novel tools, methodologies and technologies that have high impact to improve the sustainable built environment. Subsequently, the BCA co-funds up to 70% of the qualifying costs or SGD 250,000, whichever is lower, at project implementation.

RESEARCH & DEVELOPMENT

ERI@N, supported mainly by the EDB, NRF and EMA and other key government agencies, focuses on the areas of sustainable energy, energy efficiency infrastructure and socio-economic aspects of energy research. Its mission is to be a centre of excellence for conducting advanced research, development, and demonstration of innovative solutions, which have both regional and global impact. The Institute has considerable expertise and strength in areas of offshore energy, which includes wind, wave, floating solar and tidal energy, and complementary technologies, such as energy storage, microgrids, and smart energy systems, and collectively provide an integrated set of expertise from materials design & synthesis, device fabrication and modelling, and systems integration and optimization.

ERI@N's Wind and Marine (W&M) research programme is aimed at improving the performance, lowering costs, and accelerating the deployment of offshore renewable technologies specific to the tropics, where unique technology challenges exist. It advances technology development and commercialization through early collaboration with industry. It works closely with government agencies to understand regional needs, and with local and global renewable energy firms to identify technology gaps.

TECHNOLOGY DEMONSTRATION

TEST SITES

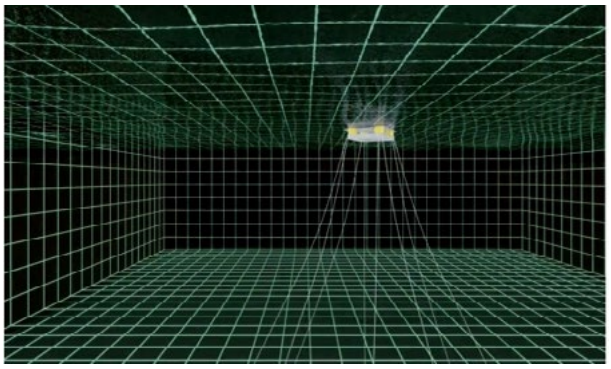
Sentosa – ERI@N Tidal Site

The Sentosa Tidal Test Site is a joint collaboration between Sentosa Development Corporation (SDC) and ERI@N, funded by the Ministry of Trade and Industry's Core Innovation Fund. This project aims to showcase tidal energy extraction as a feasible and sustainable energy generating technology in Singapore and to provide opportunities to develop local technologies to harness the energy available in the narrow channel between Singapore and Sentosa. In November 2013, ERI@N and SDC officially launched the Sentosa Tidal Test Site (NTU, 2013).

ERI@N developed Tidal turbine system

Recent developments on the test site include the deployments of customized tidal turbines supported from the floating barges. Also, novel concepts such as floating solar systems, anti-biofouling coatings are being evaluated for better field performance. The power developed is used for electric lighting on the boardwalk. This was further developed towards a floating tidal turbine system. For feasible power capture, tidal generators are preferably located at natural coastal features which can converge and amplify water flow, such as channels and estuaries. The current testbed benefits from amplified flow due to the narrowed channel between Singapore and Sentosa islands and bridge piers which provides manmade flow convergence. Presently the ERI@N W&M team focuses on low flow wind turbines, tropical tidal turbines, floating solar and low wave height harvesting devices that are uniquely optimized using machine learning algorithms based on bio-inspired ideas. The actual demonstration units have been test bedded in the Singapore waters and complementary technologies such anti-biofouling and corrosion resistance coatings, etc have been included. The deployments have been demonstrated as a remote site capable of using distributed grid concepts and energy storage integration and are commercialized through the Industrial collaborating partners.

TCOMS – Ocean basin Facility



Ocean Basin Facility – TCOMS

Technology Centre for Offshore and Marine Singapore (TCOMS) is a joint venture between the National University of Singapore (NUS) and the Agency for Science Technology and Research (A*STAR). A key feature of the TCOMS is the state-of-the-art Deepwater Ocean Basin, a massive water containment facility that can simulate the harsh environment of Deepwater oceans. The Deepwater Ocean Basin can hold a volume of water equal to over 20 Olympic-sized swimming pools and has a 50m deep centre pit. Armed with smart sensing, modelling and data analytics capabilities, the next-generation Deepwater Ocean Basin can reproduce the wave and current systems of ultra-deep waters. This enables researchers to study the complex ocean state and understand the deep-sea challenges facing the M&OE industry. Ultimately, this helps researchers to develop innovative solutions such as intelligent floating platforms, marine robotics, and subsea systems to help the M&OE industry improve safety and enhance efficiency in rough ocean waters.

TCOMS is currently working with its industry partners to solve real-world problems in the Marine & Offshore Engineering operations using state-of-the-art simulation techniques to better predict the behaviour and response of marine and offshore systems, such as rigs, smart vessels, and underwater systems.

Key Research Thrust areas of TCOMS are:

- To enhance the predictability of the operating environment and the behavior and response of ocean systems in challenging and complex sea states.
- To advance research and technological innovation in maritime autonomous surface ships.
- a digital twin of the metocean environment for the waters around Singapore and for locations of offshore assets of interest.

Experimental Power Grid Centre – EPGC

ERI@N has a megawatt-scale grid facility that is one of the largest in this region. Located on Jurong Island, which is home to Singapore's petrochemical hub, the Experimental Power Grid Centre (EPGC) houses one of the largest and most comprehensive integrated energy Facilities.

It consists of a comprehensive range of generation sources, energy storage systems, and loads, which allows equipment manufacturers and system integrators to test out their technology or configuration at actual power before deployment. The experimental power grid has been valuable to industry partners to develop and demonstrate concepts such as microgrids for rural electrification. Throughout the years, ERI@N/ EPGC have built up various testing platforms:

- 200 kW ESS testing platform
- 500 kW motor testing platform
- Real-time simulation and HIL testing platform
- 100 kW PV inverter testing platform
- Intelligent Building Energy and Environmental
- Monitoring and Control System (iBEEMS) testing platform

EPGC's facilities can be used for testing a wide range of equipment such as electrical drives, inverters, power converters, machines, transformers, micro-grid controllers and energy storage systems.

PLANNED DEPLOYMENTS

Renewable Energy Integration Demonstrator-Singapore (REIDS)

The Renewable Energy Integration Demonstrator - Singapore (REIDS) is a Singapore-based R3D (Research, Development, Demonstration and Deployment) platform dedicated to designing, demonstrating and testing solutions for sustainable and affordable energy access-for-all in Southeast Asia as well as the future of urban electricity distribution. REIDS is the largest hybrid microgrid test and research platform in the tropics. REIDS is supported by (EDB) and (NEA). REIDS and its partners are testing and demonstrating the integration of solar, wind, tidal, diesel, storage as well as waste-to-energy and power-to-gas technologies & end-use technologies and solutions suitable for deployment in Southeast Asia. ERI@N(REIDS) team promotes research/ tech capabilities in flexible reconfiguration capabilities of grids, the LVMGC platform developed enables comprehensive multi-microgrid test scenarios, dynamic system optimization, energy exchange and interoperability, which are instrumental to exploring pre-competitive R&D opportunities in the energy sector for future microgrids.

REIDS Offshore

The offshore renewable energy integration and demonstration (Offshore REIDS) project, also termed as Tropical Marine Energy Centre (TMEC), has been initiated by ERI@N and financially funded by the ClassNK firm (a Japanese classification society) and seeks to pave the way for establishing the world's first scaled marine renewable energy testing facility for tropical needs. In March 2015, the feasibility study for the test sites was officially launched and completed in December 2017. During this project, the resource mapping methodologies were well utilized to identify the ocean energy potential of the southern islands of Singapore that have been identified from the Maritime Port Authority of Singapore (MPA). Environmental impact assessment (EIA) for the test sites was done to understand the impact of ocean energy system deployment on marine life and environment. The EIA included investigating the baseline conditions, possible effects of the test sites in the surroundings, and other associated research, such as underwater acoustics, water purity, sea-level changes, tidal flow effects, etc. Geotechnical and geophysical surveys are also being planned. The outcome of this project will be extended towards Singapore's guidelines and standards development by working with Spring Singapore to support the local supply chain's marine energy resource mapping guidelines of new regions, such as our neighboring region of Southeast Asia and other tropical islands and remote coastal regions. Overall, the present project aims to develop technologies and deployment methodology for meeting energy needs in the remote island region.

Deployment of Clean Energy Powered Water Generation System in Southern Islands of Singapore

Southern islands of Singapore act as spots for tourist attractions. The energy and water demand in the island are mainly due to tourism and other governmental facilities in the islands. The islands consist of bungalows /campsites for tourists, temples, beaches, fishing and

Southern Islands of Singapore

picnic spots in addition to the governmental facilities. Currently, the islands use diesel power generation and water transported by the mainland. Energy Research Institute @ Nanyang Technological University (ERI@N) with support from Singapore Land Authority (SLA) has deployed clean energy powered water generation system and renewable systems in southern islands of Singapore in order to support the water and energy needs of southern islands which attracts a large number of tourists every year. Presently, deployment of renewables and water generation systems in one of the islands is completed and discussion towards deployment in other islands is in progress.

Singapore Decarbonization efforts

Jurong Island is planned to serve as a "living" testbed for sustainable solutions, as the industrial estate transforms into a sustainable energy and chemicals park. Jurong Town Corporation, a Singapore government agency has launched two innovation calls aimed at coming up with solutions to boost the circular economy and reduce carbon footprint. The first - Jurong Island Innovation Challenge - crowdsources innovative ideas from start-ups and small- and medium-sized enterprises (SMEs) to enhance the sustainability and circularity of resources. Industry players such as Chevron Oronite, Shell and Singapore LNG Corporation has participated in the call, and have come together to submit 10 challenge statements. The challenge statements cover four key themes that will boost resource efficiency efforts: Energy efficiency, emissions reduction, water management and chemical waste management. SMEs that put forth proposals will gain opportunities to work with large corporates and will also receive funding support for the development of their solutions. Under the enterprise track, qualifying start-ups and SMEs can tap on ESG's Enterprise Development Grant, which can provide support for up to 80% of the qualifying solution development costs. For selected challenge statements, awarded solution providers will receive up to S$2 million in grant support under the National Innovation Challenge, for solution development and industry adoption. The second innovation call is a request for proposals for energy solutions that can reduce the island's carbon footprint. This call focuses on test-bedding renewable energy and energy storage systems such as high-efficiency solar panels and solar deployment on pipe racks and storage tanks.

Jurong Island, Singapore

Floating Solar Deployment

- Construction of a 60-megawatt peak (MWp) floating solar photovoltaic (PV) system on Tengeh Reservoir was completed by Sembcorp in 2021. This will offset 7% of PUB's energy needs and reduce PUB's carbon footprint.
- Singapore's national water agency PUB is also planning the installation of two floating solar projects with a combined capacity of 144 MWp as part of efforts to utilise the city-state's reservoirs for renewables generation.
- G8 subsea deployed first offshore floating solar substation platform of 5 MW capacity near the coast at north of Woodlands Waterfront Park, along the Straits of Johor.
- ERI@N is also currently developing and deploying 100 kW offshore floating solar system for deployment in waters depths of 20 – 30 m. The initial testbed is being planned for deployment in a seawater lake near Sentosa, Singapore.

60 MW Floating Solar in Tengah Reservoir

RELEVANT NATIONAL EVENTS

8th Workshop on Tidal Current Extractable Energy: Modelling, Verification and Validation

The main goal of this workshop was to prepare a Tidal Energy Resource Modelling Guideline report through the study of the various factors affecting the result of the simulations. This is likely to be a joint exercise effort concentrating on the accurate modelling and reporting of tidal energy resources. As a great multitude of tools and techniques are used to determine the amount of tidal resources and to quantify the resources available in different parts of the world, establishing a standard in extractable resource modelling can pave the way in promoting the adoption of tidal energy among the various stakeholders, as it can provide confidence in the amount of available resources. International Tidal Energy Working Group is thus consequently formed and various research teams can conduct extractable resource studies to share their results and methodology, and work towards creating a standard report for modelling in harnessing tidal energy. This workshop was organised and hosted by Energy Research Institute @ NTU (ERI@N), Singapore through teleconferencing on March 2021.

Singapore International Energy Week (SIEW)

The Singapore International Energy Week (SIEW) is an annual platform for energy professionals, policymakers, and commentators to share best practices and solutions within the global energy space. The 14th edition of SIEW 2021 addressed a forum focused on Investing in an Inclusive and Just Energy Transition. The forum brought together international energy leaders to discuss and exchange views on mobilising investments to support and shape an inclusive energy transition.

Singapore and IRENA co-hosted a High-Level Forum at SIEW, with the theme "Investing in an Inclusive and Just Clean Energy Transition". The Forum provided a platform for Ministers, CEOs and thought leaders to explore and discuss the need to finance renewable and clean energy projects in order to facilitate the energy transition. The forum focused on these key areas:

- Mobilising Investment to Support the Energy Transition
- Shaping an Inclusive and Just Energy Transition
- The Role of Technology in Driving the Energy Transition

3.19 SPAIN

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OVERVIEW

The most noteworthy news of what happened in Spain in 2021 in the field of ocean energy is the impetus that the Spanish Government has given to this sector with the publication of the "*Roadmap for the Development of Offshore Wind and Energy in Spain*", which sets as a goal to reach 40-60 MW of installed power of the sea, basically wave energy, in a 2030 horizon.

Additionally, it is remarkable that two developers, WELLO and WAVEPISTON, began testing their prototypes at BiMEP and PLOCAN respectively, and Mutriku Wave Power Plant completed another full year generating electricity from the waves.

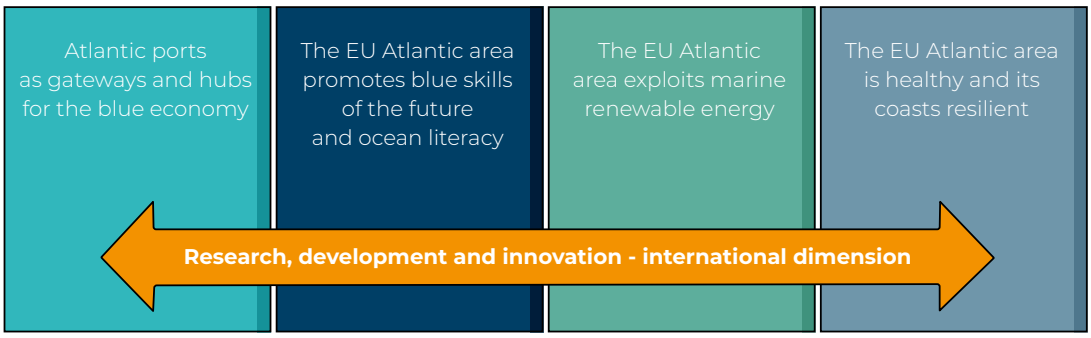
SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

A number of steps have been taken in 2021 to establish a new legal framework for ocean energy development. On the one hand, the Maritime Spatial Planning Plan continues to move forward in June 2021, the consultation and public information phase of the draft Royal Decree that will approve the maritime spatial planning plans in search of inputs and improvements.

Previously, several rounds of meetings had already been held with the sectors involved: fisheries energy environment maritime transport tourism etc., as well as with the regional administrations. Subsequently, the mandatory strategic environmental study of the Maritime Spatial Planning Plan has been started. This plan will be reviewed every 7 years. Although it is not reserved in any area of priority use for ocean energies because it is still far from its commercial phase, there will be no restrictions to promote R&D projects in areas reserved for other uses provided that the general legal framework is complied with.

In 2013 the European Commission put forward an Atlantic Action Plan to implement the Atlantic Maritime Strategy. The Action Plan went through a mid-term review and identified seven goals under four thematic pillars through concrete actions mobilising all relevant Atlantic stakeholders. The coordination of Pillar III – Marine Renewable Energy – was awarded to



EVE (Basque Energy Agency) who presented a roadmap to the Atlantic Strategic Committed. This Committee approved the roadmap and EVE, together with the task force set up for this purpose, worked on its deployment.

Moreover, in March 2021, the final version of the National Integrated Energy and Climate Plan 2021-2030 (PNIEC) was approved, which proposes that in 2030 renewables contribute 42% of the final energy in Spain and 74% of electricity. In its final version, it does not set specific targets for ocean energies, but it appears a section of Other Energies with installed power targets of 40 MW for 2025 and 80 MW for 2030.

And finally, in December 2021, the Spanish Government has published the Roadmap for the Development of Offshore Wind and Energy in Spain, which sets as a goal to reach 40-60 MW of installed power of the sea, basically wave energy, by 2030.

MARKET INCENTIVES

There are no specific market incentives for ocean energy in Spain but for renewable energy installations in general.

Royal Decree 413/2014 established that the support for new renewable facilities is granted through competitive public tender processes. Through these auction processes, bidders propose the initial value for the investment that they will be willing to accept, and the MW auctioned are allocated to the most competitive offers (the lower ones).

Royal Decree 960/2020, of November 3, which regulates the economic regime of renewable energies for electricity production facilities and Order TED / 1161/2020, of December 4, which regulates the first auction mechanism for the granting of the economic regime of renewable energies and establishes the indicative calendar for the period 2020-2025, will allow starting the tender calendar for the next five years. This Order establishes a tender of 20 MW every two years focused on “Other Technologies”, where ocean energy is included, reaching 60 MW for 2025 The next auction is expected for April 2022.

PUBLIC FUNDING PROGRAMMES

The Basque Energy Agency (EVE) launched a new call of its “Demonstration and validation of emerging marine renewable energy technologies” programme in 2021. The programme has a budget of 2.5 M€ for a maximum of 3-year duration projects.

RESEARCH & DEVELOPMENT

EuropeWAVE

Horizon 2020 project EuropeWAVE was launched in January 2021 and has the objective to bridge the gap to commercialisation of wave energy technology using pre-commercial procurement. The project brings together over €22.5m of national, regional and EU funding to provide the boost to Europe's wave energy innovation community necessary to transition to commercial viability. WES (Wave Energy Scotland) is the coordinator of the project and acts as lead procurer in the 'Buyers Group' formed by WES (Scotland) and EVE – Basque Energy Agency (Basque Country). The consortium is completed by Ocean Energy Europe, the sector's representative body, who will enable the widest possible engagement with those influential stakeholders able to maximise the environmental, economic and social benefits of wave energy technology for Europe.

EuropeWave project's main activities during 2021 have been:

- Publication of Prior information notice: Design, develop, and demonstrate wave energy converter systems (EuropeWave PCP), 26/02/2021
- Publication of Pre-Commercial Procurement: Design, develop, and demonstrate wave energy converter systems (EuropeWave PCP), 02/07/2021
- Publication of EuropeWave PCP Independent Experts tender, 28/07/2021
- Contracting of EuropeWave PCP Independent Observer
- Selection of the 7 successful projects (subject to contract):
  - Waveram Ltd: The Waveram
  - Mocean Energy Ltd: Blue Horizon 250
  - IDOM Consulting, Engineering, Architecture SAU: MARMOK Atlantic
  - CETO Wave Energy Ireland Ltd: ACHIEVE
  - Bombora Wave Power Europe Ltd: emWave
  - Arrecife Energy Systems SL: Trimaran
  - AMOG Consulting Limited: Sea-Saw WEC

TURBOWAVE

The Basque Energy Agency (EVE) has launched in December 2021 a Preliminary Market Consultation for the TurboWave project. The TurboWave Public Procurement of Innovation action aims to accelerate the development of air turbine technologies that are tailored to the needs of the wave power industry in general and the specific technical requirements of the Mutriku Wave Power Plant. The TurboWave project is expected to progress through 4 phases. These are currently identified as:

- **Phase 1:** Concept development
- **Phase 2:** Design refinement and laboratory testing
- **Phase 3:** Detailed design, manufacturing and on-site tests at Mutriku wave power plant
- **Phase 4:** Procurement of a minimum of 2 and a maximum of 8 turbines

In this regard, EVE has decided to call the Preliminary Market Consultation so that, if appropriate and as a phase prior to the call for tenders, it can be taken into account in the design and preparation of the future tender.

OCEANset

This 3-year project with a total budget of 1 million euros is focusing on providing support to ocean energy implementation plan of the European Strategic Energy Technology Plan (SETPlan). This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 840651. Project members are: Sustainable Energy Authority of Ireland (SEAI) – coordinator, Wave Energy Scotland (WES), Direção Geral de Energia e Geologia (DGEG), France Energies Marines, Ocean Energy Europe, ENEA, Basque Energy Agency (EVE), the University of Edinburgh and PLOCAN.

OCEANERA-NET

OCEANERA-NET Cofund project is now in its fifth year and has successfully implemented two Joint Call for collaborative, trans-national research, development and demonstration projects to tackle some of the key challenges and opportunities for ocean energy.

WESE

WESE project ended its activity in October 2021. Two final events were celebrated: the first one in the framework of the EWCTEC conference in Plymouth (UK) and another one fully online on October 2021. Specific details of the results and outcomes of the project can be found on the website of the project: http://wese-project.eu/.

Funded by the European Maritime and Fisheries Fund (EMFF) through is Executive Agency for Small and Medium-sized Enterprises (EASME) and launched in November 2018, WESE - Wave Energy in

Southern Europe project aims to improve the current knowledge of the potential environmental impacts of ocean wave energy projects and consequently reduce the uncertainty about these impacts in order to better inform decision-makers and managers on environmental real risks and reduce environmental consenting across Spain and Portugal.

The WESE Consortium, led by the RD&I Basque center AZTI, includes a multidisciplinary team of partners bringing together technology device developers (BiMEP and IDOM from Spain and AW-Energy from Finland), Environmental Impact Assessment consultants (WavEC from Portugal and CTN from Spain), academic experts and data managers (HIDROMOD from Portugal), aiming to involve the wider community of ocean energy key stakeholders from across Portugal and Spain.

SafeWAVE

SafeWAVE project started on October 2021 and will run until September 2023. During summer 2021 some of the monitoring activities started in SEM-REV (seafloor integrity inspection with ROV and side scan sonar and underwater sound monitoring) and BiMEP (underwater sound monitoring and first trials of the ItsasDrone device for fish monitoring).

Funded by the European Maritime and Fisheries Fund (EMFF) through is Executive Agency for Small and Medium-sized Enterprises (EASME) and launched in November 2020, the Safe WAVE - Streamlining the Assessment of Environmental Effects of Wave Energy share common objectives and builds on the results of the WESE project representing the second effort of the EU in the objective of overcoming the non-technological barriers that could hinder the development of ocean wave energy (WE) projects in EU: (i) the environmental risk and uncertainty about the potential environmental impacts of WE developments trough an environmental research demonstration strategy based on the collection, processing, modelling, analysis and sharing of environmental data collected in WE sites from different European countries where WE devices are currently operating (Mutriku power plant and BIMEP in Spain, Aguçadoura in Portugal and SEMREV in France); (ii) the need of a Maritime Spatial Planning (MSP) approach to overcome the potential competition and conflicts between WE and other marine users and the complex and long consenting processes trough a consenting and planning strategy based on providing guidance to ocean energy developers and to public authorities tasked with consenting and licensing of WE projects in France and Ireland and the application of the MSP decision support tool developed for Spain and Portugal in the framework of the WESE project and (iv) the opposition among host communities of future WE deployments through a public education and engagement strategy based on a collaborative work with coastal communities in France, Ireland, Portugal and Spain, to co-develop and demonstrate a framework for education and public engagement (EPE) of ocean wave energy projects.

The SafeWAVE Consortium, led by the RD&I Basque center AZTI, includes a multidisciplinary team of partners bringing together technology device developers (BiMEP from Spain, WELLO from Finland, CorPower Ocean from Sweden and GEPS Techno from France), Environmental Impact Assessment consultants (WavEC from Portugal, CTN from Spain and RTSYS from France), academic experts (University College Cork – National University of Ireland, Cork (UCC) from Ireland and Ecole Centrale de Nantes (ECN) from France) and data managers (HIDROMOD from Portugal), aiming to involve the wider community of ocean energy key stakeholders from across Portugal, Spain, France and Ireland. The project started in October 2021 and will run until September 2023. During summer 2021 some of the monitoring activities started in SEM-REV and BiMEP.

ELBE PLUS

The ELBE PLUS project is part of the European Union's COSME "Cluster Go International" programme. ELBE aims to develop an internationalization strategy to contribute to positioning Europe as a world technological and industrial leader in Blue Energy, with a focus on emerging areas such as offshore wind, wave and tidal energy. The consortium gathers seven European clusters in Scotland, Belgium, Sweden, Denmark, France and Norway, under the coordination of the Basque Energy Cluster. In the case of ocean energy, it specifically targets the promotion of international cooperation with The US, Canada, Japan, Republic of Korea and Taiwan region.

ETIP Ocean

TECNALIA has led, in collaboration with Ocean Energy Europe and the University of Edinburgh, a socio-economic study within the context of ETIP Ocean, the European Technology and Innovation Platform on Ocean Energy. This analysis gathers evidence on the direct and indirect impacts of ocean energy on local communities, in terms of job creation, training needs and business opportunities along the value chain.

DTOceanPlus

The DTOceanPlus project, funded under the H2020 programme and coordinated by TECNALIA, has developed and demonstrated an integrated open-source suite of design tools for the selection, development and deployment of ocean energy systems. This comprehensive toolset will accelerate the progress of the ocean energy sector by enabling stakeholders to evaluate the viability of full arrays, individual devices or subsystems in terms of performance, reliability, economics, and environmental and social aspects.

More information: https://www.dtoceanplus.eu/ and https://gitlab.com/dtoceanplus

VALID

The VALID project, funded under the H2020 programme, is developing a new methodology for accelerated testing of critical wave energy components. It combines numerical and experimental modelling approaches in an integrated and open hybrid testing platform, which will reduce the product developing time, cost and uncertainties. In 2021, the project has produced several technical reports on critical component identification, accelerated testing requirements, modelling limitations, and specifications of the user cases.

More information: https://www.validhtp.eu/

NEMMO

The NEMMO project (2019-2022), funded under the H2020 programme and coordinated by TECNALIA, has surpassed its equator with promising results focussed on boosting the competitiveness of tidal energy by optimising tidal turbine blade design and performance. New antifouling strategies, accelerated testing procedures, LED models for improving the design of the blade's geometry and a fully refurbished blade geometry have been defined. Those advances will be implemented in a full-scale set of 6 blades that will be tested during 2022 in the prototype owned by Magallanes Renovables. In 2021 the project produced several public deliverables that can be downloaded from the project website (http://nemmo.eu/).

PORTOS

PORTOS project, co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_784/2018), aims to assess, develop and promote the integrated use of renewable energy resources in Atlantic Area ports and increase their energy efficiency, establishing a roadmap to a more competitive and sustainable sector. With respect to technologies for harvesting Marine Renewable Energies (MRE), although there are already proven technologies to harness MRE which only require being adjusted to the installation site conditions, new concepts are continuously being invented by academic, non-academic and industry inventors and entrepreneurs, which do not have enough resources to put their ideas forward. Based on this fact, PORTOS aims to make available through a Transnational Access, the experimental facilities and knowledge of some partners (University of Porto, University of Plymouth, University of Oviedo and IHCantabria) to test proof of concepts of emerging technologies.

Within this transnational access, two concepts of wave energy converters have been tested at IHCantabria facilities. The first one, designed by IDOM, aimed to improve the fundamental knowledge and modelling approaches for non-linear effects prediction on heaving spar type WECs, as well as the hydrodynamic stability and viscous forces characterizations that influence to some extent the power performance and loads on other subsystems. The second device, designed by Rotary Wave S. L. in collaboration with Typsa, was based in the Rotary Axis technology and consisted in an arm-float system that is expected to be installed in Valencia Port (Spain). This device was tested under operating and survival conditions to evaluate its dynamic behavior.

BLUEGIFT

Blue Growth and Innovation Fast Tracked, is a €2.5M European Regional Development Fund project that aims to help Atlantic Area companies test the next generation of Marine Renewable Energy (MRE) technology in real sea environments and prove power can be economically generated from the ocean. The project will result in a minimum of 8 MRE floating wind, wave or tidal pre-commercial demonstrations, over 24,000hrs of operation, work with over 20 SME's, sustaining 30+ jobs and helping to secure €15M investment into MRE companies. The BLUEGIFT consortium is integrated by test centres covering the major geographical spread and resource types and are evenly distributed across the Atlantic Area programme area: EMEC in Orkney, UK; SEENEOH in Bordeaux, France; SmartBay from Galway, Ireland; Centrale Nantes/SEM-REV in Nantes, France; PLOCAN in the Canary Islands; WavEC in Portugal; and BiMEP in Spain.

TEST SITES

BiMEP is an open sea full scale grid connected test centre managing two sites: one located off the coast of Armintza, in the province of Bizkaia, and the other one onshore at the port of Mutriku, in the province of Gipuzkoa. Operating since June 2015, BiMEP offers technology developers an offshore area with suitable wave and wind resources, thereby enabling the demonstration and validation of the technical and economic viability of different concepts of energy converters, equipment and materials prior to commercial development.

Mutriku Wave Power Plant, the first multi-turbine wave energy facility in the world, has been integrated into BiMEP infrastructure, being now a second facility of BiMEP. The plant was connected to the grid in July 2011, and in 2021 it has continued its successful operation, adding another year of continuous operation. Two of the air chambers are prepared to test OWC components (air turbines, electrical generators, power converters and control systems).

PLOCAN offers a test site for marine energy converters among other uses. It includes an offshore multipurpose platform providing workshops, laboratories, classrooms, training rooms and open working areas around a test tank to facilitate sea trials and launching vehicle to the sea.

PROJECTS IN THE WATER

WELLO OY

In 2021 the company WELLO OY (from Finland) installed its PENGUIN2 prototype at BiMEP. PENGUIN2 arrived to BiMEP on June 2021 and was deployed off on December 2021 for inspection, maintenance and repairs. During this deployment, the Penguin WEC has been feeding clean electricity to the national grid of the Basque Country. The Penguin's power and energy production followed the expectations and calculations made before the deployment based on wave data and wave tank tests. There have been several storms during this deployment and waves have reached up to 11 m Hmax. The Penguin has not faced the most energetic wave of the Bay of Biscay yet, but these experiences already give a very good understanding of the performance of the technology. Wello has had the benefit to having the support of offshore giants Saipem, experts in the offshore industry, who have been responsible for the towing and deployment of the WEC and they shall continue to have a role in the project as the O&M operator for the deployed device. The access to the test site has been funded by BLUEGIFT Project, and received the support of the Basque Energy Board (EVE).

Wavepiston prototype

WAVEPISTON

The Danish company Wavepiston installed two full-scale modules of its wave energy converter (WEC) at the Test Site of the Oceanic Platform of the Canary Islands (PLOCAN). Their device allows the conversion of wave motion into electricity and desalinated water.

The access to the test site has been funded by the European Commission through the grant offered by the Blue-GIFT project, that aims to help Atlantic Area companies to test their next generation ocean energy technologies in real sea environments and thus demonstrate that ocean energy is economically feasible. The Blue-GIFT project will result in a minimum of eight pre-commercial demonstrations of floating wind, wave or tidal technologies, over 24,000 hours of operation, work with more than 20 small and medium enterprises (SME), creation of more than 30 jobs and will help to secure €15M investment into marine renewable energy (MRE) companies.

Wavepiston's wave energy prototype was assembled in the Port of Las Palmas and towed to PLOCAN's test area. The system comprises a chain of wave energy collectors stretched between two anchored buoys. The plates of the collectors move when waves roll along the system, pumping pressurized sea water into a pipe leading to a turbine or a reverse osmosis system, in order to obtain energy or desalinated water. The main characteristics of this technology are its flexible, robust and light structure, its modular design and its low impact on the marine environment.

HARSHLAB PLOCAN

Harshlab 0.5 is a laboratory for the evaluation of materials in real sea conditions. This infrastructure is suitable for testing corrosion phenomena or the interaction between marine environment and material such as biofouling. During 2021, 4 different studies have been carried out thanks to this infrastructure. Different additives with antifouling and antibite properties are being tested in the framework of the H2020 project FLOTANT; corrosion models for the offshore wind sector are being developed thanks to the comparison with the real corrosion within the H2020 WATEREYE project; a cutting edge coating which include nanoparticles was demonstrated by the SmartCoat project; and different samples made of different materials are now exposed in order to characterize the harsh conditions of the test site.

Upgraded version of HarshLab in the port of Bilbao ready for its final destination at BiMEP

HARSHLAB BiMEP

The first version of TECNALIA's advanced floating laboratory for the evaluation of standardized probes and components in an offshore environment (https://harshlab.eu/) has been hosting research projects in BiMEP since September 2018. Three years later, the second version of the laboratory hit the waters of the Port of Bilbao in November 2021 and is now waiting for a suitable weather window for its final commissioning in BIMEP. This upgrade opens the door to new testing activities related not only to materials and coatings, but also to testing bigger and more complex equipment, such as sensors, communications systems, actuators, electrolysers, etc., adding two additional exposition zones (confined and seabed) to the already existing splash, immersion and atmospheric. The final stage of the development is the connection of the laboratory to BiMEP's submarine cable, which will take place during the summer of 2022.

PLANNED DEPLOYMENTS

The Danish company Wavepiston will continue with the test initiated in 2021, through the project W2EW (Wave to energy and water) founded by the European Union's Horizon 2020 Research & Innovation FTI Instrument Programme. The consortium plans to roll out the W2EW solution on off-grid islands and isolated coastal communities to replace diesel generators and deliver renewable energy and desalinated water. In the long term the utility-scale market opens, potentially combined with wind and solar energy to improve reliability and grid balancing of renewable energy. This prototype will be installed in the PLOCAN test site.

RELEVANT NATIONAL EVENTS

BEC (Bilbao Exhibition Centre) together with EVE and the collaboration of Basque Energy Cluster, TECNALIA and IDOM organized the Ocean Energy Conference (OEC) 2021. OEC joins World Maritime Week (WMW) as a follow-up to the already established marine energy sessions held since 2005.

The city of Donostia-San Sebastian (Basque Country) will host the **International Conference on Ocean Energy (ICOE)** in 2022 (18-20 October).

3.20 SWEDEN

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OVERVIEW

In 2021, the Swedish ocean energy developers took major steps moving closer to industrialization and commercialization. For example, Minesto has been operating a DG100 device with satisfactory results in Vestmannasund, Faroe Islands. Minesto has also presented a new generation of the design, called the Dragon Class. A device from Novige was in 2021 tested for 2 weeks in ECN's LHEEA wave testing facility in France. Novige has also received a 2.1 MEUR funding from EU's LIFE Programme for a 4-years project that will include offshore testing of the first pre-commercial 500 kW unit. Regarding CorPower's progress, dry testing has been performed on the C4 power-take-off-system, to prepare for the ocean deployment in Agucadoura, Portugal. Also, a mobile factory has been set up in Viana do Castelo for producing full-scale composite buoy hulls. The plan is to produce the first C4 hull early 2022 before integration with PTO and subsequent ocean deployment. A full-scale UMACK anchor (which is installed using vibro-driving technique) has been produced and delivered to Portugal, ready to be deployed in 2022.

Swedish R&D activities on ocean energy focus on developing cost-effective and environmentally sustainable electricity production systems that can be commercialized before 2030. In 2021, over 20 R&D projects were running, covering topics such as reliability & survivability, material improvements, wave prediction, WEC array optimization and environmental studies.

NATIONAL STRATEGY

In 2016, the government together with several other political parties agreed on a long-term bipartisan energy policy for Sweden. The agreement includes a target of 100% renewable electricity production by 2040 and no net emissions of greenhouse gases in the atmosphere by 2045. Furthermore, a new Climate Act was introduced in 2018, which states that each government has an obligation to pursue a climate policy based on the climate goals adopted by the Riksdag. At the beginning of 2020, the government additionally published Sweden's integrated national energy and climate plan[1], which presents how Sweden contributes to reaching the European Union's goals in renewable energy and energy efficiency by 2030.

In 2015, the Ministry of Enterprises, Energy and Communications enacted a national maritime strategy[2] which identifies areas where actions are needed to promote sustainable development in the Swedish maritime sector. Ocean energy is one of many areas included. However, there is no national energy policy specifically for ocean energy.

In December 2019, the Swedish Agency for Marine and Water Management submitted the Swedish marine spatial plan proposals to the Swedish government. Marine spatial planning will form the basis for governmental agency and municipal decisions regarding the most appropriate usage of a marine area, taking into account the character and location of the area and the existing needs. No specific area has been designated for ocean energy usage to date.

MARKET INCENTIVES

The long-term Swedish energy policy relies on economic policy instruments, including a carbon tax, international emissions trading and a renewable electricity certificate system. These instruments provide incentives for renewable energy while remaining technology neutral. There are no instruments in place to specifically incentivise ocean energy deployment.

PUBLIC FUNDING PROGRAMMES

Swedish governmental agencies support academic and private sector R&D at various stages of technology maturity. Funding providers include:

- Swedish Energy Agency (SEA), which is responsible for facilitating a sustainable energy system in Sweden. To this end, the agency funds relevant research, business and technology development and technology demonstration.
- Swedish Research Council (VR), which is tasked with funding fundamental research and research infrastructure for a wide range of topics.
- Swedish Innovation Agency (VINNOVA), which supports business and technology development through funding.

In addition, regional authorities may also grant funding.

In 2018, the second phase of the Swedish Energy Agency´s national ocean energy program was started. The activities and priorities of the program are formulated in the Swedish Energy Agency's strategy for ocean energy, which was finalised in 2017[3]. The

1 The complete document in English can be found here: https://ec.europa.eu/energy/sites/ener/files/documents/se_final_necp_main_en.pdf
2 A summary in English can be found here: http://www.government.se/contentassets/9e9c9007f0944165855630ab4f59de01/a-swedish-maritime-strategy--for-people-jobs-and-the-environment
3 http://www.energimyndigheten.se/nyhetsarkiv/2017/energimyndigheten-antar-strategi-for-havsenergi/

programme ends in 2024 and has a total budget of around 10,2M€. Since 2018 three calls have been held, resulting in a total number of 21 funded projects. The programme supports research, experimental development and demonstration of technical solutions within the following focus areas:

- Improved knowledge regarding environmental impact during installation, operation and decommissioning
- Improved reliability and durability
- Development of systems, subsystems and components for cost-effective conversion of marine energy
- Tests and demonstration of systems in marine environments
- Improved installation, operation and maintenance strategies

The Swedish Energy Agency is also involved in OCEANERA-Net Cofund, which is a collaboration between national/regional funding organisations and the EU to support the ocean energy sector and fund transnational projects.

RESEARCH & DEVELOPMENT

Swedish companies, universities and institutes have been involved with several research and development projects during 2021. Below are just a few examples.

Untapping Blue Energy – Improving water pre-treatment for harvesting osmotic power

Current methods to utilize the osmotic energy that is released when two streams with different salinity mix are membrane-based technologies that suffer from membrane fouling. To overcome this issue, pre-treatment processes, that are highly energy-intensive, are employed prior to the membranes. In this project, the pre-treatment processes are improved to reduce the power demand by exploring different membrane materials and mitigating the fouling issue by ozonation. In the current phase of the project, a test rig is being built to evaluate the interaction of dissolved ozone with membrane materials under controlled lab conditions. Also, tests with simulated seawater and freshwater are being used to determine the dosage of ozone required for reducing membrane fouling. Results of the lab tests will be used for designing a membrane-based osmotic power generation process and to evaluate the system performance taking into account the energy demand for the pre-treatment and pumping of seawater and freshwater. Based on this, the effectiveness of the ozonation pre-treatment on the overall power generation capacity will be investigated and quantified. The project is being carried out by KTH Royal Institute of Technology in collaboration with Ozone Tech Systems AB.

INTERACT - Analysis of array systems of wave energy converters (WECs)

This project is developing new design and assessment methods together with advanced simulation models that can be used to design array farms, accounting for interaction effects for optimum system performance e.g. power, fatigue life, LCoE. This is achieved by systems engineering, risk analyses and fully coupled hydrodynamic and structure response simulations. Several showcases of different WEC technologies, sites of operation and array systems are simulated, analysed and optimised. The project is carried out by Chalmers University of Technology, NKT Cables AB, RISE Research Institutes of Sweden, CorPower Ocean AB, Waves4Power AB, Novige AB and Seaflex AB.

SEASNAKE (OCEANERA-Net Cofund)

This project aims to provide a step change in the overall performance of medium voltage cable systems - ensuring that they are highly reliable while reducing the risks of ocean energy installations. Project objectives are:

- to increase the economic viability of OWC systems by reducing the LCOE by at least 20%.
- to prove that 95% availability can be achieved with an improved design for reliability, maintainability and survivability of all cable sub-systems, validated in a relevant environment, reaching TRL7.
- de-risk and optimise the offshore operations.
- demonstrate dynamic cable solutions.
- minimise environmental impact.

The project is carried out by RISE Research Institutes of Sweden, Chalmers University of Technology, CorPower Ocean AB, I-Tech, MWA Coatings, NKT Cables AB, Ocean Harvesting Technologies, Université Gustave Eiffel, WavEC, Waves4Power AB and WaveVenture.

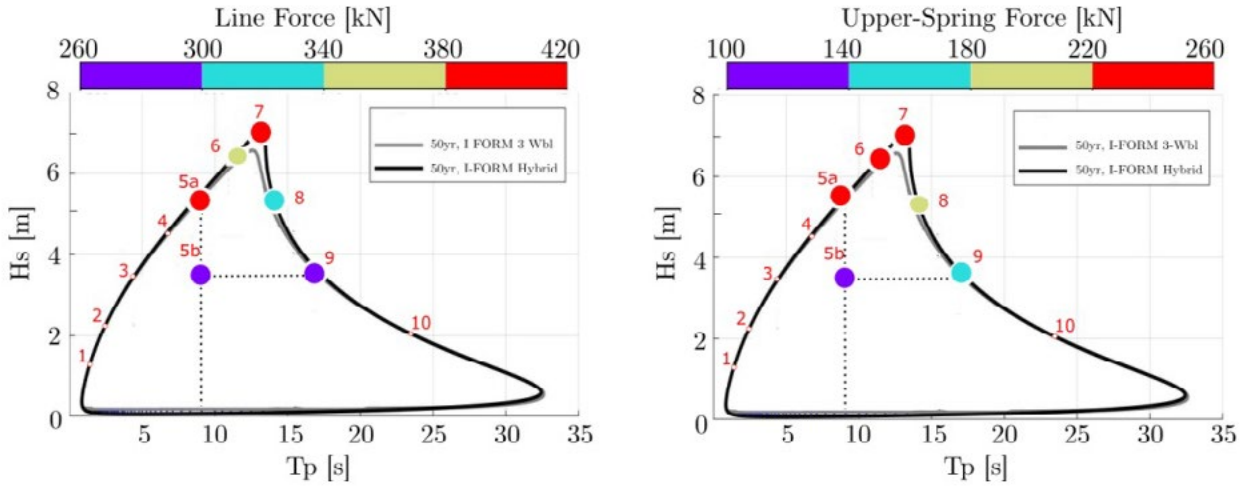
Improved reliability and survivability of mechanical wave energy subsystems

In this project, the wave loads on mechanical wave energy components are measured and computed,

and the impact on the survivability of the system is analysed. In 2021, several important results were obtained in the project:

- Extreme waves at potential sites for ocean energy in the North Sea and Baltic Sea have been identified and characterized.
- Extreme wave impact on a 1:30 scale wave energy converter with linear damping has been analyzed using experimental data obtained from wave tank tests carried out at Ålborg University, Denmark, and the COAST laboratory, Plymouth University, UK.
- Numerical models were extended and improved using the CFD software OpenFOAM as well as the software WEC-Sim, and validated with the obtained experimental data. The mooring line dynamics and its impact on critical loads have been investigated using the MooDy code.
- Both experimental and numerical results have shown that the wave representation affects the dynamics and extreme wave impact to a large degree – different results are to be expected depending on if the waves are modelled as harmonic, irregular or focused waves.

The project is carried out by Uppsala University, Chalmers University of Technology, Sigma Energy & Marine, Plymouth University, RISE Research Institutes of Sweden, and Ålborg University.



Colormap visualization of the maximum force in the connection line (left) and the maximum force (right) on the upper end-stop spring along the environmental contour line. From Katsidoniotaki, E., Nilsson, E., Rutgersson, A., Engström, J., & Göteman, M. (2021). Response of Point-Absorbing Wave Energy Conversion System in 50-Years Return Period Extreme Focused Waves. Journal of Marine Science and Engineering, 9(3), 345.

UMACK - Universal Mooring, Anchor & Connectivity Kit Demonstration (OCEANERA-Net Cofund)

The UMACK project addresses ocean energy affordability, survivability, reliability and installation through the demonstration of a generic anchor-foundation-mooring-connectivity system. The project aims to reduce capital and installation costs by up to 50% and is tailored for offshore installations in sites with sand and clay soil. UMACK brings together wave and tidal energy developers, CorPower (wave) and SME (tidal), mooring experts TTI Marine Renewables, Ternan Energy (offshore geotechnical experts), EMEC (an ocean energy test and verification facility), and University of Edinburgh (marine renewable energy modelling experts).

Design validation of InfinityWEC´s power take-off in a HIL test rig at scale 1/10

Ocean Harvesting Technologies AB has during 2021 built a scale 1:10 hardware-in-the-loop test rig and validated the functionality of the power take-off and control system of the InfinityWEC wave energy converter, including i) instant force control capability with a combination of ball screw actuators and a hydraulic pre-tension spring, enabling efficient predictive control to be applied to maximize the energy output from every individual wave, and ii) passive survival function with a novel two-stage end stop system that softly stops the buoy motion and holds it submerged through the crest of large waves, ensuring survival and reliable power production even in the harshest sea conditions.

A new case study together with Lundin Energy Norway has investigated the possibility to power oil & gas platforms with wave energy. The study has included development of specifications, manufacturing strategy, handling procedures and life cycle cost assessment for a commercial-scale wave farm to supply an oil & gas platform with constant power supply all year around. Power balancing requirements have been analysed and compared with wind power, showing that the wave farm requires 30% less storage capacity and 50% less energy passing through the energy storage. It was also found that combining wave and wind power improves the overall power balancing for wind power, reducing the cost to create a stable electricity supply.

InfinityWEC PTO in hardware-in-the-loop test rig (© Ocean Harvesting Technologies)

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

Uppsala university – Lysekil test site

Data from a force measurement buoy deployed at the Lysekil test site in 2019 has been analysed by Uppsala university using extreme value methods and the results have been submitted to a scientific journal. The force measurement buoy was deployed again in November 2020 to collect data during the winter season and is currently in operation.

Seasnake project – Medium voltage cable systems

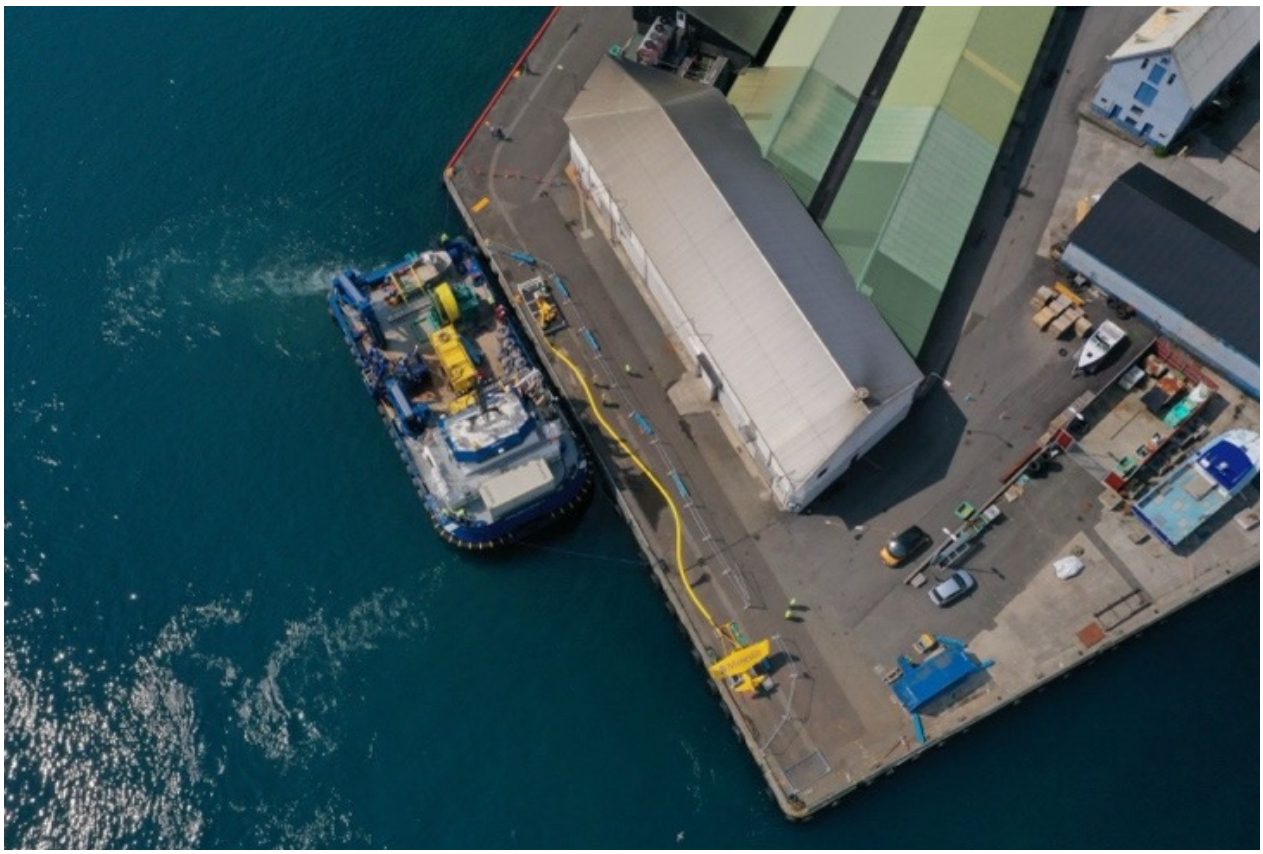
Anti-fouling and coating tests have taken place at the Kristineberg test site in Sweden as well as in Lisbon, Portugal. Further, laboratory testing of the cable has been conducted in France (Université de Gustaf Eiffel).

Novige/NoviOcean

Novige is developing NoviOcean WEC, a point absorber that via a basic hydraulic cylinder, pumps high-pressure water up to a high-efficiency Pelton turbine that runs a generator. The concept is called HPAS (short for Hydro Power Plant at Sea) due to its similarities with hydropower. After receiving 0.9 MSEK funding from Vinnova by the end of 2020 as well as 4.2 MSEK from the Swedish Energy Agency in early 2021, the Novige team was able to apply the lessons learned from previous testing both offshore and in wave tank in 2019/2020. Therefore, improvements on the 1/5 scale prototype have been made and the prototype (now called NO2) was prepared for further testing.

In the summer of 2021, with support from the MaRINET2 programme, the NO2 unit was further tested for 2 weeks in ECN's LHEEA wave testing facility at Nantes, France, with results indicating that the full-scale NoviOcean 500 kW system (called NO500) can reach its full nominal output from 3.5-meter waves and higher.

NoviOcean in a towing tank at the Research Laboratory in Hydrodynamics, Energetics and Atmospheric Environment (LHEEA) in Centrale Nantes. (© Novige)



Minesto - Vestmannasund, Faroe Islands

In 2021, Minesto's grid-connected DG100 tidal energy converter were successfully operated in Vestmannasund, Faroe Islands. The Faroe Islands testing has verified offshore operational procedures, functionality and power production performance of Minesto's Deep Green technology, delivering electricity to the Faroese grid over full tidal cycles with satisfactory performance. Key aspects of test operations and electricity production with the DG100 system have been third-party verified by DNV in accordance with international standards. These results were achieved by the DG100/DGIM2/DGIM project, which was co-funded by the European Union's Horizon 2020 SME Instrument programme, and by the Swedish Energy Agency.

Deployment of Minesto's DG100 system in Vestmannasund, Faroe Islands (© Minesto)

PLANNED DEPLOYMENTS

In 2021, **Novige** received 2.1 MEUR funding from the LIFE Programme of the European Union. With a total budget of 4.5 MEUR, the LIFE NOVIOCEAN project focuses on detailed design, manufacturing, deployment, and offshore testing of the first pre-commercial NO500 pilot unit over a 4-years period.

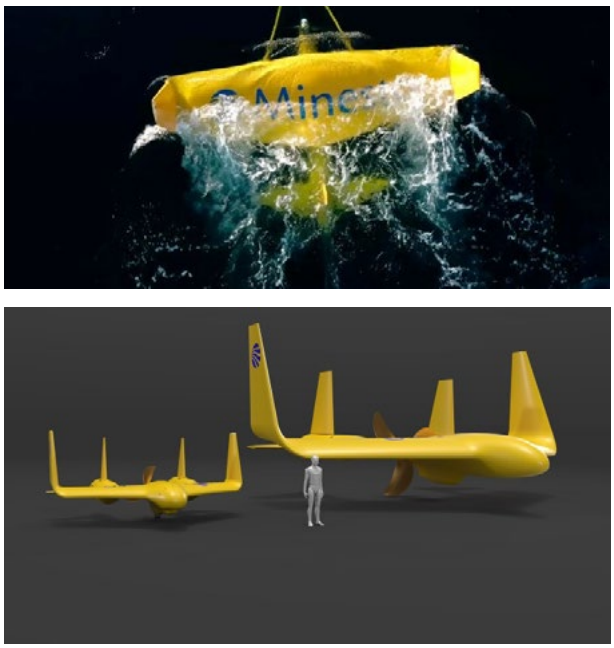
The NO2 prototype from Novige has been improved for further demonstration in offshore environments. The plan is to deploy the prototype in Stockholm's archipelago by Feb 2022 for an extended period to monitor the production and functions under long-term operation. Afterward, with the support provided by the

Swedish Energy Agency, the prototype will be improved further and tested in a wave tank.

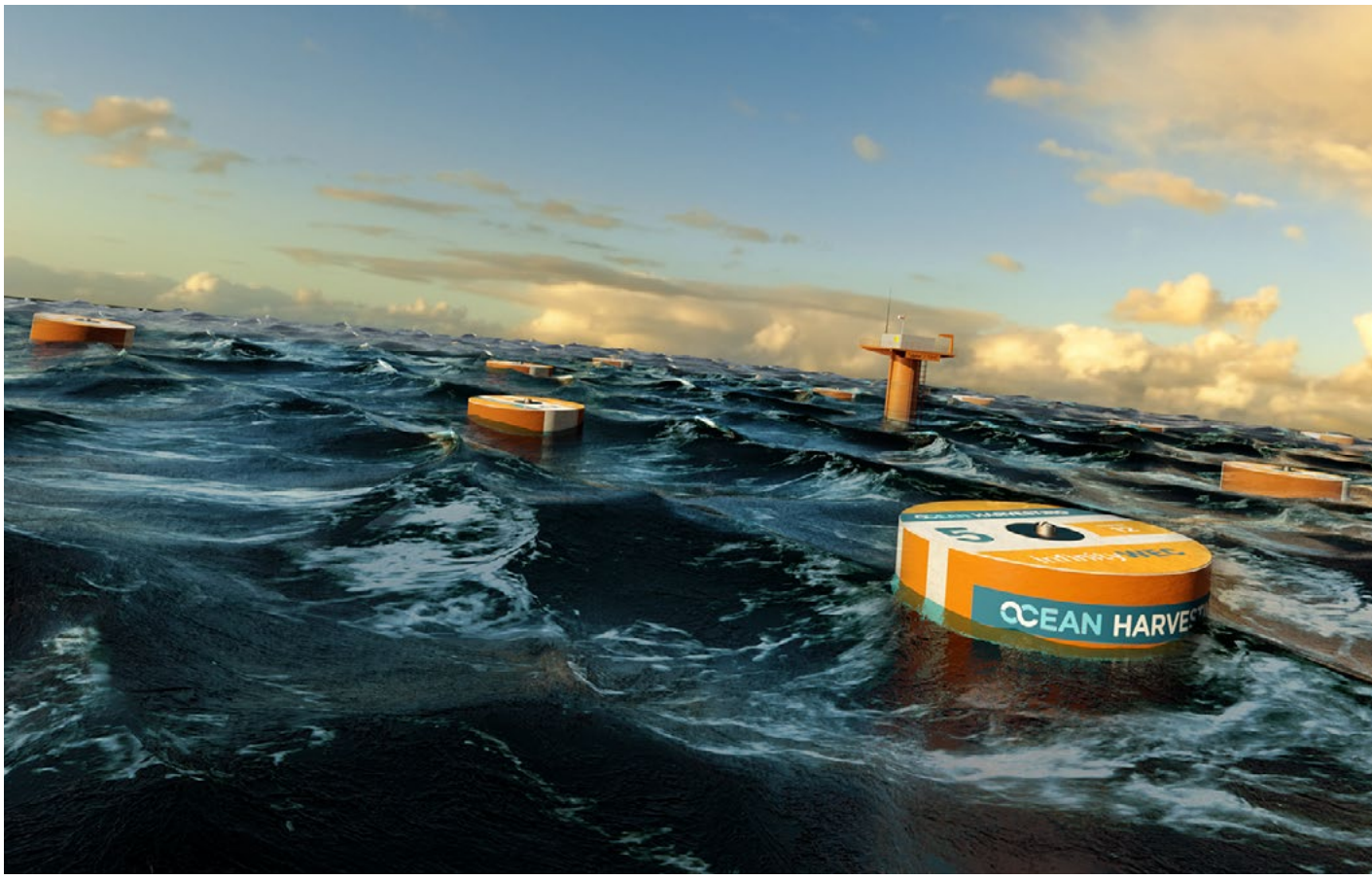
Minesto has introduced the new Dragon Class design which is intended for commercial rollout. Minesto plans to install and commission the Dragon 12 (1.2 MW) utility scale system in 2022 as a first step towards installing the 10 MW commercial arrays currently under development in the Faroe Islands and Wales.

In 2022, Minesto also plans to commission Dragon 4 systems in the Faroe Islands and in France where Minesto collaborates with EDF as part of the EU-funded TIGER project.

Ocean Harvesting Technologies (OHT) is preparing for a sea trial project to start in 2022. An InfinityWEC in scale 1:3 is to be tested near Lysekil in Sweden. The project is aligned with a stage 3 project in the OES framework for ocean energy technology. A Hardware-In-the-Loop test rig will be used to verify the power take-off and control system functionality before the complete InfinityWEC wave energy converter is deployed in the sea. Together with RISE biofouling will be evaluated, including the effect on performance on the full system.



Minesto's current design DG100 in operation and the new Dragon Class design. (© Minesto)



Visualization of InfinityWEC devices in the sea. (© Ocean Harvesting Technologies)

CorPower Ocean is developing compact high-efficiency WECs, inspired by the pumping principles of the human heart. It uses advanced control technology to significantly increase the structural efficiency of wave energy. HiWave-5 is CorPower's flagship demonstration project. It is designed to bring a bankable product offering to market, by proving the survivability, performance and economics of a grid-connected array of full-scale devices, with type certification from DNV-GL. HiWave-5 is performed in two stages:

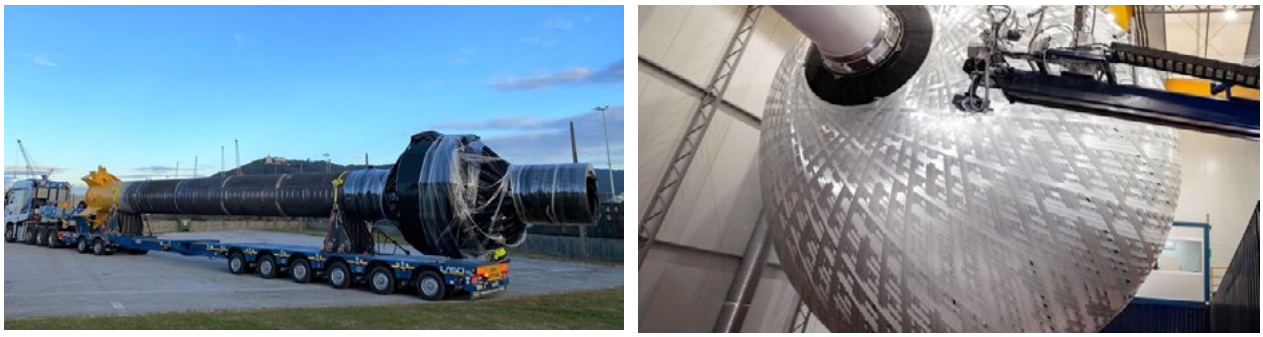
- **Stage 4 (2019-2022):** Demonstration and prototype certification of a single device full-scale C4 WEC, taking the technology from TRL 6 to TRL 7.
- **Stage 5 (2022-2024):** Demonstration and type-certification of a pilot array with three additional C5 WECs, taking the technology from TRL 7 to TRL 8.

The activities and deliverables of HiWave-5 have been carefully designed in dialogue with customers and stakeholders including utilities and project developers. The ocean deployment will take place at the Aguçadoura site in northern Portugal, where an existing substation will be used to connect the project to the Portuguese national grid.

During 2021, the C4 Power Take-Off (PTO) was commissioned in CorPower's full-scale facilities in southern Stockholm. It has been connected to the world's largest and most advanced dry-test rig with 7.2 MW capacity that was developed in collaboration with ABB and additional supply chain partners. An extensive dry test campaign has been performed on the C4 PTO, using simulated wave loads representing the ocean conditions of the Aguçadoura site, aimed at stabilizing and debugging the system before ocean deployment.

At CorPower's facility in Viana do Castelo in northern Portugal, a novel mobile factory cell for on-site fabrication of full-scale composite buoy hulls has been commissioned, and the process qualified with DNV as certification body. The first C4 structures had been fabricated by 2021, with the project on track to deliver a C4 hull in early 2022 before integration with the PTO and subsequent ocean deployment. The UMACK project has developed and verified a novel type of pile anchor that offers a step-change improvement to the required size and cost of ocean energy foundations. The UMACK anchors are installed using a high-speed environmentally friendly and low-noise vibro-driving technique. Following multiple-scale tests in the UK, Germany and Portugal, the first full-scale UMACK anchor was fabricated and delivered to Viana do Castelo in 2021, ready to be deployed offshore Agucadoura early 2022.

Corpower C4 PTO in dry-test rig in southern Stockholm. (© Corpower)



UMACK anchor to be delivered to Spain (left) and Corpower's new composite buoy hull (right). (© Corpower)

3.21 UNITED KINGDOM

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OVERVIEW

With the eyes of the world focussed firmly on Glasgow for the hosting of the 26th UN Climate Change Conference, there hasn't been a better opportunity to review the current status of the UK's ocean energy sector. Despite being a challenging year, 2021 saw sustained innovation and cross-border collaboration, leading to continued offshore testing and deployment of state-of-the-art ocean energy devices. The UK continues to be recognised as a global leader in the wave and tidal energy sector, both in terms of its natural resources and in its technical capabilities. As a result, the UK ocean energy sector continues to move from strength to strength; Orbital Marine Power's O2 tidal turbine has commenced generation at the European Marine Energy Centre (EMEC) in Orkney; Nova Innovation's confirmed expansion of the world's first tidal array in Shetland and demonstration of an electric vehicle charging point powered entirely from a tidal energy source; and the ORE Catapult led Tidal Stream Industry Energiser (TIGER) project to evidence tidal stream cost reduction continues to make steady progress. The UK Environmental Audit Committee's Call for Evidence on tidal energy also emphasised the need to capitalise on and support the substantial potential of the tidal sector to contribute to the UK's renewable energy mix and the socio-economic benefits associated with it. However, despite the progress made there is still a pressing need for a reduction in the overall costs of marine energy for the sector to become competitive with alternative low-carbon technologies and contribute meaningfully to the UK's 2050 net-zero targets.

Wave

Throughout 2021, the wave energy sector continued to engage in innovative R&D to drive the sector towards higher TRLs and commercialisation:

- Wave Energy Scotland (WES) has maintained its position as the central focus for wave energy R&D activity in the UK and has helped to bolster confidence in the industry as two of its pilot projects, AWS Ocean Energy and Mocean Energy, moved towards and achieved real sea testing, respectively.
- EMEC welcomed Mocean Energy's Blue X wave energy prototype to their Scapa Flow test site in June 2021 for initial sea trials. The 10 kW device completed 154 days at sea, delivering steady outputs of up to 5 kW.
- In 2021, Europewave announced the projects that have been successful in progressing through stage 1 of its innovative Pre-Commercial Procurement process, which will eventually culminate with wave energy developers testing at EMEC and the Biscay Marine Energy Platform.

Tidal Stream

2021 was a strong year for the continued commercialisation of tidal stream devices, with a number of industry milestones achieved:

- Orbital Marine Power's 2 MW tidal stream turbine, the O2, was successfully towed to Orkney in April and has since commenced operation at EMEC's Fall of Warness test site.
- Magallanes second-generation 2 MW tidal platform, ATIR, was successfully reinstalled at EMEC, supported by the Interreg NWE Ocean DEMO project.
- The Perpetuus Tidal Energy Centre (PTEC) continued its collaborative work with EMEC, sending clear market signals that there is an increasing appetite to commit resources to the tidal stream sector in the UK. PTEC have also entered into an agreement with Orbital Marine Power to utilise its O2 tidal stream turbine to deploy 15 MW by the end of 2025.
- Nova Innovation successfully deployed its commercial direct-drive tidal turbine 'Eunice' in its Shetland Tidal Array. In August it was announced that Nova had secured £2m funding from Scottish Enterprise for its VOLT project, which aims to develop Europe's first assembly line to mass manufacture tidal turbines.
- There is continued high-level, cross-country collaboration between the UK and France to deliver the TIGER project, the largest Interreg project yet awarded at €45.5m. The project aims to drive the growth of tidal stream energy in the UK and France with significant economic benefits for coastal communities and the planned installation of 8 MW of tidal energy capacity by 2023.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

Energy policy within the UK is made more complex by the presence of devolved administrations, who have differing levels of autonomy. On a national level, matters of energy policy are mainly devolved to Northern Ireland and partly devolved to Wales and Scotland. The responsibility for enacting policy designed to tackle climate change is devolved to Wales, Scotland and Northern Ireland, however the UK government retains control over many energy and emissions reductions policy areas.

UNITED KINGDOM

The Climate Change Act (2008) set in legislation the UK's approach to tackling and responding to the global climate emergency and sets the UK's long-term legally binding target to achieving Net Zero emissions by 2050. The UK is committed to maintaining a robust and resilient climate policy framework that ensures global temperature rise is limited to 1.5°C. Within the UK, the responsibility for tackling climate change and developing energy policy lies with the Department for Business, Energy and Industrial Strategy (BEIS). BEIS has a wide policy remit that covers energy and clean growth, science, research and innovation and climate change. The Department's energy-related strategic objectives are to:

- Ensure the UK's energy system is reliable and secure;
- Deliver affordable energy for households and businesses;
- Support clean growth and promote global action to tackle climate change

In line with its decision to host COP26, the UK government has set out plans to establish the UK as a world leader in green energy, bolstering its commitment towards net-zero emissions by 2050 with a series of high-level policy papers published by BEIS.

- "The Ten Point Plan for a Green Industrial Revolution", published in 2020, laid the groundwork for ambitious policies and significant new public investment, while seeking to mobilise private investment.
- The "Net Zero Strategy: Build Back Greener", published in 2021, aims to keep the country on track for meeting the UK carbon budgets, our 2030 Nationally Determined Contribution, and net zero by 2050. In addition to this, the report also acknowledges that the UK possesses some of the best ocean energy resources in the world and highlights the ongoing efforts to explore their role in meeting our net zero targets.

The UK government has also adopted the Committee on Climate Change's Sixth Carbon Budget into law, placing the UK firmly on the path to reaching net zero

emissions by 2050, with robust reduction targets also set for 2030. The Sixth Carbon Budget acknowledged that there continues to be a requirement for large-scale funding to bring nascent renewable technologies, such as wave and tidal, to fruition. The government has also indicated that accelerated renewable deployment will be achieved by continuing the support offered by the CfD scheme, with the fourth allocation round offering a total of £285m. This represents the largest commitment yet by the government and is considered crucial to fulfilling the ambitious targets to double the capacity of renewable energy secured in the 2019 round.

WALES

The Welsh Government remains committed to unlocking the energy potential contained in Welsh waters by supporting the delivery of marine energy projects. In March 2021, the Senedd Cymru approved a net zero target for 2050, compared to 1990 levels. Wales also has a target of producing 70% of its electricity needs from renewable resources by the year 2030, with an aim of capturing at least 10% of the potential tidal stream and wave energy off the Welsh coastline by 2025. Current European Regional Development Fund (ERDF) grants support a number of projects aimed at establishing Wales as a centre for marine energy production. This includes the Marine Energy Test Area (META) and Morlais test and demonstration zones, as well as technology developers such as Bombora, Minesto, Nova Innovation and Marine Power Systems.

Marine Energy Wales (MEW) is the industry-led stakeholder group representing the wave, tidal and floating offshore wind industries in Wales. MEW brings together project and technology developers, test centres, wider sectoral alliances, the supply chain, academia, and the public sector to establish Wales as a global leader in sustainable offshore energy generation. To date, over £150m has been spent in Wales on the development of the marine energy industry, also including supply chain and academic research interests. This included an investment of £29.1m over the last year, indicating that the sector continues to grow and show resilience in spite of the economic uncertainty brought on by COVID-19. This success is owed in part to the rising domestic interest in the sector, supported by a comprehensive government led policy drive. The MEW 2021 State of the Sector report details that 20 emerging renewable energy developers are actively progressing projects in Wales and that 465 MW of marine energy sites have been leased in Welsh waters.

Wales continues to build a pathway towards the commercialisation of the sector, with leading marine energy developers Bombora and Minesto establishing assembly and export centres close to the Pembrokeshire and Morlais Array Demonstration Zones. In addition to this, Wales has invested £8.5m into the development of a national test centre network; the Marine Energy Test Area at Milford Haven; the TIGER tidal test site at Ramsey Sound; and the ORE Catapult delivered Marine Energy Engineering Centre of Excellence. These will continue to attract not only the interests of UK based technology developers, but also continue to nurture successful international relationships.

Major developments with benefits for marine energy in Wales announced in 2021 include:

- The launch of the Welsh Government's Marine Energy Programme: Tidal Lagoon Challenge, inviting parties to submit expressions of interest for tidal range projects in Wales.
- The Climate Change Ministry in Welsh Government, which brings together key government departments to ensure a cohesive approach to Wales's climate change response.
- Consents secured for META, Wales' National Marine Energy Test centre and the Morlais Tidal Array Demonstration Zone.
- Welsh Government's ongoing commitment in their new Programme for Government in support of the marine energy sector.
- A dedicated pot for tidal stream energy in the CfD allocation round.
- Welsh Government's Deep Dive into Renewable Energy, highlighting a series of recommendations to reduce barriers and enable the accelerated development of the sector.
- In December the Welsh Government announced its intention to establish an emerging marine technology revenue support mechanism to sit alongside the UK Government's CFD.

SCOTLAND

The Scottish Government has committed to achieving net zero emissions by 2045, compared to 1990 levels. In December 2020, the Scottish Government updated its Climate Change Plan, outlining a desire to implement a green recovery from the COVID-19 pandemic and charting a pathway to the emissions reductions set by the Climate Change (Scotland) Act 2019. This included a successful call for reform of the UK Government CfD mechanism to deliver focussed support for marine

energy generation, an issue on which the Scottish Government has worked closely with the marine energy industry for a number of years.

Scotland's transition to net zero is supported by the Scottish Energy Strategy, published in 2017, which sets out the Scottish Government's vision for the future of the energy sector until 2050 and includes a target to meet the equivalent of 50% of Scotland's heat, transport, and electricity consumption from renewable sources by 2030. The Scottish Government will support the continued growth of the marine renewables sector with a strengthened framework of support, to be outlined in a refreshed Scottish Energy Strategy in 2022. The creation of the role of Cabinet Secretary for Net Zero, Energy and Transport in 2018, currently held by Michael Matheson MSP, has elevated issues regarding the renewable energy industries, climate crisis and net-zero policy to the cabinet level.

The Scottish Government has a strong track record of promoting the marine energy sector and supports RD&D activities designed to maintain Scotland's position as a world leader in the marine sector. Since 2014, the Scottish Government has invested nearly £50m in the WES programme, resulting in the deployment of a prototype device from Mocean Energy and the planned deployment of AWS Ocean Energy in 2022, both at EMEC, and the launch in 2021 of the EuropeWave programme in partnership with the Basque Energy Agency. The Scottish Government's Saltire Tidal Energy Challenge Fund, supported the deployment of major tidal stream projects by Orbital Marine Power and Simec Atlantis Energy. The Scottish Marine Energy Industry Working Group provides a forum for the sector to speak with one voice about its priorities and the collective actions needed to maintain Scotland's competitive advantage. As part of this, a number of industry-led subgroups are exploring key opportunities and barriers to the sector's continued growth.

At a national level, marine planning in Scotland's inshore and offshore waters is governed by the Marine (Scotland) Act 2010), establishing a legislative framework to ensure that increasing demands for the utilisation of the marine environment are managed responsibly and sustainably. Crown Estate Scotland is a public corporation that holds responsibility for the licensing of renewable energy generation in Scotland's offshore waters. All revenue profit generated by Crown Estate Scotland is returned to the Scottish Government and capital is reinvested in the Scottish Crown Estate, with £11.5m returned in the 2020/21 financial year to aid in public spending and Scotland's green economic recovery. In February 2021, Crown Estate Scotland published their first Climate Change Action Plan and directly acknowledged the significant potential value offered by focussed support and development of the wave and tidal sector.

MARINE ENERGY COUNCIL

Since its formation in 2018 the UK Maine Energy Council (MEC) has facilitated collaboration between, and represented the interests of, leading wave and tidal technology and project developers, supply chain companies, consultants and renewable industry associations in the UK. MEC has been instrumental in improving the policy landscape and outlook for the sector through coordinating engagement and communicating clearly to the UK Government, devolved administrations and other key stakeholders with a unified voice.

In August 2021, MEC hosted the then Energy and Scottish Ministers at the European Marine Energy Centre to highlight how the sector was strongly positioned to support the UK Government's aims:

- To deliver a green economic recovery by supporting a sector with a potential £1.4bn value to the UK economy by 2030
- Level up communities across the home nations creating 4000 jobs by 2030
- Support its Global Britain ambitions through accessing an export market estimated to be worth £76bn by 2050

The MEC also played a vital role in coordinating the ocean energy sector's overall position as to why it would be suitable to be included in a ring-fenced funding pot in the UK Government's newly restructured CfD scheme.

On the international front, to support collaboration and advance the sector's interests, MEC signed a cooperation agreement with Syndicat des Energies Renouvelables, in September 2021. The Franco-British collaboration will facilitate the sharing of analyses, best practice and formalises collaborative actions and synergies in realising the significant potential of renewable marine energies. 2022 will be a key year for the sector with the expected announcement of the CFD AR4 funding allocation in the summer, MEC will continue to advocate for increased R&D funding for wave technologies, work with the UK Government to establish a 2030 target for tidal stream and build support for Innovation Power Purchase Agreements.

COP 26

The UK hosted COP26 in Glasgow between 31st October and 12th November 2021, with the aim of bringing parties together to accelerate action towards the goals of the Paris Agreement and the UN Framework Convention on Climate Change. In the lead-up to and at COP26, the UKRI Supergen programme hosted and participated in a range of engagement and communication activities on the role of offshore renewable energy in achieving net-zero greenhouse gas emissions, holding a public 'fishbowl' conversation to discuss net zero energy strategy. The Scottish Government and Scottish Enterprise came together to host an event as part of 'Scotland's Climate Ambition Zone', where UK marine energy developers were optimistic about deploying commercial devices by 2030, but urged government to offer similar support frameworks as have been seen for other renewable technologies. COP26 was attended by many of the organisations listed in this report, providing an excellent platform to showcase the exciting progress made by the sector and presenting an opportunity to demonstrate why marine energy should play an increasing role in the domestic energy mix.

MARKET INCENTIVES

Contracts for Difference

The Contracts for Difference (CfD) scheme is the UK government's flagship program for supporting the generation of low-carbon electricity. Based on top-up payments between a wholesale market reference price and a strike price, CfDs offer long-term price stabilisation and are awarded via competitive auctions. The CfD scheme incentivises investment in renewable energy by providing developers of renewable energy projects, normally projects with high upfront costs and long lifetimes, protection from volatile wholesale prices. To date, there have been three allocation rounds which have seen a number of different renewable energy technologies compete in auctions for a contract. Ocean energy technologies are however yet to gain a CfD through the competitive auction process, primarily because they have been in the same CfD 'pot' as established, mature technologies such as offshore wind.

In November 2021, the UK Government announced its biggest investment in a generation into tidal power, when it was announced that the fourth allocation round (AR4) of the CfD scheme, due to open in December and totalling £285m, will contain a £20m ring-fenced fund solely for the use of tidal stream energy projects. This is in addition to £31m that tidal and wave developers can bid into as part of 'pot 2' in AR4 for emerging technologies. This provides the opportunity for the UK's marine energy sector to continue developing its technology and lower its operating costs at a rate similar to the countries world-leading offshore wind industry. The delivery of this fund is evidence of the strong collaborative atmosphere across the sector, that has witnessed many of the leading industrial actors, academic partners and policymakers working together to make the case for the much-needed investment in the marine energy sector.

PUBLIC FUNDING PROGRAMMES

The UK government has made available a number of alternative public funding programmes to support the development of the ocean energy sector. Some of these initiatives are described in the following section.

UK Research and Innovation (UKRI)

In operation since April 2018, UKRI brings together seven research councils to support and coordinate research and innovation in the UK. Independently chaired, UKRI has a £8bn budget funded primarily through the Science Budget by the Department for Business, Energy and Industrial Strategy. The research councils and bodies operating within UKRI are Innovate UK, Research England, Engineering and Physical Sciences Research Council, Arts and Humanities Research Council, Biotechnology and Biological Sciences Research Council, Economic and

Social Research Council, Medical Research Council, National Environment Research Council, and the Science and Technology Facilities Council.

www.ukri.org

EPSRC

The Engineering and Physical Sciences Research Council (EPSRC) is the main funding body for engineering and physical sciences research in the UK, part of the UKRI. It was announced in 2021 that EPSRC will support 8 new wave energy converter research projects with a £7.5m investment:

- Bionic Adaptive Stretchable Materials for Wave Energy Converters – University of Strathclyde. EPSRC grant: £975,000
- Flexible responsive systems in wave energy - University of Plymouth. EPSRC grant: £984,000
- Holistic Advanced Prototyping and Interfacing for Wave Energy Control – University of Strathclyde. EPSRC grant: £987,000
- Mooring analysis and design for offshore WEC survivability and fatigue – University of Manchester. EPSRC grant: £997,000
- MU-EDRIVE – Newcastle University. EPSRC grant: £776,000
- Wave-Suite – University of London. EPSRC grant: £987,000
- Novel high-performance wave energy converters with advanced control, reliability and survivability systems through machine-learning forecasting – Lancaster University. EPSRC grant: £798,000
- System-level co-design and control of large capacity wave energy converters with multiple PTOs – Queen Mary University of London. EPSRC grant: £986,000

https://epsrc.ukri.org/

Innovate UK

A member of UKRI, Innovate UK is a funding body that supports businesses in their development of new technologies and concepts, helping them to reach commercial success. Innovate UK awards grant and loan funding across all sectors to business-led and high-value innovation in the UK. The organisation also cultivates networks between innovators and investors, researchers, industry, policymakers, and future customers on a domestic and international scale.

www.gov.uk/government/organisations/innovate-uk

Wave Energy Scotland

Wave Energy Scotland (WES) has continued to use Scottish Government funding to develop solutions to the technical challenges facing the wave energy sector. The WES programmes aim to drive innovative technology projects towards commercialisation through a competitive stage-gate process. The stages of R&D activities guide projects from concept to prototype testing. Within the WES programme separate funding streams exist for the development of novel wave energy devices, power take-off systems, control systems, quick connection systems and materials. 2021 saw the successful deployment of Mocean Energy's half-scale Blue X wave energy converter at EMEC, and the completed construction of AWS Ocean Energy's WaveSwing device (ready for 2022 sea trials at EMEC), both of which received funding from WES. WES has to date awarded £48M through 107 contracts, including 250 organisations from 13 countries.

www.waveenergyscotland.co.uk/

KEY R&D INSTITUTIONS

Supergen Offshore Renewable Energy (ORE) Hub

The Supergen ORE Hub was established in July 2018 with an initial £5m of funding from the EPSRC, and a subsequent second award of £4m in June 2019. Led by the University of Plymouth, the Supergen ORE Hub brings together expertise from multiple UK institutions including University of Edinburgh, University of Aberdeen, University of Exeter, University of Hull, University of Manchester, University of Oxford, University of Southampton, University of Strathclyde and University of Warwick. Some key updates as

announced by the organisation in 2021 are as follows:

- The Supergen ORE Hub Third Annual Assembly took place virtually from 18 – 22 January 2021, bringing together over 475 delegates.
- In May 2021, it was announced that the Supergen ORE Hub had awarded almost £800,000 to 8 projects at UK institutions through its flexible funding scheme, designed to support ambitious research in offshore renewable energy.
- Across 2021, the Supergen ORE Hub awarded £140,000 to 17 projects at UK institutions through its Early Career Researcher fund.
- Supergen ORE Hub and the Policy and Innovation Group at Edinburgh University, published a new study quantifying the potential economic benefit that the UK stands to gain through the deployment of innovative offshore technologies.
- Ahead of COP26, the Supergen Hubs hosted a net zero conference exploring the role of energy research in the pathway to net zero.
- Also ahead of COP26, the Supergen ORE Hub launched a briefing paper on the role of offshore renewable energy in delivering net zero.
- Throughout 2021, the Supergen ORE Hub has responded to the UK Government's successful CfD consultation, 'Floating Offshore Wind Market' Survey, 'Potential of Marine Energy Projects' call for evidence, 'UK Parliament call for evidence on Tidal Energy' and a response to the UK Energy White Paper.

https://www.supergen-ore.net/

ORE Catapult

Offshore Renewable Energy (ORE) Catapult is the UK's flagship technology and innovation research centre for offshore energy and a key actor in helping to deliver the UK's net zero targets. ORE catapult plans to accelerate the creation and growth of UK companies in the offshore renewable energy sector by combining their unique research and development capabilities and access to demonstration and testing facilities. Since 2013, ORE Catapult had supported 1040 Small Medium Enterprises (SMEs) with the development, demonstration and commercialisation of their technologies, engaged in 705 academic collaborations and been involved 1051 industry collaborations across the globe. ORE Catapult also leads on the TIGER project and is also involved in the Ocean Energy Scale Up Alliance (OESA) project.

https://ore.catapult.org.uk/

KEY R&D PROJECTS

Floating Tidal Energy Commercialisation (FloTEC)

The FloTEC project, led by Orbital Marine Power and part-funded by a €9.8m contribution from the European Commission's Horizon2020 programme, finished in August 2021. The project sought to demonstrate the potential for floating tidal stream turbines to provide low-cost, high-value energy to the European grid mix. The aim was to demonstrate an advanced, full-scale device in real conditions with high levels of reliability and survivability, while developing a greater understanding of factors such as installation, operation and decommissioning costs.

The Orbital O2 2 MW tidal energy turbine was deployed at EMEC's Fall of Warness grid-connected test site in Orkney in 2021 and is scheduled to operate at EMEC for the next 15 years. The O2 features a number of innovations, including up to 50% greater energy capture through enlarged rotors, full onsite access to all turbine systems through an optimised platform configuration, high performance blades and compatibility with local supply chain and infrastructure. Through a follow-on long term demonstration programme, a highly detailed dataset on power performance, component reliability and environmental monitoring will be gathered, while producing clean electricity for Orkney residents.

http://www.flotectidal.eu/

Enabling Future Arrays in Tidal (EnFAIT)

The EnFAIT project is a €20.2m flagship EU project, led by Nova Innovation, that has been running since 2017. It aims to demonstrate the development, operation and decommissioning of the world's first offshore tidal array (six turbines) over a five-year period to prove a cost reduction pathway for tidal energy that can make it cost competitive with other forms of renewable energy. By December 2021, the project has achieved the following:

- A 30% reduction in the cost of tidal energy, towards the 40% sought by December 2022
- 95% turbine availability against a target of 80%
- 18 months non-stop turbine operating period, against

a target of 6 months
- A European supply chain that has grown from four countries to 19 countries
- No negative effects on marine life recorded in over 10 years monitoring of the site

The fourth turbine in the array – an innovative, direct drive, 100 kW "Nova M100D" model named "Eunice", developed by Nova in the H2020 D2T2 project – has been deployed and operational at the site since 2020. The improved efficiency and reliability of the direct drive design has slashed the cost of energy by 30% compared to Nova's previous, geared turbine model. The M100D has operated fully automatically for over 12 months in the array, demonstrating exceptional performance, with availability >95% and no need for any interventions. A further two M100D turbines will be deployed in the site in 2022.

https://www.enfait.eu/

Integrating Tidal Energy into the European Grid (ITEG)

Funded by the Interreg North-West Europe programme and led by EMEC, the ITEG project has been running since 2017 and has received €11.79m of EU funding. The project seeks to address energy related carbon emissions in North West Europe by providing an integrated tidal and hydrogen solution for generating clean energy, that also tackles the grid export limitations faced in remote communities.

The integrated solution combines Orbital's next generation 2 MW floating tidal energy converter, the Orbital O2, with a custom built 500 kW Elogen electrolyser and an onshore energy management system (EMS), both of which will be deployed at EMEC's hydrogen production site on the Orkney island of Eday. The ITEG project brings together partners from across Europe. It aims to open new market opportunities for the ocean energy sector through hydrogen production and energy storage. It will also optimise the EMS and fast-track a clean energy generation, management and storage solution, while building a roadmap to support the replication of the project in other remote, grid-restricted areas.

https://www.nweurope.eu/ITEG

DTOceanPlus

This €6.7m European Commission funded project, culminated in August 2021 after three successful years. Led by Tecnalia, the consortium had 16 European partners, including, from the UK: The University of Edinburgh, WES, Energy Systems Catapult, Orbital Marine Power, and Nova Innovation. The project developed a suite of second-generation advanced design tools for the selection, development, and deployment of ocean energy systems. The tools were then demonstrated using the real projects and technologies of the industrial partners. In September 2021, the open-source DTOceanPlus software suite was released along with associated documentation on GitLab, representing the culmination of the projects deliverables. Additionally, a series of market analysis reports were produced during the project, published on the project website.

https://www.dtoceanplus.eu/

Strategic Environmental Assessment of Wave energy technologies (SEAWave)

The SEAWave project, coordinated by EMEC, aims to address long-term environmental concerns around the development of wave and tidal energy converters in the marine environment. The potential environmental externalities associated with the marine energy sector are generally site specific making it difficult to draw conclusions about a specific sector or impact pathway. SEAWave aims to address this shortfall by undertaking a gap analysis regarding the environmental impacts associated with deploying wave and tidal energy converters. The project is funded by the European Commission European Maritime and Fisheries Fund and is supported by a diverse range of project partners across Europe. Through April 2021, the SEA Wave project ran a series of sector-specific focus groups to raise awareness of online consenting resources and tools for use the marine energy community, helping to ensure the best available scientific evidence and tools are used during the consenting process.

http://www.seawave-emff.eu/

Marine Energy Alliance

The Marine Energy Alliance (MEA) is a European Territorial Cooperation project running from May 2018 to May 2022. The project has a total budget of €6m and is supported by Interreg North West Europe, who provide €3.6m of ERDF funding. The aim of MEA is to progress the technical and commercial maturity level of early-stage (TRL 3 – 4) marine energy technology companies with the overall goal of reducing the risk of device failure in subsequent demonstration phases. In 2021 it was announced that two MEA SME's, Mocean Energy and Waveram, had been selected to be part of Europewave's Pre-Commercial Procurement (PCP) process. They will share a €2.4m budget alongside five other companies to further develop their wave energy

device concepts in the first half of 2022. Through the Marine Energy Alliance (MEA) project, EMEC has been working with 16 early-stage technology developers to de-risk development prior to demonstration at sea, delivering a range of services aimed at aligning early-stage testing with international standards and providing technical assessments.

https://www.nweurope.eu/projects/project-search/nwe-mea-north-west-europe-marine-energy-alliance/

Ocean Power Innovation Network (OPIN)

The Ocean Power Innovation Network (OPIN) running until 2022, includes ORE Catapult and Scottish Enterprise as members. The project has a total budget of €2.6m, with €1.5m contributed by Interreg North West Europe from ERDF. OPIN is a cross-sectoral collaborative network that aims to accelerate the growth of the ocean energy sector and its supply chains across the partner regions of Europe. The premise of OPIN is to encourage both cross-sectoral and cross-regional collaboration for SMEs working in offshore renewable energy. OPIN will also create a forum for collaboration and technology exchange across the partner regions. Companies from regions with ocean energy expertise will interact with potential collaborators from regions that are world leaders in other technology fields, aiming to provide a mechanism to transfer expertise and address the disparities in innovation and economic development.

https://www.nweurope.eu/projects/project-search/opin-ocean-power-innovation-network/

Ocean Energy Scale-Up Alliance (OESA)

Led by the Dutch Marine Energy Centre (DMEC), and involving EMEC and ORE Catapult, OESA is a three-year pan-European project running until July 2022, with the aim of accelerating the development of marine energy technologies through strategic partnerships and international collaborations. With a total budget of €6.2m, where Interreg NWE provides €3.1m of financial support, the project partners encompass 13 European organisations specialising in offshore engineering, market development and ocean energy testing and technology development. OESA seeks to accelerate the development, evaluation and promotion of a defined transnational scale-up offer, with promotion beginning in 2022. In addition, OESA aims to deploy four scaled-up ocean energy pilots to unlock up to 20 MW, with two pilots scheduled to deploy arrays in the next two years.

https://northsearegion.eu/oesa

Tidal Stream Industry Energiser (TIGER)

Led by ORE Catapult, the TIGER project is an ambitious €46.8m project running from October 2019 until June 2023. With the European Regional Development fund contributing €29.9m of the overall funding, the project falls within the category for low-carbon technologies of the Interreg France (Channel) England Programme. The TIGER project aims to build testing and demonstration capabilities between the leading tidal turbine technology developers and tidal test sites across the Channel region. The ultimate aim of the project, the largest across the Interreg programme, is to utilise the learning opportunities to make a stronger, cost-effective case for tidal stream energy as part of the UK/France energy mix and as a result the project will install up to 8 MW of new tidal capacity. Additionally, the project has been supporting the growth of the tidal energy supply chain, coordinating a series of supply chain webinars, and working with the investment community to reduce risk and increase confidence in the sector.

http://www.interregtiger.com/

Ocean DEMO

Launched in January 2019 and funded by Interreg NorthWest Europe, the Ocean DEMO project is a €12.85m project. Built upon the FORESEA project, it aims to accelerate ocean energy's transition from single prototype to multidevice farms by providing free access to key European test centres: EMEC, DMEC, SEM-REV and SmartBay. In 2021, Ocean Demo awarded recommendations for support to 6 offshore renewable energy developers under its 4th call for applications. The following technology developers were recommended for support packages, with two of them already starting testing in real sea conditions: Aquantis; Dutch Wave Power; LHYFE Labs; Mocean Energy; OV Wind and University of Edinburgh.

www.oceandemo.eu

SELKIE

Launched in 2019, SELKIE is funded by the EU's Ireland-Wales co-operation programme and is led by University College Cork in partnership with Swansea University, Marine Energy Wales, Menter Môn, DP Energy Ireland and Dublin-based Gavin and Doherty Geosolutions. The three year, €5.2m project will see the development of a streamlined commercialisation pathway for the marine energy industry by establishing a cross-border network of developers and supply chain companies in Ireland and Wales. In June 2021, Swansea

University deployed a quarter-scale converging beam acoustic Doppler current profiler through the support of the SELKIE project at META. In November 2021, an interactive workshop was held which provided experienced stakeholders with detailed descriptions of three new Selkie design tools.

www.selkie-project.eu

ELEMENT

ELEMENT (Effective Lifetime Extension in the Marine Environment for Tidal Energy) is a €5m EU H2020 project led by Nova Innovation with the participation of ORE Catapult as one of an 11-strong international consortium, running until May 2023. The consortium identified an opportunity to improve performance of tidal energy technologies using artificial intelligence. In a world-first, the ELEMENT team is using behavioural modelling and machine learning to control tidal energy turbines to improve efficiency and reduce costs. This approach will reduce the dependency on external instrumentation and sensors which can struggle to withstand the immense forces exerted by the tides. As well as improving reliability and lowering costs, the project will turbo-charge the collection and analysis of ocean data at tidal energy sites, providing valuable learnings that can feed into turbine designs in the future. By extending tidal turbine lifetime, improving efficiency and increasing availability, the project is expected to deliver a 17% reduction in the levelised cost of tidal energy over the life of the project. As of December 2021, hardware-in-the-loop testing of the direct drive turbine is underway at ORE Catapult's 1 MW drivetrain testing facilities in Blyth, Northumberland.

www.element-project.eu

MONITOR

Finishing in December 2021, MONITOR (Multi-model Investigation of Tidal Energy Converter Reliability) was an Atlantic Area €1.6m Interreg-funded project led by Swansea University, which investigated the reliability of tidal energy convertors, with a particular focus on identifying critical parameters for blades and support structures. The project partners, including EMEC and Ore Catapult, studied monitoring systems suitable for the Magallanes Renovables S.L. and Sabella S.A.S. two tidal energy developers in the consortium. The monitoring system design changes focussed on lowering engineering safety factors, thus lowering the overall cost of tidal energy converters, while also improving reliability.

https://www.monitoratlantic.eu/

Wave Energy Scotland

2021 saw continued progress in the WES stage-gate research, development, and innovation programmes, with a number of projects that WES are actively involved in achieving significant milestones. Mocean Energy's Blue X device completed a 5-month sea trial at EMEC and AWS completed construction of their WaveSwing device, ready for deployment at EMEC in early 2022. WES granted £1.8m to Apollo Offshore Engineering, Blackfish Engineering Design and Quoceant to demonstrate technology that enables the quick connection and disconnection of wave energy convertors. It is expected that this will help to reduce operating costs, improve the safety of offshore deployment and ultimately lower the overall cost of wave energy. WES supported the development of Tension Technology International's NetBuoy™ design tool and Arup's Convex concrete viability tool through its Structural Materials and Manufacturing Processes programme. Both tools will assist the sector to evaluate options to utilise lower-cost alternatives to steel structures.

https://www.waveenergyscotland.co.uk/

EuropeWave

EuropeWave is a five-year cross-border collaborative R&D programme to advance designs for wave energy converter systems to a level from which they can be developed to commercial exploitation. The project, which is a partnership between WES and the Basque Energy Agency with match-funding by the European Commission via its Horizon 2020 programme, will invest almost €20m to procure R&D services that will lead to the at-sea deployment of scaled prototypes. The programme uses a "pre-commercial procurement" model to identify the most promising wave energy technology solutions from developers across Europe. EuropeWave announced the selection of the seven technologies to enter the programme in December 2021. The five most promising technologies will be selected at the end of phase 1 to progress to a second phase where project teams will undertake more extensive design, modelling and testing. A final phase will see three projects deploy their devices at test facilities off the coasts of the Basque Country and Scotland in 2025.

www.europewave.eu/

FORWARD-2030

Orbital Marine Power has announced that it will lead a pan-European consortium tasked with delivering the €26.7m FORWARD-2030 project, set up to deliver the

accelerated commercial deployment of floating tidal energy. The FORWARD-2030 project consortium will receive €20.5m of grant support from the European Union's Horizon 2020 research and innovation programme to develop a system that will combine predictable floating tidal energy, wind generation, grid export, battery storage and green hydrogen production. As both the project coordinator and lead technology developer, Orbital Marine Power will oversee the installation of the next iteration of the company's turbine, which will be coupled with a hydrogen production and battery storage facility at EMEC.

LABORELEC will assess large-scale integration of tidal energy to the European energy system, develop a smart energy management system and an operational forecasting tool. EMEC will host the demonstration, facilitate hydrogen production, deliver a comprehensive environmental monitoring programme, and develop a live environmental monitoring system and test programme. The University of Edinburgh will deliver a techno-economic analysis of tidal energy, and the MaREI Centre at University College Cork will be responsible for addressing marine spatial planning issues for wide scale uptake of tidal energy.

Website launch in 2022

TECHNOLOGY DEMONSTRATION

TEST CENTRES & DEMONSTRATION ZONES

The European Marine Energy Centre (EMEC)

Established in 2003, EMEC is the world's leading centre for testing and demonstrating wave and tidal converters. As a plug-and-play facility, EMEC helps reduce the cost, time and risk of testing offshore with pre-consented grid-connected demonstration sites. EMEC is the world's only accredited test facility for marine energy, accredited by the United Kingdom Accreditation Service (UKAS), and is the first International Electrotechnical Commission (IEC) Renewable Energy Testing Laboratory (RETL) for ocean energy. EMEC has to date hosted the highest numbers of marine energy converters around the world.

In 2021 EMEC hosted demonstrations by Mocean Energy's Blue X wave energy converter at its Scapa Flow scale wave test site and has worked closely with AWS Ocean Energy to help gear up to deploy the Archimedes Waveswing WEC at EMEC in early 2022. At EMEC's Fall of Warness tidal test site, Magallanes Renovables reinstalled the 1.5 MW ATIR tidal platform in April 2021, and Orbital Marine Power began testing the new 2 MW O2 floating turbine. The EMEC-led Interreg Ocean DEMO project continues to support technology demonstrations across North-West Europe. As well as demonstrating ocean energy converter technologies, EMEC's sites have been busy with subsystem demonstrations and environmental monitoring activities including a series of acoustic surveys run by EMEC, a multi-sensor flow measurement platform by the University of Edinburgh, mooring solutions by TFI and InnoTECUK's robotic biofouling solution.

EMEC preparing wave rider buoy for deployment (© EMEC)

EMEC has continued to strengthen its international reputation, expanding its operations outside of Orkney: EMEC led the reconsenting works at the Perpetuus Tidal Energy Centre (PTEC) in the Isle of Wight which was granted planning permission in December 2021 making it eligible to bid into the UK Government's CfD scheme; and following EMEC being designated RETL status in 2020, EMEC delivered the world's first international power performance assessment for Verdant Power's New York tidal power array. EMEC continues to host the International WaTERS (Wave and Tidal Energy Research Sites) network to encourage collaboration, knowledge sharing and cross-border project development with ocean energy test centres around the world.

https://www.emec.org.uk/

Wave Hub

Wave Hub is a pre-installed grid-connected site off the north coast of Cornwall for the testing of large-scale offshore renewable energy devices. Wave Hub is owned by Cornwall Council and operated by Wave Hub Limited. The site consent has been reconsented for floating offshore wind and is being sold off to a private buyer. As a partner to the £60m Pembroke Dock Marine project announced in June 2020, Wave Hub Ltd will deliver the Pembrokeshire Demonstration Zone (PDZ), a consented and grid connected offshore test site. In 2021 Hexicon, a leading Swedish floating offshore wind technology and project developer, completed its acquisition of the Wave Hub test site from Cornwall Council.

https://www.wavehub.co.uk/

Perpetuus Tidal Energy Centre (PTEC)

The Perpetuus Tidal Energy Centre is a 30 MW commercial tidal stream project situated off the south coast of the Isle of Wight and will be England's first multi-megawatt tidal stream power generation project. In December 2021, planning permission for the onshore elements of the ground-breaking tidal energy generation project was granted, meaning that PTEC now has all the consents in place to proceed with their proposal and will also be eligible to bid for the newly restructured CfDs. PTEC, with consenting activities being managed by EMEC, has already signed an agreement with technology developer Orbital Marine Power to deploy its innovative and proven O2 turbine with the project. Onshore construction work is anticipated to commence in 2023, for completion by 2025.

https://perpetuustidal.com/

FaBTest

FaBTest is a 2.8km^2 test site in Falmouth Bay on the south coast of Cornwall with 10 years proven track record. The relatively sheltered location of the bay from the west allows for marine energy converter concept devices and components to be tested, whilst being occasionally exposed to more significant weather form the east. The pre-consented site, leased from the Crown Estate, has a 9 metre 1-in-100-year return period significant wave height, and is highly accessible from Falmouth Harbour.

http://www.fabtest.com/

Marine Energy Test Area (META)

META, situated in the Milford Haven Waterway, is managed by Marine Energy Wales and is part funded by the ERDF through the Welsh government, the Coastal Communities Fund and the Swansea Bay City Deal. Aiming to bridge the gap between tank testing and the Welsh Demonstration Zones, these grid-connected sites will be suitable for a range of component, sub-assembly and marine renewable energy device tests. As one of the partners in the £60m Pembroke Dock Marine Project, META will enable technology developers to test their marine energy devices close to their base of operation. In 2021, META signed a lease with The Crown Estate for the opening of the META Open Water test site, enabling the testing of wave and tidal energy devices in more energetic sites on Pembrokeshire's south coast.

https://www.meta.wales/

Morlais Demonstration Zone (MDZ)

The Morlais Demonstration Zone (MDZ), located in West Anglesey, encapsulates 35km^2 of sea bed around the promontory of Holy Island. The zone, which has been leased for 45 years, boasts powerful tidal current resources and relatively low wave regimes, representing a prime site for future exploitation of tidal energy. The planning application for the MDZ has been recently approved by Welsh Government. The Environment Regulator, Natural Resources Wales, has also recently granted a marine licence to the development. Subject to ongoing planning conditions being met, there is now strong hope that the physical development of the site will begin in early 2022, starting with establishing connectivity to the electricity grid. The MDZ has drawn interest from around the world, with seven developers and manufacturers having signed agreements for berths.

http://www.morlaisenergy.com/

ARRAYS AND DEMONSTRATION PROJECTS IN THE WATER

This section is a non-exhaustive list of key projects tested, installed in the sea, and operating in 2021.

MeyGen

The MeyGen project is currently the largest planned tidal stream project in the world and the only commercial multi-turbine array to have commenced construction. MeyGen is owned and operated by SIMEC Atlantis Energy in Scotland's Pentland Firth and comprises four 1.5 MW turbines, utilising Atlantis AR1500 and Andritz Hydro Hammerfest AH1000 MK1 turbines. In November 2021, SAE entered into a collaborative agreement with Nova Innovation, to work together to deliver tidal turbines at the MeyGen site and beyond. Neighbouring the MeyGen site to the east is the Ness of Duncansby project which has the potential to support the installation of up to 100 MW of tidal energy capacity by 2024.

https://simecatlantis.com/projects/meygen/

Deployment of SIMEC Atlantis' AR1500 turbine at MeyGen (© SIMEC Atlantis)

Magallanes Renovables

Spanish tidal developer Magallanes Renovables' second generation tidal turbine device, the ATIR, was successfully deployed at EMEC's Fall of Warness tidal test site in 2019. Funded by the Fast Track to Innovation pilot scheme, part of the EU's H2020 research and innovation programme, the device generated its first electricity into the UK national grid at EMEC in March 2019. In April 2021, after removal for optimisation, the 1.5 MW ATIR tidal generator returned to EMEC, where it was connected to the national energy grid, thus helping to demonstrate that it is possible to build, launch, install, operate and maintain a commercial tidal platform. Finishing the year on a high note, Magallanes has received a £1.2m grant by the British Energy Entrepreneurs Fund to design the next generation of the ATIR.

https://www.magallanesrenovables.com/

Magallanes Renovables ATIR (© Magallanes Renovables)

Minesto

Swedish marine energy developer Minesto has had a physical presence in Wales since 2015, where its activities are focussed on verifying the functionality and power production of its Deep Green Technology at utility scale at their Holyhead Deep test site. Since May 2019, Minesto has received €14.9m of EU funding for the commercial development of its tidal energy scheme in Wales. There are hopes that the initial 0.5 MW Deep Green system will eventually be expanded into a 10 MW commercial array. In 2021 it was announced that Minesto had signed a two year extension for its tidal energy site in the Vestmannasund strait, with analysis supporting a potential expansion from the current 200 kW site to a 4 MW commercial array. Finally, it was announced in September 2021 that Minesto will introduce a new range of power plants – the Dragon Class – an upgraded design of the company's Deep Green technology.

https://minesto.com/

Nova Innovation's newest tidal turbine – Eunice (© Nova Innovation)

Nova Innovation

In 2016, Nova Innovation installed the world's first offshore tidal energy array, the Shetland Tidal Array, at Bluemull Sound in Shetland. In 2018, Crown Estate Scotland granted an extension to Nova's existing seabed lease, increasing the overall potential capacity from 0.5 MW to 2 MW and extended the lease period until 2041. This extension allowed the progression of the EnFAIT project, with a further three 0.1 MW Nova M100 turbines to be installed between 2020 and 2022, bringing the overall installed capacity to 0.6 MW.

In 2021, Nova Innovation secured five new sources of funding to advance their innovative subsea tidal turbines.

- £2m of funding through Scottish Enterprise for their Volume Manufacturing and Logistics for Tidal Energy (VOLT) project.
- £6.4m from the Scottish National Investment Bank to fund manufacturing and distribution of its innovative subsea tidal turbines.
- £200,000 of funding from Innovate UK to deliver a feasibility study for a 7 MW tidal array in the Larantuka Strait in Indonesia, which could lead to delivery of the Indonesia's first tidal energy array.
- £800,000 through the BEIS Energy Entrepreneurs Fund in Nova Innovation's CREATE (Cost Reduction Acceleration in Tidal Energy) project. This project aims to slash the operation and maintenance costs of tidal energy in remote areas.
- €2.5m from the European Innovation Council Accelerator Fund to finance the UpTEMPO (Upscaling Tidal Energy Manufacturing and Production Output) project – a two-year campaign to design, build, and demonstrate an enhanced version of Nova's tidal turbine.

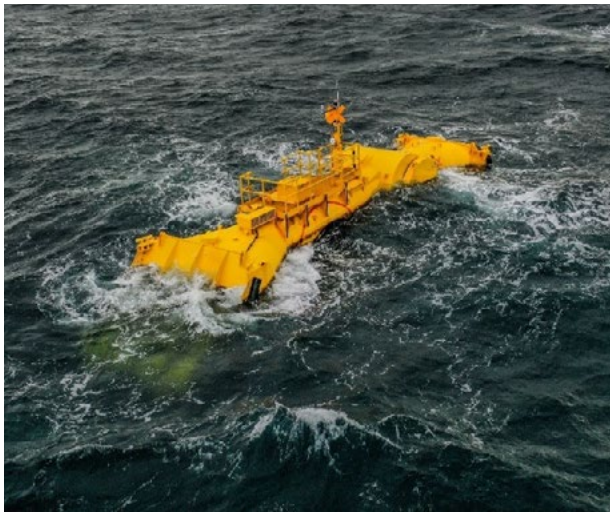
In 2021, Nova entered into a Memorandum of Understanding with SABELLA, a leading French tidal energy company, to accelerate development of tidal energy sites for both Scottish and French companies. In 2021, Nova Innovations also announced plans for a project to produce Scotch whisky, with the distillation process powered by a tidal array placed in the Sound of Islay. In November 2021, Nova Innovation announced a collaboration agreement with Atlantis Energy, with the stated aim of turbo charging the domestic tidal industry and delivering more UK-built turbines. There is an initial focus to deliver Nova and Atlantis turbines at the MeyGen array in the Pentland Firth, before moving on to international markets.

https://www.novainnovation.com/

Mocean Energy

Mocean Energy successfully deployed its first prototype device, 'Blue X', at EMEC in Orkney in June 2021. The project, funded through the WES's WEC programme, provides learning towards Mocean's "Blue Horizon" technology for large-scale power and "Blue Star" device for subsea power applications. The Blue X was tested for 5 months, experienced sea states up to 2.3 m Hs, generated sustained power outputs of 5 kW, and provided invaluable data and learning towards numerical model validation and future developments. Following the success of its prototype testing, the next step for Mocean Energy are to deploy Blue X along with subsea equipment to demonstrate reliable power and communications in a real-world application, further the development of the Blue Horizon technology through the EuropeWave programme, and commercialise the small-scale WEC product lines for launch in 2023.

https://www.mocean.energy/

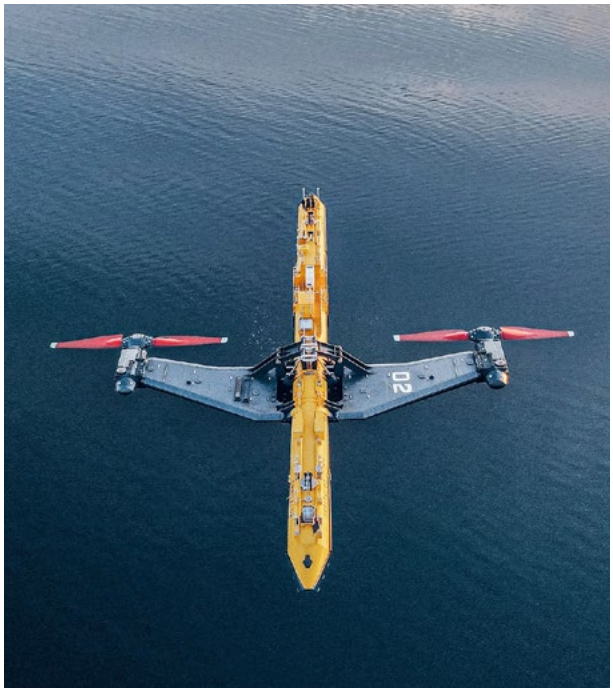


Testing of Mocean Energy's 'Blue X' device at EMEC's Scapa Flow test site (© Colin Keldie)

Orbital Marine Power

In May 2021, Orbital Marine Power successfully installed the world's most powerful tidal stream turbine, the O2, at EMEC's Fall of Warness tidal test site and commenced generation of electricity to the local grid. The O2 represents the culmination of more than 15 years of innovation and development, demonstrating that the tidal energy sector is moving ever closer to commercial deployment. The O2 features a range of innovations focussed on driving down the cost of tidal stream energy, including twin 20m rotor diameters - the largest swept area on a single tidal energy converter to date, pitching hubs for floating tidal energy and a new 'gull wing' leg retraction system to allow low cost, onsite access to the entire generating unit. The O2 project has been supported via funding from a range of collaborative partners including the European Union's Horizon 2020 research and innovation programme under the FloTEC and TOPFLOTE project, the Scottish Government's Saltire Tidal Energy Challenge Fund, and Interreg North-West Europe programme under the ITEG project. In October 2021, Orbital Marine Power was selected as one of only twelve companies to take part in the Global Investment Summit, a programme designed to showcase the most innovative green technologies and companies already operating in the UK.

https://orbitalmarine.com/



Orbital Marine Power's O2 turbine (© Orbital Marine Power)

Bombora Wave Power

Australian wave energy developer Bombora Wave Power has established its European operations in Pembrokeshire, Wales and is currently progressing the 1.5 MW mWave™ Pembrokeshire Demonstration Project supported by ERDF funding through the Welsh Government. In 2021 it was announced that Bombora Wave Power had received a subsidy from the Japanese Ministry of Economy, Trade and Industry to work with Japanese shipping giant Mitsui O.S.K. Lines to evaluate the prospects of the wave energy business in Japan and Asia. It was also announced that Bombora has formed a strategic partnership with TechnipFMC to develop a floating wave and wind power project. The partnership will initially focus on TechnipFMC and Bombora's InSPIRE project.

https://www.bomborawave.com/

Marine Power Systems (MPS)

In May 2021, Swansea-based wave energy developer Marine Power Systems confirmed that they have been successful in selecting the Biscay Marine Energy Platform (BiMEP) as the site for testing their grid-connected commercial megawatt-scale device. Part-funded by the European regional Development Fund, this project will prove the reliability and effectiveness of their technology at scale, as well as supporting the certification process. In August 2021, MPS were completed its crowdfunding campaign, raising over £4m from investors committed to helping MPS continue developing in the sector. Finally, in October MPS announced plans to work with London-based Marine2oto develop integrated solutions to support the production of green hydrogen utilising marine vessels to transport this energy vector to market.

https://www.marinepowersystems.co.uk/

Bombora Wave Power's 1.5 MW mWave prototype (© Bombora Wave Power)

PLANNED DEPLOYMENTS FOR 2022

AWS Ocean Energy

2021 has been an exciting year for AWS Ocean Energy, with completion of its prototype 16 kW Archimedes Waveswing wave energy converter in October 2021 and ongoing testing at the Muir of Ord ahead of its deployment at EMEC in January 2022. AWS's prototype Waveswing is a modular fully submergible pressure differential absorber, suitable for integration into multi-absorber platforms or single use in remote power applications. The development was the recipient of a £3.4m grant from the WES programme, highlighting another successful instance of industry collaboration. The opportunity to test AWS's device at EMEC's Scapa Flow test site allows for validation of the devices performance and reliability, as well as providing valuable experience with regards to the manufacturing, installation, operations, and maintenance for this promising technology.

http://www.awsocean.com/

Completed Archimedes Waveswing Prototype (© AWS)

RELEVANT NATIONAL EVENTS

Relevant events for the ocean energy sector that took place in the UK in **2021** include:

- **18th – 23rd January**, Supergen ORE Hub Annual Assembly, virtual
- **27th – 29th January**, Marine Energy Wales Annual Conference, virtual
- **23rd – 25th February**, International WaTERS workshop, virtual
- **23rd – 24th March**, Scottish Renewables Annual Conference, virtual
- **23rd June**, Scottish Renewables Marine Conference, virtual
- **18th – 19th August**, All-Energy
- **2nd September**, Orkney International Science Festival, virtual
- **5th – 10th September**, 14th European Wave and Tidal Energy Conference (EWTEC), hybrid
- **1st – 12th November**, Conference of Parties 26 (COP26)

The UK will also be hosting some important events in **2022**:

- **18th – 20th January**, Supergen ORE Hub Annual Assembly, virtual
- **22nd – 23rd March**, Marine Energy Wales Conference 2022
- **11th – 12th May**, All-Energy
- **25th May**, Scottish Renewables Marine Conference

3.22

UNITED STATES OF AMERICA

AUTHORS
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OVERVIEW

Ocean energy has made great progress in the United States during 2021. Four current energy converters and one wave energy converter were deployed this past year. Larger-scale wave energy demonstrations are on the horizon for early 2022 in Hawaii. PacWave South, the United States' first accredited, grid-connected, open-ocean wave energy testing facility, is steadily moving along with construction and build out of its open water test berths. In addition to testing and demonstration, there was a substantial amount of research and development activity this past year. This included investigation of a wide range of R&D, from biofouling to resource characterization to best practices for community engagement for ocean energy devices.

Towards the end of 2021 there was great excitement with the passage of the Infrastructure Investment and Jobs Act. This legislation will provide billions of dollars in federal funding to a variety of infrastructure and clean energy projects across the country, including funds applicable for ocean energy. The Water Power Technologies Office (WPTO) at the U.S. Department of Energy (DOE) has seen growth in its annual budget and is looking forward to the numerous activities planned for next year.

SUPPORTING POLICIES FOR OCEAN ENERGY

NATIONAL STRATEGY

The United States has several national, regional, and local strategies and policies relevant to ocean energy. At the national level, WPTO leads research, development, demonstration, and deployment efforts for ocean and river energy. WPTO aligns itself with federal goals for ocean resource utilization and works with other agencies, such as the National Science Foundation (NSF), Bureau of Ocean Energy Management (BOEM), the U.S. Navy, the National Oceanic and Atmospheric Administration (NOAA), Federal Energy Regulatory Committee (FERC), among others, to advance federal ocean priorities.

In November 2021 the U.S. Congress passed the Infrastructure Investment and Jobs Act, a large piece of legislation that provides billions of dollars for infrastructure, clean energy, and climate change mitigation projects across the country. The legislation provides $110.4 million for ocean energy research led by WPTO, and this is in addition to the office's annual funding. It also provides funding to support infrastructure upgrades for ports and rural coastal communities which could support future ocean energy activities. As of this writing, Congress is considering additional pieces of legislation that might also provide increased funding, including tax provisions, for ocean energy projects.

President Biden has committed to achieving a net-zero economy by 2050 and a nationally determined contribution (NDC) to reduce net greenhouse gas emissions to 50-52 percent below 2005 levels in 2030. At COP26 in November 2021 the U.S. released its Long-term Strategy which outlines actions the U.S. plans to take across all key sectors that will put it on track to reach net-zero greenhouse gas emissions by 2050.

MARKET INCENTIVES

While there are no dedicated ocean energy market incentives in the U.S., there are clean energy incentives which may be applicable in some regions. These include:

- Clean Renewable Energy Bonds
- Qualified Energy Conservation Bonds
- Renewable Portfolio Standards and other voluntary renewable energy goals
- Public Benefit Funds

For more information on these funding mechanisms please consult the 2018 and 2019 OES Annual Report.

PUBLIC FUNDING PROGRAMMES

There are several sources of public funding for ocean energy research, development and demonstration (RD&D). WPTO is the primary group covered under this country report as it provides the bulk of federal funding that supports ocean energy R&D, but this work could not be done without the help from other federal agencies and offices. For example, the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) actively supports R&D of various renewable energy conversion technologies, including wave energy. NAVFAC EXWC's funding efforts focus on advancing technology development to harness ocean energy resources to ensure energy security and to power U.S. Navy and Marine Corps assets both on- and off-shore. NAVFAC is funding and actively managing the Navy's Wave Energy Test Site (WETS) in Hawaii. In 2021 NAVFEC provided $6 million to the University of Hawaii at Manoa to provide research and logistical support to WETS.

Other federal offices such as the U.S. Department of Energy Advanced Research Projects Agency – Energy (ARPA-E), BOEM, NOAA, and NSF also provide funding support ocean energy research projects.

Since 2008, WPTO's funded projects for ocean energy have been split evenly among private companies, universities, and the DOE national laboratories. The bulk of this funding to date has been allocated toward wave energy research, followed by cross-cutting RD&D that supports multiple resource types, and then current energy technologies.

Ocean energy technology developers can seek WPTO funding through several different competitive funding mechanisms. **Funding Opportunity Announcements (FOAs)** are topic-specific competitive opportunities designed for industry and academia to form partnerships in conducting research and testing. Some FOAs are available to international applicants.

Small Business Innovation Research (SBIR) and **Small Business Technology Transfer (STTR)** programs are methods through which federal agencies with R&D missions set aside a fraction of their funding for competitions among small businesses to pursue early-stage research. Small businesses that win awards in these programs keep the rights to any technology developed and are encouraged

to commercialize the technology. DOE also has a **Technology Commercialization Fund (TCF)** which leverages federal RD&D funding, paired with private partners, to mature promising energy technologies with high impact potential. Lastly, DOE administers prize competitions, which can attract new innovators and investment to specific challenge areas.

WPTO identifies and funds qualified projects within specific topics that support program objectives, depending on available funds. In evaluating all proposals for new energy developments or new adaptations of existing technology, WPTO assesses whether individual applications clearly meet the goals of the topic area and their potential to advance the industry. More information on available funding opportunities can be found at: https://energy.gov/eere/water/water-power-funding-opportunities

To see other examples of all WPTO funded projects, visit the online project database map at: https://www.energy.gov/eere/water/water-power-technologies-office-projects-map

RESEARCH & DEVELOPMENT

R&D OVERVIEW

There are numerous universities, private companies, organizations, non-profits, and national laboratories that lead ocean energy research in the United States. Collectively, these institutions represent approximately 40 unique testing facilities for ocean energy technologies. To foster ocean energy technology research, education, and outreach, WPTO has partnered with nine universities to operate four National Marine Renewable Energy Centers (NMRECs). These NMRECs are:

- Pacific Marine Energy Center (PMEC)
- Hawaii National Marine Renewable Energy Center (HINMREC)
- Southeast National Marine Renewable Energy Center (SNMREC)
- Atlantic Marine Energy Center (AMEC) - NEW

DOE's national laboratories possess unique instruments and facilities capable of addressing large-scale, complex R&D challenges with research expertise and an approach emphasizing translating basic science to innovation. WPTO partners with several of these laboratories to support R&D in ocean energy, including:

- National Renewable Energy Laboratory (NREL)
- Pacific Northwest National Laboratory (PNNL)
- Sandia National Laboratories (SNL)
- Oak Ridge National Laboratory (ORNL)
- Argonne National Laboratory (ANL)

In 2021, NREL and SNL were bestowed with an R&D 100 Award from R&D World for their efforts in developing WEC-Sim, an open-source code for simulating WEC dynamics. There are numerous other R&D institutions within the U.S. that work on related ocean technologies such as the Applied Physics Laboratories, U.S. Navy Research Lab, U.S. Navy Office of Naval Research, and the Marine Environmental Laboratories operated by NOAA.

R&D HIGHLIGHTS

Below are funded R&D activities that were carried out during 2021 in support of ocean energy technology development.

Prizes and Challenges:

- **Ocean Observing Prize:** This prize competition is jointly offered by WPTO and NOAA and includes two separate competitions that will award up to $2.4 million in cash prizes for teams to design, build, and test a wave energy powered autonomous underwater vehicle for hurricane monitoring. In April 2021 seven contestant teams were issued awards after completing the DESIGN Contest. In subsequent contests the contestants will build and then test their prototypes in a test facility and the open water.

- **Waves to Water:** This prize competition will accelerate the development of wave-powered desalination systems to provide drinking water in disaster relief and coastal locations. $3.3 million in cash prizes will be provided over five different stages or contests. In September 2021, WPTO announced the five winners of the CREATE Stage who will go on to the final round of the competition.

- **2021 Marine Energy Collegiate Competition:** University teams compete for cash prizes with preliminary technical designs and business plans which explore new opportunities for marine energy. Teams are also given the option to build and test their prototypes. In 2021, WPTO wrapped up the 2021 competition which had 16 teams comprised of 21 educational institutions and launched the 2022 competition which has 17 teams comprised of 26 institutions.
- **Build to Scale – Blue Economy Industry Challenge:** WPTO, in partnership with the U.S. Economic Development Administration (EDA), is supporting seven awardees with grants of $300k to $650k to support energy innovation in the blue economy. Throughout 2021 this cohort supported a variety of startups and other blue economy activities across the country.

Testing Infrastructures:

- **PacWave South:** This grid-connected, pre-permitted test site is designed for wave energy devices and arrays with combined capacities of up to 20 MW. The site, led by Oregon State University (OSU), will have four test berths located approximately seven miles offshore of Oregon. In 2021, after receiving the necessary federal license and lease, the test site started construction. By October, the OSU-led team officially completed offshore horizontal directional drilling for electrical cabling.
- **Testing & Expertise for Marine Energy (TEAMER):** Launched in 2020, TEAMER is a 3-year testing campaign that will provide low-cost access to testing infrastructure at pre-certified facilities and subject matter experts from the nation's leading marine energy R&D institutions. This $16 million program is anticipated to fund testing of over 100 projects. In 2021 TEAMER made several calls for technical support applications. In July the program selected 14 projects for its third call, and in November the program selected nine marine energy projects as part of its fourth call. TEAMER is sponsored by WPTO and directed by the Pacific Ocean Energy Trust (POET). In 2021 POET also established the Foundational Research Network Facilitator: Marine Energy Knowledge Hub.
- **Infrastructure investments at the national labs:** In March 2021, WPTO announced that seven projects across five DOE national labs will receive $7.1 million to invest in lab infrastructure in support of advancing marine energy technologies. Awards were made under two topics: (1) infrastructure needed to support the development of marine energy technologies power diverse markets and scientific missions identified through WPTO's Powering the Blue Economy Initiative (PBE) and (2) to support the labs' development of roadmaps on long-term infrastructure needs for marine energy.

Competitive Funding Opportunity Solicitations:

- In June 2021 WPTO announced $2.4 million in funding for twelve new Phase I **Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)** marine energy research and development projects under two topic areas: (1) Co-Development of Marine Energy Technology at Smaller Scales; (2) Low-Cost, User-Friendly Monitoring Tools for Marine Energy Sites.
- In July 2021, WPTO announced funding for Phase II projects in the **Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program**, including $8.1 million for seven hydropower and marine energy projects. Each recipient receives grants ranging from $1.1-1.5 million to explore the technical feasibility of innovative solutions in hydropower and marine energy.
- In July 2021, WPTO announced up to $27 million in funding for wave energy R&D projects under the **"Advancing Wave Energy Technologies through Open Water Testing at PacWave"** FOA. Projects selected through this solicitation will be the first round of activities supported at the PacWave South open water test site. Topic areas of interest include: (1) Testing WEC Technologies at PacWave; (2) Advancing WEC Designs for PacWave; and (3) Open Topic: Wave Energy R&D at PacWave.
- In November 2021 WPTO announced a new solicitation through the **Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program**, of interest to ocean energy are topics related to: (1) co-development of marine energy technologies with end user partners (CMET); (2) technology solutions for advancing ocean co-existence and co-use with marine energy and communities; (3) development of cost effective subsea wet-mateable connector technologies; and (4) community-driven solutions for a just and equitable energy transition.

Other Projects and Initiatives:

- **Energy Transitions Initiative Partnership Program (ETIPP)** – In April 2021 WPTO, in partnership with six other DOE offices and national labs, made 11 awards to remote and island communities interested in pursuing energy transition efforts. These groups will receive technical assistance to address energy challenges, build capacity, accelerate the sharing of best practices and innovations between similarly situated regions, and leverage specialized, local expertise.
- **Resource Characterization** - At the end of 2020, DOE developed a methodology and released new models and characterization data on the U.S. wave energy resource, including the highest resolution, most comprehensive wave data set publicly available to date. The new methodology, created by the multi-lab resource characterization project, supports a more complete accounting of how wave energy totals are estimated, resulting in a 30% increase in the estimate of the U.S. wave energy resource potential. With funding from WPTO and led by NREL with support from PNNL and Sandia, the project developed the refined wave resource assessment methodology, enabling an accounting of the effect of local winds blowing on the ocean surface within the U.S. Exclusive Economic Zone, as well as the waves that arrive at U.S. coastlines from the open ocean.
- In 2021, four marine energy students were selected through the **Marine and Hydrokinetic Graduate Student Research Program** to work with DOE national labs, industry, and a native tribe in the Pacific Northwest conducting marine energy research.
- In March 2021, WPTO in partnership with the Northeast Sea Grant Consortium, the U.S. Department of Energy's Wind Energy Technologies Office, and NOAA's Northeast Fisheries Science Center, announced $1 million in funding to improve understanding of offshore renewable energy interactions with fishing and coastal communities to optimize ocean co-use.

TECHNOLOGY DEMONSTRATION

PROJECTS IN THE WATER

In May 2021 **Verdant Power** performed a retrieve-and-replace operation on one of three tidal power turbines that had been deployed for the past six months, part of their Roosevelt Island Tidal Energy (RITE) Project in New York City's East River. The turbine was swapped out as part of a scheduled test plan and replaced with a turbine design featuring three new thermoplastic blades. The one-half scale demonstration tidal array operated continuously for six months. By July it had generated more than 300 MWh—a U.S. record for marine energy production.

Roosevelt Island Tidal Energy (RITE) Project (Courtesy: Verdant Power)

In August 2021, **Ocean Renewable Power Company (ORPC)** of Portland, Maine installed a second RivGen river turbine in Igiugig, Alaska.

In August 2021, a tidal turbine designed by **Littoral Power Systems** was installed for testing at the Bourne Tidal Test Site in Cape Cod, Massachusetts. This is the first time a tidal turbine has been installed at this test site.

In September 2021, **CalWave Power Technologies** commissioned its CalWave x1 wave energy device off the coast of San Diego, California near Scripps Institute of Oceanography. The device will be deployed for approximately six months for testing.

CalWave x1 wave energy converter (courtesy CalWave Power Technologies)

This past Fall 2021, the **Alaska Center for Energy and Power** tested a second generation of Renerge's Water Horse hydrokinetic energy harvester on Tanana River in Alaska for ten days. The device captures energy from vortex shedding off a submerged bluff body.

Triton-C wave energy converter (courtesy Oscilla Power)

PLANNED DEPLOYMENTS

- **C·Power** is preparing for deployment of its SeaRAY autonomous offshore power system (or SeaRAY AOPS) at WETS in Hawaii, USA. The duration of the deployment is estimated to last for six months and will commence in 2022. C-Power Project partners, BioSonics and Saab, will bring their ocean technologies to be powered by the SeaRAY. BioSonics' subsea environmental monitoring system will search for underwater dangers and collect environmental data. Saab will pair the SeaRAY with its surfboard-sized Sabertooth autonomous underwater vehicle to recharge the vehicle with renewable energy.
- As of this writing, **Oscilla Power** is working on final assembly of their Triton-C wave energy converter which will soon be deployed offshore of Hawaii. The device is approximately 10m x 7m 100 kW variant called Triton-C which is scheduled for a year-long test commencing in March 2021 at WETS in Hawaii.

RELEVANT NATIONAL EVENTS

President Biden was inaugurated on January 20, 2021, and shortly thereafter announced that the U.S. was re-entering the Paris Agreement. At the most recent Conference of the Parties 26 (COP26) in November 2021, there were several new ocean-specific commitments and declarations that the U.S. Government signed onto. One such commitment is the U.S. joining the High-Level Panel for a Sustainable Ocean Economy. This multinational initiative aims to harness the power of the ocean to tackle the climate crisis, provide jobs and food security, and accelerate sustainable uses of the ocean. As a member of the Ocean Panel, the U.S. will develop a national plan to sustainably manage our ocean area under national jurisdiction.

4.

SNAPSHOT OF OCEAN ENERGY

INSTALLED CAPACITY (KW) IN THE OES MEMBER COUNTRIES

OCEAN ENERGY PROJECTS OPERATIONAL IN 2021, UNDER DEVELOPMENT OR WITH CONSENT AUTHORISED

AUSTRALIA

Project	Technology Developer	Place	Project Status	kW
WAVE ENERGY				
King Island Demonstration Project	Wave Swell Energy	King Island, Tasmania	Operational	200

CANADA

Project	Technology Developer	Place	Project Status	kW
TIDAL CURRENTS				
Sustainable Marine	Sustainable Marine	Grand Passage, Nova Scotia	Operational	280
Uisce Tapa Project	Andrtiz Hammerfest Hydro	FORCE site, Nova Scotia	Under development	9000
Sustainable Marine	Sustainable Marine	FORCE site, Nova Scotia	Under development	9000
Big Moon Power	Big Moon Power	FORCE site, Nova Scotia	Under development	4000
Nova Innovations	Nova Innovations	Petit Passage, Nova Scotia	Under development	1500
Jupiter Hydro	Jupiter Hydro	Minas Passage, Nova Scotia	Under development	2000
New East Energy	New East Energy	Minas Passage, Nova Scotia	Under development	800
Big Moon Power	Big Moon Power	Minas Passage, Nova Scotia	Under development	5000
Yourbrook Energy Systems	Yourbrook Energy Systems	Haida Gwaii, British Columbia	Under development	500
RIVER CURRENTS				
Sagkeeng Hydrokinetic	New Energy Corp	Winnipeg River, Manitoba	Under development	25

CHINA

Project	Technology Developer	Place	Project Status	kW
TIDAL RANGE				
Jiangxia Tidal Power Plant	China Long Yuan Power Group Corporation	Wenling, Zhejiang Province	Operational	4100
Haishan Tidal Power Plant	Haishan Tidal Power	Maotian Island, Zhejiang Province	Operational	250
TIDAL CURRENTS				
LHD Tidal Current Energy Demonstration Project	Hangzhou United Energy Corporation	Xiushan Island, Zhejiang Province	Operational	1700
Zhoushan Tidal Current Energy Demonstration	China Three Gorges Corporation (CTG)	Hulu Island, Zhejiang Province	Under development	450
WAVE ENERGY				
Wanshan 1 MW (2×500 kW)	Guangzhou Institute of Energy Conversion (GIEC)	Wanshan Island, Guangdong Province	Under development	1000

DENMARK

Project	Technology Developer	Place	Project Status	kW
WAVE ENERGY				
Exowave wave energy converter	Exowave	North Sea, Denmark	Under development	10
Exowave wave energy converter	Exowave	North Sea, Denmark	Under development	1
CrestWING's Tordenskiold	CrestWING	North Sea, Denmark	Under development	50
Resen Waves Smart Power Buoy	ResenWave	North Sea, Denmark	Under development	0,5
Commercial scale PTO dry test rig (PTO TWIN)	Floating Power Plant A/S	Nakskov, Denmark	Under development	200

FRANCE

Project	Technology Developer	Place	Project Status	kW
TIDAL RANGE				
La Rance Barrage	EDF	La Rance estuary, Brittany	Operational	240000
TIDAL CURRENTS				
OceanQuest	HydroQuest	Bréhat-Paimpol test site, Brittany	Operational	1000
Sabella D10	Sabella	Ushant island, Brittany	Operational	1000
Phares	Sabella	Ushant island, Brittany	Under development	1000
Flowatt	Hydroquest	Raz Blanchard, Normandie	Consent authorised	17500
Nepthyd	SIMEC-Atlantis	Raz Blanchard, Normandie	Consent authorised	12000
WAVE ENERGY				
Wavegem	Gepstechno	SEMREV test site, Le Croisic	Operational	150

INDIA

Project	Technology Developer	Place	Project Status	kW
TIDAL CURRENTS				
NIOT Off-grid hydrokinetic turbine	NIOT	Andaman & Nicobar	Under development	5
WAVE ENERGY				
Wave powered Navigational Buoy	NIOT	Chennai, Tamil Nadu	Operational	900
OTEC				
OTEC powered Desalination plant	NIOT	Kavaratti, Lakshadweep Islands	Under development	60

ITALY

Project	Technology Developer	Place	Project Status	kW
TIDAL CURRENTS				
GEMSTAR Demonstration II	Seapower Scrl	Messina, Thyrrenian Sea	Under development	300
WAVE ENERGY				
REWEC3 @ Civitavecchia	Mediterranean University of Reggio Calabria	Civitavecchia, Tyrrhenian Sea	Operational	20
Overtopping Breakwater (OBREC)	University of Campania Luigi Vanvitelli	Napoli, Thyrrenian Sea	Operational	8
MaREnergy	ENI, Wave for Energy, Politecnico di Torino	Ravenna, Adriatic Sea	Operational	50
Marina di Pisa H-WEP 1	Enel Green Power	Pisa, Thyrrenian Sea	Operational	50
ISWEC revamp	ENI, Wave for Energy, Politecnico di Torino	Pantelleria, Mediterranean Sea	Under development	250
ISWEC MED	ENI, Wave for Energy, Politecnico di Torino	Pantelleria, Mediterranean Sea	Under development	1000

MONACO

Project	Technology Developer	Place	Project Status	kW
WAVE ENERGY				
S3 - SBM Offshore	SBM Offshore	Monaco	Under development	0,5

NEW ZEALAND

Project	Technology Developer	Place	Project Status	kW
WAVE ENERGY				
Azura	Azura Wave Power	New Zealand	Operational	500
RIVER AND TIDAL CURRENTS				
Ruka Marine Turbine	Environment River Patrol-Aotearoa	Whangarei	Under development	-
Aquantis Advanced Turbine Technology	Aquantis	New Zealand	Under development	-

PORTUGAL

Project	Technology Developer	Place	Project Status	kW
WAVE ENERGY				
Corpower's Hiwave-5 C4	Corpower Ocean	Aguçadora	Under development	300
Corpower's Hiwave-5 C5	Corpower Ocean	Aguçadora	Consent authorised	900

REPUBLIC OF KOREA

Project	Technology Developer	Place	Project Status	kW
TIDAL RANGE				
Sihwa Lake Tidal Power Station	K-Water	Ansan, Gyeonggi, Korea	Operational	254000
TIDAL CURRENTS				
Uldolmok Tidal Pilot Power Plant	KIOST	Jindo, Korea	Operational	80
WAVE ENERGY				
Youngsoo OWC Pilot Plant	KRISO	Jeju, Korea	Operational	500
OWC WEC with Breakwater	KRISO	Jeju, Korea	Under development	30
OTEC & SWAC				
OTEC Pilot Plant	KRISO		Under development	1000
OTEC Pilot Plant	KRISO	Goseong, Korea	Operational	20
SWAC Pilot System	KRISO	Goseong, Korea	Operational	-
SWAC Semi-commercial model	KRISO	Haenam & Wolseong, Korea	Operational	-

SPAIN

Project	Technology Developer	Place	Project Status	kW
WAVE ENERGY				
Mutriku Wave Power Plant	EVE	Mutriku, Gipuzkoa	Operational	296
Penguin2 - Wello	Wello	BiMEP	Operational	600
WavePiston	WavePiston	PLOCAN	Operational	200

UNITED KINGDOM

Project	Technology Developer	Place	Project Status	kW
TIDAL CURRENTS				
MeyGen	SIMEC-Atlantis Energy	Pentland Firth, Scotland	Operational	6000
Enabling Future Arrays in Tidal (EnFAIT)	Nova Innovation	Bluemull Sound, Shetland, Scotland	Operational	600
ITEG	Orbital Marine Power/EMEC	Orkney Islands, Scotland	Operational	2000
ATIR	Magallanes Renovables	Orkney Islands, Scotland	Operational	1500
Floating Tidal Energy Commercialisation (FloTEC)	Orbital Marine Power/EMEC	Orkney Islands, Scotland	Under development	6000
Holyhead Deep	Minesto	Holyhead, North Wales	Under development	500
WAVE ENERGY				
Blue X	Mocean Energy	Orkney Islands, Scotland	Under development	10
mWave™	Bombora Wavepower	Pembrokeshire, Wales	Under development	1500
Archimedes Waveswing	AWS Ocean Energy	Orkney Islands, Scotland	Under development	16

USA

Project	Technology Developer	Place	Project Status	kW
TIDAL CURRENTS				
ORPC Cook Inlet	Ocean Renewable Power Company (ORPC)	Cook Inlet, Alaska	Under development	5000
RIVER CURRENTS				
Verdant - RITE Project	Verdant Power	East River, New York	Decommissioning	105
Igiugig ORPC	Ocean Renewable Power Company (ORPC)	Kvichak River, Igiugig, Alaska	Operational	35
Littoral Power at BTTS	Littoral Power Systems	Bourne Tidal Test Site, Cape Cod, MA	Operational	-
Water Horse Field Trials	Renerge Inc	Tanana River, Alaska	Operational	1,5
WAVE ENERGY				
CalWave x1	CalWave	Scripps Pier, San Diego, California	Operational	
Northwest Energy Innovations (NWEI)	Northwest Energy Innovations (NWEI)	Wave Energy Test Site, Hawai	Under development	250
OE Buoy	Ocean Energy Ltd,	Wave Energy Test Site, Hawai	Under development	500
SeaRay k20	C-Power	Wave Energy Test Site, Hawai	Under development	20
SeaRay k2	C-Power	Wave Energy Test Site, Hawai	Under development	1
TigerRay	C-Power	Puget Sound, WA	Under development	0,1
Triton-C	Oscilla Power	Wave Energy Test Site, Hawai	Under development	100
AquaHarmonics	AquaHarmonics	Wave Energy Test Site, Hawai	Under development	-
ORPC Cobscook Bay	Ocean Renewable Power Company (ORPC)	Cobscook Bay, Eastport, Maine	Consent authorized	-

5.

APPENDICES

APPENDIX 1

MEMBERSHIP OF THE EXECUTIVE COMMITTEE

CABINET 2021

CHAIRMAN
Dr. Yann-Hervé De Roeck
France Energies Marines
France

VICE-CHAIR
Dr. Ir. Matthijs SOEDE
EC DG Research & Innovation
European Commission

VICE-CHAIR
Dr. Purnima Jalihal
NIOT
India

SECRETARY
Dr. Ana Brito e Melo
WavEC Offshore Renewables
Portugal

DELEGATES

Country	Delegate	Alternate
Australia	**Dr. Mark Hemer** CSIRO Oceans and Atmosphere	**Mrs. Stephanie Thornton** Australian marine Energy Taskforce (AMET)
Belgium	**Dr. Ludovic Mouffe** Federal Public Service Economy	**Dr. Vicky Stratigaki** Ghent University
Canada	**Mr. Ghanashyam Ranjitkar** Natural Resources Canada	**Mrs. Elisa Obermann** Marine Renewables Canada
China	**Mr. Peng Wei** National Ocean Technology Center, SOA	**Mr. Wang Ji** National Ocean Technology Center
Denmark	**Mrs. Laerke Scov Hansen** Danish Energy Agency	**Dr. Kim Nielsen** Ramboll
European Commission	**Dr. Ir. Matthijs SOEDE** EC DG Research & Innovation	
France	**Dr. Yann-Hervé De Roeck** France Energies Marines	

Germany		**Mr. Jochen Bard** Fraunhofer Institute for Energy Economics and Energy Systems Technology IEE
India	**Dr. G A Ramadass** National Institute of Ocean Technology	**Dr. Purnima Jalihal** National Institute of Ocean Technology
Ireland	**Mr. Declan Meally** Sustainable Energy Authority of Ireland	**Mr. Shadi Kalash** Sustainable Energy Authority of Ireland
Italy	**Mr. Luca Benedetti** Gestore dei Servizi Energetici (GSE)	
Japan	**Dr. Yasuyuki Ikegami** Institute of Ocean Energy, Saga University	**Dr. Shuichi Nagata** Institute of Ocean Energy, Saga University
Korea	**Mr. Man Wook Hoe** Ministry of Oceans and Fisheries	**Dr. Jin-Hak Yi** Korea Institute of Ocean Science & Technology
Mexico	**Dr. Rodolfo Silva Casarín** CEMIE – Océano	**Dr. Juan Carlos Alcéreca Huerta** CEMIE – Océano
Monaco	**HE Bernard Fautrier** Government of the Principality of Monaco	**Mr. Jérémie Carles** Fondation Prince Albert II de Monaco
Netherlands	**Mr. H.W.Boomsma** Ministry of Economic Affairs	**Mr. H.P.E.M. Reijnders** Netherlands Entreprise Agency
New Zealand	**Mr. Martin Knoche** AWATEA	**Mr. Vladislav Sorokin** AWATEA
Portugal	**Prof. Luis Gato** Instituto Superior Técnico (IST)	**Prof. António Falcão** Instituto Superior Técnico (IST)
Singapore	**Prof. Subodh Mhaisalkar** Energy Research Institute	**Dr. Srikanth Narasimalu** Energy Research Institute
Spain	**Mr. Luis Hilario Alonso Mijares** Ministry of Industry, Energy and Tourism	**Mr. Yago Torre-Enciso** BIMEP - Biscay Marine Energy Platform
Sweden	**Ms. Maria Olsson** Swedish Energy Agency	**Mr. Lars Karlbom** Swedish Energy Agency
UK	**Mr. Tim Warham** Department for Business, Energy and Industrial Strategy (BEIS)	**Mr. Henry Jeffrey** The University of Edinburgh
USA	**Mr. Tim Ramsey** U.S. Department of Energy	**Mr. David Hume** U.S. Department of Energy

APPENDIX 2

EXECUTIVE COMMITTEE MEETINGS

Meeting	Date	Local	Country
1	19 October 2001	Paris	France
2	21 - 22 March 2002	London	UK
3	31 October 2002	Brighton	UK
4	4 March 2003	Paris	France
5	15 - 16 September 2003	Cork	Ireland
6	26 - 27 February 2004	Lisbon	Portugal
7	4 - 5 November 2004	Copenhagen	Denmark
8	4 March 2005	Paris	France
9	16 - 17 November 2005	Brussels	Belgium
10	1 - 3 May 2006	Vancouver	Canada
11	14 - 15 November 2006	Lisbon	Portugal
12	20 - 21 March 2007	Mexico City	Mexico
13	16 - 17 October 2007	Messina	Italy
14	15 - 16 April 2008	New York city	USA
15	13 - 14 October 2008	Brest	France
16	30 - 31 March 2009	Bilbao	Spain
17	4 - 5 September 2009	Oslo	Norway
18	22 - 23 April 2010	Wellington	New Zealand
19	30 Sep - 1 Oct 2010	Dublin	Ireland
20	26 - 27 April 2011	Washington DC	USA
21	13 - 14 September 2011	Madeira	Portugal

22	17 - 18 May 2012	Daejeon	Korea
23	22 - 23 October 2012	Aalborg	Denmark
24	14 - 15 May 2013	Guangzhou	China
25	22 - 23 October 2013	Cape Town	South Africa
26	13 - 14 May 2014	Paris	France
27	10 - 11 November 2014	Halifax	Canada
28	12 - 13 May 2015	Kassel	Germany
29	11 - 12 November 2015	Cancun	Mexico
30	9 - 10 May 2016	Gothenburg	Sweden
31	20 - 21 October 2016	Singapore	Singapore
32	10 - 11 April 2017	Monaco	Monaco
33	14 - 15 November 2017	Chennai	India
34	14 - 15 June 2018	Cherbourg	France
35	29 - 30 November 2018	Las Palmas	Spain
36	26 - 27 March 2019	Riviera Maya	Mexico
37	2 - 3 October 2019	Dublin	Ireland
38	18 – 22 May 2020	Online meeting	
39	4 - 6 November 2020	Online meeting	
40	10 - 11 March 2021	Online meeting	
41	19 - 20 May 2021	Online meeting	
42	15 - 16 September 2021	Online meeting	
43	8 December 2021	Online meeting	

About IEA-OES

Ocean Energy Systems (OES) is a Technology Collaboration Programme (TCP) within the International Energy Agency (IEA)

The **International Energy Agency (IEA)** works to ensure reliable, affordable and clean energy for its 29 Member Countries and beyond. Founded in 1974, the IEA was initially designed to help countries coordinate a collective response to major disruptions in the supply of oil such as the crisis of 1973/4. While this remains a key aspect of its work, the IEA has evolved and expanded. It is at the heart of global dialogue on energy, providing authoritative statistics and analysis.

The IEA examines the full spectrum of energy issues and advocates policies that will enhance the reliability, affordability and sustainability of energy in its 29 Member Countries and beyond. The four main areas of focus are:

- energy security: promoting diversity, efficiency and flexibility within all energy sectors;
- economic development: ensuring the stable supply of energy to IEA Member Countries and promoting free markets to foster economic growth and eliminate energy poverty;
- environmental awareness: enhancing international knowledge of options for tackling climate change;
- engagement worldwide: working closely with non-member countries, especially major producers and consumers, to find solutions to shared energy and environmental concerns.

Technology Collaboration Programmes (TCPs) are independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues. TCPs currently cover topics related to:

- efficient end-use (buildings, electricity, industry, transport);
- cleaner fossil fuels (greenhouse-gas mitigation, extraction, supply, transformation);
- renewable energy and hydrogen (technologies and policies for deployment);
- cross-cutting issues (modelling, technology transfer, project financing);
- fusion power (safety, physics, materials, technologies).

www.ocean-energy-systems.org