Technology Collaboration Programme
by IEA

ANNUAL REPORT

AN OVERVIEW OF OCEAN ENERGY ACTIVITIES IN 2022

OES OCEAN ENERGY SYSTEMS

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Cover page: The 420kW PLAT-I 6.40 platform deployed at Grand Passage, Nova Scotia

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Chairman's Message

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

Advocacy remains urgent, because in this world in crisis, even the best solutions cannot rely on their evidence without raising their voice sufficiently high.

2022, crisis, what crisis?

Nobody would like to be seen so provocative when so many hurdles over the planet stand in the way of hope for a peaceful and reasoned progress, respectful of our environment. Nonetheless, for ocean energy systems, this year has been deeply encouraging. Indeed, the paradigm that ranked the costs of electricity production has been overturned, with soaring prices for all fossil resources, prompting investors to rethink their view on renewable energies, especially towards those with the lowest externalities.

This leads to a deserved resurgence of interest in the ocean energy sector, which is moving forward, with more than 60 developers worldwide, from Australia, through Asia and Europe to Americas. Grid-connected long lasting demonstrations are reaffirming the potential role of ocean energy in the achievement of decarbonization goals. At the OES, as a living complement to this documented report, our group of experts hold three public webinars a year, among others, to share the state of progress in our respective regions.

Then, to consolidate the technological progress, in terms of power, reliability, survivability, maintainability, and ultimately affordability, many countries have also decided to implement market instruments, for the ocean industry to progress towards industrialization: such as feed-in tariffs, auctions and tenders, legally binding targets or purchase obligations for renewables. Seldom, however, are these instruments specific to ocean energy. The creation and implementation of policies to reduce administrative barriers such as Marine Spatial Plans are also very useful, in view of a deployment at utility scale, with LCOE targets proposed as for example in the European SetPlan, at 10ct€/kWh for tidal and 15c€/kWh for wave in 2030. Very attractive figures in comparison with present mean prices of electricity…

Meanwhile, global awareness of the need for resilience has joined the sustainable development goals. For instance, the need expressed by isolated islands or coastal communities changes the scale of technically and economically relevant solutions. On this regard, OES has cheerily welcome experts from the Small Island Developing States (SIDS) as observers. The same developing trend is true for ensuring the sustainable, and therefore fossil-free, development of the blue economy and its various offshore economic activities. For instance, a bright light was shed this year by one of our reports on offshore aquaculture, in order to detail how it can be considered

as a market for ocean energy. It's our common duty to end up with solutions that are practical, affordable and with an exemplary life cycle analysis.

The development of hybrid systems continues, combining wave power and wind or solar power on floating platforms. Hence the relevance for our group to link collaborations with other groups, namely the TCP Wind about the design of parameters for surface to bottom components of offshore energy converters. We also deepen our efforts to assess the pertinence of ocean thermal energy conversion, on the technical and the economical points of view. Note also that osmotic energy is resurfacing in the form of an ambitious project.

Reading this report should provide you with a lot of information, while inviting you to download our publications for robust references. In order to foster the dissemination of our works, a joint publication with the IEC provides to funding agencies the consensual principles of evaluation for wave and tidal technologies, while supporting the translation of leaflets. Advocacy remains urgent, because in this world in crisis, even the best solutions cannot rely on their evidence without raising their voice sufficiently high. I trust my dear colleagues, that I had the honour of chairing during the 2021-2022 term, to pursue this side of our mission as TCP devoted to ocean energy systems.

New Chairman's Biography

Matthijs Soede
European Commission
IEA-OES Chairman (2023)

Matthijs Soede studied at the Delft University of Technology and has a PhD in Chemical Engineering.

He began his career at the Ministry of Economic Affairs in the Netherlands, as specialist in international research cooperation.

In 2008 he joined the European Commission in DG Research and Innovation as policy officer in Industrial Technologies and moved to Clean Energy Transition being responsible for offshore renewables.

He is member of the IEA Renewable Energy Working Party and since 2019 vice-chair of the Technology Collaboration Programme on Ocean Energy Systems.

Since 2021 he is member of the MI Clean Hydrogen Mission co-leads team and appointed as Mission Director.

Executive Summary

Ana Brito e Melo
IEA-OES Executive Secretary

Introduction

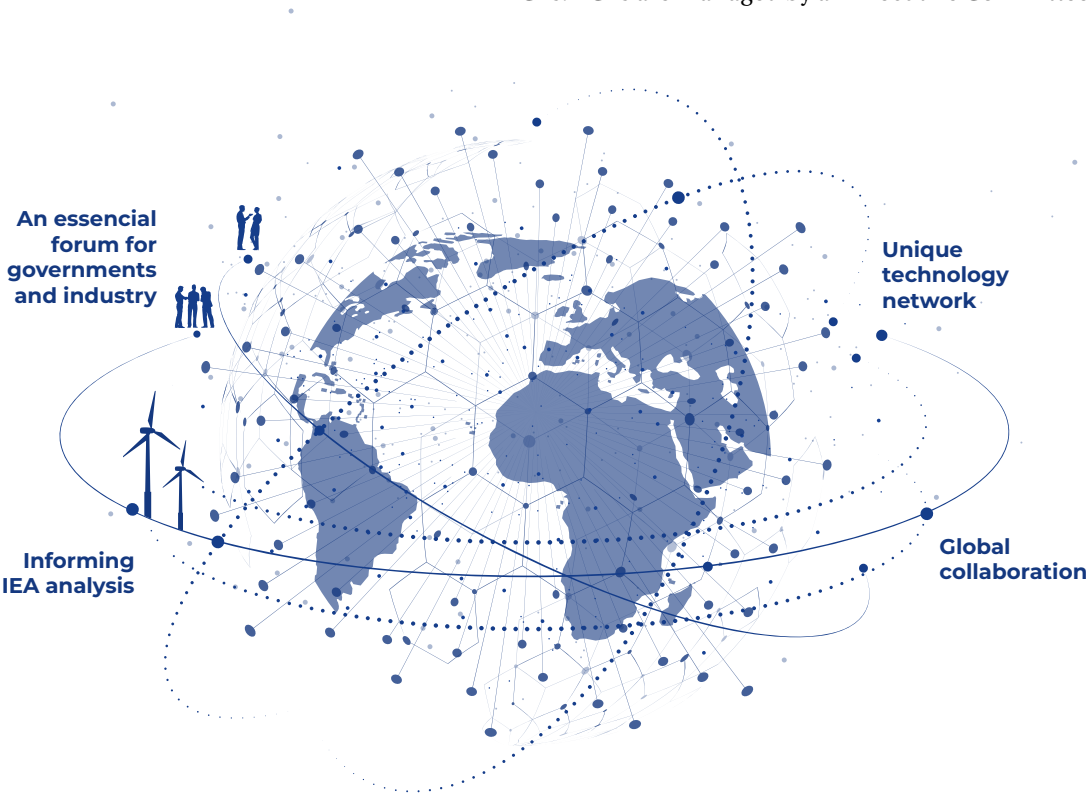
IEA-OES is a Technology Collaboration Programme (TCP) on Ocean Energy Systems within a framework created by the International Energy Agency (IEA).

The TCP mechanism is a flexible and effective means created by the IEA to research breakthrough technologies, to fill existing research gaps, to carry out deployment or demonstration programmes – in short to encourage technology-related activities in line with the IEA shared goals of energy security, environmental protection and economic growth, as well as engagement worldwide. Today, there are about 40 TCPs working in the areas of:

- Cross-Cutting Activities (information exchange, modelling, technology transfer)
- End-Use (buildings, electricity, industry, transport)
- Fossil Fuels (greenhouse-gas mitigation, supply, transformation)
- Fusion Power (international experiments)
- Renewable Energies and Hydrogen (technologies and deployment)

Each of these areas are overseen by specialised Working Parties that report to the Committee on Energy Research and Technology (CERT), the main IEA body promoting the development, demonstration and deployment of technologies to meet challenges in the energy sector. The IEA-OES report to the Renewable Energy Working Party (REWP).

Work is funded by participants, and there is a close cooperation with the IEA-secretariat in Paris, which also provides a legal framework. The IEA offers clear rules for engagement and equitable sharing of rights and obligations, but also flexibility to adjust to evolving needs and interests of the Participants in TCPs. TCPs are managed by an Executive Committee (ExCo).



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 2022, 21 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-two active members are: Australia, Belgium, Canada, China, Denmark, European Commission, France, Germany, Japan, Korea, India, Ireland, Italy, Monaco, New Zealand, Netherlands, Portugal, Singapore, Spain, Sweden, United Kingdom, and United States of America. In 2022, SIDS DOCK, representing 32 small islands and low-lying developing states across the globe, was invited as Observer.

The 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 showcases the key achievements and recent outcomes of the IEA-OES collaborative efforts on a global scale, as well as updates on ocean energy policy, research, and deployment advancements in all participating countries.

Key achievements in 2022

The IEA-OES work programme is led by an Executive Committee consisting of representatives from each participating country and organization. As of the end of 2021, there were fifteen established Tasks within the IEA-OES programme, with ten currently active.

Throughout 2022, the following publications were released:

MARCH
Marine Renewable Energy: An Introduction to Environmental Effects

APRIL
Offshore Aquaculture: a Market for Ocean Renewable Energy

JULY
Using Sea Water for Heating, Cooling and Power Production

OCTOBER
Supporting Ocean Energy Technology Development and Commercialisation

NOVEMBER
Evaluation and Guidance Framework for Ocean Energy Technology: An Introduction to funders (in English, Spanish and Chinese)

Progress with strategic tasks has continued:

The **OES-Environmental (OES-E) Task** now has sixteen participating countries and is led by the US Department of Energy (DOE) and implemented by the Pacific Northwest National Laboratory. The publicly accessible knowledge management system, *Tethys* (https://tethys.pnnl.gov), has been updated and expanded to include papers, reports, and other information related to the environmental impact of marine renewable energy. Outreach and engagement with the marine renewable energy community has been ongoing through workshops, webinars, and conferences. In 2022, the initiative focused on streamlining the consenting and licensing process through the development of a risk retirement process, as well as evaluating existing information on the environmental impact of marine renewable energy in tropical, subtropical, and southern hemisphere waters and other underrepresented regions of OES member countries.

Two OES tasks are dedicated to the **modeling, verification, and validation of ocean energy technologies.** One, focused on wave energy, is led by Ramboll in Denmark, and the other, focused on tidal energy, is led by the Energy Research Institute at Nanyang Technological University in Singapore. Both teams have been working with experts from universities, research institutions, and companies and comparing results from different numerical codes.

A group of member countries – Japan, India, China, Korea, Singapore, France and the USA – have collaborated on exploring the potential of **Ocean Thermal Energy Conversion (OTEC)** globally and evaluating the current state and plans for its implementation. A White Paper on OTEC was published in 2021 with recommendations for the widespread adoption of OTEC and in 2022 a new study to analyse the economics of OTEC was commissioned. The outcomes of this study will be published in 2023.

OES has been developing efforts on the topic of **international performance evaluation of ocean energy technologies** with significant contributions from the European Commission, the U.S. Department of Energy and from Wave Energy Scotland. The aim of this Task is to support the definition of a fully defined set of metrics and success criteria for ocean energy technologies and develop an internationally accepted approach. In 2021,

the OES published a report titled *"An International Evaluation and Guidance Framework for Ocean Energy Technology"* which highlights the benefits of a common evaluation system for the ocean energy sector and promotes consensus building. In 2022, the OES decided to strengthen the framework's user acceptance, starting with public funding entities. The joint publication with the International Electrotechnical Commission (IEC), *"Supporting Ocean Energy Technology Development and Commercialisation"* lays out a consensus path for the successful development of ocean energy. Later in the year, a 3-page document was created for funding entities to assist in designing efficient public funding programs using a stage-gate process and was translated into Spanish and Chinese.

In 2022, the IEA-OES launched a Task to review its **vision for the international deployment of ocean energy**. The study, designed to serve as a roadmap for the future growth and deployment of the ocean energy industry with a particular emphasis on tidal stream and wave energy, is planned to be published in 2023.

OES has been collaborating on providing an understanding of the opportunities for ocean energy in **alternative markets**: ocean energy can contribute to decarbonise island energy generation and enhancing resilience, while reducing release of pollutants. Further, offshore industries (e.g. aquaculture, marine macroalgae), water supply (desalination), science (e.g. oceanographic research), and security activities offer a growing potential of direct use. In 2022 a study was published providing an understanding of the potential of ocean energy to co-locate with aquaculture and to supply energy for this secto. The report *"Offshore Aquaculture: a Market for Ocean Renewable Energy"* gives an overview of the current and planned status worldwide of both sectors and then focus on opportunities for potential pilot projects, also provide recommendations for a way forward.

The IEA-OES has been collaborating with the **International WaTERS network** to establish a database for open-sea testing led by the European Marine Energy Centre (EMEC) that will provide information about open-sea testing facilities worldwide. It is anticipated that the database will be launched in early 2023.

IEA-OES also strives to collaborate with other organisations and networks. In 2022 a collaboration was initiated with the **Wind TCP** on the design of parameters for surface to bottom components of offshore energy converters. It is recognized that the development of the ocean energy sector will be linked with developments in other sectors, such as offshore wind energy, exploiting positive synergies in technology developments (e.g., components) as well as with infrastructure, supply chain and policies.

In 2022, the Basque Energy Cluster (BEC) together with IEA-OES, in collaboration with Ocean Energy Europe (OEE) come together to combine a unique reference event, **ICOE-OEE 2022**, bringing together the global ocean energy sector in the Basque Country. During October 18-20, the Kursaal Congress Center brought together more than 600 attendees from all over the world. IEA-OES hosted a Poster Award session, a prize to students selected by an international jury, composed by members of the IEA-OES, intended to identify an early career individual expected to continue to make significant contributions to ocean energy progress.

The IEA-OES continued to seek new members globally. The organization is open to welcoming new members from around the world and invites key representatives from potential new member countries to attend its Executive Committee meetings as Observers.

Country highlights in 2022

Policy Landscape

Policymakers in several member nations have been working to promote the growth of ocean energy by adapting legislation and implementing supportive policies. This is due to the significant untapped potential of ocean energy for energy generation and security.

Governments have taken various approaches to support this development, including providing national funding programs, establishing new regulatory frameworks for permitting, setting deployment targets, creating test zones, and implementing marine spatial planning policies that include dedicated areas for marine energy.

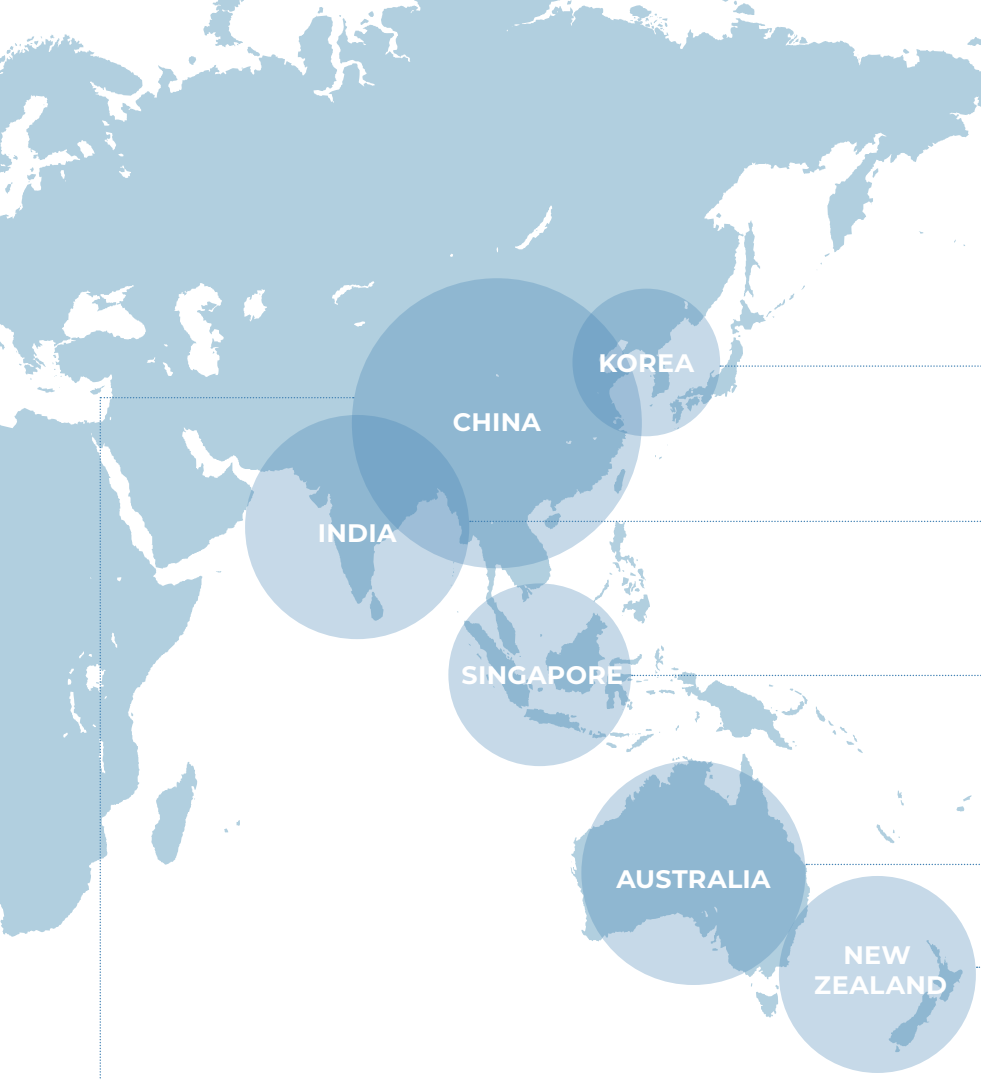
Table 1 showcases recent important initiatives in member countries with impact on ocean energy development.

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

Australia	Australian Offshore Electricity Infrastructure Bill 2021 came into force providing a consistent and transparent regulatory regime for the construction, operation and decommissioning of offshore renewable energy projects and transmission infrastructure; it covers offshore wind and solar farms, wave energy plants and undersea interconnectors.
Belgium	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.
Canada	Offshore Renewable Energy Regulations (ORER) A new legislation that enables the Canada Energy Regulator (CER) to review and authorize activities related to offshore renewable energy (ORE) in Canada's offshore areas. Investment tax credit for clean technnologies The Government of Canada's 2022 Fall Economic Statement included a refundable 30% investment tax credit for clean technologies that will cover tidal, wave, and river current technology.
China	Release of 14th Five-Year Plan for Renewable Energy Development According to the plan, China will continue to implement tidal current energy and wave energy demonstration projects and explore the application of ocean energy in multi-energy complementary power systems on islands.
Denmark	North Sea Summit 2022 In May 2022, Denmark hosted the North Sea Summit gathering the leaders of the Netherlands, Denmark, Germany, Belgium, and the European Commission, aiming to discuss how to accelerate the buildout of renewable energy in the North Sea.

European Commission	**Horizon 2020 call for demonstration of sustainable tidal energy farms** with €40M EU funding budget; a similar call was announced for wave energy arrays in 2023. **Innovation Fund** one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies; calls were launched in 2022 to help with the demonstration of first-of-a-kind highly innovative projects. **REPowerEU Plan** setting out a series of measures to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition, while increasing the resilience of the EU-wide energy system.
France	**Innovative «experimentation contract» for renewable energies** to support innovation in 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. **"Investment for the Future"** managed by the Ministry for the Ecological Transition, for the energy topics, is the major provider of market 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).
Ireland	**Offshore Renewable Energy Development Plan (OREDP)** highlights Ireland's focus on stimulating industry-led projects for ocean energy. Its updated plan, OREDP II, was drafted by the end of 2022 and it updates the offshore renewable energy potential in Ireland's maritime area. **Updated of the Climate Action Plan 2023** In 2022, Ireland launched the second update to the Climate Action Plan and introduced economy-wide carbon budgets and sectoral emissions ceilings.
India	**Deep Ocean Mission** Deep Ocean Mission launched in 2021 and implemented by the Ministry of Earth Sciences (MoES), is supporting the Blue Economy Initiatives of the Government of India.
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. This plan is beeing revised and a long-term roadmap is beeing prepared.
Monaco	**National Green Fund** dedicated to financing actions for the reduction of GHG emissions, energy efficiency and development of renewable energies.

Portugal	Technological Free Zones (ZLT) The government announced a ZLT for marine renewable energies projects located Offshore northern Portugal and published its legal framework. ZLTs 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.
Singapore	Renewable Energy Integration Demonstrator - Singapore (REIDS) a Singapore-based Research, Development, Demonstration and Deployment platform dedicated to designing 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.
Sweden	Swedish Energy Agency´s national ocean energy programme (2018 – 2024) With a total budget of €10.4m resulting up to now in a total number of 21 funded projects addressing key topics such as environmental issues, improved eliability and durability, cost reduction, testing in marine environments and improved O&M.
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; as a follow up, the Spanish government is developing a new legal framework for the licensing of renewable marine energy plants. Maritime Spatial Planning Plan the mandatory strategic environmental study of the Maritime Spatial Planning Plan was completed at the end of 2022 and it is expected to be approved in short term.
UK	Scottish Government's Draft Energy Strategy prepared during 2022, outlining the vast potential of tidal stream technology and plans to consult across government on ambitions for realising its potential. Wave Energy Scotland (WES) programme continues to drive wave energy R&D activity in the UK and to build confidence in the sector's technology. Marine Energy Wales (MEW) the industry-led stakeholder group representing the wave, tidal and floating offshore wind industries has received its longest ever funding package from the Welsh Government. 5th allocation round of the UK's flagship CfD program with both wave and tidal stream being placed in the auction pot reserved for less-established renewable energy technologies, increasing their chances of placing a successful bid.
USA	Inflation Reduction Act of 2022 expected to have a significant impact on the development and financing of clean energy projects in the US over the next decade. Water Power Technologies Office's Marine Energy Program to fund research and development to improve the reliability and affordability of marine energy technologies; it takes a strategic approach to tackle the challenges faced by U.S. marine energy stakeholders.



Significant project milestones

The ocean energy sector saw significant progress in 2022 with the completion of fabrication phases, successful testing programs, and the deployment of new devices. Many ocean-based projects generated clean electricity and demonstrated increased reliability and availability. The industry is shifting from small-scale demonstrations and pilot projects to higher technology readiness levels.

Currently, there are almost 60 active teams - developers and research groups - in OES member countries demonstrating their projects in the open sea. The following is a brief overview of notable highlights from projects with significant activities in 2022.

CHINA

- The **LHD tidal current energy project** has exceeded 60 months of operation until December 2022 and their new turbine was installed and connected to the grid.
- The **Zhoushan Tidal Current Energy** Demonstration Project has also been upgraded and will start working in 2023.
- A first **tidal-PV power station** was built in the Jiangxia Tidal Power Station reservoir and it was connected to the grid in 2022.
- A group of companies, including GIEC, China Southern Power Grid, and China Merchants Heavy Industry Company, have been making progress on their **Wanshan 1 MW** wave energy project. They have built two units of 500 kW and tested them near Wanshan, Guangdong Province.
- The **Penghu wave energy platform** for offshore aquaculture, developed by GIEC, has completed 28 months of successful operation and GIEC is planning to build more offhsore aquaculture platforms.

KOREA

- KIOST is developing a **TEC-ESS hybrid system** for remote off-grid islands that utilizes dual vertical axis Darrius turbines, which were tested near the Uldolmok Tidal Power Pilot Plant. Further tests in open sea conditions are planned for early 2023.
- KRISO is researching wave energy converters for use on breakwaters in remote islands and has installed one **OWC plant in a micro-grid system** at Mook-ri Port on Chuja Island.
- The KRISO-Wave Energy Test Site (WETS) in Jeju Island has been in operation since 2019 and is used to test several small wave energy projects, with the **Yongsoo OWC pilot plant** being one of the 5 test berths.
- The **Uldolmok Tidal Power Pilot Plant**, which consists of a vertical axis Darrius turbine, continues to operate and generated 8.88 MWh of electricity from September 2021 to May 2022.

INDIA

- NIOT is evaluating and enhancing the performance of various components of the OTEC and LTTD cycle, including turbines.
- IIT-Madras carried out preliminary testing in the sea of a small-scale point absorber-based wave energy device called "Sindhuja".

SINGAPORE

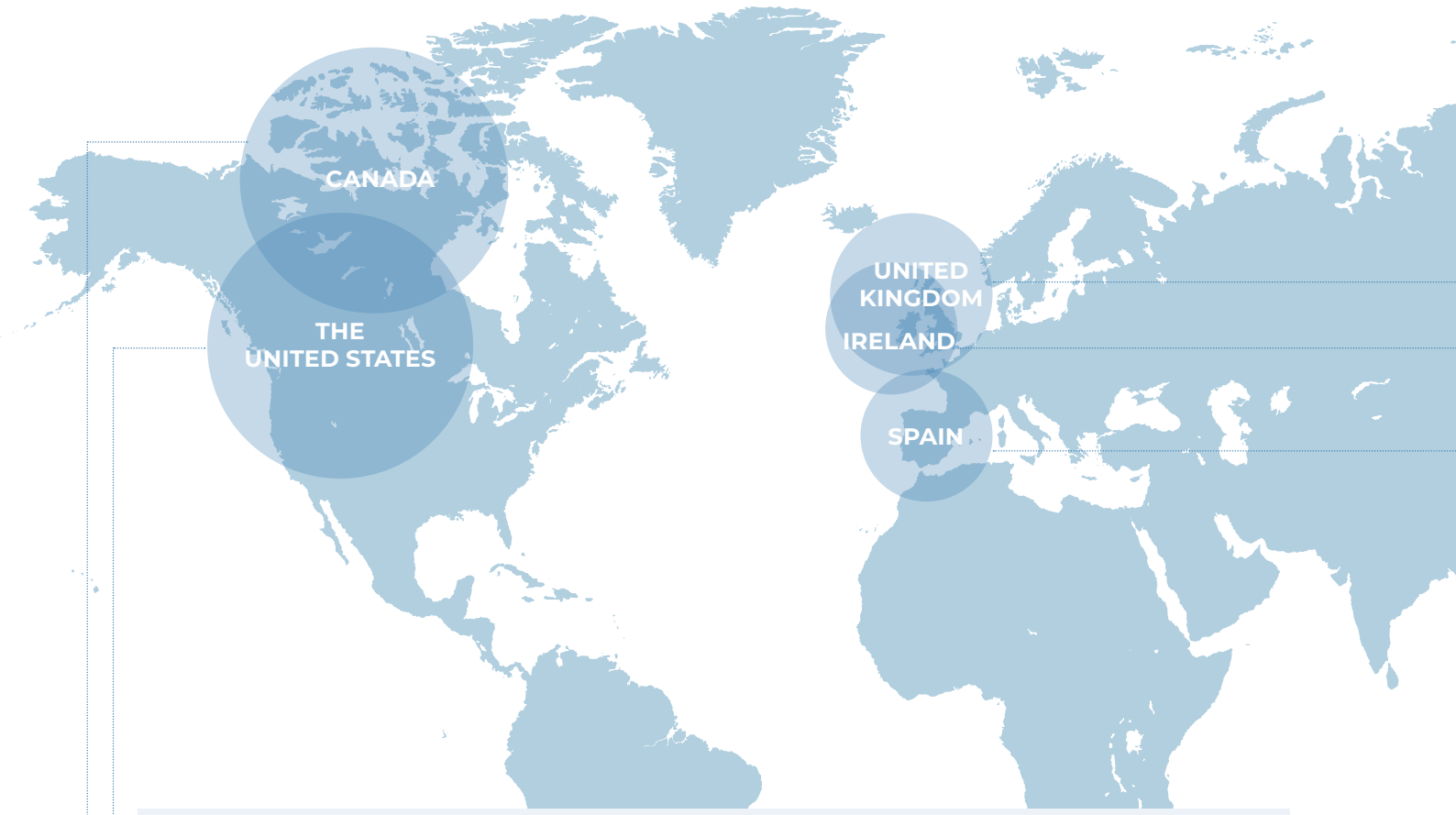
- **REIDS** and its partners are testing and demonstrating the integration of solar, wind, tidal, diesel, storage as well as waste-to-energy and power-to-gas technologies & end-use technologies and solutions suitable for deployment in Southeast Asia.
- Preliminary engineering design and feasibility studies have been conducted for larger scale floating solar PV systems.
- **Jurong Island** is now planned to serve as a “Living” test-bed for floating renewables.

AUSTRALIA

- **Wave Swell Energy** has successfully completed its wave energy demonstration project in King Island, Tasmania, where it operated and delivered electricity into the local Hydro Tasmania hybrid electrical grid for over a year until it was decommissioned successfully.
- **Altum Energy**, formerly MAKO Tidal Turbines Pty Ltd., received financial support from a UK investor to proceed with their modular tidal turbines for slow-flowing tidal and river sites. A demonstration of their turbine is currently underway at a port in northwestern Australia.
- Australian companies such as **Carnegie Clean Energy, Marine Energy Research Australia (MERA) and AZURA-EHL Australia** have plans for wave energy deployments.
- Other innovative initiatives also underway include the **Smart Barge team** developing a floating, autonomous, tidal energy electricity harvesting, storage and delivery system; and **Cockatoo Island tidal** in Kimberley, WA that aims to develop a multi-user, deep-water supply base and logistics hub on Cockatoo Island.

NEW ZEALAND

- The **Azura technology**, initially developed by the NZ government, was licensed to Taranaki Engineering company EHL in 2013 and has since been tested in Hawaii with funding from the US DOE.
- Other devices in a preliminary phase include the **Aotea Buoy** developed by University of Auckland, **Aquantis** and **Ruka Marine Turbine**.



THE UNITED STATES

- **Ocean Renewable Power Company** is set to deploy its improved RivGen Power System in 2023.
- **CalWave** concluded its open-ocean wave energy pilot after 10 months of operation off the San Diego's coast.
- **Ocean Motion Technologies** deployed a wave energy prototype that generate power from waves created by boat wakes.
- **Verdant Power** completed its project with valuable insights on installation, operation, and maintenance. Its tidal energy TriFrame system had a 99% availability rate and produced 210 MWh over 6 months of operation.
- **Oscilla Power** and **C-Power** have completed fabrication and onshore testing and are now ready for installation at WETS, Hawaii.
- **Ocean Energy**'s OE35 buoy has completed hull repairs and is waiting for favorable weather conditions to install at WETS.

CANADA

- **Sustainable Marine** has delivered the first floating in-stream tidal power to Nova Scotia's grid, the 420 kW PLAT-I 6.40 platform.
- **ORPC Canada** successfully launched its first RivGen Power System, at the Canadian Hydrokinetic Turbine Test Center in Manitoba.
- **DP Energy** is progressing with the planning of phase 1 of the 9 MW Uisce Tapa project, which will deploy 6 Andritz Hammerfest Hydro (AHH) MK1s with the first turbine scheduled to be installed and commissioned in mid-2024.
- **Big Moon Power** is involved in the assembly of its first device for deployment.
- **Jupiter Hydro** continues planning for its project in the Bay of Fundy.
- **NewEast Energy** is working towards the deployment of its 800 kW project in the Bay of Fundy.
- **Nova Innovation** is continuing the development of its 1.5 MW tidal energy project in Petit Passage, Nova Scotia with fabrication complete and the first phase (500 kW) targeted for deployment in spring 2023.

EUROPE

UNITED KINGDOM

- **Orbital Marine Power** with their flagship device, the O2, in continuous operation at EMEC since 2021, reported a peak power of 2.5 MW.
- **Nova Innovation** built three 100 kW direct drive turbines, one for deployment in Bluemull Sound, Shetland, and one to Petit Passage, Canada. The company was award an Option Agreement by Crown Estate Scotland to develop a 15 MW tidal array at Yell Sound, Shetland – their largest array to date.
- **MeyGen** Phase 1, in operation since 2018, installed four 1.5 MW turbines and has delivered over 45 GWh to the local Shetland distribution network as of October 2022. This phase incorporated two different turbine technologies, Simec Atlantis Energy's AR1500 and Andritz Hydro Hammerfest AH1000 MK1.
- Swedish marine energy developer **Minesto** deployed their 100 kW Dragon 4 tidal energy converter in Vestmannasund, Faroe Islands and recorded new energy production records.
- **Mocean Energy** successfully tested its first prototype device, 'Blue X', at EMEC in Orkney for 5-months and recently collaborated with energy storage company Verlume to showcase an operational renewable remote power system.
- The Australian **Bombora Wave Power** progressed with the final testing and assembly of the 1.5 MW mWave™ Pembrokeshire Demonstration Project in Wales.
- **AWS Ocean Energy** tested its 16 kW Archimedes Waveswing wave energy prototype at EMEC's test site in Scapa Flow, Orkney, UK.

IRELAND

- New Wave Technology trading as **Ocean Energy** is waiting access to the US Navy's WETS test site in Hawaii after beeing transported from Oregon in November 2019.

SPAIN

- The **HarshLab** testing laboratory was commissioned in Bimep area in June 2022. This new version of HarshLab enables the testing of new materials and innovations for the offshore industry, in a real environment and under controlled conditions.
- **Mutriku Wave Power Plant** has been incorporated into the BiMEP infrastructure. The plant was connected to the grid in July 2011, and has continued its successful operation in 2022, adding another year of continuous operation. The total energy generated since the start of the plant is close to 2.8 GWh.

PORTUGAL

- **Corpower**'s HiWave-5 wave energy array demonstration project off the coast of Aguçadoura in northern Portugal has installed a new submarine power export cable and their innovative UMACK® anchor. The first full-scale unit 'C4' is prepared for deployment in early 2023.

FRANCE

- A ¼ scale prototype of the **DIKWE** wave energy converter, designed to be integrated into port infrastructure, was installed off the Sainte Anne du Portzic local dyke. Tests were conducted in partnership with GEPS Techno, Ifremer, and GROUPE LEGENDRE.
- **Sabella**'s D10-1MW tidal turbine was deployed again in the Fromveur passage and the company connected a small electrolyser to the D10 to experiment with green hydrogen production.
- After **Hydroquest** successfully tested its 1 MW vertical axis tidal turbine for a year at the Paimpol-Bréhat test site in 2021, and the company now aims to deploy a 7 x 2.5 MW pilot farm in the Raz Blanchard/Alderney Race by 2025.
- **Sweetch** and Compagnie du Rhône are developing a salinity gradient system demonstrator in Port-Saint-Louis-du-Rhône on the Mediterranean coast with the goal of it being operational in 2024.

MONACO

- In Monaco, 80 seawater heat pumps produce 17% of the Principality's energy consumption through the use of the sea as a renewable energy source for a **heat pump system**. Two new thalossothermal loops connected to the heat pumps are under construction.

ITALY

- The **REWEC3** wave energy device in the port of Civitavecchia (Rome) and OBREC in the port of Naples, continue to operate and be monitored after a few years of operation as examples of wave energy converters integrated into breakwaters.
- Two prototypes of the **ISWEC**, which use the gyroscope technology developed by Polytechnic of Turin, have been tested and progress is being made towards a new 250 kW.
- **Ocean Power Technologies**'s PowerBuoy deployed in the Adriatic Sea since November 2018 by the Italian Oil&Gas company Eni has generated over 1 MWh of energy since November 2018.
- The Ocean's Kite – **GEM** - designed by ADAG and SeaPower continues to advance towards the installation of a 300 kW unit in the Strait of Messina.

DENMARK

- In October 2022, **EXOWAVE** successfully demonstrated its wave energy prototype in Oostende, Belgium, and is now working on deploying the project offshore at DanWEC in 2024.
- **Wavepiston** is in the process of installing its full-scale system at the PLOCAN test site in Gran Canaria, which is expected to be operational in 2023.
- **Floating Power Plant FPP** combines wave and wind energy on a common floating platform and is exploring Power-to-X through the integration of hydrogen. It is moving forward with its plan to deploy a combined system at PLOCAN in 2025.
- **Resen Waves Waves** is part of the www.ProjectGreensand.com and provides small scale 300 W Smart Power Buoys for autonomous power.
- In 2022, **Crestwing** advanced their development of a hinged raft, following results from half-scale testing in Kattegat. The company also received funding from EUDP for further development.

BELGIUM

- The **Blue Accelerator** open sea test site located about 500 m off the port of Ostend is aiming at offering a grid connection by 2023 for offshore renewable energy projects. It offers a broad range of services, e.g. marine sensors, fast and communications and transfer data system, energy supply in a secure and safe environment.

NETHERLANDS

- **Tocardo**'s Oosterschelde Tidal Power Plant (OTP) consisting of five 250 kW tidal turbines, continued to operate successfully throughout 2022.
- **Slow Mill** deployed their 1:25 scale wave energy device in the North Sea and is planning to demonstrate a 40 kW device off the coast of Texel .
- **SeaQurrent** is moving towards a demonstration of its fourth TidalKite system at Ameland.
- **REDstack** is producing Blue Energy by harnessing the difference in salinity between river and sea water at Afsluitdijk.

SWEDEN

- **Minesto** completed the commissioning of the Dragon 4 (100 kW) tidal power plants in Vestmannasund, Faroe Islands.
- **Corpower** has installed the first commercial-scale UMACK anchor and the C4 wave energy converter (WEC) in Aguçadoura, Portugal, to support the HiWave-5 demonstration project. The C4 power take-off system has gone through a year-long on-land testing program in Stockholm and is scheduled for deployment in early 2023.
- **Novige** has continued developing and testing its NoviOcean2 (NO2) wave energy converter, both onshore in a test rig and offshore, in the Stockholm archipelago.
- **Ocean Harvesting Technologies** has completed a test rig project for the InfinityWEC Power Take-Off system with a 1:10 scale control system and is now preparing for sea trials at a 1:3 scale.

GERMANY

- In June 2022, **SCHOTTEL HYDRO** and its partner Sustainable Marine officially began their tidal energy operation in Canada and are now supplying electricity to Nova Scotia's power grid.
- **SKF**, a German bearing and seal specialist, is participating in the TiPA project which intends to demonstrate the development, operation, and decommissioning of a tidal power array of six turbines.

Summary of installed capacity

Ocean energy projects in the OES Member Countries in 2022

AUSTRALIA

PROJECT	TECHNOLOGY DEVELOPER	PLACE	PROJECT STATUS	KW
WAVE ENERGY				
King Island Demonstration Project	Wave Swell Energy	King Island, Tasmania	Decommissioning	200

CANADA

PROJECT	TECHNOLOGY DEVELOPER	PLACE	PROJECT STATUS	KW
TIDAL CURRENTS				
Sustainable Marine	Sustainable Marine	Grand Passage, Nova Scotia	Operational	280
Sustainable Marine	Sustainable Marine	FORCE site, Nova Scotia	Under development	9000 (420* de-ployed)
Uisce Tapa Project	Andrtiz Hammerfest Hydro	FORCE site, Nova Scotia	Under development	9000
Big Moon Power	Big Moon Power	FORCE site, Nova Scotia	Under development	4000
Big Moon Power	Big Moon Power	Minas Passage, Nova Scotia	Under development	5000
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
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
ORPC Canada	ORPC Canada	CHTTC site, Manitoba	Operational	80

* 420 kW temporarily installed in Grand Passage and planed to be installed at Force permanently.

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	Operational	1
Exowave wave energy converter	Exowave	North Sea, Denmark	Under development	100
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	Decommissioned	1000
Sabella D10	Sabella	Ushant island, Brittany	Operational	1000
Sabella D08	Sabella	Gulf of Morbihan	Consent authorised	500
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
DIKWE	Gepstechno/ Groupe LEGENDRE	Brittany	Under development	800
SALINITY GRADIENT				
SARBACANNE	Sweetch Energy	Port-Saint-Lois-de-Rhone	Under development	-

INDIA

PROJECT	TECHNOLOGY DEVELOPER	PLACE	PROJECT STATUS	KW
TIDAL CURRENTS				
NIOT Off-grid hydrokinetic turbine	NIOT	Andaman & Nicobar	Under development	1-5
WAVE ENERGY				
Wave powered Navigational Buoy	NIOT	Chennai, Tamil Nadu	Operational	1
OTEC				
OTEC powered Desalination plant	NIOT	Kavaratti, Lakshadweep Islands	Under development	65

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	RSE	Civitavecchia, Tyrrhenian Sea	Operational	15
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

NETHERLANDS

PROJECT	TECHNOLOGY DEVELOPER	PLACE	PROJECT STATUS	KW
TIDAL CURRENTS				
Oosterschelde Tidal Power Plant (OTP)	Tocardo	Oosterschelde	Operational	1250
Slow Mill	Slow Mill	Texel	Operational	40
TidalKite	SeaQurrent	Ameland	Under development	150
SALINITY GRADIENT				
REDstack	REDstack	Afsluitdijk	Operational	4-50

NEW ZEALAND

PROJECT	TECHNOLOGY DEVELOPER	PLACE	PROJECT STATUS	KW
WAVE ENERGY				
Azura	Azura Wave Power	New Zealand and Hawwai	Under development	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 Power Pilot Plant	KIOST	Jindo, Korea	Operational	80
TEC-ESS hybrid system	KIOST	Jindo, Korea	Under development	100
WAVE ENERGY				
Youngsoo OWC Pilot Plant	KRISO	Jeju, Korea	Operational	500
OWC WEC with Breakwater	KRISO	Jeju, Korea	Operational	30
OTEC & SWAC				
OTEC Pilot Plant	KRISO	Goseong, Korea	Operational	20
SWAC Pilot System	KRISO	Goseong, Korea	Operational	60 RT
SWAC Semi-commercial model	KRISO	Haenam & Wolseong, Korea	Operational	500RT & 100RT

SPAIN

PROJECT	TECHNOLOGY DEVELOPER	PLACE	PROJECT STATUS	KW
WAVE ENERGY				
Mutriku Wave Power Plant	EVE	Mutriku, Gipuzkoa	Operational	296
WavePiston	WavePiston	PLOCAN	Operational	200
Floating Power Plant A/S	Floating Power Plant A/S	Gran Canaria	Under development	1000

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
Forward 2030	Orbital Marine Power	Orkney Islands, Scotland	Operational	2000
ATIR	Magallanes Renovables	Orkney Islands, Scotland	Operational	1500
Meygen Phase 2 (CfD)	SIMEC-Atlantis Energy	Pentland Firth, Scotland	Under Development	28000
CfD project	Orbital Marine Power	EMEC Fall of Warness, Orkney Islands	Under Development	2400
CfD project	Orbital Marine Power	EMEC Fall of Warness, Orkney Islands	Under Development	4800
CfD project	Magallanes Renovables	Morlais, Wales	Under Development	5600
WAVE ENERGY				
Blue X	Mocean Energy	Orkney Islands, Scotland	Operational	10
Archimedes Waveswing	AWS Ocean Energy	Orkney Islands, Scotland	Operational	16
mWave™	Bombora Wavepower	Pembrokeshire, Wales	Under development	1500

USA

PROJECT	TECHNOLOGY DEVELOPER	PLACE	PROJECT STATUS	KW
TIDAL CURRENTS				
ORPC Cook Inlet	Ocean Renewable Power Company (ORPC)	Cook Inlet, Alaska	Under development	5000
ORPC Cobscook Bay	Ocean Renewable Power Company (ORPC)	Cobscook Bay, Eastport, Maine	Under development	80
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	75
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	2
TigerRay	C-Power	Puget Sound, WA	Under development	1
Triton-C	Oscilla Power	Wave Energy Test Site, Hawai	Under development	100
AquaHarmonics	AquaHarmonics	Wave Energy Test Site, Hawai	Under development	-

Open sea test sites

Open sea testing facilities have become a crucial part of ocean energy development in various countries and are considered vital innovation centers for the ocean energy industry. These facilities offer hands-on experience with the installation, operation, maintenance, and decommissioning of prototypes and farms, as well as providing support for standardizing procedures.

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

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

There are numerous open sea test sites worldwide, each offering unique services to developers. Despite their differences, many face similar challenges. To address these challenges, the IEA-OES joined forces with the International WATERS network to create a centralized online database that provides information about the infrastructure, equipment, services, and testing programs available at each test center. This database is under development.

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

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)	Jindo (under development)

SINGAPORE

TEST SITE NAME	LOCATION
Sentosa Tidal Test Site	Sentosa island

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

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.

Most ocean energy technologies are being developed to produce electricity, although some of them are being developed to deliver other or multiple products, derived from the physical and chemical properties of seawater (e.g. fresh water and sea water air conditioning).

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 2022, 22 Member Countries[1] and the European Commission are 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.

1 Mexico asked to be Observer temporarally during 2022

CONTRACTING PARTIES

YEAR OF SIGNATURE	COUNTRY	CONTRACTING PARTY
2001	Portugal	Laboratório Nacional de Energia e Geologia (LNEG)
	Denmark	Ministry of Transport and Energy, Danish Energy Authority
	United Kingdom	Department of Energy and Climate Change (DECC)
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	TECNALIA
	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	Blue Economy Cooperative Research Centre (Blue Economy CRC)

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 the 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 2022, three ExCo meetings were held, two of them online and one presential:

- The 44th ExCo meeting was held as a Virtual meeting in two separate sessions on 10-11 March 2022 with 18-19 participants in each session.
- The 45th ExCo meeting was held as a Virtual Meeting in two separate sessions on 29-30 June 2022 and there were 17-14 participants in each session.
- The 46th ExCo meeting was held on the 17th October 2022, in San Sebastián, in the Basque Country, Spain, at the *Centro Kursaal*, hosted by BiMEP - Biscay Marine Energy Platform, with 17 participants. In the same week, ICOE-OEE 2022 conference (18 – 20 October) took place in San Sebastián.

Dr. Yann-Hervé De Roeck of France Energies Marines chaired the three ExCo meetings, with Dr Purnima Jalihal of NIOT and Dr Matthijs Soede of the European Commission in the roles of Vice-chairs.

At ExCo46, a new cabinet was approved for 2023:

- **Chair:** Matthijs Soede, European Commission
- **Vice-Chair:** Purnima Jalihal, India
- **Vice-Chair:** Christophe Gaudin, Australia
- **Vice-Chair:** Tim Ramsey, USA

47th ExCo Meeting, 17th October 2022, San Sebastián, Basque Country, Spain

Work Programme

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.

At present, the following projects have been initiated by the IEA-OES Executive Committee:

WORK PROGRAMME

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
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	Active
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	Concluded
15	Alternative Markets on Ocean Energy	The Cabinet	Active

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.

Participation in IEA Meetings

The **IEA Governing Board** holds the governance of the International Energy Agency (IEA). It is supported by several Standing Committees that are made up of member country government officials.

The **Committee on Energy Research and Technology (CERT)** coordinates and promotes the development, demonstration and deployment of technologies to meet challenges within the energy sector. The CERT has established four working parties:

- the Working Party on Fossil Energy;
- the Working Party on Renewable Energy Technologies;
- the Working Party on Energy End-Use Technologies;
- the Fusion Power Co-ordinating Committee.

The IEA-OES is part of the Working Party on Renewable Energy Technologies (REWP). In 2022, IEA-OES participated in two IEA REWP meetings:

- 81st REWP virtual meeting, 5-6 April 2022
- 82nd REWP virtual meeting, 17-18 October 2022

On the second meeting, the OES Vice-Chair, Matthijs Soede, presented the OES Mid-term report, introducing the major milestones achieved by the ocean energy sector and the main opportunities and challenges on the Technology & Policy issues. The update was focused on those tasks with relevant achievements over the year.

2.
Communication and Dissemination

Overview in 2022

January

Webinars
Evaluation and Guidance Framework – Funders' Summit

February

International events
Oceans 2022 Chennai conference (India)

March

Reports
Marine Renewable Energy: An Introduction to Environmental Effects

Webinars
OTEC - Some Developments and Way Forward

Meetings
44 ExCo

April

Reports
Offshore Aquaculture: a Market for Ocean Renewable Energy

Webinars
Offshore Aquaculture as a Market for Ocean Renewable Energy

Meetings
85 REWP

May

New Study
Launch of the Terms of Reference for the study "Economics of OTEC"

June

Webinars
Ocean Energy Outlook in India, the Republic of Korea and Singapore

International events
Seanergy (France)
SIDS DOCK side event of UN Ocean Conf. (Portugal)

Meetings
45 ExCo

July

Reports
Using Sea Water for Heating, Cooling and Power Production

August

International event
2nd International Congress on Marine Energy CEMIE-O (Mexico)

September

International Events
Approval of the host for ICOE 2024: Blue Economy CRC, Melbourne, Australia

October

Reports
Supporting Ocean Energy Technology Development and Commercialisation

International events
ICOE 2022
Sea Tech Week (France)

Meetings
46 ExCo, Spain
(New Chairman elected)

86 REWP

November

Reports
Evaluation and Guidance Framework for Ocean Energy Technology (English, Spanish and Chinese versions)

International events
China Marine New Energy Industry Development Forum

December

International events
Grand RE2022 (Japan)

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): 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** dedicated to wave and tidal current energy projects highlighting relevant recent developments in the sector.
- **Interviews to stakeholders**: in 2022 the key topic for the publication with interviews was "*Using sea water for heating, cooling and power production*".
- **Technical publications**: several publications were released during the year as outcomes of the Tasks and promoting ocean energy activities and projects.
- **Webinars**: country webinars were organised with presentations from OES Delegates on policies, R&D and technology development.
- **Participation in Events**: the delegates usually collaborate with international events promoting OES.

OES Webinars

JANUARY 2022

Evaluation and Guidance Framework – Funders' Summit

Webinar with representatives and administrators of national and international ocean energy funding schemes. The aim of this closed event was to discuss the challenges experienced by public funders in ocean energy sectors.

SPEAKERS:
Jonathan Hodges, Wave Energy Scotland
Tim Hurst, Wave Energy Scotland
Tim Ramsey, U.S. Department of Energy
Matthijs Soede, European Commission
Olatz Ajuria, Basque Energy Agency

MARCH 2022

OTEC – Some Developments and Way Forward

Webinar on OES Perspectives on OTEC, OES activities in member countries and a panel discussion: What needs to be done to take OTEC forward?

SPEAKERS:
Martin Brown, Ocean Energy Systems ltd, Scotland
Yasuyuki Ikegami, Saga University, Japan
Luis Vega, OTEC Expert, USA
Vijay Kumar, Ministry of Earth Sciences, Government of India
James Van Zwieten, Florida Atlantic University, USA
Hyeonju Kim, KRISO, South Korea

APRIL 2022

Offshore Aquaculture as a Market for Ocean Renewable Energy

Overview of the findings in the Study of Offshore Aquaculture as a Market for Ocean Renewable Energy, highlighting case studies of research and projects conducted on co-location of these industries and lessons learned.

SPEAKERS:
Mikaela Freeman and Lysel Garavelli , Pacific Northwest National Laboratory
Eloise Wilson, Blue Economy CRC
Mark Hemer, CSIRO
Michael Abundo, OceanPixel Pte. Ltd

JUNE 2022

Ocean Energy Outlook in India, the Republic of Korea and Singapore

Ocean energy projects and key policies on 3 IEA-OES Member Countries.

SPEAKERS:
Yann-Hervé De Roeck, France Energies Marines, OES Chairman
Purnima Jalihal, India, OES Delegate
Jin-Hak Yi, Republic of Korea, OES Alternate
Srikanth Narasimalu, Singapore, OES Delegate

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/

Interviews to Stakeholders

TOPIC:

Using sea water for heating, cooling and power production

OKINAWA OTEC DEMONSTRATION FACILITY

Benjamin Martin, Project Manager, Xenesys Inc.

MAKAI OCEAN ENGINEERING'S OTEC PLANT IN HAWAII

Hermann Kugeler, Vice President of Business Development, Makai Ocean Engineering, Inc.
Hawaii, USA

1 MW OTEC POWER PLANT DEVELOPED BY KRISO

Dr. Hyeon-Ju Kim, Principal Researcher, Korea Research Institute of Ships and Ocean Engineering (KRISO), KOREA

SWAC PROJECT OF THE FRENCH POLYNESIAN HOSPITAL IN TAHITI

Cathy Tang, Project Manager, SDE- Energy Service of French Polynesia, Tahiti, French Polynesian

SEAWATER HEAT PUMP SYSTEM IN MONACO

Pierre Bardy, Directeur des Réseaux de Chaud & Froid Urbains, Societé Monégasque de L'electricité et du Gaz (SMEG), Monaco

THASSALIA POWER STATION ON FRANCE'S SOUTHERN COAST

Patrick Berardi, General Director of Thassalia, ENGIE Solutions France

International Conference on Ocean Energy

The ExCo has had an intimate link with the **International Conference on Ocean Energy (ICOE)** since its inception in 2006. ICOE conferences are held every two years and focus on the industrial development of ocean energy.

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 and presentations from previous conferences.

In 2022, the Basque Energy Cluster and Ocean Energy Europe teamed up to deliver a joint event on ocean energy, that took place on 18-20 October in Donostia/San Sebastián, in the KURSAAL Congress Centre. The unique event, ICOE-OEE 2022, gathered over 600 participants - ocean energy professionals and decision-makers - from all corners of the globe in San Sebastián / Donostia, in the Basque Country, Spain. Past ICOE conferences have been held in Germany, France, Spain, Ireland, Canada, UK and USA. OES leads a competitive process to select the host team for this conference. ICOE focus on the industrial development of ocean energy.

The next conference will be in Australia, on 18-20 September 2024, at the Melbourne Convention and Exhibition Centre, hosted by the Blue Economy CRC. The announcement was done by Dr Irene Penesis at the close session of ICOE 2022.


Living Ocean Energy - High-Level Leader's Discussion
Chair:
Rémi Gruet, Ocean Energy Europe
Speakers:
Iñigo Ansola, Basque Energy Agency
Jennifer Garson, Water Power Technologies
Matthijs Soede, DG RTD
Michael Baumann, SKF
Sue Barr, Simply Blue Group
ICOE
OCEAN ENERGY EUROPE
Donostia / San Sebastián 2022


ICOE
OCEAN ENERGY EUROPE


ICOE
OCEAN ENERGY EUROPE
LIVE OCEAN ENERGY.
THE FUTURE IS NOW!


ICOE 2024
MELBOURNE, AUSTRALIA

The OES is also the organiser and supporter of a student poster award during the ICOE conference. The Poster Award is a cash prize to students selected by an international jury, composed by members of the OES.

The winners of the ICOE Best Poster Awards in 2022 were:

1ST PRIZE

Title: How applicable are turbulence assumptions used in the tidal energy industry
Main Author: Alyona Naberezhnykh, EMEC/ Edinburgh University

2ND PRIZE

Title: Harnessing the economic potential of ocean thermal energy conversion in Indonesia with upscaling scenarios
Main author: Jannis Langer, Delft University of Technology
Collecting the Prize: Aida Astuti, DMEC


ICOE 2016
Edinburgh
ICOE 2012
Dublin
ICOE 2018
Normandie
ICOE 2014
Halifax
ICOE 2006
Bremerhaven
ICOE 2008
Brest
ICOE 2010
Bilbao
ICOE-OEE 2022
Donostia/San Sebastián
ICOE 2024
Melbourne
ICOE 2021
Virtual

Participation in other International Events

The table below lists the main events in 2022, in which the OES was represented promoting the OES activities and ocean energy:

International events in which OES was represented

EVENT	LOCAL	DATE	SPEAKER
Oceans 2022 Chennai conference	Chennai, **India**	21-24 February	Chairman (online)
Seanergy	Le Havre, **France**	16 June	Chairman
Launch of the Global Ocean Energy Alliance (GLOEA): Ocean Energy For Climate Resilient Economies	Lisbon, **Portugal**	29 June	Secretary
Sea Tech Week	Brest, **France**	26 October	Chairman
China Marine New Energy Industry Development Forum	Shenzhen city, **China**	24 November	Chairman (online)
Grand RE2022	Tokyo, **Japan**	15 December	Chairman (online)

Collaboration with International Initiatives

OES promotes international collaboration fostering and enhancing the development and sustainable use of ocean energy, with a number of organisations. **The following collaborative initiatives in 2022 are highlighted:**

iea wind

The **IEA Wind TCP** is an technology collaboration programme under the International Energy Agency to share information and research activities to advance wind energy deployment. The challenges facing uptake of ocean energy are similar to those that faced offshore wind: costs competitive with existing generation forms, grid connection, engagement of a dedicated supply chain and new challenges of working and operating in hostile marine environments. Therefore OES is striving to collaborate with the Wind TCP and during 2022 a subgroup from OES was set up to explore and work on collaborative topics between the two TCPs.

SIDS DOCK is a United Nations (UN)-recognised international organisation established in 2015, addressing climate change, resilience, and energy security in small islands. SIDS DOCK represents 32 small islands and low-lying developing states across the globe. It is so named because it is designed as a "DOCKing station," to connect the energy sector in SIDS with the global markets for finance and sustainable energy technologies. SIDS Dock, in 2022, become Observer of the OES.

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 global database, populated with information on the infrastructure, equipment, services and test programmes available at each test centre.

INORE is a network of young researchers within renewable energy whose main focus is offshore renewables. INORE was created by early stage researchers, for early stage researchers who work in all aspects related to offshore wind, wave, tidal, and other offshore energies. INORE bring together researchers from around the world to meet, collaborate, and share knowledge. In 2022, OES sponsored the following activities:

- Two Blue Energy Collaboration Scholarships
- Promotional material for the Pan American Marine Energy Conference 2022 organised by INORE
- INORE European Symposium in Spain, 11-17 October 2022

IEA-OES has a formal liaison with the **International Electrotechnical Commission (IEC) Technical Committee (TC) 114, Marine Energy – Wave and Tidal Energy Converters**. IEC-TC 114 aims 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.

WECANET, a collaborative networking platform funded by the European commission (COST Action - https://www.cost.eu/cost-actions/what-are-cost-actions/) that creates the space for dialogue between all stakeholders in wave energy. WECANET has a strong link with the OES task on wave energy numerical modelling (https://www.wecanet.eu/).

The European funded project, **SEETIP Ocean**, supports the activities of both the European Technology & Innovation Platform for ocean energy (**ETIP Ocean** - www.etipocean.eu) and the Secretariat to the SET Plan Ocean Energy Implementation Working Group (**OceanSET** - https://www.oceanset.eu/). The project brings individuals and organisations together to exchange knowledge, create new knowledge and build more and deeper connections on the oceean energy sector. It aims to enhance cooperation and collaboration amongst stakeholders both inside and outside of the European ocean energy sector. In 2022 OES initiated a collaboration with the SEETIP Ocean.

3.

Key Task Achievements

OES-Environmental

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

INTRODUCTION

The work of OES-Environmental (OES-E) continued through 2022, as part of phase 4 of the task, ending in 2024. The tasks performed by OES-E during 2022 included:

- Expanding the knowledge base for the marine renewable energy (MRE) community about environmental effects of MRE by ongoing information collection and curation of the scientific literature that is stored and made accessible through *Tethys*.
- Using *Tethys* as the platform to store and disseminate data and information collected on marine energy developments and research projects as "metadata forms".
- Continued work on the risk retirement process that included preparation and dissemination of guidance documents.
- Active dissemination of information on risk retirement and associated processes for regulators and developers to assist with consenting, including addressing the need for baseline data collection and post-installation monitoring, with a particular emphasis on collision risk for tidal turbines.
- Examination of questions surrounding the environmental effects of MRE in "new topics" such as effects of scaling up from single devices to arrays, cumulative effects of MRE, ecosystem effects of MRE, and displacement of marine animals.
- Assessing the information available on environmental effects of MRE in tropical, subtropical, and southern hemisphere waters and other underserved areas, as represented by the OES nations.
- Continuing outreach and engagement to the MRE community through workshops, webinars, conferences, and online materials with particular empha-

sis on researchers, regulators, advisors, and MRE device developers.
- Developing, compiling, and disseminating educational resources on environmental effects of MRE.

Sixteen nations are currently 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 Department of Energy continues to lead the initiative for the US, with Pacific Northwest National Laboratory (PNNL), one of the Department of Energy (DOE)'s national laboratories, serving as the Operating Agent and implementing the project.

ACHIEVEMENTS

Working with OES-Environmental Analysts

During 2022, PNNL continued to organize and lead meetings with the OES-E country analysts to coordinate cooperative work, every 3 months. The purpose of these meetings is to discuss current OES-E activities, receive input and feedback from OES-E country analysts on these activities, and provide an opportunity to learn about current MRE development in each OES country. Each country analyst is asked to present an update on MRE development and environmental research in their respective countries and regions once every two years. The analysts were also heavily involved in the new topics focus of OES-E (see New Topics About Environmental Effects section below for more details).

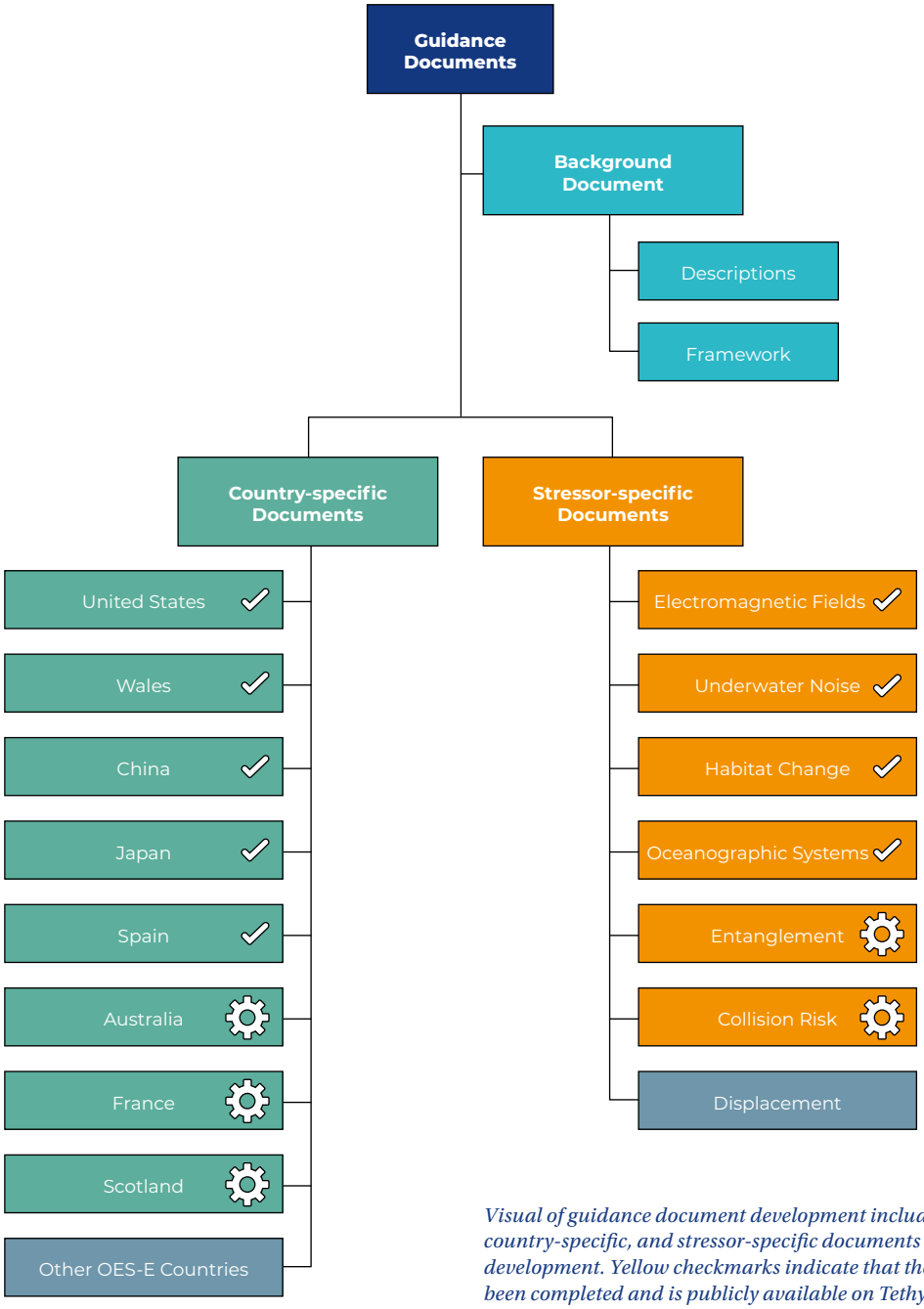
As part of their work with OES-E, each analyst continually shares updated OES-E activities and outreach information within their country, as well as providing contacts with organizations in their country to identify relevant monitoring programs, data collection, research funding, and implementation. The OES-E analysts also continue to engage their nations' regulators by reaching out to colleagues in their respective fields to initiate investigations into key areas of environmental effects that will assist the MRE industry.

Management Measures Tool for MRE

The Management Measures Tool for MRE was updated and finalized in 2022 in coordination with Aquatera Ltd. Management measures include mitigation for potential risk, planning and design of MRE devices that will minimize risk, and synergies that can be gained by deploying devices in proximity to other marine infrastructure. The functionality of the management measures tool was also updated on *Tethys*, to increase ease of access. The tool includes management measures recommended or employed in MRE projects that have been deployed since 2017, adding 339 new measures for a total of 532 measures. The PNNL and Aquatera team added more detail to the tool including addressing the advantages and challenges related to each management measure, as well as adding links to project environmental impact assessments and metadata forms that demonstrate the measures. Some of these additional details are shown within the management measures tool online, while others are available when users download the information. There is a new instructions document on the page which helps the viewer navigate the tool. This update creates a more robust tool that provides useful information on each management measure, and links to associated documents for information beyond that contained in the tool. The updates are live on *Tethys*; PNNL and Aquatera will revisit the tool and add more information every six months as needed.

Risk Retirement and Guidance Documents

During 2022, PNNL targeted risk retirement for specific stressors (entanglement and collision risk) and continued to build on the state of knowledge on displacement as a priority stressor of interest for MRE development. Evidence bases for both collision risk and entanglement were developed in 2022. Evidence bases hold key research papers, monitoring reports, and documents to inform risk retirement that have been reviewed and discussed by experts.



Visual of guidance document development including background, country-specific, and stressor-specific documents available and in development. Yellow checkmarks indicate that the document has been completed and is publicly available on Tethys, while the gear symbols indicate that it is still under development.

The OES-E Guidance documents continued to be developed in 2022, to bridge the gap between the science and the practical application that is needed for regulatory processes. These documents are intended for use by regulators and advisors as they carry out their decision-making during consenting processes and by developers as they prepare to consent and license applications for MRE. In 2022, PNNL began developing stressor-specific guidance documents for entanglement and collision risk. Stressor-specific documents bring together current knowledge on stress-receptor interactions and have been developed for electromagnetic fields (EMFs), underwater noise, habitat change, and oceanographic systems. It is understood that collision risk is not ready to be retired and requires a deeper level of investigation, this will continue to be an area of focus during 2023. Country-specific guidance documents, which aim to compile environmental regulations relevant for MRE in OES-E countries, were completed for China, Japan, and Spain in 2022 and made available on *Tethys*. Additional country-specific documents have been drafted for Australia, France, and Scotland.

A document that addresses collision risk was created which summarized the evidence to date on avoidance, evasion, and collision from reported field studies, as well as the progress made in modeling collision risk. After listing the information gaps for baseline/pre-installation assessments, post-installation monitoring, and numerical modeling, the document suggested a pathway to collect missing data. This includes future research and monitoring studies, the leverage of existing monitoring datasets, and a collision risk modeling framework. The document concluded with recommendations for advancing the knowledge of collision risk for marine mammals and fish.

Two sets of workshops were held for regulators to present the guidance documents and receive feedback. The workshops for US regulators were held on February 1st and 3rd, and the one for international regulators on December 6th 2022. Additional details are available in the Workshops section below.

New Topics about Environmental Effects

As many of the individual stressor-receptor interactions have been examined, OES-E has begun to address the larger scale questions that the industry will face in coming years. Additional questions surrounding the environmental effects of MRE ("new topics") were identified with input from the OES-E countries during 2021 and became the focus of efforts during 2022. The four new topics are:

- Environmental effects of scaling up from single devices to arrays
- Cumulative effects of MRE development with those of other anthropogenic activities
- Ecosystem effects of MRE
- Displacement as a stressor from MRE development

For the first three new topics, investigation was led by OES-E analysts from other nations, with support from the PNNL team and other OES-E analysts: Canada for "scaling up", Australia for "cumulative effects", and France for "ecosystems approach". PNNL led the fourth topic (displacement). A white paper for each new topic was drafted in 2022, each followed a roughly similar outline which included: definition and analysis of the topic area; state of knowledge of the topic in relation to MRE; significant knowledge gaps that prevent a clear understanding of the topic; recommendations for filling those knowledge gaps; and an assessment of whether the topic ought to be further pursued by OES-E and at what level of effort. The draft white papers for scaling up, cumulative effects, and ecosystem effects will be finalized in early 2023; it is expected that a journal paper will be prepared for each topic during 2023. Additionally, an invitation-only expert forum on displacement was held on December 7th, 2022, see the Workshops section below for more details. Work on displacement will continue in 2023 with an accompanying journal article.

Environmental Effects in Tropical and Subtropical Regions

Earlier efforts in OES-E have focused largely on potential environmental effects in northern hemisphere temperate waters, mainly because most of the member nations were located in these waters. With more nations engaged in OES-E from subtropical, tropical, and southern hemisphere areas, there is a need to address how potential effects might differ. The lack of pertinent information on the potential effects of MRE on tropical ecosystems led OES-E to consult the literature and reach out to those with experience in tropical ecosystem interactions. In addition to information on wave and tidal, new information was sought on the potential effects of ocean currents and ocean thermal energy conversion (OTEC), as these are more likely to come into play in the tropics. Knowledge gaps and future research were identified, and case studies on tropical and subtropical environmental effects are under development, in coordination with OES-E analysts.

Beginning in April 2022, OES-E conducted an online survey (in English and Spanish) to collect existing information relevant to the environmental effects of marine renewable energy development in tropical and subtropical countries. In June 2022, OES-E held an in-person workshop at the Pan-American Marine Energy Conference (PAMEC) to present the current knowledge on stressor-receptor interactions and to gather feedback from the attendees on the effects in tropical ecosystems (see the Workshops section below for more details). In addition, Aquatera Ltd. interviewed experts and relevant stakeholders in these regions to gather existing information and capture the views and per-

ceptions of on the potential environmental effects of MRE projects. A white paper was drafted towards the end of 2022 on the potential effects of MRE in tropical and subtropical ecosystems, summarizing the findings of the survey, interviews and workshops with experts, and examining case studies.

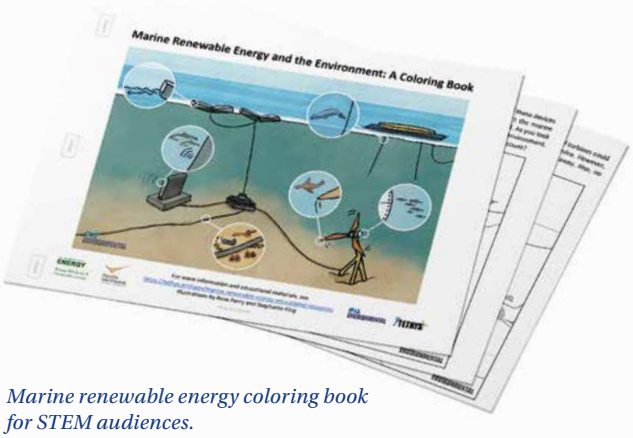
Outreach and Engagement

Outreach and engagement efforts to amplify the *OES-Environmental 2020 State of the Science Report* continued throughout 2022. Key audiences engaged included: (1) existing audiences including US and international regulators, advisors, developers, and researchers; (2) students and instructors engaged in STEM (Science, Technology, Engineering, and Mathematics); and (3) the interested public. Through webinars, workshops, and the development of new products, the rich material from the *OES-Environmental 2020 State of the Science Report* has become better known (see the Webinars and Workshops sections below). Technical material and synthesized products developed by OES-E were included in outreach efforts and were made available for download on many parts of *Tethys*. All printed OES-E material and slides at conferences and workshops now include QR codes to encourage easy download and viewing of material. OES-E outreach efforts also focused on engaging the MRE community to gain expert input on risk retirement and the guidance documents.

During 2022, a new 24-page *Marine Renewable Energy Brochure* on the environmental effects of MRE was created to familiarize readers with the latest scientific information on the potential impacts of installation and operation of MRE devices in a rapid and succinct manner. Specifically, the brochure was developed as training material for regulators and advisors who are new to MRE, following a considerable turnover in staff positions and expansion of responsibilities within regulatory agencies in multiple OES-E nations. The brochure briefly describes MRE technologies and defines stressor-receptor interactions, followed by individual sections on key environmental effects. Each section includes a description of the issue, the current status of the risk based on scientific data, recommendations for minimizing risk, and a case study from a real-world project or research study that features that risk. The brochure concludes by sharing the concepts of risk retirement and data transferability as developed by OES-E. The brochure has been sent to the OES-E's list of US regulators and advisors, as well as regulators and advisors in other OES-E nations and has been broadly disseminated. Hard copies were distributed at several conferences. The brochure will continue to be shared at future in-person and online events.

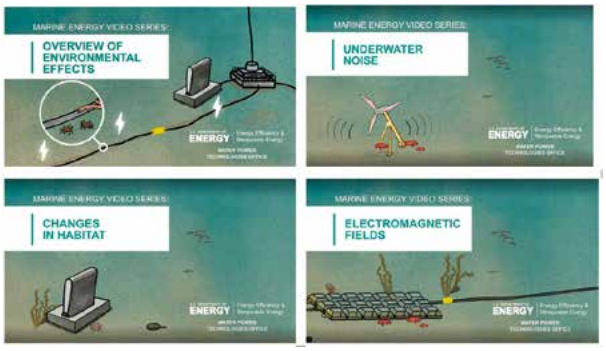
Cover and inside page of the Marine Renewable Energy Brochure which provides an introduction of the environmental effects of marine renewable energy for new regulators.

During 2022, OES-E continued to develop resources for students and instructors engaged in STEM aimed at increasing awareness and understanding of MRE and associated environmental effects, as well as to support the industry's future workforce. The Marine Renewable Energy Educational Resources page includes material that is appropriate for the whole range of student ages, from primary school through post-graduate studies. The page was updated during 2022 and includes resources and materials such as coloring pages, presentations, colored images, short science summaries, and other *Tethys* resources for download. Outreach that increases awareness of this page and its accompanying resources during 2022 targeted schools/educational programs and aquariums.



Marine renewable energy coloring book for STEM audiences.

During 2022, OES-E and PNNL Communications produced and released a MRE Video Series on the environmental effects of MRE. There are four animated videos that are each about 2-3 minutes long, focusing on underwater noise, EMFs, changes in habitats, and an overview video. The videos are hosted on the OES-E YouTube channel and can be accessed through *Tethys*. Each video links to additional information and resources that should be useful for students, the future workforce, and the general public.



Images of the initial screens for the four marine energy Video Series videos.

Efforts to reach the broader public continued in 2022, focusing on highlighting MRE and bringing information on efforts to better understand environmental effects to platforms that are accessible to the public. Throughout 2022, three podcast episodes were released through various media featuring interviews with Andrea Copping on the work of OES-E and MRE broadly. These episodes are available below:

- PNNL's SciVibe – January 2022
- Sea Change – February 2022
- In this Climate – April 2022

Dissemination of Information on Environmental Effects

Tethys acts as the platform to support OES-E activities, hosts events that highlight MRE-related activities to an international audience and provides the knowledge base that underpins our collective understanding of environmental effects. Currently, there are 3,941 documents that address environmental effects of MRE available on *Tethys* (an increase of 267 documents from 2021). A biweekly electronic newsletter, *Tethys Blast,* is sent to the broad MRE community of more than 3,300 individuals. During 2022, use of social media continued as a means to reach interested parties on a regular basis. *Tethys* accounts on all platforms (Twitter, Facebook, and Instagram) have seen consistent growth throughout 2022.

Metadata on MRE Projects and Research Studies

During 2022, PNNL staff continued to focus on collecting new metadata forms, particularly project forms, and updating outdated forms for MRE project sites and research studies. With the support of Aquatera and help from OES-E country analysts, PNNL updated metadata forms and collected additional project and research study information. Of the 185 metadata forms, 106 (54 project sites and 52 research studies) no longer require updates (projects were completed, never deployed, no longer in the water, or canceled, and the research studies were completed).

The metadata forms continue to feed the Monitoring Datasets Discoverability Matrix (matrix), OES-E's interactive tool that classifies monitoring datasets from already consented projects, analogous industries, and research studies, that can form the basis of information that can be transferred and applied to future projects. The matrix is categorized by six key environmental stressors (collision, underwater noise, EMFs, habitat change, displacement, and oceanographic systems) and five data classifications (stressor, receptor, site conditions, technology type, and project size). Results are sorted by baseline and post-installation monitoring, research studies, and key documents.

Workshops

OES-E hosted four online and two in person workshops during 2022, 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:

- Three online workshops were held for regulators and advisors to demonstrate and review the use of the guidance documents for risk retirement. Two workshops were held on February 1st and 3rd, 2022, for US regulators and advisors and had exceptional attendance, with a total of 142 experts (88 of whom were regulators) over the two days. The recording, slides, and Q&A discussion report are available here. Two other workshops were held on December 6th for international regulators and advisors with 28 international regulators and advisors from eight countries. The workshop recording and slides are available here.
- An online workshop was held during the American Geophysical Union's Ocean Sciences Meeting (OSM) on *Wave Energy in Hawaii* and was split into two 2-hour "innovative sessions", on March 1st and 2nd 2022. The goal of the workshop was to engage marine scientists to help "design" sustainable and efficient methods to extract power from waves in Hawaii. 18 people attended the workshop, a low number most likely because the event was scheduled during the main week of the conference, in parallel with 20 other concurrent scientific sessions, rather than the week prior with the other workshops. The opportunity to provide information and engage with the broader ocean science community was useful however.
- On June 18th 2022 OES-E hosted an in-person workshop at PAMEC in Ensenada, Mexico on the environmental effects of MRE. The workshop provided an overview of the potential environmental effects of MRE on marine animals, habitats, and ecosystem processes, including monitoring methods and results. Since the information collected to date has primarily focused on wave and tidal energy converters in temperate regions, OES-E organized the PAMEC workshop to expand on this understanding and discuss potential effects specific to MRE in tropical and subtropical environments. There were 20 attendees from four countries (Colombia, Mexico, Canada, USA).
- On October 19th 2022 OES-E hosted an in-person workshop in Spain at the International Conference on Ocean Energy (ICOE), in cooperation with the Offshore Renewables Joint Industry Programme (ORJIP) Ocean Energy. The workshop included presentations from OES-E and ORJIP on examples of environmental monitoring and mitigation around deployed tidal and wave projects around the world. 23 conference registrants participated in the workshop from nine countries. Presentation slides and the workshop summary can be found here.

Expert Forum

OES-E hosted an invitation-only expert forum on December 7th 2022. 17 experts from six countries gathered to reach a consensus on a proposed definition and mechanisms of displacement including species groups; spatial and temporal scales at which we need to study displacement; data needs and limitations; what information we can learn from other marine industries; project siting to minimize displacement; existing regulations; and mitigation. During the workshop, PNNL staff gave a brief presentation on risk retirement to establish the context in which we are thinking about displacement; the causes, effects, and consequences of displacement; which groups of marine animals are likely to be most susceptible; current observation methods; and knowledge gaps. A Google Jamboard was used to facilitate discussion and the workshop concluded with next steps. Participants engaged enthusiastically and continued to provide additional feedback via Jamboard through the end of December 2022. PNNL staff are revising the definition and approach to displacement based on received feedback and will prepare a journal article on the topic in 2023.

Webinars

On January 19th 2022 OES-E delivered a webinar to the US National Ocean Sciences Bowl (NOSB) participants and team coaches on the environmental effects of MRE and the role of MRE in addressing climate change. In addition to this webinar, OES-E submitted questions to NOSB that were used in the competition for high school students. The topics addressed in the questions included: stressor-receptor interactions, MRE permitting, grid-connectivity, biological and physiological effects, underwater video monitoring, and how generating energy from the ocean assists in mitigating climate change.

On September 22nd, 2022, OES-E hosted its annual public webinar *From Science to Consenting: OES-E 2022 Highlights*. The webinar provided updates on risk retirement, guidance documents, and outreach efforts, as well as detailed current focus areas for OES-E research including the new topics scaling up to arrays, ecosystem approach, and cumulative effects, tropical/subtropical environmental effects, displacement, and collision risk. There were 195 individuals registered, representing at least 20 different countries, and 64 attendees. It has become clear that many registrants prefer to download and watch the webinars at a later date, rather than attend the live webinar, partly due to the many time zones represented. All those registered received the recording of the webinar, which is available here. A post-webinar survey remained open for about a month. Survey respondents found the webinar interesting and highlighted the usefulness of the links shared during the presentation.

Conferences and Other Presentations

The OES-E team presented at several conferences and events during 2022. Each contribution from the team is detailed in Table 1.

Table 1. Events in which OES-Environmental material was presented during 2022.

DATE	EVENT	CONTRIBUTION
Feb. 27, 2022	Ocean Sciences Meeting	Presentation: International Collaboration to Advance and Share Understanding of Environmental Effects of Marine Renewable Energy
		Presentation: Taking a Broader Look at Environmental and Ecological Effects of MRE Development
March 1, 2022	Alaska Going with the Flow Conference	Presentation: Environmental Effects of Ocean and River Energy: Regulations and Environmental Risk
June 20, 2022	Pan-American Energy Conference (PAMEC)	Presentation: Guidancez on Environmental Effects to Support Decision-Making for MRE Consenting
		Presentation: Taking a Broader Look at Environmental and Ecological Effects of MRE Development
		Presentation: Feasibility and Environmental Effects of Small Scale OTEC in the United States

June 29, 2022	Small Island Developing States (SIDS)	Side event for the launch of Global Ocean Energy Alliance (GOEA): The ABCs of Ocean Energy Conversion – Technology and Potential Contributions to the Sustainable Development Goals
Aug. 22, 2022	Centro Mexicano de Innovación en Energía (CEMIE) - Océano	Keynote Presentation: Environmental Effects of Marine Renewable Energy: Going Beyond "One Animal-One Device" Interactions
Sept. 13, 2022	University Marine Energy Research Community (UMERC) + Marine Energy Technology Symposium (METS)	Poster: Facilitating Marine Renewable Energy Development through Stakeholder Engagement
		Presentation: Taking a Broader Look at Environmental and Ecological Effects of MRE Development
Oct. 4-6, 2022	Environmental Interactions of Marine Renewables (EIMR)	Four presentations on displacement, new topics, guidance documents, & environmental effects in tropical & southern hemispheres
Oct. 27-28, 2022	Department of Energy National Laboratory Day 2022	Two presentations on OES-Environmental, and stakeholder engagement
Oct. 18-20, 2022	International Conference of Ocean Energy (ICOE)	Four presentations: risk-based approach to consenting MRE devices, scaling up to arrays, ecosystem approach, cumulative effects Three posters: OES-E update, science to consenting, and biological consequences
Nov. 24, 2022	China Marine Renewable Energy Industry Forum, 2022	Presentation: Environmental Effects of MRE

Performance Metrics International Framework for Ocean Energy

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

INTRODUCTION

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 for 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 transferable technology.

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.

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

- To bring this 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.

ACHIEVEMENTS

The objectives of this Task have been achieved by delivering a series of workshops, discussions, webinars and collaborations, resulting in 3 publications over 2021 and 2022.

This Framework guides the technology development process, presenting:

- Six technology development stages: the development process split into defined stages from Concept Creation to Commercial-Scale Array Demonstration
- Stage Activities: clearly defined engineering and project activities for each stage, providing consistency in expectations between developers and investors
- Nine Evaluation Areas: the key areas in which the success of technology should be measured, in order to demonstrate progress and achieved performance
- Evaluation Criteria (or metrics): the parameters used to evaluate success in each Evaluation Area

This is a joint publication from the IEA-OES and the International Electrotechnical Commission (IEC).

The pathway from early-stage technology to commercial exploitation requires a varying mix of support and guidance, from public sector funding through various types of private investment. The goals of these supporters are wide ranging, from socio-economic growth and domestic infrastructure requirements, through to pure financial gain. Despite the differing objectives of these parties, consensus among them on the development path and the fundamental characteristics of an attractive technology enables the support provision to operate more efficiently and with a higher likelihood of success. This report discusses four such sources of guidance and is written by the providers who are collaborating to ensure they deliver a complementary and coherent set of recommendations: IEA-OES, IEC TC 114 and IECRE.

There are many standards and specifications that guide technology developers through the detailed scientific and engineering processes required in the ocean energy sector, but there was no guidance available for public funders wishing to support this technology development activity.

This publication helps funders to:

- Design effective programmes using a stage gate process
- Maximise the efficiency of public funding by enabling effective technology selection decisions
- Accelerate ocean energy development by focusing funding on the best technologies

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 The USA

OBJECTIVE

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.

ACHIEVEMENTS IN 2022

In 2022 the numerical simulation of the DTU OWC small-scale model test has been in focus. This new test case was prepared in 2021 with a single OWC chamber placed on the side wall of a 0.6-meter-wide wave flume, as shown in the figure on the right. In this way the test represents a mirrored periodic array of chambers with a distance between there centerlines of 1.2 meters.

Validation in general adapts the approach of comparing different numerical methods with experimental results. Some numerical models represent reality better than others, and some experiments are recorded more accurately than others. However, the simplicity of the tools, the speed of calculations and the accuracy of results are all important to consider.

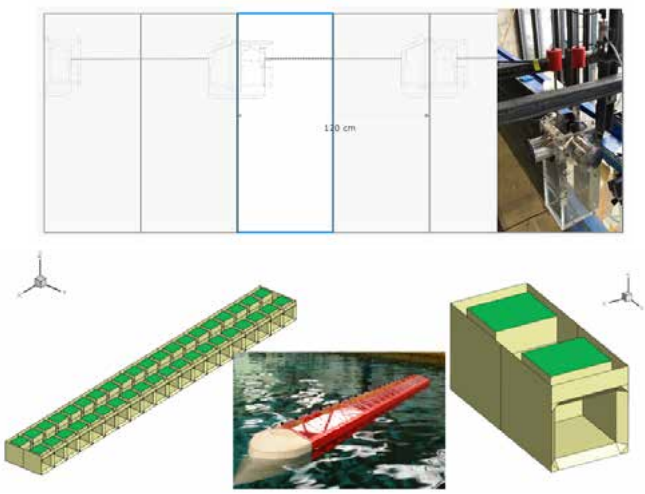
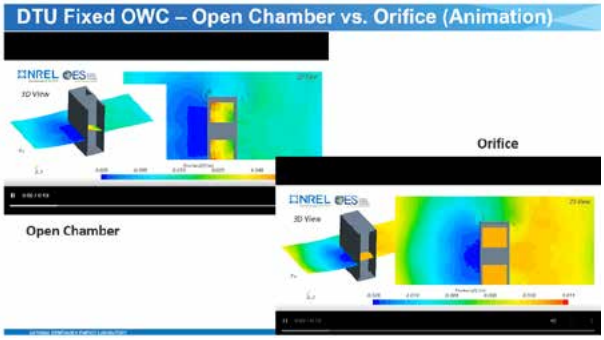


Illustration of the experimental setup of the half section of the KNSwing attenuator WEC



Visualization of NREL's CFD simulations of the Double chamber

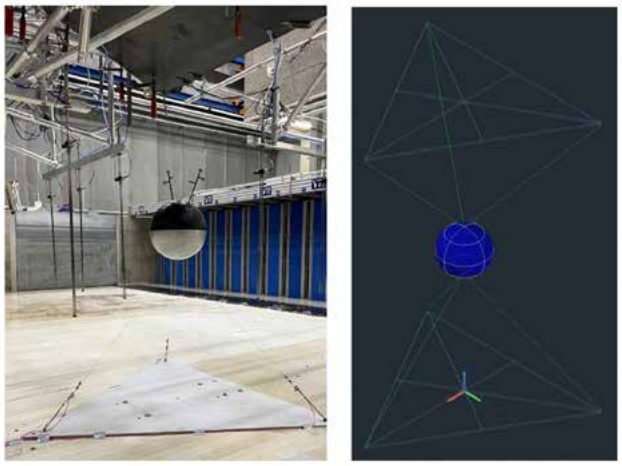


Illustration of the experimental setup of the pretensioned fixed Sphere

The participation in the present test case involves 5 partners of which 2 partners use CFD and 3 use linear and weakly-nonlinear potential flow models. By comparing these results, we obtain an understanding of the variation in results and thereby the uncertainties.

At this stage the variation between the delivered submissions is surprisingly large – this discrepancy is currently being investigated and a joint paper on the results is being prepared for submission in the spring of 2023.

Dedicated experimental Sphere-tests

In parallel, the development of test cases using a sphere to validate the hydrodynamic loads related to radiation and diffraction has continued with a 3DOF experimental setup at Aalborg University.

To measure wave loads on a fixed sphere the AAU team has developed a new set-up, and the sphere is suspended between pretensioned wires – three to the test basin floor and three lines to a frame above the basin. The experimental data will be used to validate the accuracy of the vertical and horizontal wave exciting force predicted using different numerical models such as:

- Linear potential flow models (including weakly non-linear effects, like fully non-linear Froude-Krylov forces)
- Higher order potential flow models (possibly including drag/slamming etc.)
- RANS models
- Other models

Acknowledgement

The project was initiated with the support of Bob Thresher from NREL and today Thanh Toan Tran is the point of support. Thanks also to Morten Kramer and Jacob Andersen from Aalborg University, and Harry Bingham from DTU for their lead on 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.

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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

OBJECTIVE

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:

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

INTRODUCTION

Knowing the fact that majority of the earth is covered with water, the extraction of tidal energy to generate electricity is augmenting interests of the researchers and the method is being further enhanced. In the evaluation of tidal power resources, 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 in 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 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 the IEA-OES to conduct extractable resource studies, to share their results and methodology, and work towards creating a standard report for modelling in harnessing tidal energy.

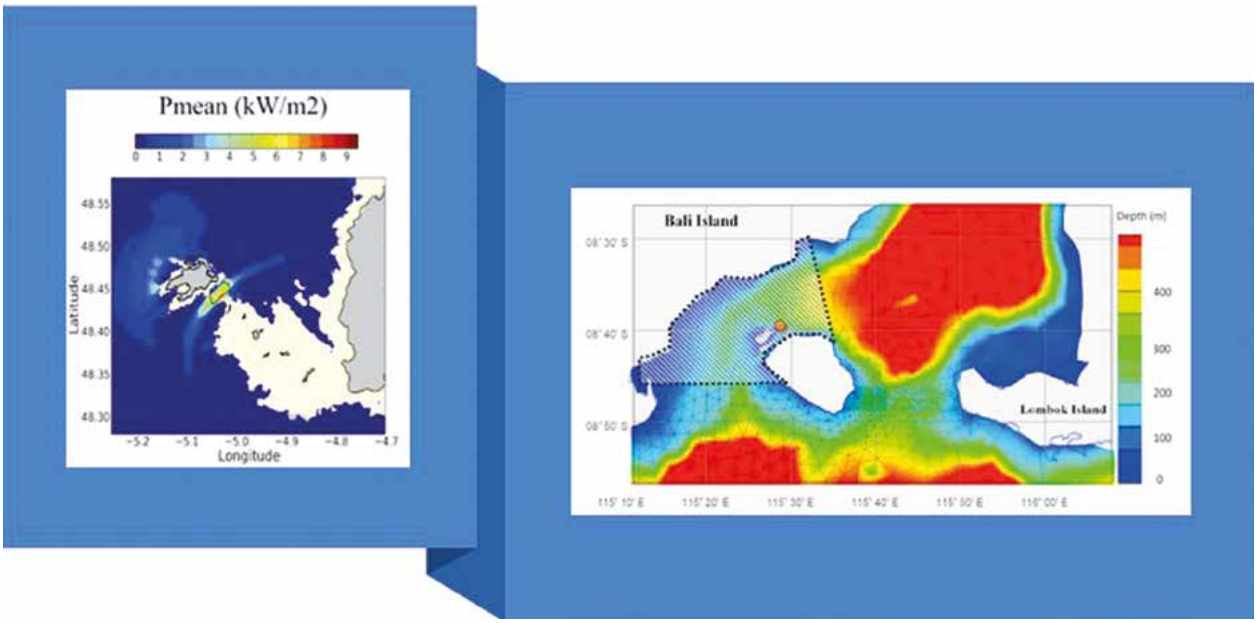
Thus, the main objective of this initiative is to develop a simulation guideline report of tidal energy resource modelling through a common case study with various factors along with code-to-code comparisons of various modelling strategies that exist in different parts of the models. It would also involve 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 study of various factors which affects 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.

These workshops are organised and hosted by Energy Research Institute @ NTU (ERI@N), Singapore through teleconferencing on a half yearly basis. 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 University of Gothenburg, Sweden; Dr. Mathew Piggott and team from Imperial College London, United Kingdom; Dr. Matt Lewis and team from Bangor University, United Kingdom; Prof. Roger Falconer and his team from Cardiff university, United Kingdom; Dr. Philip Marsh and team from university of Tasmania, Australia; Dr. Zhaoqing and team from Pacific Northwest National Laboratory; Dr. Shuxiu Liang and the team from Dalian University of Technology, China; Dr. Prasad and team from National Institute of Ocean Technology (NIOT), India; Dr. Balaji Ramakrishnan and team from IIT Bombay, India; Prof. Venugopal Vengatesan and team from University of Edinburg, UK; Dr. Craig Stevens from National Institute of Water and Atmospheric Research, New Zealand; Dr. Kadir Orhan and team from University of Kiel, Germany and Dr. Narasimalu Srikanth and his team from Energy Research Institute @ NTU, Singapore.

Based on the discussion on the workshops, the topics that are investigated 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.
- Coupling of ocean model with CFD models for turbine site match making
- 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.



- Inclusion of technoeconomic aspects and environmental effects.
- Effects of power extraction on water level, current speed and residual current.

Some of the key findings in the workshop discussions are as follows:

- In temperate waters, surface roughness influences the estimates of tidal kinetic energy in the area identified for stream-array implementation with a reduction of available power by 30% by rising z0 from 3.5 to 50 mm.
- Waves reduce tidal velocities by a small amount in 40 m water depth which is mainly attributed to waves increasing the apparent bed roughness. A strong linear relationship was found (R2 of 94%) between the wave height and the net power available over a tidal cycle (both theoretical and practical tidal Stream Energy resource). Therefore, the wave climate, including wave direction (relative to the current), should be considered when selecting sites suitable for tidal Stream Energy arrays.
- Turbine arrays could cause significant changes in the flow field of a location. Increased numbers of rows and turbines deployed resulted in a deficit of about 0.5-0.6 m/s. This corresponds to decreases in current speeds of about 25-30% average. Stronger current velocities were observed on the sides, closer to the banks due to the geometry of the strait and the proximity of turbines to the banks and near-shore shallow waters.

As further work, the international working group identified an Indonesian site of tropical waters with available validation data as 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 IEA-OES and further joint journal publications in top tier journals.

Ocean Thermal Energy Conversion (OTEC)

COORDINATOR:
Dr. Purnima Jalihal, NIOT, India

PARTICIPATING COUNTRIES:
China, India, Japan, Korea, France and USA

INTRODUCTION

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 and there is a need to disseminate information to all stakeholders. The overall work has been carried out by two groups, initially addressing the following topics:

- Estimation of OTEC potential around the globe (led by China);
- 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. In 2021 the White Paper on OTEC was released with a set of recommendations for the adoption of OTEC technology.

In 2022 a new task on the Economics of OTEC was approved. Studies conducted to date on the economic feasibility of OTEC systems suffer from the lack of reliable cost data. Therefore the ExCo discussed that data needs to be collected from various demonstration plants in several countries for understanding the economics.

OBJECTIVE

The main objective of the task initiated in 2022 is to understand the economics of OTEC and further to develop an understanding of OTEC specialists from academia, research organizations, governments, and industry.

METHODOLOGY

Historical and current estimates of capital and operational costs associated with technically sound designs of closed cycle (CC) and open cycle (OC) OTEC plants will form the original data base for this project. These will be used to estimate the levelized cost of electricity (LCOE) production under specific loan rate terms available from

different sources ranging from commercial banks to concessionary loans from development banks. The LCOE provides the rate ($/kWh) required to breakeven over the assumed life of the plant. In the case of the OC-OTEC plant the combination of electricity rate ($/kWh) and desalinated water rate ($/m3) required to breakeven will be estimated. At this stage of development, when considering commercial loans, the investment rate of return would be given by a rate charged ($/kWh) above the LCOE.

The analytical model previously documented to assess scenarios under which OTEC might be competitive with conventional technologies will be used. First, the capital cost for OTEC plants, expressed in $/kW, is estimated from current costs for the major components of OTEC systems including installation costs. Subsequently, the relative cost of producing electricity ($/kWh) with OTEC, offset when considering OC-OTEC by the desalinated water production revenue, is equated to the fuel cost of electricity produced with conventional techniques to identify scenarios (i.e., fuel cost and cost of freshwater production) under which OTEC could be competitive. For each scenario, the cost of desalinated water produced from seawater via reverse osmosis (RO) is estimated to set the upper limit of the OTEC water production credit. No attempt is made at speculating about the future cost of fossil fuels. It is simply stated that if a location is represented by one of the scenarios, OTEC could be competitive.

This work has been commissioned to Vega Consulting and Xenesys. Both parties will coordinate contact with the international OTEC community to assess the current state of OTEC specialists as well as request assistance though provision of any economic case studies or information that may further inform this work.

Ocean Energy and Offshore Aquaculture

PROJECT TEAM:
Pacific Northwest National Laboratory – Lysel Garavelli, Mikaela Freeman
Blue Economy Collaborative Research Centre – Eloise Wilson, Mark Hemer

INTRODUCTION

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.[2] 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[3]. 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.

2 State of the Science report OES https://www.ocean-energy-systems.org/publications/search/

3 https://www.oceanpanel.org/climate

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.

OBJECTIVE

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 was published in early 2022 and a webinar was hosted by PNNL.

International Vision for Ocean Energy

TEAM:
University of Edinburgh - Policy and Innovation Group
US Department of Energy – Water Power Technologies Office
Nanyang Technological University

BACKGROUND

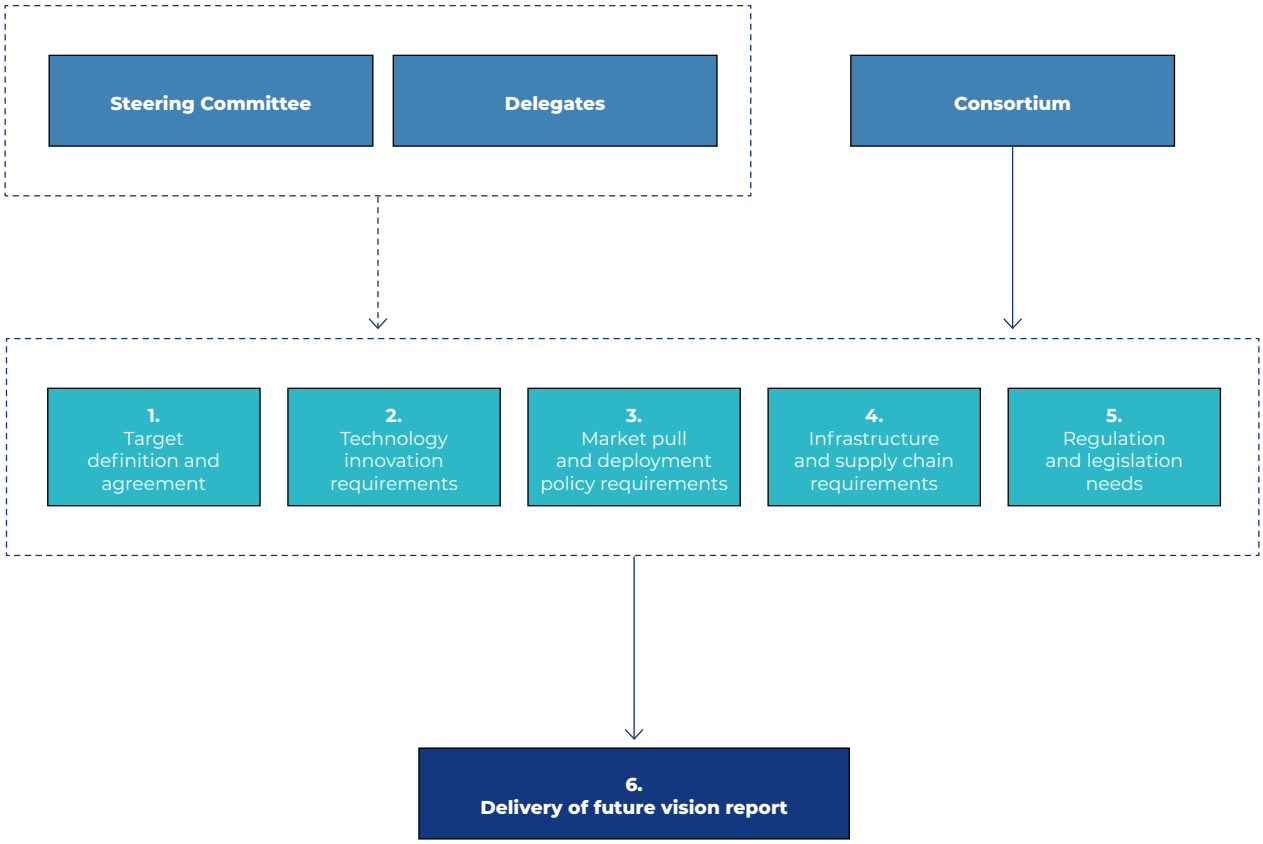
Tidal stream and wave energy sector have the potential to become a significant part of the international low-carbon energy mix. This can be achieved through research and development synergy, coordinated leadership, and a clear implementation strategy. The sector has ambitious plans for deployment, with the potential to develop 300 GW of tidal stream and wave energy internationally by 2050, which would provide up to 680,000 jobs and prevent the emission of up to 500 million tonnes of CO2. However, these figures are from 2017 and do not consider recent advances in research and innovation, supply chain maturation, and global demand for a diversified energy mix. It is crucial that the sector's potential is fully realized and commercialized on a global scale.

OBJECTIVE

The aim of this task is to produce a new **"Vision and International implementation strategy for the development and deployment of Ocean Energy".**

METHODOLOGY

The IEA OES future vision will address a number of key challenge areas to provide the sector with a clear pathway to meeting its future targets. This will involve producing a concise summary of both the present and future global development plans for the sector, including barriers to commercialisation, supply chain evolution and technology improvements to lower the localised cost of energy. There will be a need to evaluate techno-



Breakdown of tasks

logical and non-technological challenges as the sector progresses towards increasing states of TRL, with guidance provided by relevant bodies to ensure that the necessary technology innovation required to advance the sector occurs. Ensuring that the figures for job creation and gross value added for national and international economies are clearly highlighted will be important in ensuring continued financial and legislative support for the sector. Overall, a series of recommendations will be formulated and put forward to accelerate the development of tidal stream and wave technologies.

The methodology will consist of six distinct but interconnected tasks, presented in the following diagram:

The report to be published in 2023 will look to establish a clear target definition and agreement for the global deployment envisioned for the sector in Task 1, then Task 2 will look to address technology innovation requirements required to underpin the sector. Task 3 will look at market pull and policy development requirements, complemented by an analysis of infrastructure and supply chain requirements in Task 4 and a review of regulation and legislation needs in Task 5. Finally, Task 6 will combine the information in tasks 1-5 into an outline for an overall IEA OES future vision proposal. Each task will cover the following criteria:

- Relevant areas needed for the development and deployment of the technologies
- Policy or funding mechanisms required
- Type of funding entity responsible
- Timescale requirement for implementation

4.

International Activities on Ocean Energy

Australia

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OVERVIEW

Significant progress was achieved in 2022 with major developments in energy policy, successful ocean energy deployments and enabling R&D initiatives that will underpin deployments in 2023 and the growth of Australia's blue economy.

Key achievements highlighted in this report include:

- Introduction of the Offshore Electricity Infrastructure Act 2021 that facilitates and regulates the development of the offshore renewable energy sector in Australia
- Successful completion of Wave Swell Energy's (WSE) King Island wave energy demonstration project
- Portfolio of R&D initiatives and planned ocean energy deployments
- Release of the first phase of AOEG's Market Investigation identifying the potential markets for ocean energy in Australia

SUPPORTING POLICIES FOR OCEAN ENERGY

National Strategy – Policy Support

2022 has seen major developments in climate, environment, and energy policy at both the Commonwealth (Cth) and State level. With the change in Federal Government, Australia has re-engaged on the international stage on issues such as climate change as well as introducing a raft of national policies.

Introduction of the Climate Change Bill 2022

August 2022 saw the introduction of the Climate Change Bill 2022 (Cth) (Climate Change Bill) and Climate Change (Consequential Amendments) Bill 2022 (Cth). The Federal Government also updated its Nationally Determined Contribution (NDC) under the Paris Agreement with a commitment to achieve net zero emissions by 2050, and a 2030 target of 43% below 2005 levels. For more on the Climate Change Bill and other changes in climate and energy law, see Movement in Australia's climate and energy policy.

Rewiring the Nation

In October, the Federal Government announced its first step in its "rewiring the nation" election promise with

the entry into an agreement, alongside Victoria and Tasmania State Governments, for:

- $1 billion in concessional finance put towards the Marinus Link, interconnecting Victoria and Tasmania; and
- $1.5 billion in concessional finance put towards renewable energy zones in Victoria and appropriate transmission infrastructure between Victoria and New South Wales, prior to the closure of coal-fired power stations.

The Offshore Electricity Infrastructure Act 2021 and the Offshore Electricity Infrastructure (Regulatory Levies) Act 2021 commenced

In November, the Offshore Electricity Infrastructure Regulations 2022 (Cth) and Offshore Electricity Infrastructure (Regulatory Levies) Regulations 2022 (Cth) (Regulations) came into force, underpinning offshore wind proposed developments, but also a strong step forward in support of Australian ocean energy development. The Regulations and the Offshore Electricity Infrastructure Act 2021 (Cth) (OEI Act) provide a consistent and transparent regulatory regime for the construction, operation and decommissioning of offshore renewable energy generation and transmission infrastructure, and covers projects including offshore wind and solar farms, wave energy plants and undersea interconnectors. Further, the OEI Act and Regulations should work to ultimately provide a pathway to de-risking investments and reassure sponsors, financiers, and broader stakeholders alike.

Notice of Proposal to Declare an Area Bass Strait off Gippsland, Victoria

Following the passing of the above regulations, an area in the Bass Strait off Gippsland, Victoria, was declared as suitable for offshore renewable energy in December 2022. Other regions that will be considered for future offshore wind energy projects include: the Pacific Ocean regions off the Hunter and Illawarra in NSW, the Southern Ocean region off Portland in Victoria, the Bass Straight region off Northern Tasmania, and the Indian Ocean region off Perth/Bunbury in WA.

Capacity Investment Scheme

In December, the State and Territory Energy Ministers endorsed the Capacity Investment Scheme (CIS) which will provide the national framework to drive new renewable dispatchable capacity. The Government has said this new revenue underwriting mechanism will unlock around $10 billion of investment in clean dispatchable power to support reliability and security as the energy market undergoes its biggest transformation since the industrial revolution.

Australia joins Global Offshore Wind Alliance

The Australian government announced in late 2022 that Australia will join the Global Offshore Wind Alliance to boost the offshore wind industry, leveraging the knowledge, expertise and support of other nations to help establish an offshore wind industry in Australia.

National Marine Energy Standards Committee – EL066

The National Marine Energy Standards Committee completed its second full year of operation after forming in 2020. 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.

Ocean Energy Policy Initiatives by Australian States and Territories

In October 2022, the Victorian Government released Offshore Wind Implementation Statement 1, outlining the government's plans for the establishment of an offshore wind industry, including transmission and ports planning, procurements processing, and establishment of the new Offshore Wind Office Victoria. Additionally, the Victorian Marine and Coastal Strategy 2022 was released to support sustainable use and improve management of the health of the marine and coastal environment as part of the five-year action plan to begin implementing the Marine and Coastal Policy 2020.

In New South Wales (NSW) EnergyCo, the state-government controlled development body commissioned a report into the state's offshore wind capacity to provide expected strategic advice that could contribute to the design and development of an offshore renewable energy industry in NSW. EnergyCo also called for registrations of interest for developments in Renewable Energy Zones (REZ).

The Tasmanian Government continued to support the development of major national renewable energy projects through the Tasmanian Renewable Energy Action Plan including Project Marinus.

In Western Australia, The Energy and Governance Legislation Reform project has progressed in developing amendments to the State's electricity regulatory framework. This project builds on recent reforms to the governance and institutional arrangements that were implemented on 1 July 2021. The need for further energy sector governance reforms was highlighted in the Energy Transformation Strategy Stage 2: 2021-2025. No specific plan for ocean renewable energy is established yet.

Market Incentives

The Australian Ocean Energy Group (AOEG) completed the first phase of its Market Investigation in June 2022, which sets out to provide evidence that potential demand for ocean energy exists, identify potential early-adopter customers and identify the constraints and opportunities to accelerate its uptake. The AOEG also launched its Member Spotlight program which builds visibility for members activities in ocean energy. Additionally, OES Australian delegates and the OES Australia Working Group assisted with the design, preparation, and distribution of Australian Marine Renewable Energy (MRE) Regulator's survey which were published in 2022 as a report titled: The Australian MRE Regulator Survey Report. Australian OES delegates also actively guided the development of the OES Strategic Plan 2022-2026.

Public Funding Programmes

Several national funding programs are in place which supports ocean energy developments 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 and 2021 report and support continues from the following bodies including:

- The Australian Renewable Energy Agency (ARENA) supported two ocean energy projects: Wave Swell Energy's UniWave200 200 kW wave energy converter on King Island, Tasmania, and through its International Engagement Program supporting Australia's participation in the International Energy Agency Ocean Energy Systems Technology Collaboration Program.
- Cooperative Research Centre (CRC) program which supports Australian industries ability to compete and produce, by helping industry partner with the research sector to solve industry identified issues, including funding for the Blue Economy CRC detailed further below.
- National Energy Resources Australia (NERA) who provided supporting funding for AOEG's Market Investigation.
- Australian Research Council (ARC) which administers several active ocean energy projects across several Australian universities, including the University of Western Australia, RMIT and the University of Melbourne.
- Clean Energy Finance Council (CEFC) who aim to catalyse private sector investment in Australia's clean energy sector and provide concessional funding for interconnector projects.

State Funding

In addition to Commonwealth public funding programs, state government public funds are also supporting R&D for ocean energy development. Of these, the Western Australia Governments ongoing support of the Marine Energy Research Australia (MERA) is the most notable. Other funding support includes the Victorian Government's offer of financial support to offshore renewable energy projects through the Energy Innovation Fund (EIF) and the NSW Governments Clean Technology Research and Development Grants Program.

RESEARCH & DEVELOPMENT

Significant investment in ocean energy R&D projects occurred in 2022 through the following initiatives:

Blue Economy Cooperative Research Centre

The Blue Economy CRC-Co Ltd is an independent not-for-profit company established under the Australian Government's Cooperative Research Centre Program. Australia is positioned adjacent to the world's largest markets for seafood and energy and has enormous opportunity to grow sustainable marine industries – our blue economy. Established in 2019, Blue Economy CRC is one of the largest funded cooperative research efforts (> AU$300 million program) and brings the aquaculture, offshore engineering and renewable energy sectors together to address the challenges of offshore food and energy production. The Blue Economy CRC draws together the knowledge, skills and experience of 43 partners from industry, research and government from ten countries, over 10 years to develop systems, structures and capabilities that will transform the future of Australia's marine-based industries.

Already in its third year, this CRC has built an impressive portfolio of projects and continues to actively support a diversified range of new projects, to underpin the successful growth of ocean energy in Australia. Together with Pacific North Western National Laboratories (PNNL), the Blue Economy CRC completed the *OES Study on the Energy Requirements of Offshore Aquaculture as a Market for Ocean Energy*. This work helped industry to understand the size and scope of the decarbonisation challenge for offshore aquaculture market and options for ocean energy solutions.

Meeting the global challenge to decarbonise ocean-based industries requires new ways of thinking, and new technologies. The Blue Economy CRC is supporting several wave energy projects; led by Carnegie Clean Energy the Moorpower Scaled Demonstrator is a solution to support decarbonising aquaculture operations and the Mooring Tensioner for WECS – MoTWEC developing, proof testing and demonstrating a novel energy storage element, the Mooring Tensioner, enabling the use of rotary electrical generators for WECs. These two projects have in-sea demonstrations planned for early-2023. In addition, with support from the Western Australian Government, the University of Western Australia is leading the Seeding Marine Innovation in SW WA with a WEC Deployment in Albany, with in-sea demonstration planned for late-2023. By building and showcasing these emerging technologies we are showing what is possible as well as re-risking future adoption by industry.

Marine Energy Research Australia (MERA)

Marine Energy Research Australia (MERA) is a branch of the University of Western Australia and is located in Albany in Southwestern Australia. As official HQ of MERA, the main occupant of the Facility, senior decision-makers in local and State Government and executives in the tertiary sector have visited. The Facility is recognised to also host a hub within the United Nations Regional Centre of Expertise in Education for Sustainable Development.

The UWA Great Southern Marine Research Facility has a strong outward-facing focus and has been acknowledged as a community asset for education and outreach; the main engagement space hosts a 3-metre long wave flume with automated paddle to demonstrate wave climates at the two main wave energy development sites around Albany, Moodrenup-Sandpatch/Torbay (open ocean) and King George Sound (natural outer harbour). In addition, the outreach program includes a 1-metre wave tank (portable) and 3D-printed WEC technology models.

The Facility and technical support also used for maintenance as part of the IMOS "New Technology Proving Sub-Facility" for low-cost wave buoy technology, mobilisation HQ of fieldwork off Ocean Beach, Denmark WA, as part of collaboration with WA Department of Water & Environmental Regulation and the UWA Oceans Institute project on wave run-up at the popular, hazardous rockfishing location Salmon Holes. In September 2022, the Facility led the Australian fieldwork component of the international Southern Right Whale Tagging Program.

MERA, in partnership with the Western Australian Department of Primary Industries and Regional Development and the Blue Economy CRC, is continuing to support the deployment of a prototype version of

the M4 ("Moored MultiModal Multibody") WEC in King George Sound, Albany, in late-2023. UWA Great Southern Marine Research Facility is primarily the workshop and vessel/equipment storage for the WA Government and Blue Economy CRC co-funded M4 wave energy demonstration project. As part of this project,

- Fieldwork conducted in 2022 included site surveys for benthic habitat assessment using side-scan sonar and towed video (June/July 2022); this assessment constitutes an essential component of the approval and licensing requirements for the M4 WEC anchor installation due to sensitivities around seagrass in the proposed deployment area.
- Collaboration with local shellfish aquaculture company Harvest Road commenced in November 2022 to investigate an alternative anchoring solution at the proposed M4 wave energy site.
- The M4 Project includes a feasibility study into Albany as a potential site for an Integrated Ocean Energy Marketplace – a concept of coastal microgrid that includes offshore ocean technology inputs, such as wave energy from the M4 demonstrator. This project is jointly led by UWA-MERA and the Australian Ocean Energy Group and works collaboratively with Xodus Group and Discovery Bay.
- The Australian Maritime College (AMC), University of Tasmania prepared scale experimental investigation work of the M4 wave energy convertor for testing in 2023 in AMC's Model Test Basin. AOEG continues to provide support for the market investigation as part of the project.

MERA acted as an adviser for the Compressible Degree of Freedom (CDOF) project for Sandia National Laboratories in the US, with Scotland-based Mocean Energy as a partner.

University of Western Australia (UWA)

- As part of Australian Research Council (ARC) Linkage Project LP210100397 "Efficiently unlocking full-scale WEC dynamics for industry cost reduction", in collaboration with CorPower Ocean and AOEG, UWA conducted tests on an idealised WEC in the wave flume at the UWA Coastal and Ocean Engineering Laboratory (COEL) to investigate simplified nonlinear force representations.
- Also in COEL, UWA tested a submerged pressure differential WEC with flexible membranes and simplified PTO, as part of a Master's project supported by RiverLab.
- Work on phase-resolved wave prediction for WECs continued with a 3-month deployment of an array of 3 Sofar Spotters in the open ocean off Albany, upwave of a Datawell Waverider Mk IV.
- Wave energy developer ROC-Tech completed 1:100 physical model testing of the D-Spar WEC at COEL in December 2021, with reporting done in 2022. Engagement continues until today with a planned testing at a bigger scale and potentially at the Swan River.
- A techno-economic feasibility study on the potential of a wave-solar-wind microgrid system to supply residential demand in Albany, Western Australia highlighted the benefits of including wave energy in the renewable energy mix. The study was conducted as part of the Parliament of Western Australia's Parliamentary Research Program.

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

2022 marked the end of a 4-year project funded by the Australian Renewable Energy Agency (ARENA) which provided funding for OES membership along with other ORE knowledge-sharing initiatives. In-kind contributions from CSIRO and the Australian Ocean Energy Group contributed to the success of the project. The Project Report highlights including: a stronger within country ORE network with the establishment of the OES Australia working group, a comprehensive market development program, stronger engagement with ORE sectors in NZ, the US and UK, and an enhanced profile for the Australian ORE sector. At the closure of the project, the Australian OES delegation was transferred from CSIRO to the Blue Economy CRC. At the outset of the CSIRO delegation, and the project, a key objective was to transfer the OES Delegation to an appropriate entity to represent the Australian ORE sector. The Blue Economy CRC emerged as the appropriate organisation, and they were formally accepted as the Australian delegate to the OES in August 2022. This marks the start of a new chapter, as the Australian sector progresses through the innovation chain, and establishes markets, ideally with government support and incentives.

In 2022 CSIRO was commissioned by WaveSwell Energy to perform a study into the 'Dispatchability and energy storage costs for wave, wind, and solar PV', which demonstrated that system level capital cost reductions

Wave Swell UniWave200 experiencing a large storm wave event during deployment

can be achieved by including wave energy when the cost of energy storage required to achieve a reliable energy supply is considered in electricity networks that include solar PV and wind turbine generators.

Wave Swell Energy Ltd

Data generated during the deployment of Wave Swell's WEC at King Island, Australia allowed the turbine's variable speed algorithm to be optimised during its deployment, resulting in the UniWave200 reaching an average wave-to-wire efficiency across all conditions of 48%. The performance of the project has been independently validated by the Australian Maritime College (AMC - a specialist institute of the University of Tasmania) and data from the project has been provided to, assessed, and analysed by the US DOE's Pacific Northwest National Laboratory (PNNL). In collaboration with the AMC, WSE will continue to utilise data from the project to further optimise and improve the technology, with the realistic aim of achieving a wave-to-wire efficiency in excess of 50% for its next project. Additionally, Wave Swell Energy Ltd (WSE) commissioned CSIRO to provide an independent analysis of the cost benefit for using wave power as a reliable supply of renewable energy. The new study, 'Wave Energy Cost Projections', analysed the potential for capital cost and levelised cost of electricity reductions of WSE's proprietary unidirectional oscillating water column wave energy converter technology. Investigation of scour processes around WECS during operations of the UniWAve200 was also performed in collaboration with researchers at the University of Queensland.

Carnegie Clean Energy

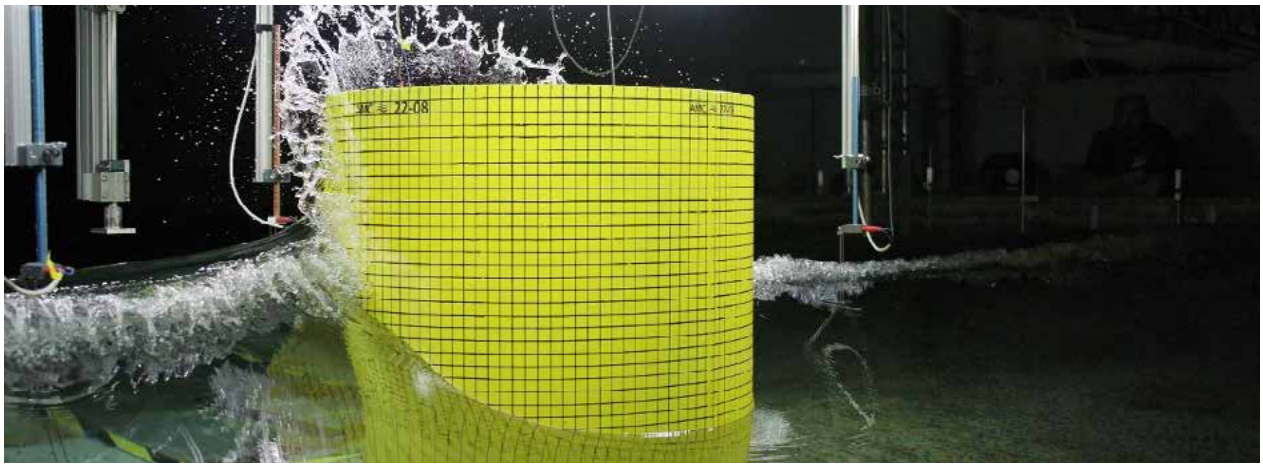
Carnegie Clean Energy and its international subsidiaries continue progressing its core wave energy technologies, including CETO and MoorPower, along a defined product validation roadmap.

Following completion of the CETO Digital Development pathway in which key innovations were incorporated to reduce cost and improve performance of the CETO technology, CETO is currently being advanced towards commercialisation in the EuropeWave PCP Programme. During Phase 1, design activities and tank testing were undertaken. In September 2022, CETO was selected as 1 of 5 to continue in Phase 2 of the EuropeWave Programme. During Phase 2, the team will advance the design through Front End Engineering Design, PTO testing, further tank testing and associated commercial and certification activities. Subject to successful selection for Phase 3, this leads to the full design, manufacture, deployment and operations of a CETO prototype in Europe.

Carnegie's MoorPower technology is a spin-off that incorporates core aspects of CETO technology and know-how into a novel wave energy converter system for use in offshore energy demand applications. The initial market is the offshore aquaculture sector. As the aquaculture sector moves operations further offshore, new challenges are encountered to access clean and reliable energy. Without shore-based power, energy intensive offshore aquaculture operations such as feeding barges are reliant on diesel generators with many associated costs, risks and carbon emissions. This is also true of many moored vessels across the blue economy. In October 2021, Carnegie launched the $3.4m MoorPower Scaled Demonstrator Project with support from the Blue Economy CRC and a consortium of partners including Huon Aquaculture and Tassal. This important project will take MoorPower from concept to an operating prototype and allow future users to see the technology in action. The MoorPower scaled demonstrator will be deployed and operated just offshore from Carnegie's office and research facility in North Fremantle, Western Australia. Operations will commence in early 2023.

Australia-China Joint Research Centre of Offshore Wind and Wave Energy Harnessing: University of Adelaide

The Australia-China joint Research Centre for Offshore Wind and Wave Energy was launched in February 2020, led by the led by the University of Adelaide and Shanghai Jiao Tong University. The Centre includes collaboration with five Australian partners, supported by the Australian Department of Industry, Science, Energy and Resources, the Chinese Ministry of Science and Technology and six Chinese partners. The aim of the Joint Research Centre is to address the scientific and business challenges in the global renewable energy industry by developing lower cost and sustainable combined wind and wave power generation technology. The commercial benefits will lead to improved energy security, reduced fossil fuel emissions, economic growth and job creation. Research completed in 2022 included a series of experiments at the AMC Model Test Basin that investigated hydrodynamic interactions between co-located offshore wind and wave energy devices under operational and extreme wave conditions as shown in figure below.



Focused wave slamming on a fixed offshore wind turbine model in the AMC wave basin

Australian Research Council Discovery Project on wave energy: RMIT University

Supported by the Australian Research Council (ARC), RMIT Discovery Project grant aims to develop a novel speed amplified flux-switching electromagnetic wave energy harvester that takes advantage of the hydrodynamic forces from ocean surface heave movement to convert wave kinetic energy to electrical energy. A prototype of the novel speed amplified mechanism was built and validated by lab testing in 2022, with a scale-down prototype planned to be tested in wave tank and at sea in 2023.

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. A project is under development. In addition to the abovementioned, several Universities continue to be active in ocean energy R&D (and supervising Masters and PhD students) including the University of New South Wales, University of Melbourne, Swinburne University of Technology, Curtin University and the University of Queensland.

TECHNOLOGY DEMONSTRATION

Projects in the Water

Wave Swell Energy (WSE)

Wave Swell Energy has successfully completed its King Island, Tasmania, Australia wave energy demonstration project, having operated and delivered electricity into the local Hydro Tasmania hybrid electrical grid for more than 12 months. The WEC is now (at the time of writing) in the process of satisfying its final milestone condition of being successfully decommissioned, as stipulated in WSE's funding agreement with the Australian Renewable Energy Agency. During its successful period of deployment, the UniWave200 operated with an availability of just over 80%. The WEC has also survived without incident for two years in Southern Ocean conditions. The King Island UniWave200 Wave Energy Converter won the Sir William Hudson Award at the 2022 Engineers Australia Excellence Awards.

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. A turbine demonstration is currently underway at a port in North-western Australia.

Projects Planned for Deployment

EuropeWave PCP

Carnegie Clean Energy's subsidiary CETO Wave Energy Ireland and AMOG Consulting Limited (See-Saw WEC) were two of the five wave energy projects selected for Phase 2 of EuropeWave's Pre-Commercial Procurement (PCP) funding programme. The programme is providing the five projects a budget of €3.6 million over the next nine months to continue the development of their wave energy device concepts. Phase 2 will focus on the front-end engineering design (FEED) of scale prototype devices intended for open-water trials at BiMEP and EMEC test sites during Phase 3.

Carnegie Clean Energy

Planned deployments by Carnegie Clean Energy include a scaled demonstrator of the MoorPower (a CETO-derived wave energy technology for the aquaculture sector) and MoTWEC mooring tensioner technology in North Fremantle, Western Australia in early 2023. Carnegie's subsidiary CETO Wave Energy Ireland is also working towards a CETO deployment in Europe if selected to continue into Phase 3 of the EuropeWave PCP programme.

Marine Energy Research Australia (MERA)

MERA are planning the deployment of the M4 ("Moored MultiModal Multibody") wave energy converter (WEC) in King George Sound, Albany, demonstrating the capacity to power the aquaculture industry.

AZURA-EHL Australia

The AZURA technology is a wave energy product of EHL, who have locations in both New Zealand and Australia. The AZURA technology is pre-commercial and designed to provide both water and/or power, with three major projects in development.

Smart Barge (Qld and NSW)

The Smart Barge team are 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.

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, is in the very preliminary stages of taking steps to secure expressions of interest from global tidal energy providers and local industry.

RELEVANT NATIONAL EVENTS

Relevant events in 2022:

OES Australia Working Group

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 met online twice in 2022. 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.

Blue Economy CRC's 3rd Annual Participants Workshop

The Blue Economy CRC's 3rd Annual Participants Workshop, themed 'Towards a Sustainable Blue Economy' was held in May 2022 in Hobart, Australia. The event coincided with the *2022 Tasmanian Salmon Symposium* and *AOEG's Australian Ocean Energy Market Summit* earlier in the week, followed by the two-day workshop and on-site tours of participants Tassal and Huon Aquaculture's operational feed centres, hatcheries, and feed barges. A total of nearly 300 attendees

from our participant organisations attended the workshop, 124 virtual and 173 in person. PhD Scholars presented their research work.

2022 Australian Ocean Energy Market Summit

The 2022 Australian Ocean Energy Market Summit organised by the Australian Ocean Energy Group (AOEG) and facilitated by UK-based Aquatera, was designed to create meaningful, information-based connections between Australian market representatives and industry leaders, such as project developers, technology providers, supply chain, investors, funders, researchers, stakeholders, policy makers and communities. The Summit was a highly interactive event open to anyone with an interest in the 'blue economy' that congregated more than 150 attendees, 90 virtual and 69 in person. The Ocean Energy Market Summit identified priority markets for wave and tidal technologies and integrated ocean energy systems in Australia, examined opportunities and challenges faced in relation to energy transition and decarbonisation and identified key research to support the market's adoption of ocean energy and the sustainable development of Australia's ocean energy industry.

Blue Economy CRC Webinar Series

The Blue Economy CRC also hosts monthly webinars on topics of national and international relevance with expert presenters from all over the world. During 2022, held five webinars on ocean energy, offshore wind and green hydrogen developments. See webinar recordings at: https://blueeconomycrc.com.au/webinars/.

Relevant events planned for 2023 and 2024 in Australia include:

- Blue Economy CRC Summer School in Albany, Western Australia (January 2023), hosted by the University of Western Australia (UWA). The Summer School is open to all Blue Economy CRC PhD and Masters Scholars.
- Blue Economy CRC Annual Participants Workshop (May 2023), in Fremantle, Australia
- AOEG Ocean Energy Market Summit (October 2024), Albany, Australia
- 10th International Conference on Ocean Energy (ICOE 2024) (18-20 September 2024), in Melbourne, Australia

Belgium

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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.

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 session 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 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 2022, Belgium had a binding national target for renewable energy equal to 13% of the gross final consumption of energy.

By the end 2022, 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 CO2 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.

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 2262 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 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 internationalization 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.

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 project 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 co-fund 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 support of the Blue Cluster is 8 million Euro.

RESEARCH & DEVELOPMENT

Fundamental research projects at the Coastal Engineering Research Group of Ghent University (UGent-CERG) dedicated to ocean energy research

The Coastal Engineering Research Group (UGent-CERG, http://awww.ugent.be) is led by Professor Peter Troch, and is situated within the department of Civil Engineering. UGent-CERG 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 and know-how include 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.

Coastal & Ocean Basin

he new Coastal and Ocean Basin (COB) (https://www.cob.ugent.be/) in Ostend is operational. 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.

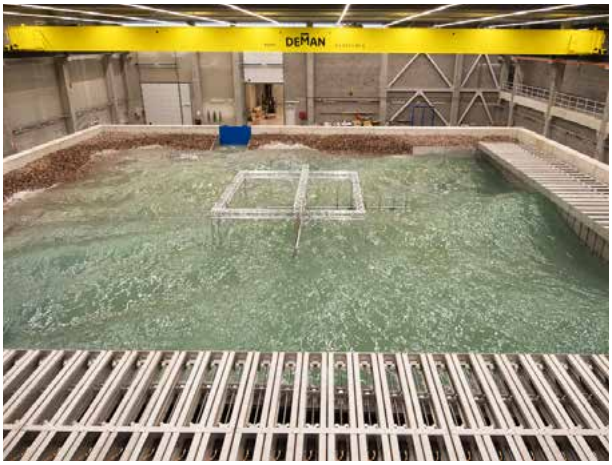
The exploitation is managed by Ghent University, KU Leuven and Flanders Hydraulics Research. The basin is equipped with a unique combination of a narrow paddle wave generator in L-shape and a bidirectional current system, to achieve high quality short-crested waves at almost any relative angle with the 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. The facility is fully equipped with a state-of-the-art Qualisys motion tracking system.

Ghent University presented recently the new COB facility:

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, http://awww.ugent.be). 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 2022, WECANet has funded research collaborations through Short Term Scientific Missions, on-line international meetings, dissemination activities and scientific publications on wave energy. WECANet supports actively OES-IEA activities.

The "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.

Location of the Blue Accelerator test site (Top); Interior of the Blue Accelerator platform (Middle); The Blue Accelerator open sea test site at Ostend, Belgium (Bottom)

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 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 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.

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 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.

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) and conducted by the following partners: Elicio, Marlinks, Yuso, Enersynt and KUL. 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.

SMARAGD (2021 – 2023)

SMARAGD ("SMart Autonomous Reliable Aquatic Goods Drone") runs from 2021 to 2023 with the following partners: GEOxyz, MULTI.engineering, e-Bo Enterprises and ERPA Industrial Supplier. The objective of the SMARAGD-project is to create and 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. Bringing the onshore warehouse closer to the offshore workplace will improve the efficiency of the offshore works. 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.

OPIN

Sirris from Belgium is partner in OPIN (Ocean Power Innovation Network), an Interreg North West 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 complex and rapidly changing world where the 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:
https://northsearegion.eu/non-stop/about/

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:
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.

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 focusses 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 liason 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 defense 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/

RELEVANT NATIONAL EVENTS

Planned in 2023:

- **July 2023:** The Blue Growth Summer School organised by Ghent University
- **March 2023:** Final Conference of the WECANet COST Action CA17105 organised by UGent-CERG (https://www.wecanet.eu/) in Ghent, 6-7 March 2023
- **March 2023:** ENCORE stakeholder event organised by UGent (www.energisingcoasts.eu)

Canada

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Elisa Obermann, Marine Renewables Canada

OVERVIEW

2022 has been a year of milestones for Canada's marine renewable energy sector with device deployments, completion of fabrication phases, and successful R&D activities.

On the east coast of Canada, developers working in the Bay of Fundy - DP Energy, Sustainable Marine, Big-Moon Power, Jupiter Hydro, NewEast Energy and Nova Innovation - continue with planning and development of in-stream tidal energy projects. Sustainable Marine successfully deployed its floating in-stream tidal energy platform – a first for Canada. It is delivering clean electricity to Nova Scotia's grid reliably, every day. The Fundy Ocean Research Centre for Energy (FORCE)'s Risk Assessment Program for Tidal Energy has successfully developed a science-based and transparent tool that can estimate the probability that valued fishes will encounter an offshore energy device at the FORCE site – a key metric that is important for environmental permitting processes.

The Canadian sector continues to focus on realizing opportunities in marine renewable energy for remote and coastal communities that are reliant on diesel for electricity generation – a major market in Canada and also globally. Notably, Ocean Renewable Power Company (ORPC) Canada successfully deployed its RivGen device in Manitoba at the Canadian Hydrokinetic Turbine Test Centre (CHTTC). BMT Canada has also succeeded in working with project partners to deploy its Smart Grid Controller technology in Nova Scotia at the Sustainable Marine substation, a demonstration designed to integrate multiple energy sources and regulate energy distribution for islands and remote communities, increasing the opportunity for use of renewable sources of energy while reducing the dependence on diesel power generation. The University of Victoria's Pacific Regional Institute for Marine Energy Discovery (PRIMED) also continues work to support wave and tidal energy development and uptake in British Columbia's remote communities.

The Government of Canada advanced its initiative to establish offshore renewable energy regulations that will govern activity on federal seabed and announced an investment tax credit that will support wave, tidal, and river current development beginning later in 2023.

SUPPORTING POLICIES FOR OCEAN ENERGY

National Strategy

Government of Canada

In 2022, the Government of Canada commenced Phase Two of its 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 are being developed under the *Canadian Energy Regulator Act*. 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 the 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 closed in early 2022 and focused on soliciting feedback on the technical requirements and proposed structure of the regulations. The next step will be pre-publication of the ORER in Part 1 of the Canada Gazette for public comments.

In April 2022, the Government of Canada and the provinces of Nova Scotia and Newfoundland and Labrador announced the intent to establish a joint management regime for offshore renewable energy by amending legislation that would expand the mandates of the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) and Canada-Newfoundland and Labrador Offshore Petroleum Board (CNLOPB). The *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act* and *Canada-Newfoundland and Labrador Offshore Petroleum Resources Accord Implementation Act* ("*The Accord Acts*") will be amended accordingly, establishing both existing boards as the regulator for offshore renewables for their respective provinces. These changes will impact offshore renewable energy projects such as offshore wind, wave, and tidal energy proposed to take place on federal seabed.

Nova Scotia

Nova Scotia Department of Natural Resources and Renewables (DNRR) introduced amendments to the *Marine Renewable-energy Act* to provide greater clarity regarding the Act's licensing system to address industry concerns, improve and clarify the administration of the Act's Demonstration Permit Program, and respond to lessons learned through the ongoing administration of the legislation and address other administrative changes. The amendments received Royal Assent on April 22, 2022.

Notable amendments include:

- Changes to the licence framework to allow projects to be sited closer to one another and to share common infrastructure, such as anchors or moorings. Allowing infrastructure to be shared has the potential to further reduce the amount of deployed infrastructure, reduce project costs, and support project investment decisions and project planning, ultimately leading to the deployment of projects. This will also add greater clarity around the rights provided with a license and the geographic area of a licence.
- Improvements to the administration of the Demonstration Permit Program that will create a competitive evaluation process instead of providing permits on a first-come, first-served basis. The process will ensure the projects that offer the best value to Nova Scotians are approved.

Market Incentives

Government of Canada

The Government of Canada's 2022 Fall Economic Statement included a refundable 30% investment tax credit for clean technologies that will cover tidal, wave, and river current technology. Final details will be established in 2023.

Nova Scotia

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/kWh 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.

RESEARCH & DEVELOPMENT

BMT Canada – Ocean Energy Smart Grid Integration Project

BMT Canada's Ocean Energy Smart Grid Integration project is designed to integrate multiple energy sources and regulate energy distribution for islands and remote communities, increasing the opportunity for use of renewable sources of energy while reducing the dependence on diesel power generation. BMT partnered with Sustainable Marine Energy, Rainhouse Manufacturing Canada, the University of Victoria, and Turtle Island Innovations (TII) to design, build, and test a smart grid controller.

The project teams have worked in close collaboration, advancing through technology readiness levels (TRLs) at a steady pace to reach the biggest project milestone yet in September 2022 – the project entered full-scale testing at the Sustainable Marine Energy substation in Nova Scotia, with teams on the ground from BMT, Sustainable Marine Energy, and TII to connect solar, tidal, and other energy sources to the BMT Smart Grid Controller to regulate and distribute power to a microgrid. The primary renewable energy source will be provided by Sustainable Marine's PLAT-I tidal energy device. The BMT Smart Grid Controller is designed to efficiently manage and integrate an unlimited number of energy sources in a fully off-grid remote microgrid. The integration of additional renewable energy sources is easily handled by modifying the control parameters versus expensive hardware changes.

Fundy Ocean Research Centre for Energy (FORCE)

FORCE is now in the third year of a $2 million research project, the Risk Assessment Program (RAP) for Tidal Energy funded by NRCan's Emerging Renewable Power Program (ERPP) to support greater regulatory clarity around tidal project development. FORCE's RAP has developed a science-based and transparent tool to address a key question in the permitting process: estimating the probability that valued fishes will encounter an offshore energy device at the FORCE site. While the current predictive models are applicable to the FORCE site, the models are designed to be easily modifiable and applicable to other sites with tidal energy potential. RAP is a collaborative effort between FORCE, the Ocean Tracking Network at Dalhousie University, the Confederacy of Mainland Mi'kmaq, Acadia University, and Marine Renewables Canada, and fishing industry representatives.

This collaboration brings together the expertise and knowledge needed to evaluate and minimize environmental harm from tidal power devices, by integrating

the knowledge and expertise from academia, industry, government, indigenous, and community groups. The collaboration also works hard to foster trust and provide a vehicle to ensure the legitimate questions and concerns of the Nova Scotia community are properly addressed. The collaborative design of the RAP for marine renewable energy addresses concerns of stakeholders about the environmental effects of extracting clean energy from renewable sources and establishes the foundation for future environmental effects monitoring programs and best practices.

To date, RAP has required tag detection data from 22 different telemetry projects and environmental data, demonstrating FORCE's ability to coordinate with dozens of collaborators and synthesize multiple types of data to answer questions about marine species interactions with ocean energy devices.

RAP is assessing the co-occurrence of fish and tidal turbines in the Bay of Fundy's Minas Passage, where the probability of encounter will be determined by combining two data sets: physical oceanographic (flow Atlas) and biological (fish atlas). The Flow Atlas represents breakthrough, radar-based data collection – delivering real-time ocean current distribution and visualization. RAP has established a high-resolution radar network in the Minas Passage, which is now generating spatiotemporal (space and time) data on physical oceanographic features. This is the basis for real-time mapping and flow atlas development for the primarily tidal currents in the Minas Passage. The Fish Atlas has been developed through a collaboration amongst many of the project partners noted above. Through this collaborative effort, RAP is building the largest spatiotemporal, multi-species fish distribution atlas in the Bay of Fundy ever created that collects, combines and analyses multiple data sets from hydroacoustic fish-tagging studies – both existing and new.

A major goal of RAP has been to increase community and Indigenous participation in fish tagging, gathering visual material, learning from the results of the RAP program, combining traditional and scientific knowledge to understand how principles of Netukulimk (appropriate resource use) and Etuaptmumk (two-eyed seeing) align with the biological fish distribution atlas, and reaching out to community members for information sharing to support the graphic user interface.

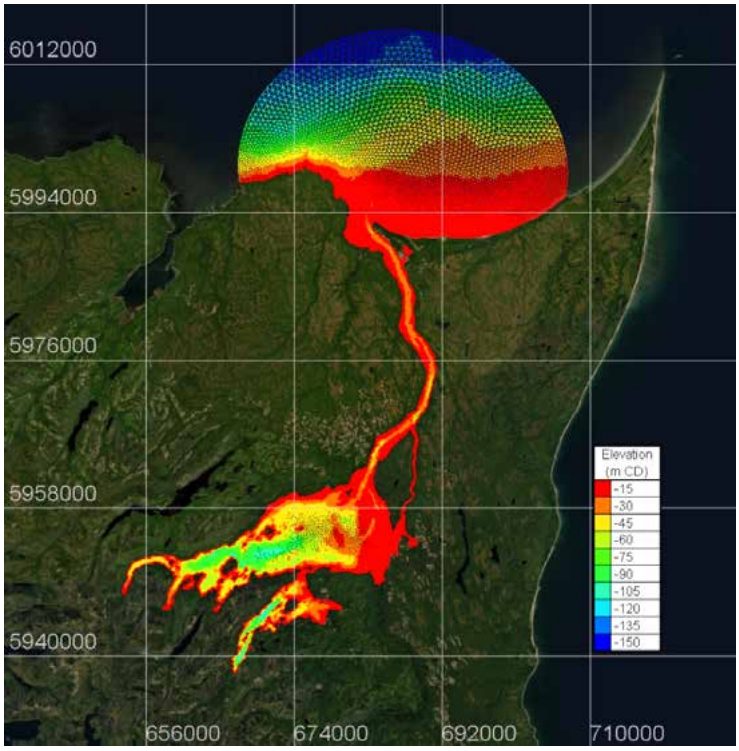
National Research Council (NRC)

National Research Council Canada's Ocean, Coastal and River Engineering Research Centre (NRC-OCRE) embarked on a project to improve understanding of Canada's river hydrokinetic energy (HKE) resources. The ongoing research leverages field data collection, numerical modelling, and analytical methods to improve broad understanding of HKE resources across Canada, as well as detailed understanding of HKE resources at several specific sites. Close collaboration with the University of Ottawa has led to detailed field data collection at several river reaches in Ontario and Québec and the development of numerical models that can be used to simulate flows and estimate theoretical energy resources at select field sites. A review of existing HKE resource assessments and supporting analytical methods was completed. Ongoing research in 2023 will be focusing on improving understanding of HKE resources at the national scale, identifying opportunities for additional field data collection and detailed resource assessment in the Arctic, and dissemination and publication of research findings.

Natural Resources Canada – CanmetENERGY-Ottawa

NRCan's CanmetENERGY-Ottawa (CE-O) continued to advance its research and development initiatives in tidal and river hydrokinetic energy projects in collaboration with stakeholders. The focus of these efforts was on resource assessment and technical development, with the aim of providing clean energy to Northern and remote communities that lack access to the electrical grid and rely heavily on fossil fuels for their electricity supply.

The Hydrokinetic Resource Assessment using SAR Satellites (HyRASS) tool, developed in partnership with the University of Manitoba and NRCan's Canada Centre for Remote Sensing (CCRS), has been validated and used to identify high-energy areas in rivers for over 120 remote communities. The datasets of attractive river hydrokinetic sites, focused on remote communities, have been submitted to the Federal Geospatial Platform (FGP) for publication. Additionally, optical satellite datasets for river ice-free locations covering nearly all provinces and territories have also been submitted to the FGP for publication. These open-water areas with sufficiently high-water velocities to inhibit ice formation during Canadian winters are potential sites for hydrokinetic turbines.



Model domain, mesh, and its interpolated Digital Elevation Model (DEM) for Masset Inlet, Haida Gwaii, British Columbia

CE-O and the Pacific Regional Institute for Marine Energy Discovery (PRIMED) at the University of Victoria (UVic) recently conducted a feasibility study to assess the potential for tidal energy development in Masset Inlet, Haida Gwaii, British Columbia. As part of the assessment, a computational model of tidal flows in the area was created with a refined mesh and validated with field measurements using an Acoustic Doppler Current Profiler (ADCP). This data was used to estimate the extractable energy at proposed tidal energy conversion (TEC) sites and make annual energy predictions.

CE-O, NRC, and Laval University are collaborating to create general guidelines for simulating hydrokinetic turbine arrays and for layout of hydrokinetic turbine arrays in rivers. The guidelines will cover various aspects of hydrokinetic energy, including the review and theory of governing equations and hydrodynamic forces on energy converters, as well as the optimization of power performance in arrays of energy converters. The guidelines will also provide methodologies for numerical and physical modelling of turbine arrays and a case study demonstrating the effective use of modelling tools for turbine array layout. These guidelines are scheduled to be published in March 2023.

University of Victoria (UVic)

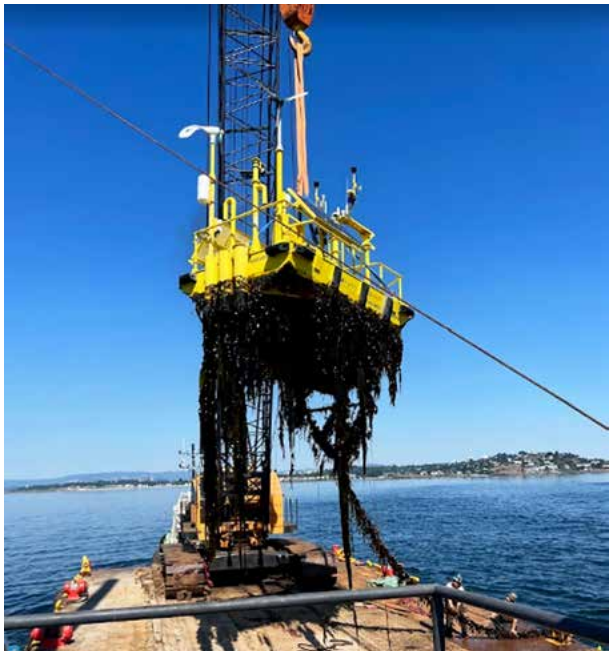
The University of Victoria (UVic) continued to make progress leading several projects and initiative focused on wave energy and clean energy for remote community development working with local suppliers, industry, researchers, and Indigenous communities. UVic continues to lead this work through its established 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 2022 included:

- **Yuquot Wave Energy Project**: The Yuquot Wave Energy Project focuses on front end engineering and design planning for the integration of a wave energy device as a component of Yuquot's future renewable energy microgrid and is being led via a partnership between the Mowachaht/Muchalaht First Nation, Barkley Project Group and Environmental Dynamics Inc. A request for information from wave energy developers will be released in 2023 to determine an optimal technology partner for the community. This

FLiDAR redeployed for further data collection and validation

will be a first of its kind wave energy project in Canada that can pave the way for future projects and help prove wave energy as a component of community microgrid that could be replicated elsewhere.

- **Wave measurement buoy testing:** In partnership with AXYS technologies, PRIMED has been testing of a FLiDAR at Trial Island, British Columbia. The buoy was recovered in 2022 and re-deployed with the help of Salish Sea Industrial Services. In 2022, PRIMED also recovered the the WatchMate at Amphitrite Bank and the TriAXYS at Long Beachand replaced them with alternates so the originals could be brought back to shore for data collection and maintenance.
- **Marine Energy Atlas:** Work continues in collaboration with the National Research Council Canada (NRC) on the Marine Energy Resources Atlas Canada (MERACAN). The website is live (https://meracan.ca/) with additional datasets being added from PRIMEDs field work activities along with other project collaborators. The Atlas allows for easy access and analysis of marine resource data to support academia, industry, and stakeholders interested in marine renewable energy. The Atlas will be iteratively updated with measurement data to provide more information on Canada's marine energy resources.



July recovery of FLiDAR for maintenance

TECHNOLOGY DEMONSTRATION

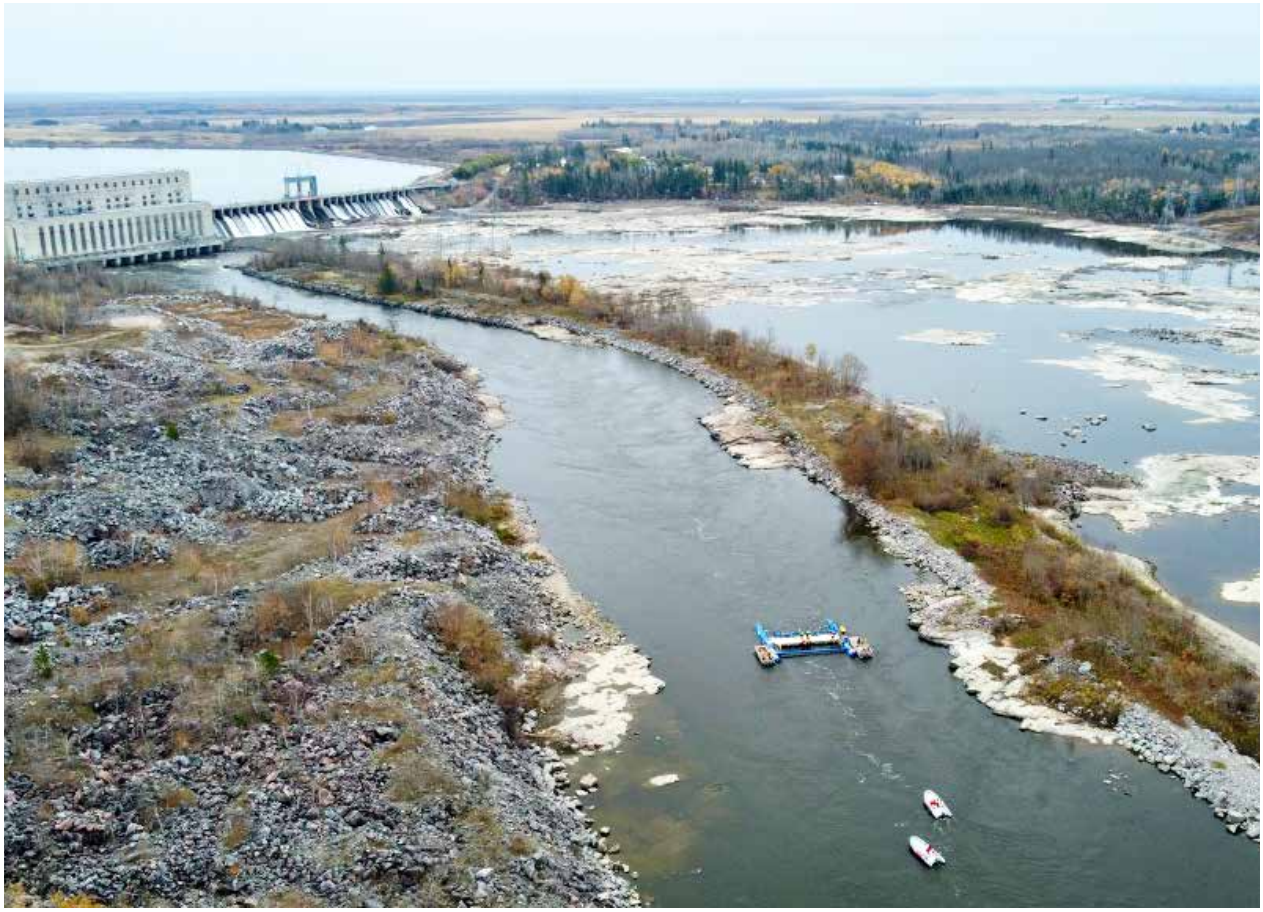
Existing Open Sea Test Sites

FORCE is Canada's lead 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 2022, tidal energy projects led by Sustainable Marine, BigMoon Power, and DP Energy continue to advance, achieving key project development milestones.

Projects in the Water

Ocean Renewable Power Company (ORPC) Canada

ORPC Canada successfully launched its first RivGen Power System, which generates electricity from free-flowing rivers and tidal currents, at the Canadian Hydrokinetic Turbine Test Center in Manitoba. This project will serve to demonstrate the baseload renewable energy system to the Canadian market, particularly to off-grid and Indigenous remote communities. The launch at CHTTC included a number of "firsts" for ORPC – it was the deepest deployment of a RivGen device to date (approximately 12 m/40 ft to the riverbed) and the first bow-down deployment of a RivGen device. Leading up to deployment, ORPC ensured participation and inclusion of Indigenous communities' knowledge in open house activities as well as assembly site visits.



ORPC RivGen® device arriving at CHTTC project site, with Manitoba Hydro's Seven Sisters Generating Station in the background

Sustainable Marine

In May 2022, Sustainable Marine announced it had delivered the first floating in-stream tidal power to Nova Scotia's grid, using the 420 kW PLAT-I 6.40 floating tidal energy platform built in Nova Scotia. The platform was deployed and supported by its multipurpose construction vessel called the Tidal Pioneer, and moored via the company's Swift Anchors technology. The Tidal Pioneer is a multicat, and is 26 m long and 11 m wide. Its offset superstructure allows for a large working deck area, and the square bow is equipped for pushing barges.

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

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

Planned Deployments

Big Moon Power

In 2021-2022, BigMoon has been engaged in the assembly of its first device at East Coast Metal Fabrication in the Sydport Industrial Park. BigMoon plans to build a total of 18 devices, each generating about half a megawatt of electricity, or enough to power about 500 homes. East Coast Metal Fabrication has stated that assembling the unit creates up to 20 full-time jobs for up to six months. Each unit has a large wheel suspended between the pontoons of a 30-metre barge anchored to the ocean floor. The barge swivels to face the current in both directions. The "Falcon" was first launched in September 2022 and is currently in trials.

DP Energy

From November 2021 to April 2022, Haligonia Tidal Energy (DP Energy) deployed and retrieved a small monitoring platform in Berth E. The monitoring platform contained sensors used to demonstrate equipment functionality at the FORCE site. DP Energy plans to deploy 6 Andrtiz Hammerfest Hydro (AHH) MK1s; the Mk1 has an 18.4 m diameter rotor and rated power of 1.5 MW for a project total of 9 MW. The turbine is a horizontal axis, 3 bladed, seabed mounted tidal turbine, which has been successfully deployed (3 machines) at MeyGen in Scotland. The first of the MK1 turbines is scheduled to be installed and commissioned in mid 2024, subject to regulatory approval and final investment decision by the parties.

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. Fabrication has been completed and deployment for the first phase is targeted for spring 2023.

ORPC Canada

In 2022, ORPC Canada completed two years of community visits, resource assessment activities, and research and analysis, of the hydrokinetic potential of the Qikiqtani region, Nunavut, working in partnership with the Nunavut Nukkiksautiit Corporation, which seeks to promote economic enhancement opportunities through renewable energy development for Nunavut Inuit.

Sustainable Marine

Sustainable Marine is preparing to deliver the world's first floating tidal array at FORCE, using its demonstration site at Grand Passage, Nova Scotia to prove up its technology and environmental monitoring systems, before commencing deployments in the Minas Passage. It has developed 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 completed construction of the Tidal Pioneer, an advanced inshore construction vessel that is now operating and will be used to perform complex tasks for the high-flow site at FORCE.

Yourbrook Energy Systems

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.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

In June 2022, Marine Renewables Canada entered in a Memorandum of Understanding (MOU) with the European Leaders of Blue Energy (ELBE) to support partnerships, knowledge transfer and supply chain growth in tidal energy, offshore wind and wave energy amongst their collective memberships.

RELEVANT NATIONAL EVENTS

Marine Renewables Canada 2023 Annual Conference November 14-16, 2023 Ottawa, Ontario

China

AUTHOR:
Peng Wei, National Ocean Technology Center

OVERVIEW

In 2022, in order to achieve the goal of "carbon peak and carbon neutral", China released and implemented a series of strategies and actions to support the development of wind energy, solar energy, ocean energy and other new energies, and released a series of implementation plans and supporting measures in relevant sectors and industries, with a view to building a "1+N" policy system of carbon peak and carbon neutral. China will continue to 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 2022, the National Development and Reform Commission and the National Energy Administration jointly released the *14th Five-Year Plan for a Modern Energy System*. According to the plan, China will develop and utilize ocean energy in accordance with local conditions, and promote the application of ocean energy in such fields as island power supply and offshore energy supply.

In 2022, The National Development and Reform Commission, the National Energy Administration, the Ministry of Finance, the Ministry of Natural Resources and several other ministries jointly released the *14th Five-Year Plan for Renewable Energy Development*. According to the plan, China will continue to implement tidal current energy demonstration projects and actively promote the application of MWs tidal current energy power generating units. China will explore and promote the construction of demonstration projects for wave energy generation, and promote the application of various forms of wave energy generation devices. China will carry out multi-energy complementary demonstration of renewable energy on islands, and explore the application of ocean energy in multi-energy complementary power systems on islands.

Market Incentives

In December 2021, in order to actively respond to climate change, guide and encourage more funds to be invested in addressing climate change, accelerate the formation of a policy environment conducive to climate investment and financing, and support the development of low-carbon industries and technologies, the Ministry of Ecology and Environment and several other ministries launched pilot programs for climate investment and financing. In August 2022, the Ministry of Ecology and Environment released a list of the first batch of pilot cities.

Public Funding Programmes

In order to promote the innovation and development of renewable energy technologies, the Ministry of Science and Technology continues to support research on the efficient conversion mechanism and key technical equipment of ocean energy. A new round of support is expected to start in 2023.

RESEARCH & DEVELOPMENT

The 120 kW module wave energy generation device, developed by the Zhuhai Tianyue Technology Company, the Institute of Electrical Engineering and the Tianjin Research Institute of Water Transport Engineering, has completed construction and is expected to begin sea trials in 2023.

The Guangzhou Institute of Energy Conversion has carried out research and industrialization of wave energy technology for marine instruments power supply. The "Hai Ling" and "Hai Xing" series wave energy offshore buoy power supply devices have been applied in the waters near Zhuhai.

120 kW module wave energy generation device

"Hai Ling" and "Hai Xing" series wave energy offshore buoy power supply devices

TECHNOLOGY DEMONSTRATION

Existing Open Sea Test Sites

The Ministry of Natural Resources continues to promote the construction of the National Marine Comprehensive Test Site. At present, the Ministry of Natural Resources has signed agreements to cooperate on jointly building the National Marine Comprehensive Test Site (Weihai), the National Marine Comprehensive Test Site (Deep Sea) and the National Marine Comprehensive Test Site (Zhuhai) with the local governments of Shandong Province, Hainan Province and Guangdong Province respectively.

Projects in the Water

The Zhejiang Wenling Tidal-PV Complementary Power Station: On May 30, China's first tidal-PV complementary power station was connected to the grid in Zhejiang Province. The PV power station was built in the reservoir area of the Jiangxia Tidal Power Station, with a total installed capacity of 100 MW and an estimated annual generating capacity of over 100 million kWh.

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 Company and other units. Two 500 kW WECs have been built and deployed to open sea

Zhejiang Wenling tidal-PV complementary power station

test near Wanshan, Guangdong Province, during which they successfully withstood several typhoons. The project is scheduled for demonstration operation in 2023.

Wave Energy Aquaculture Cage: The semi-submersible aquaculture platform Penghu had 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. Based on the semi-submersible aquaculture platform technology, GIEC has completed the final design and construction of several types of deep-water aquaculture platforms to meet the needs of users in different sea areas, and has obtained a number of commercial orders.

LHD Tidal Current Energy Demonstration Project: The continuous operation time of the LHD tidal current energy demonstration project has exceeded 60 months until December 2022. In March 2022, the new MWs turbine developed by LHD was deployed and connected to the grid.

Zhoushan Tidal Current Energy Demonstration Project: The Zhoushan tidal current energy demonstration project was developed by the China Three Gorges Corporation. The project has completed the technical upgrade and installation of the tidal current energy turbine, and will carry out grid-connected demonstration operation in 2023.

500 kW WEC "Zhoushan"

500 kW WEC "Changshan"

Deep-water aquaculture platform

LHD demonstration project in operation

RELEVANT NATIONAL EVENTS

On 24-26 November, the **China Marine Economy Expo 2022 (CMEE2022)** was held in Shenzhen. As part of CMEE2022, the China Marine New Energy Industry Development Forum was held on 24 November. The forum was themed "*Promoting the High-Quality Development of Marine New Energy Industry to Achieve the Goals of Carbon Peak and Carbon Neutrality*". With the goal of achieving a comprehensive replacement of fossil energy with green energy in the marine field as early as possible, this forum held discussions over hot issues of the marine new energy industry including guidance and schemes, skills and innovation, industrial application demonstration, public services, as well international cooperation to attract relevant entities of the whole supply chains to actively participate in China's technological innovation and management innovation in the marine new energy industry, to build a national exchange platform for realizing high-quality industrial development. 14 representatives from the OES-TCP, the Pacific Northwest National Laboratory, the European Marine Energy Centre, the University of Strathclyde, the China Three Gorges Corporation and other institutions gave keynote speeches and professional presentations. More than 1,000 people participated in the forum online and offline.

China Marine New Energy Industry Development Forum 2022

Denmark

AUTHOR:
Kim Nielsen, Ramboll

OVERVIEW

Wavepiston is preparing their full-scale installation at the test site PLOCAN in Gran Canaria to be in operation Q2-2023. **EXOWAVE** deployed and tested its first wave to water plant in Oostende, Belgium at the Blue Accelerator test center. EXOWAVE has also been awarded a large grant from EUDP to develop and deploy a scaled up demonstration wave to electricity plant at DanWEC between 2023-2024. **Floating Power Plant** is progressing with its project to deploy its combined wind (4.2 MW), wave (1 MW) and hydrogen (1.2 MW) commercial demonstration project at PLOCAN. The hydrogen is to be provided by TechnipFMC. The development and construction of a 200 kW PTO dry test facility is progressing, with support from the EUDP, which will be commissioned in 2023. **Resen Waves** is part of the Project Greensand and provides small scale 300 W Smart Power Buoys for autonomous power and real time data communication between the sensors on the seafloor and the office on shore at the Nini A fields in the North Sea. **Crestwing** received 1m€ support from EUDP for further development.

As part of the Danish Royal Visit to the Netherlands 2022 his royal highness, the Crown Prince Frederik of Denmark, paid a visit to the Dutch Marine Energy Centre (DMEC). As chairman for the Partnership for Wave Power in Denmark I had the great honour to be invited by the Embassy of Denmark in the Netherlands to present the Danish development of Wave Power Systems for his royal highness. The Crown Prince was very interested and recalled that he had paid a visit to WaveStar at DanWEC 10 years earlier in 2012.

Danish Partnership for Wave Power www.wavepartnership.dk

SUPPORTING POLICIES FOR OCEAN ENERGY

National Strategy

In May 2022 the North Sea Summit gathered the heads of the Netherlands, Denmark, Germany, Belgium, and the European Commission in a decisive and historic step paving the way for green energy production amongst the democracies sharing the marine space of the North Sea.

The Danish, Dutch and EU Marine and Ocean Energy associations used this opportunity to send a joint statement to the Dutch and Danish governments and parliaments to also integrate wave energy into the energy strategy for the North Sea region by setting both national and regional deployment targets.

Wave energy is a central part of Europe and the North Sea region's future renewable energy system. The EU's Offshore Renewable Energy Strategy includes a 40 GW target for ocean energy and highlights the North Sea as a renewable energy hotspot. Adding wave energy aligns well with the vision for the North Sea Marine Spatial Plan and can count on stakeholder support from other sea space users.

Market Incentives

There are no incentives for ocean energy in DK.

Public Funding Programmes

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

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

Each of these funding programmes support 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 is big in Denmark and even after more than 40 years of development, it still requires a large amount of funding for further development.

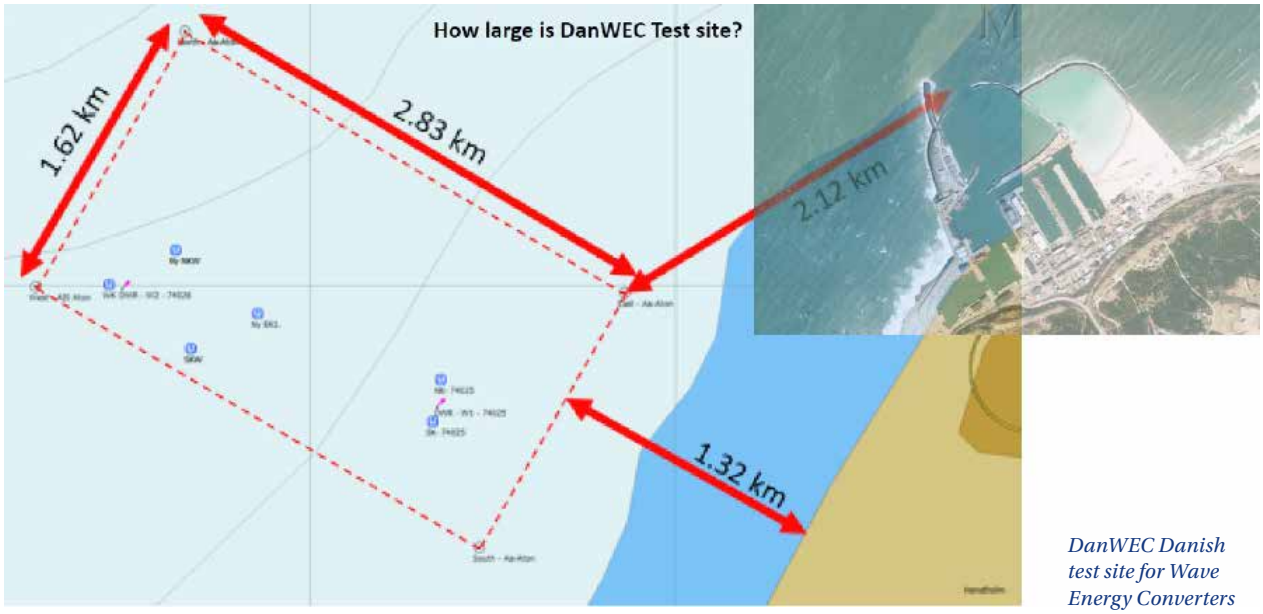
RESEARCH & DEVELOPMENT

In this section we present the status of the R&D developments undertaken by the WEC developers and Universities:

Aalborg University and the Danish test site DanWEC and FPP are Danish partners engaged in the Ocean Energy Scale-Up Alliance (OESA) supported by the EU North Sea Region (NSR) to contribute to the accelerated greening of the region. Aalborg University has collaborated with Exowave on modelling and tank testing of their system prior to prototype testing. AAU is partner in the ongoing EU Horizon2020 projects. LiftWEC and VALID, and the two EUDP projects OES Task 10 and PTO Twin (FPP dry test rig).

DTU is involved in numerical modelling under OES Task 10 but also supporting the development of numerical models for several of the Danish WECs. In 2022 two DTU master projects investigated the wave induced bending moment on the floating attenuator KNSwing in the lab.

Finally, the Marine Energy Alliance (MEA) in 2022 has been supporting development with technical and commercial advice on how to advance the KNSwing.



DanWEC Danish test site for Wave Energy Converters

TECHNOLOGY DEMONSTRATION

Existing Open Sea Test Sites

DanWEC is the Danish test site for Wave Energy Systems and can provide documented wave conditions that can help validate tests. DanWEC is both an offer to help developers and a test site for the state and private companies to find the most convincing wave energy technologies. The test site has a water depth from 10 meters to 25 meters, and the area marked measures 1.6 km by 2.8 km, as shown in the figure above. DanWEC has a geological report on the bottom conditions carried out by GEUS in 2015.

Projects in the Water

EXOWAVE completed in October 2022 the demonstration of its wave to water plant in Oostende, Belgium. The plant was installed at the Blue Accelerator test site. Prior to that, extensive onshore testing took place in Denmark. The plant installed was configured as a single wave energy converter. The installation of the prototype (figure on the right) can be viewed on this link:

https://www.pomwvl.be/nieuws/nieuwe-testen-gestart-bij-blue-accelerator

EXOWAVE prototype tested in Oostende

Projects Planned for Deployment

Wavepiston has started their installation of the full-scale system at the test site PLOCAN in Gran Canaria. It will be in operation by Q2-2023. A string of energy collectors will pump seawater to the PLOCAN platform for power generation and desalination. Initial testing was carried out at the PLOCAN test site in 2020 – 2021.

Exowave is kicking off in Q1 2023 the development of its up=scaled wave to electricity plant to be deployed offshore at DanWEC in 2024. The plant will be configured as a block of 3 wave energy converters, providing pressurized sea water to a Pelton hydro turbine for power generation.

Floating Power Plant FPP is combining 2-3 MW wave and 10-15 MW wind power on a common floating platform and is involved in several development tracks including Power-to-X with the integration of hydrogen. FPP is progressing its project to deploy its combined wind (4.2 MW), wave (1 MW) and hydrogen (1.2 MW) commercial demonstration project at PLOCAN in 2025. The company now has 15 employees and significant engagement for commercial deployments in the UK in 2026-2027.

Resen Waves Waves is part of the Porject GreenSand (www.ProjectGreensand.com) and provides small-scale 300 W Smart Power Buoys for autonomous power and real time data communication between the sensors on the seafloor and the office on shore at the Nini A fields in the North Sea.

Crestwing has during 2022 worked on 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. Just before Christmas 2022 – Crestwing received positive news of 1m€ support from EUDP for further development. Crestwing has established a range of industrial and financial partnerships that is aimed at the sale of the first farm of multiple 2.5 MW Crestwing devices in 2023-2024. For this work, Crestwing has received €1m from EUDP.

Other Danish Concepts Under Development

Other Danish concepts like **Wavestar** and **Wave Dragon** are seeking funding to continue development. WaveDragon is an overtopping WEC technology and WaveStar completed a half-scale test at the Danish test site DanWEC in 2013, where performance and availability data were collected. This data is now included in the IEC TC 114 TS 64 100 as an example of performance measurements.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

The Danish participation in the OES Task 10 on numerical modelling and validation including the two Danish Universities DTU and AAU, coordinated by Ramboll and including FPP as a partner is funded by EUDP.

DTU and Wavepiston are involved in the Horizon 2020 supported VALID project in relation to hybrid and accelerated testing of the Wavepiston energy collector pumps.

European Commission

AUTHORS:
Matthijs Soede, Xavier Guillou and Céline Frank (European Commission)
Evdokia Tapoglou (EC, Joint Research Centre)
Francesca Harris (EC Climate, Infrastructure and Environment Executive Agency)

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[4].

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 EU funding programmes. The new Horizon Europe programme for Research, Demonstration and Innovation has launched new calls in 2022. The new Innovation Fund support programme has been launched in 2020 and published new calls in 2022 with deadlines in 2023.

As part of the Clean Energy Technology Observatory the Joint Research Centre of the European Commission has published the report 'Ocean energy in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets'. It provides an evidence-based analysis feeding the policy making process and hence increasing the effectiveness of R&I policies for clean energy technologies and solutions. It monitors EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal; and assesses the competitiveness of the EU clean energy sector and its positioning in the global energy market.

4 https://ec.europa.eu/oceans-and-fisheries/ocean/blue-economy/sustainable-blue-economy_en

SUPPORTING POLICIES FOR OCEAN ENERGY

European Strategy

The European Commission presented the European Green Deal[5] in 2019. It is 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.

In response to the hardships and global energy market disruption caused by Russia's invasion of Ukraine, the European Commission presented the REPowerEU Plan.

REPowerEU is a plan for 1) saving energy, 2) producing clean energy and 3) diversifying their energy supplies. The plan sets out a series of measures to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition, while increasing the resilience of the EU-wide energy system. It is backed by financial and legal measures to build the new energy infrastructure and system that Europe needs. It is confirming that renewables are the cheapest and cleanest energy available, and can be produced domestically, reducing our need for energy imports. REPowerEU will speed up the green transition and spur massive investment in renewable energy. We also need to enable industry and transport to substitute fossil fuels faster to bring down emissions and dependencies. In the context of ocean energy, the REPowerEU proposes the speed up of permitting processes by recognising renewable energy as 'an overriding public interest'. Moreover, renewable energy projects will be fast-tracked by the introduction of "go to areas" for renewables development. Regulatory sandboxes were also proposed for testing of innovative technologies, products and services'.

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. In 2022 a study on regulatory barriers and recommendations for clean energy transitions on EU islands was commissioned. The study was delivered in January 2023.

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. So far, the integration of ocean energy in the NECPs has been limited but a few EU Member States (Ireland, Portugal, and Spain) have included targets for tidal and/or wave energy production in their plans. At the end of 2022 the European Commission has invited all Member States to revise/update their plans. We expect that with the upcoming revision of these plans and the progress of the ocean energy sector, more MSs might take it into account.

5 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 more than 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.

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

Horizon Europe is the successor of Horizon 2020 and the total budget for Research and Innovation is 95.5 billion EUR. The programme started in 2021 and includes topics on ocean energy development under the Climate, Energy and Mobility subprogramme.

In 2021/2022 there was a call for projects with the following topics ' Demonstrations of wave energy devices to increase experience in real sea conditions', 'innovative foundations, floating substructures and connections systems for floating PV and ocean energy devices', and 'Demonstration of innovative rotor, blades and control systems for tidal energy devices'.

In 2022 a call for projects open for the demonstration of sustainable tidal energy farms (EU funding budget 40 million Euro). In 2023 a call will be opened for the demonstration of wave energy farms (Eu funding budget 38 million Euro) and the development of innovative power take-off and control systems for wave energy devices (EU funding budget 8 million Euro).

The Innovation fund launched also in 2022 calls to help with the demonstration of first-of-a-kind highly innovative projects. A specific call was opened for mid-sized projects. A higher degree of innovation is expected, but not yet large-scale demonstration or commercial production. If the project is successful, the proposed technology should move to the next stage of a large-scale demonstration or first-of-a-kind commercial production. This specific call seems suitable for further development of ocean energy towards the market.

The European Maritime, Fisheries and Aquaculture Fund (EMFAF) is the follow-up of the EMFF programme and runs from 2021 to 2027 and supports the EU common fisheries policy (CFP), the EU maritime policy and the EU agenda for international ocean governance. It provides support for developing innovative projects ensuring that aquatic and maritime resources are used sustainably.

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.

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 Horizon 2020 and Horizon Europe R&D projects in the last four years and which are still ongoing or just finished in 2022, is presented in the table below, focusing on the objective of the newly announced projects. In 2022 a project was funded with the focus of OTEC and two projects supporting substructures for floating PV. 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 and Horizon Europe (2022 onwards) projects awarded since 2019. 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
2022	MAXBLADE	Maximising tidal energy generation through Blade Scaling & Advanced Digital Engineering	FMC Technologies	The project will specifically focus on delivering a 70% increase in rotor swept area of the technology by addressing design, reliability, condition monitoring, maintenance and control issues relating to tidal turbine blades.
2022	SUREWAVE	Structural Reliable Offshore Floating PV Solution integrating circular concrete floating breakwater	SINTEF	The project will develop and test an innovative concept of Floating Photo-Voltaic (FPV) system consisting of an external floating breakwater structure acting as a protection against severe wave-wind-current loads on the FPV modules, allowing increased operational availability and energy output, thus unlocking the massive deployment of Offshore FPV.

2022	PLOTEC	Tested Optimised Floating Ocean Thermal Energy Conversion Platform	PLOCAN	The project is to achieve a successful demonstration of the novel designs and materials for an ocean thermal energy conversion (OTEC) platform capable of converting solar heat energy stored in the oceans surrounding the Overseas Countries and Territories of the EU, Small Islands and Developing States, and the Asian and African continent into reliable, baseload power with an economical cost model.
2022	NATURSEA -PV	Novel Eco-Cementitious materials and components for durable, competitive, and bio-inspired offshore floating PV structures	Tecnalia	The main objective of the project is to improve the overall lifetime, reliability, and maintainability of marine substructures for offshore floating PVs and thus reduce its LCOE. It will develop innovative structural designs capable of handling the marine conditions, at the same time ensuring the durability and minimizing (un) installation costs.
2022	WEDUSEA	Wave Energy Demonstration at utility Scale to Enable Arrays	New Wave Technologies Ltd (Ocean Energy)	The project led by Irish Wave Energy Developer, Ocean Energy, will demonstrate a grid connected 1MW OE35 floating wave energy converter (known as the OE Buoy) at the European Marine Energy Test Site (EMEC) in Orkney, Scotland.
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 technologies from developers across Europe.
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.

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/EMFAF projects awarded since 2019. 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
2022	FLORA	FLORA (Floating Radar) is an autonomous, in-situ ocean station powered by wave energy and designed for continuous, long-term operational oceanography including bird tracking.	Wedge	The core energy system is based on a [point absorber type] wave energy converter integrated with battery storage. This technology has been developed by us over the past 10 years as a wave energy converter which will now be hybridized with photovoltaic capacity. The real innovation of the project will be the technical compatibility that we will enable between our existing system and a 3D bird radar as well as the associated telemetry.
2020	Wavefarm	WaveRoller Wave Farm Scale-Up - Preparing to deploy the world's first commercial wave energy farm	AW-Energy (Finland)	This project will prepare AW-Energy to deliver the world's first large-scale WaveFarm, with up to 24 integrated WaveRoller units. Two public energy companies stand ready as customers for pilot developments: in Sri Lanka (5 MW,) and Indonesia (10 MW).
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 WE through the collection, processing, analysis and sharing of environmental data around devices operating at sea and modelling of cumulative impacts of future larger scale WE deployments.

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).
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.

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
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
BlueGIFT	Atlantic Area	No	€2,500,000	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

Study on regulatory barriers and recommendation for clean energy transition on islands (released January 2023

https://clean-energy-islands.ec.europa.eu/insights/publications/study-regulatory-barriers-and-recommendation-clean-energy-transition-eu

Clean Energy Technology Observatory: Ocean energy in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets

https://setis.ec.europa.eu/ocean-energy-european-union_en

The EU Blue economy report 2022

https://op.europa.eu/en/publication-detail/-/publication/156eecbd-d7eb-11ec-a95f-01aa75ed71a1

EU programmes; Funding & tender opportunities

https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities

France

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OVERVIEW

In 2022, French activity in Ocean Energy remains 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, in several locations among which in the Raz Blanchard which is one of the most significant potential tidal energy sites in the world. Meanwhile, testing proceeds for specific turbines, wave energy converters and hybrid systems designed for non-interconnected sites or for alternative usage. Now that a fast growing community of engineers, researchers and skilled professionals firmly supports the deployment of ORE in the country, the Ocean Energy sector takes its share in this momentum.

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.

The Pluri-annual Energy Policy is currently being revised. Both the new international energy market paradigm and the recent progress in the ocean energy sector could lead the government to include targets for the most advanced sectors (at least tidal). The new version of the Policy is expected to be published in 2024.

It is also worth recalling the latest report of the French Transmission System Operator (TSO) called "Energy Pathways 2050" dedicated to the elaboration of carbon

neutral scenarios to 2050, as it can provide a framework for the evolution of this Policy. Indeed, 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).

The policies, permitting and incentives for offshore energies depend on the Ministry of Ecological Transition, and their deployment can rely on a marine spatial planning with a planning guideline called the Strategic Seaboard Document (DSF), also to be periodically revised. An enlightened public debate is promoted 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 and a forthcoming update in 2023) 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 TSO, 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 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 yearly labelling process, called CORIMER, 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. At the time being, this support begins with the ADEME. The cumulative budget for ocean energy projects (any type of offshore wind excluded) awarded in or before 2022 by ADEME is 78 M€, which includes 7 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.

RESEARCH & DEVELOPMENT

Collaborative projects of the Institute for the Energy Transition FEM

As a national public-private research centre (teams in Brest, Nantes, Marseille and since November 2022 in Le Havre) France Energies Marines initiates collaborative ORE R&D projects, in line with its roadmap as Institute for the Energy Transition. The public support comes from the French National Research Agency, ANR, as part of the Investment for the Future Program. 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, open to public access and namely the ORE sector since January 2022. Reports, complete metadata and all kinds of project and field data can be viewed and downloaded on a GIS portal, compliant with the PRIMARE database.
- 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

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

- OCEANSET – support implementation of the OE component of the SET-Plan terminated in 2022.
- ELEMENT – based upon Nova Innovation's RE50 tidal turbine, undergoing onshore laboratory testing and offshore tow testing, before being deployed at the "Etel Ria" located in Brittany over a period of two months from February to March 2023. Prior to this estuary testing, France Energies Marines, involved in the project, performed hydro-kinetic resource assessment and turbulence characterisation. The bio-colonisation process was also characterised by setting up in situ samples for 2 years, in order to assess any potential issue and design an optimal maintenance process.

Biofouling plates for growth rate assessment during the Element project in ria d'Etal. © France Energies Marines

Physical simulations in tank tests for tidal energy converters

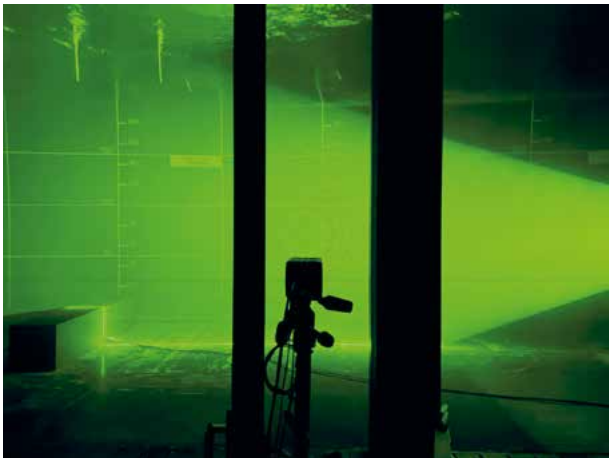
Ifremer, the national research centre for the sustainable exploitation of the seas, performs studies and experiments in close collaborations with many ocean energy developers. Numerical and physical simulations complement each other, before scaled or real-size demonstration at sea. At the Boulogne test tank, after conducting in 2021 a generic study to quantify the impact of vertical velocity profiles on bottom-mounted obstacles in terms of load variations, the wave effects on vortex emission and their dynamic have been quantified in 2022. The distinction of cases of wave propagation, against or with the current, is useful to better understand the energetic exchanges in the wake of large obstacles in a tidal stream.

The effects of such coherent flow structures on the response of a ducted bottom-mounted twin vertical axis tidal turbine (2-VATT) have been studied. The tests have been conducted on a 1/20 scale model of the HydroQuest 1 MW turbine, either with a flat bed or downstream a wide bathymetry obstacle, at a constant far upstream velocity. The results reveal a drop in the average power and loads coefficients of the 2-VATT combined with significantly larger fluctuations. The velocity deficit and the high level of turbulence in the obstacle wake is responsible for a lower average power coefficient and a higher standard deviation compared to the flat-bed configuration. The loads standard deviations are multiplied by 2 to 10 when the 2-VATT is downstream the strong bathymetry obstacle, which increases the risks of structural fatigue failure. However, the turbine drift or toppling risks remain lower than with the flat-bed. The power fluctuations increase appear to be mostly due to the flow shear in the obstacle wake, whereas the loads fluctuations are mostly due to the periodical passing of the coherent flow structures. Thus, a proper characterisation of the flow at each precise turbine locations prior deployment at sea seems highly recommended to design their structure accordingly.

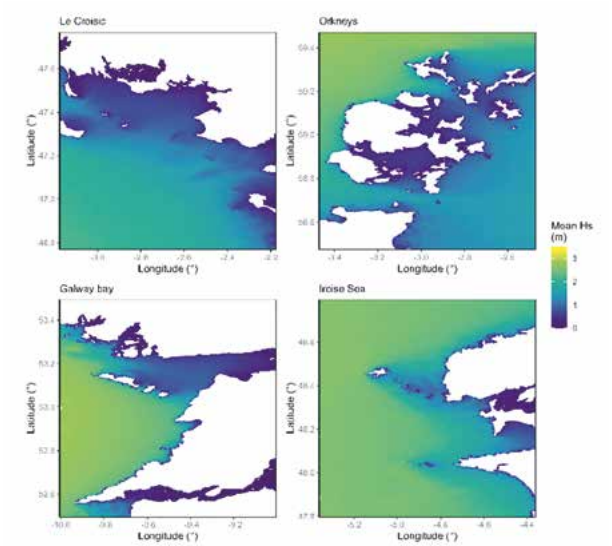
Wave energy refined resource assessment

The ResourceCODE Marine Data Toolbox, resulting from a collaboration programme (Ocean ERA-NET Cofund) between Research Institutes (IFREMER, Centrale Nantes, University of Edinburg and University College

HydroQuest 1 MW prototype at 1/20 scale © Ifremer



PIV measurement in the wake of a bottom-mounted obstacle under wave and current sollicitation © Ifremer



Mean Significant Wave Height. Zoom on different locations extracted from the hindcast dataset

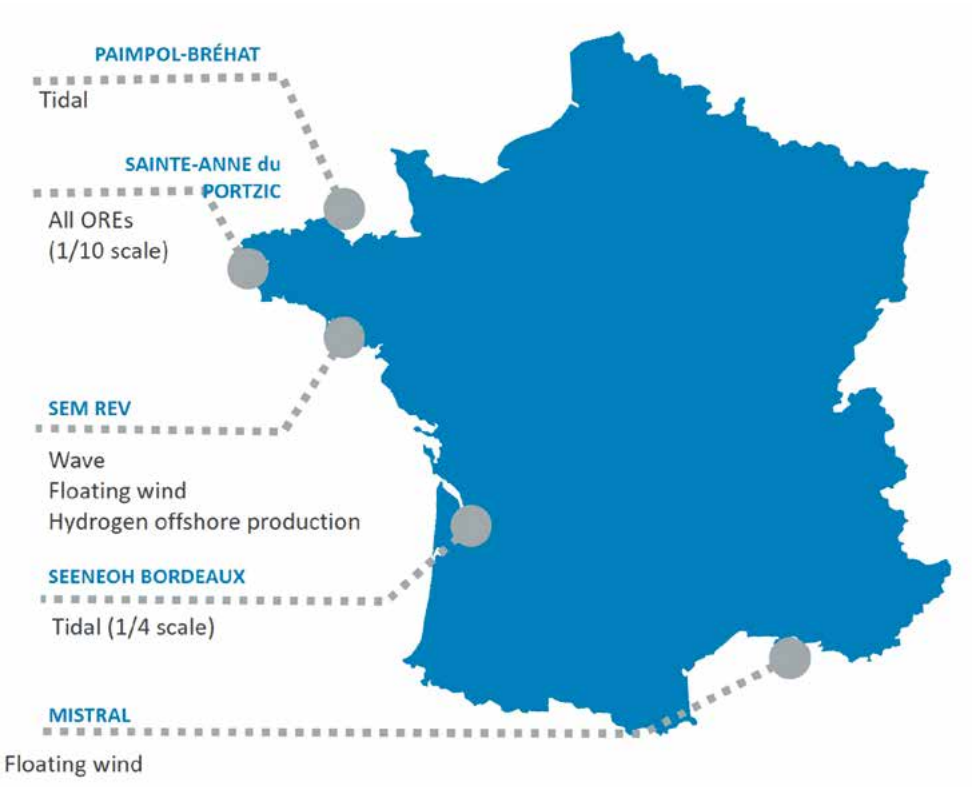
Dublin), Marine Tests Sites (EMEC and BlueWise Marine) and SMEs (Innosea and OceanDataLab), was delivered and made available in open access early 2022 (www.resourcecode.ifremer.fr). The Marine Data Toolbox combines a 27-year high-resolution wave hindcast database, covering the western European waters, together with a set of analytical tools and standard functions for resource assessment, systems design and operations planning. Its main objective is to provide the technology developers with up-to-date advanced tools enabling the capacity to conduct the necessary assessments to reduce uncertainty in expected environmental conditions, and de-risk investment in future technology design.

TECHNOLOGY DEMONSTRATION

Existing Open Sea Test Sites

France offers 4 test sites dedicated to ocean renewable energies, and one additional site specifically dedicated to offshore wind energy. Their operation is gradually being transferred to the Open-C foundation, whose inception dates from December 2022. The co-founders come from the private and the public sectors, with namely Ifremer, Ecole Centrale de Nantes and France Energies Marines as the 3 co-funding research entities.

To date, those test sites can accommodate a total of 12 prototypes for a connection capacity of 35 MW through 52 km of cables at depths ranging between 5 and 75 m. Their development ambitions to reach 16 prototypes for a total of 95 MW between 5 and 195 m depth.



Open-C test sites covering all technologies over the 3 French shorelines

Connexion upgrade at Paimpol-Brehat tidal site: former wet-mate replaced by dry-mate

The **Paimpol-Bréhat test site** has been operating for 12 years by EDF and SEENEOH/Energie de la Lune, with the support of the Brittany Region and Bretagne Ocean Power. It is appropriate for full-scale tidal turbines, 4 prototypes of which have been tested to date. The subsea connection system has been upgraded in 2022 to facilitate the connection of the devices to the 3 MW cable. The site now benefits from a three-phase alternating current connection through a terminal plug that can be connected out of the water, avoiding the underwater connection by divers. This more standard dry-mate connection is meant to improve the attractiveness of the site for developers. These reconfiguration works were performed as part of the European "TIGER" (Tidal Stream Industry Energizer) project under the sponsorship of the Brittany Region and EDF and with co-funding from the INTERREG Channel programme. Within TIGER framework, the Paimpol-Bréhat test site has also contributed to some academic actions from French universities, e.g. current-turbulence coupling modelling (UniCaen) or material ageing testing (ULHN), for which SEENEOH/Energie de la Lune has achieved the marine operations. SEENEOH/Energie de la Lune has started some additional physical and environmental monitoring of the site in order to improve its tidal resource assessment and complete its environmental baseline, which will support the renewal of the permits for OPEN-C.

The **Bordeaux river site SEENEOH** is dedicated to intermediate scale tidal prototypes. 5 such prototypes have been tested there since its inception in 2018.

Regarding multi-technology capacities, the development of the **SEM-REV test site** by Ecole Centrale de Nantes was initiated in 2007 to support, as a first step, the wave energy conversion research and industry (certification in 2011). After its certification for the testing of floating wind turbines in 2013, it became the first European offshore and multi-technology test site. It now offers the capacity to connect 3 different devices/technologies to the grid at the same time.

The **Sainte-Anne du Portzic test site** is designed to accommodate 1/10 scale prototypes of floating offshore wind and wave technologies in a marine environment close to real conditions. As an ongoing test, the DIKWE prototype is described further.

Projects in the Water

Tidal Energy Projects

A total of five tidal energy projects are currently planned for (or in) deployment, pilot or demonstration.

In April 2022, **Sabella**'s D10-1MW bottom-fixed tidal turbine was redeployed, in the Fromveur passage, the second French hotspot for tidal resource off the Western coast of Britany. This happened in the framework of the PHARES project [1], which mixes wind, tidal and solar energy, and storage capacity to feed the off-grid Ushant island with more than 80% of renewable electricity. The turbine has been operating successfully accumulating operational hours, and a new electro-technical smoothing system before injection into the local grid has been validated. In December 2022, Sabella also connected a small electrolyser to the D10 turbine to experiment the green hydrogen production with a tidal turbine. The experiment has been successful, driving to new opportunities for energy storage.

Wave Energy Projects

The ¼ scale prototype of **DIKWE**, a wave energy converter designed to be inserted in port infrastructures, has been installed in April 2022 off the local dyke of Sainte Anne du Portzic. Tests will finish in March 2023. The TRL is 6-7. The device consists of an Oscillating Surge Wave Energy Converter with a top horizontal axis included in a chamber. The tests, conducted in partnership with GEPS Techno, Ifremer and GROUPE LEGENDRE, have confirmed the system's performance in terms of platform stability and energy conversion thanks to various control strategies of the Power Taker Off.

Projects Planned for Deployment

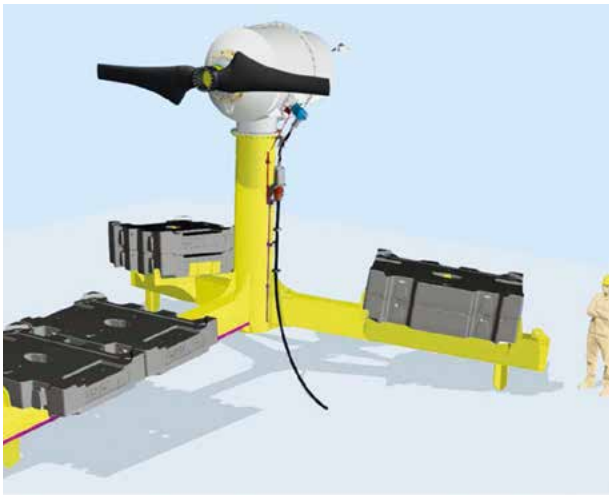
Tidal Energy Projects

After one year of successful testing of its 1 MW vertical axis tidal turbine at Paimpol-Bréhat test site in 2021, **Hydroquest** now ambitions to deploy a 7 x 2.5 MW pilot farm in the Raz Blanchard/Alderney Race by 2025, which is the hotspot for tidal resource in France. This deployment is planned in the framework of the Normandie Hydro project which is supported by the FloWatt consortium (Hydroquest, Qair and CMN).

In the Gulf of Morbihan, **SABELLA** is planning to deploy early 2024 two 250 kW tidal turbines, in the framework of the TIGER project. This experimentation will last for 3 years and will aim at testing new improvements to reduce OPEX costs and improve reliability of the equipment.

A 3-month test of the RE 50 tidal device prototype developed by the Scottish company Nova Innovation was granted in late 2022 for a deployment in ria d'Etel, Southern Brittany, as part of the European research project Element.

DIKWE device, Sainte Anne du Portzic test-site, © Ifremer, Olivier Dugornay



Computer aided design sketch of the Nova RE 50 with its gravity foundation system for ria d'Etel, Element project

Wave Energy Projects

For **DIKWE**, project phase 3, the technical studies are on the way for the construction and the installation of an 800 kW demonstrator, in the western part of Britany. The target time for the installation is Q3 2024.

Salinity Gradient Project

The French company **Sweetch**, together with the utility Compagnie du Rhône, develops the demonstrator of a salinity gradient system in Port-Saint-Louis-du-Rhône (Mediterranean coastline) that aims to be operational in 2024.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

The Tidal Stream Industry Energiser Project, known as TIGER, is the biggest ever Interreg project (46 M€) 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, new multi-MW deployments are prepared, updating consenting process and expecting the agreement of a specific feed-in tariff;
- Paimpol-Bréhat (whose upgrade has already been mentioned as an outcome of the TIGER project);
- Morbihan Gulf (South of Brittany), on a site consented in 2020, where Sabella will deploy two 250 kW turbines.

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 2021 figures are available. The main results focusing on ocean energies are:

- 395 full-time equivalents (20% more versus 2020, but now 6% of the ORE sector, down from 11% in 2020 due to the rocketing figures in the bottom-fixed and floating offshore wind sector);
- 11 M€ of turnover.

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 3,000 international players (politics, contractors (energy operators and industrials), technological experts, NGOs, researchers, investors and subcontractors) - around an exhibition space with 200 exhibitors, industrial and 80 technical conferences, B2B meetings, job-dating sessions, pitches, an interview stage, research area and local technical visits. The 6th edition of SEANERGY has taken place from June 15 to 17 June 2022, in Le Havre. Next edition will take place from June 20 to 21 2O23 for the 1st time in Paris, a convenient place for an international attendance.

Germany

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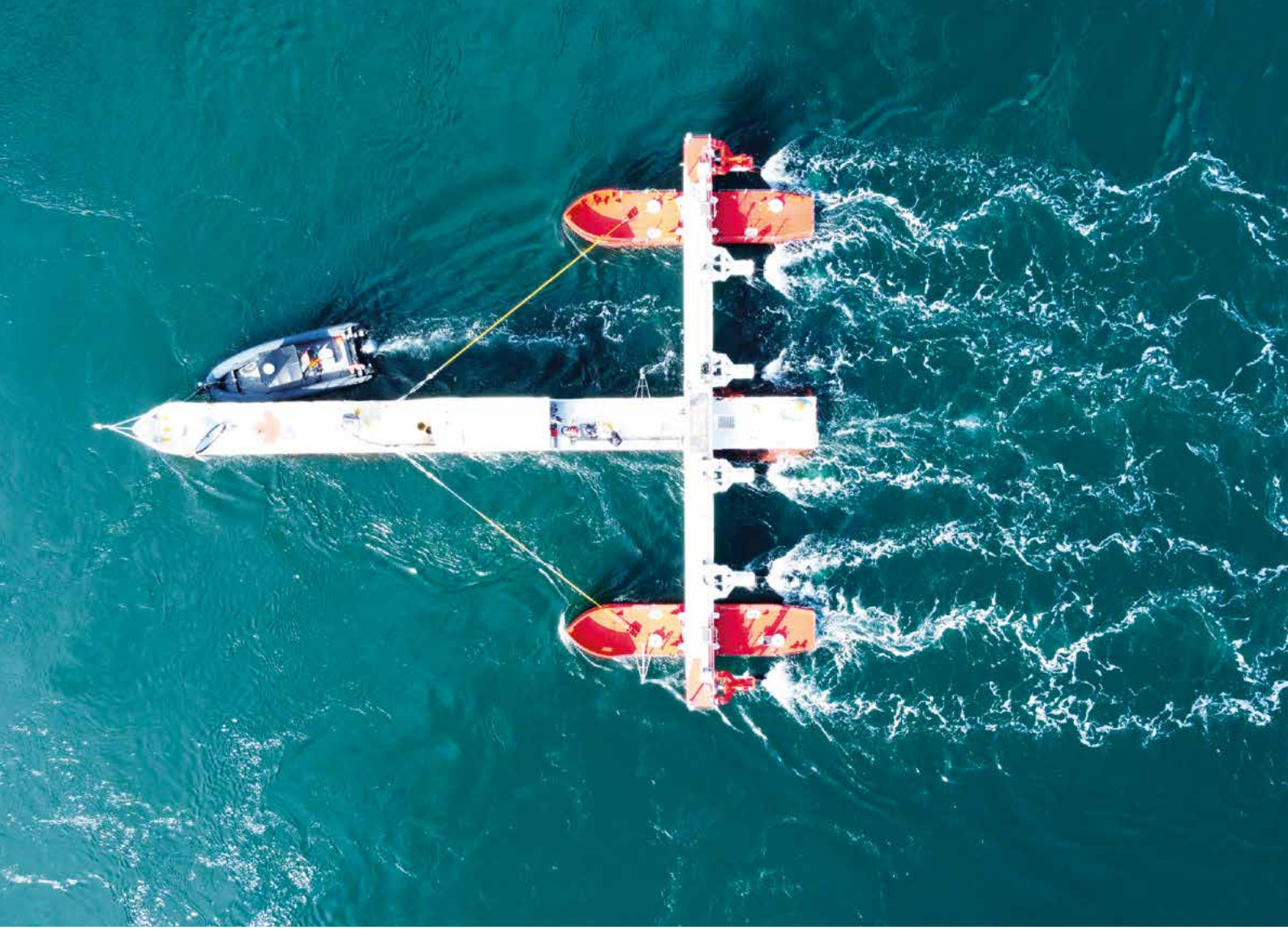
RESEARCH & DEVELOPMENT

SCHOTTEL HYDRO

Tidal power developer SCHOTTEL HYDRO with its partner Sustainable Marine have officially powered up their tidal energy operation in Canada in June 2022 and are commercially delivering electricity to Nova Scotia's power system. Their PLAT-I 6.4 floating platform is deployed at Grand Passage, Bay of Fundy, and delivered its first kWh to the grid in May 2022, making it the first to deliver in-stream tidal power to the grid in Canada. A detailed test programme has been conducted to prove the performance of the system.

During autumn, the system also used to power a micro-grid integration project, that has been conducted at the Grand Passage substation in collaboration with Canadian company BMT, proving the integration of ocean energy and renewable energy solutions to reduce the dependence of diesel power in island or remote communities. The PLAT-I system, equipped with six SCHOTTEL Instream Turbines rated at 70 kW each, will eventually be re-located to the FORCE demonstration site in the Minas Passage and form part of the world's first floating tidal energy array in the "Pempa'q Project".

SCHOTTEL HYDRO and Sustainable Marine cooperate with German marine energy players Leibniz University Hannover Institute of Production Engineering and Machine Tools (IFW) and M&D Composites in the EvoFoil project. The two-year project aims at delivering a series of design innovations to optimise the performance of tidal turbine blades, while driving down production and operation costs. It is receiving research and development funding from the National Research Council of Canada-Industrial Research Assistance Program (NCR IRAP). Furthermore, SCHOTTEL HYDRO and RWTH Aachen's Chair for Wind Power Drives have won a grant by the German Government in 2022 to conduct the ReCORD (Reduction of Investment, Operation and Development Costs of Marine Current Devices) project. The aim is to reduce the levelized cost of energy of SCHOTTEL HYDRO's SIT turbine technology by at least 30 % by introducing a load monitoring system and facilitating future model driven developments. The project is to start in January of 2023 and will run for three years.



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

SKF

German bearing and seal specialist SKF is participating in the TiPA project. In cooperation with tidal turbine developer Nova Innovation and other partners, the focus of the project is to replace the gearbox and conventional generator in a tidal turbine with a power take-off featuring a high-efficiency, low-maintenance direct drive generator. The lifetime cost of tidal power is expected to be reduced by 20% through this development. SKF was also engaged in the EnFAIT project with Nova Innovation, which concluded in June 2022. The project aimed to demonstrate the development, operation and decommissioning of a tidal power array of six turbines.

India

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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. The National Institute of Ocean Technology (NIOT), an institute under the Ministry of Earth Sciences (MoES), Govt. of India, has mandate to develop technologies for harnessing ocean energy resources. Development and demonstration of ocean energy devices including desalination has received a boost recently through the call for proposals by Ministry of New and Renewable Energy (MNRE) and Dept. of Science & Technology (DST), Govt. of India. Ocean Energy and Fresh Water vertical under 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. NIOT-MoES works towards technology development of ocean energy devices.

Market Incentives

MNRE recently floated calls to fund various proposals related to renewables including wave and tidal. MNRE had earlier notified considering ocean energy such as tidal, wave, OTEC as renewable energy and thus, it shall be eligible for meeting the non-solar Renewable Purchase Obligations (RPO). A call for desalination technologies had been launched by DST for funding proposals related to desalination including powering it through marine energy. Call for funding proposals in ocean energy under Deep Ocean Mission was recently initiated by MoES.

Public Funding Programs

Energy and freshwater from the Ocean is one of the components of Deep Ocean Mission funded by MoES, Govt. of India. As part of this, studies and detailed engineering design for high capacity offshore Ocean Thermal Energy Conversion (OTEC) powered desalination plant and demonstration of scaled down pipe bundle in deep sea are planned to be carried out by NIOT.

Work on a new desalination plant of 100 m^3/day capacity at Kavaratti Island powered by OTEC is currently underway by NIOT. Detailed engineering of the plant components including cold water conduit is under final stages for fabrication.

DST has sanctioned a project on wave powered desalination to IIT-Madras and a start-up.

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 of OTEC and LTTD cycle including turbines. These studies will be helpful for understanding the performance of the integrated large capacity OTEC and Desalination plant. Studies on offshore platforms and cold water conduit(s) have been undertaken towards design of large scale offshore OTEC plant.

Testing of Sindhuja-I off Tuticorin port

Wave Energy

IIT-Madras has attempted a small-scale point absorber based wave energy device called 'Sindhuja'. Experiments were carried out in wave basin of IIT-Madras and preliminary testing in sea was carried out.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

- NIOT will be the 'Project Sponsor' of a study on design of large capacity offshore OTEC plants near Andaman & Nicobar Islands under United States Development Agency (USTDA) call for proposals. This study will be carried out by US based consortium headed by PCCI, Inc. along with an Indian offshore company.
- Shell International Exploration & Production Inc. is funding NIOT for high capacity OTEC related designs.
- An international webinar on "*OTEC – Some Developments and Way Forward*" was organised by NIOT under the aegis of IEA-OES on 29 March 2022 with keynote speakers from USA, Japan, South Korea, Malaysia, Indonesia and Netherlands.

Ireland

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OVERVIEW

Ireland has one of the best offshore renewable energy resources in the world with a sea area of 490,000 km^2 which is approximately seven times the size of our landmass[6]. Because of Ireland's location at the Atlantic edge of the EU, there is more offshore energy potential than most other countries in Europe, with significant long-term potential of offshore renewable energy (wind – fixed and floating, wave and tidal) within 200 km of the coastline.

In 2022, Ireland launched the second update to the Climate Action Plan and introduced economy-wide carbon budgets and sectoral emissions ceilings[7]. The Climate Action Plan 2023[8] implementations of carbon budgets and sectoral emissions ceilings sets out a roadmap for taking decisive action to halve Ireland's emissions by 2030 and reach net zero no later than 2050. It reflects the ambitious targets set in 2020 through the Programme for Government[9] to progress offshore energy in Ireland including a target to achieve at least 5 GW of offshore wind by 2030 and increasing the offshore renewable energy target with an additional 2 GW for green hydrogen production by 2030. Offshore wind will be a key driver for Ireland to meet its second carbon budget with electricity emissions ceiling of 20 MtCO2eq. for the period 2026-2030 and setting the country on a long-term trajectory for a net zero electricity system. Post 2030, additional offshore floating wind and ocean energy technologies will be required to meet the net zero electricity system ambition.

There are four broad areas that are being prioritized to progress offshore renewables in Ireland, namely legislation, a new consenting regime, a dedicated offshore Renewable Energy Supporting Scheme (RESS) auction, expanded ocean energy research and development programme[10].

6 https://www.gov.ie/en/press-release/07331-transition-of-offshore-renewable-projects-announced/

7 https://www.gov.ie/en/press-release/dab6d-government-announces-sectoral-emissions-ceilings-setting-ireland-on-a-pathway-to-turn-the-tide-on-climate-change/

8 https://www.gov.ie/en/publication/7bd8c-climate-action-plan-2023/

9 https://www.gov.ie/en/publication/7e05d-programme-for-government-our-shared-future/

10 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 identified 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 set out key principles, policy actions and enablers for the delivery of Ireland's significant potential in this area. In 2021, an update to the OREDP commenced, the OREDP II will update 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)[11]. As indicated in the Climate Action Plan 2021; Action 116; the OREDP II was drafted by the end of 2022 and will undergo public consultation in the first quarter of 2023[12]. In addition to the Plan, a Strategic Environmental Assessment (SEA) scoping and Appropriate Assessment (AA) screening report were completed as part of the assessment process to evaluate potential impacts and inform the direction of the plan and went to consultation for 6 weeks in May and June 2022 respectively. The full SEA and AA reports were also subject to a public consultation alongside the draft OREDP II to receive views from statutory consultees, coastal, marine communities and specific stakeholders which will refine and finalise the draft plan.

Policy development for Marine Consenting

Ireland's ambitions for the offshore renewable energy sector are contingent on delivering an 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 National Marine Planning Framework (NMPF), Ireland's first comprehensive marine spatial planning framework, 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 the Irish 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, whilst taking account of the existing network of designated European sites under the Birds and Habitats Directives.

The Marine Area Planning Act

The Marine Area Planning (MAP) Act was enacted into law in December 2021 superseding the Foreshore Act of 1933. 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 (the national planning authority) and the coastal local authorities. It

11 https://www.gov.ie/en/publication/a4a9a-national-marine-planning-framework/

12 https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/

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 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, 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, licenses and offshore planning permissions. The new State Agency; MARA; is expected to become operational in 2023[13].

Offshore Wind Delivery Taskforce

In 2022, a cross-Departmental Offshore Wind Delivery Taskforce was established to accelerate and drive delivery and capture the wider and longer term economic and business opportunities associated with the development of offshore renewables in Ireland. The challenge is to bring these together in a coherent whole of a government plan that provides the necessary structures, governance, project management and delivery supports to ensure the medium-term, 2030 and post-2030 targets will be delivered.

To meet this challenge, the key objectives of the Taskforce are to:

- develop a system wide project plan, to identify all aspects of work on the critical path, identify gaps, opportunities and proactively manage risks to ensure delivery of offshore wind and related targets.
- identify opportunities to accelerate and align delivery of medium-term outcomes;
- identify options to maximise economic and societal benefits
- ensure consistent messaging to the public and all stakeholders
- ensure alignment with biodiversity workstreams

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

In Q4 2021, the Department of the Environment, Climate and Communications (DECC) opened a consultation on the draft terms and conditions for the first auction to supply electricity from offshore wind under the Renewable Electricity Support Scheme (ORESS 1).

In 2022, a follow-up public consultation for the draft rules and guidance for ORESS 1 Community Benefit Funds (CBF) was opened which aims to collate stakeholder feedback on the CBF proposals.

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 an ambition of 7 GW 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 7 GW installed capacity target[14].

13 https://www.gov.ie/en/press-release/d13b0-maritime-area-planning-bill-2021-passes-through-all-stages-of-the-oireachtas/

14 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/

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[15].

Table 1: RESS Future Auction Schedule

AUCTION TYPE	INDICATIVE AUCTION VOLUME (GWH)	INDICATIVE AUCTION DATES	INDICATIVE AUCTION COMMERCIAL OPERATION DATES
Onshore RESS 2	1,000-3,500	Q2 2022	2024
Offshore RESS 1	7,500-10,000	Q2 2023	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 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 contribute to Ireland's transition to a clean and secure energy future. A total of €20M million was invested in the programme in 2022. 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 policymakers and public bodies through results, outcomes and learning from supported energy projects

In 2021, eleven offshore energy projects were granted funding under the RD&D with an approximate budget of €7 million. The breakdown for offshore energy projects related to the 2022 research funding call will be available in Q1 2023.

OCEANERA-NET Cofund

The Ocean Energy ERA-NET Cofund (OCEANERA-NET COFUND) project was a five-year action that secured support through the European Union's Horizon 2020 Programme for Research and Innovation in 2016. This programme built on the work of OCEANERA-NET and with an increased budget and financial support from the EU

15 https://assets.gov.ie/212080/be6fa505-d4e7-4634-80d9-64fd9d1a0800.pdf

Commission, the COFUND programme focuses on collaborative projects that demonstrate and validate innovative technologies for Ocean Energy[16].

During 2022 three projects have closed under the funding support of Ocean ERA-NET whilst four projects remain ongoing and fully funded by SEAI.

Projects closed in 2022:

- **WEC 0** - to improve wave energy converters (WECs) and the WEC development process by focusing on fundamental, early-stage performance and cost analyses
- **SeaBlade** - to reduce the cost of tidal turbine blades using epoxy powder and glass fibre and an innovative proprietary manufacturing technology with advantages for weight, performance, efficiency, reliability, maintenance and costs.
- **ResourceCode** - to support investment and growth in the wave and tidal energy sector through the creation of an integrated marine data toolbox.

Projects ongoing:

- **OE BUOY** - to test a floating water column device at US Navy WETS facility in Hawaii
- Optimor - to deliver a multi-MW crossflow tidal power system for deployment in European markets
- **WEC4PORTS** – to explore the integration of wave energy converters in port breakwaters in order to develop a cost-effective mechanism of delivering renewable energy for significant transport hubs.
- **SeaSnake** - to provide a step change in the overall performance of a medium voltage cable system, aiming for a 20% cost reduction while ensuring that it is highly reliable and lowers the risks of ocean energy installations.

SEAI/LIR NOTF Industry access programme

The Sustainable Energy Authority of Ireland (SEAI) and LIR National Ocean Test Facility (NOTF) in UCC MaREI 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. Funded by SEAI the industry access fund is open to any type of ORE technology (wave, wind, tidal, floating solar) that can be tested at the Lir NOTF. A pilot call ran successfully in Q4 2021 with the testing of six different Ocean Energy technologies (add split of technology by type) completed in Q1 2022.

After the success of the pilot programme in 2021, a second call was launched in Q2,2022. Six applications were successful (5 wave, 1 tidal) and tested their prototypes before end of December 2022. The programme will run again in Q1,2023 (further information can be found on LiR Website[17]).

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.

16 https://www.oceancofund.eu/

17 http://www.lir-notf.com/

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 2022. Further details about funded projects can be found on the SEAI national energy research database[18]:

- **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.

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 250 researchers across 13 partner institutes in Ireland working with over 103 industry partners focusing on defined global challenges such as 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[19].

Eu Projects

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

18 https://www.seai.ie/data-and-insights/seai-research/research-database/

19 https://www.marei.ie/

- **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) is a 3-year H2020 funded project from 2019-2022. 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 objective is to assess the progress of the ocean energy sector and to monitor national and EU funded projects in delivering successful supports. It will also identify the shortcomings and how to maximise the benefit of the funding streams provided across the regions, member states and the EC. The project has closed in 2022 and findings of the sector in 2020 showed that a total of 141 ocean energy projects were supported by member states and that 34 projects at later stages of development achieved a TRL of 7 or above proving that the overall sector is well supported. 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 new 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
- **INTERRnewNWE OPIN (Ocean Power Innovation Network):** is a three-year project running from 2019 to 2022. It is a cross-sectoral, cross-regional collaborative network that aims to accelerate the growth of the ocean energy sector and its supply chains across the partner regions of Ireland, the UK, Belgium, France, the Netherlands and Germany. The project provides practical support to ocean developers such as free access to technical workshops and events, networking opportunities and technical assessments.
- **INTnewEG 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 a single machine to a 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[20].
- **H2020 SEETIP Ocean:** is a 3-year funded project running from 2022-2025 and will leverage from its predecessors, the ETIP Ocean and OceanSet projects. SEETIP will support the activities of both the European Technology & Innovation Platform for ocean energy (ETIP Ocean) and the SET Plan Ocean Energy Implementation Working Group. The aim of the project is to accelerate the deployment of the ocean energy sector by fostering collaboration amongst ocean energy sectoral stakeholders in all key SET Plan countries and to facilitate the greater integration of ocean energy into the wider energy system, industrial supply chains, infrastructure, local ecosystems, and European society. SEAI are project partners of SEETIP.

20 https://www.nweurope.eu/projects/project-search/oceandemo-demonstration-programme-for-ocean-energy-pilot-farms-and-supporting-technologies/#tab-6

TECHNOLOGY DEMONSTRATION

Existing Open Sea Test Sites

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 that cover all Technology Readiness Levels (TRLs) from 1 – 9 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.

SmartBay Marine and Renewable Energy Test Site

The Smartbay Marine and Renewable Energy Test Site is located on the north side of Galway Bay, 2.4km south-east of Spiddal village, which is located 19 km west of Galway city and approximately 1.5km offshore. The area of the site is 37 hectares, and it has water depths of 20-25 m. 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[21].

Atlantic Marine Renewable Energy Test Site (AMETS)

The Atlantic Marine Energy Test site in Belmullet Co. Mayo is being developed by SEAI 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. 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.

The project includes site development; onshore civil works for substation build; grid reinforcements; and offshore works for electricity export cable deployment. Currently, the focus is on building of the onshore Substation, which is scheduled to be completed in 2025.

Planned Deployments

New Wave Technology trading as **Ocean Energy** plans to deploy a near full-scale model to test in US Navy WETS facility in Hawaii. The project is co-funded by both SEAI and Department of Energy (DOE) in the United States. The project has been in place since 2016 and up to now has focussed on, building, transport and

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

access to the site. The technology was transported from Oregon to Hawaii in November 2019 and is 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 SmartBay Quarter Scale test site – during which the device accumulated over 24,000 hours of open water testing.

A commercial full-scale wave energy conversion test and demonstration project (Saoirse) consisting of a 5 MW and an array of 16 wave energy converter units 4 km off the west coast of Clare is being developed by Simply Blue Energy.

OE Buoy during construction in Oregon

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

Atlantic Maritime Strategy - Marine Renewable Energy

The main objective of the European Commissions' Atlantic Action Plan 2.0 is to unlock the potential of blue economy in the Atlantic area while preserving marine ecosystems and contributing to climate change adaptation and mitigation. The plan includes four pillars that are interconnected and trans-regional by nature and address key challenges and aim to foster sustainable blue growth and contribute to greater territorial cooperation and cohesion in the EU Atlantic area.

Pillar III Marine renewable energy (MRE) sets one specific goal; namely to promote carbon neutrality through MRE in the Atlantic area. It sets out a number of actions to encourage innovation and foster collaboration between the four Member States to help them achieve the goal.

In July 2022 the second term of Pillar III commenced with Ireland appointed Pillar lead for Marine Renewable Energy, led by the Sustainable Energy Authority of Ireland (SEAI).

The revised priorities for the coming term (2022-2024) will focus on four Task priority areas:

1. Progressing the Pillar III Roadmap.
2. Researching the changing policy landscape in the Member States.
3. Assessing technological developments and progress of the rollout of MRE in the Member States.
4. Fostering collaboration between Member States and Atlantic Stakeholders

RELEVANT NATIONAL EVENTS

SEAI 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 2022, this conference focused on the theme of Societal Transformation for delivering Ireland's energy revolution. It featured speakers from a wide range of disciplines, covering topics from the role of psychology in sustainable energy solutions, early public engagement, and behavioural change, to community-led initiatives to develop, deliver and benefit from sustainable energy.

OPIN network: During 2022, an annual symposium (update on OPIN's activities and impact over the past years), 4 masterclasses (environmental impact and monitoring, cabling, blockchain for marine waste management, risk and policy requirements) and 2 webinars (overview of the services offered by OPIN, offshore health and safety) were hosted by SEAI under the umbrella of the Ocean Power Innovation Network.

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. The show took place in March at the RDS in Dublin[22].

Marine Renewables Industry Association: The MRIA which represents and promotes development and implementation of policy for the Marine Renewables Emerging Technologies have hosted a number of forums in 2022. Presentations on Ireland's ORE policy developments, technology developments on ocean energy devices and progress in the ocean sector were presented at these forums.

22 https://www.seai.ie/events/seai-energy-show

Italy

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OVERVIEW

In the wake of the past two years, 2022 was also characterized by a reduced rhythm of marine projects development. Nevertheless, some relevant advances concerning ocean energy occurred, especially regarding projects with an already defined development path, which continued their way towards technological maturity. From a strategic point of view, relevant preparatory work has been carried out for the implementation of new public funding plans, considering both capital grants and market incentives, also including National Recovery and Resilience Plan (NRRP) resources. These changes are described in the report, together with the annotation of the most relevant 2022 events.

SUPPORTING POLICIES FOR OCEAN ENERGY

National Strategy

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 National Integrated Energy and Climate Plan (NECP) issued in 2020 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 "Fit for 55" package and REPowerEU plan recently issued by the European Commission, which aims at reducing the greenhouse gas emissions by at least 55% within 2030 compared to 1990. In particular, Decree 199/2021 envisages the definition of tenders for innovative technologies; in 2022 the preparatory work has been carried out, with a dedicated implementing decree expected in 2023.

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 the country's society and economy. Within NRRP, two specific investments (Green Islands and Innovative plants) provided dedicated resources to the development of innovative plants and solutions, including marine energies.

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 for 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.

As mentioned above, in 2023 new specific decrees are expected, defining new incentive procedures and tariffs from innovative technologies, also including marine energies. 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 Italian legislation via the D. Lgs 201/2016.

Public Funding Programmes

The "Green Islands Program" was launched by the Ministry of Environment and Energy Security. The Programme has a budget of €200m provided by Investment 3.1 of the National Recovery and Resilience Plan (PNRR), Mission 2 Component 1. The Programme is aimed at promoting the improvement and strengthening, in environmental and energy terms, the Municipalities of the 19 smaller non-interconnected Islands, through the promotion of renewable energies, the implementation of integrated energy and water efficiency projects, sustainable mobility, waste cycle management and circular economy. The Program is aimed at the 13 Municipalities of the 19 non-interconnected smaller islands. Among the projects presented by the municipalities in April 2022, the installations of systems for the production of renewable energy from wave motion are planned on two islands. In September 2022, through a directorial decree, a formal approval was given to the presented projects, which will have to be realized in the upcoming years.

In the National Recovery and Resilience Plan (NRRP), another investment (1.3 of Mission 2C2) is concerned with the promotion of innovative plants, including marine energy converters, to which €680m 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 CO2. During 2022 the preparatory work for the implementation of the program has been carried out, with a dedicated decree expected in 2023.

RESEARCH & DEVELOPMENT

Research Activities and Infrastructures

ENEA, the national agency for alternative energies, has long been involved in ocean energy research. ENEA has developed two innovative models 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 the Straits of Gibraltar, the Dardanelles and the Bosphorus;
- **WAVES:** the wave prediction system that guarantees resolution up to 800 m in marine and coastal areas with high energy potential. Both models use the ENEA supercomputer "CRESCO6".

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 m/s, the production of energy could reach 125 GWh per year, an amount sufficient to meet the energy needs of cities like Messina itself.

In Italy, 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 WEC technology appears to be more promising for the Mediterranean environment. 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 the development of marine renewable the 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.

The MOREnergy Lab is a research centre of Politecnico di Torino, Italy, active in all areas of offshore renewable energy, notably wave energy and floating offshore wind. The MOREnergy Lab has developed an open-access web-based platform, dubbed MORE-EST that gives users access to wave and wind energy resources in any location in European seas and oceans, as well as some maritime spatial planning information and examples of productivity evaluation. It has been designed to support maritime stakeholders in the exploitation of wave and wind energy resources, offering wave data for the period 2010 to 2019, as well as the power matrix of different wave energy converters.

http://www.morenergylab.polito.it/more-est-platform/

Towing Tanks

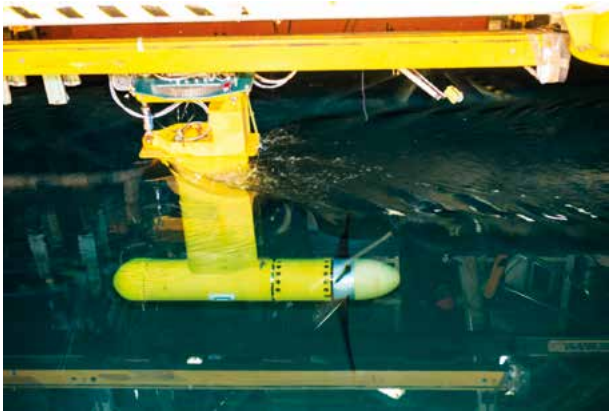
Small and medium scale prototypes are tested in wave flumes and wave tanks where a specific sea state can be artificially created, and power production and device survival assessed:

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. 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.

University of Naples Naval Tank: The Naval Tank of the Department of Industrial Engineering – Section Naval

of the University of Naples Federico II. 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, limits the working and running environment of the dynamometric wagon on rails arranged on the edges of the basin.

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. The system 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.



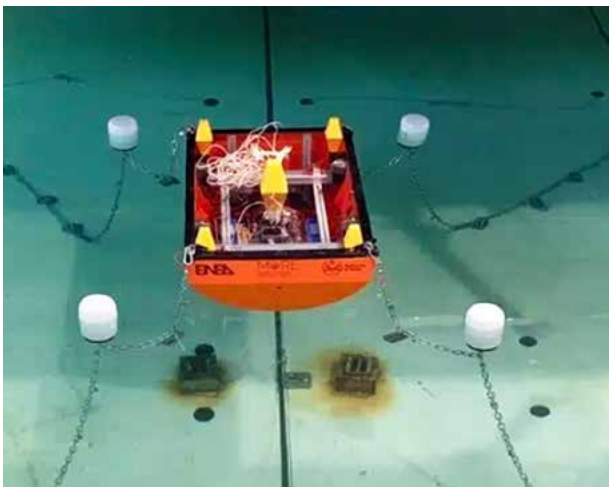
Examples of vertical-axis marine current turbines (VACT) models tested in the CNR-INSEAN towing tank (Kobold turbine) of a straight basin, a dynamometric wagon and a wave generator

The Naval tank of University of Naples Federico II

Innovative Converters

PeWEC

The new and improved version of PEWEC (Pendulum Wave Energy Converter), being developed by Italy's national agency ENEA and the MOREnergy Lab of Politecnico di Torino, could prove to be an ideal solution for small and medium-sized islands across the Mediterranean as they transition to net-zero future. PEWEC 2.0 features some technological improvements compared to the previous version: a 1:25 scale prototype was tested at the Naval Tank of the Federico II University of Naples to study the response of the hull and moorings to extreme waves. The Politecnico di Torino Lab team developed advanced numerical codes for technology development and PEWEC device manufacturability prediction. Genetic optimization codes have been adopted to reduce the energy cost of the device.



Testing phase of the 1:25 prototype at the University of Naples naval tank

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 wave energy. Two turbines were installed in Lipari island (150 W 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.

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. 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.

Wave tank experimental test on large scale model of Pivot

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.

Wave 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 OWC wave energy converter. This device has been conceived for its integration in coastal structures (e.g. harbours and ports). Main advantages 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 1:20 scale model 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 of 15 KW was installed in the port of Civitavecchia. In the first months of operation, the relation between hydraulic power, turbine power and electricity generation were studied, leading to satisfying results.

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

REWEC3

The Mediterranean University of Reggio Calabria has been developing the REsonant Wave Energy Converter (REWEC3), which is a particular type of OWC technology 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. 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 in-

dependent 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) in 2012 and 2014. 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.

Inertial Sea Wave Energy Converter (ISWEC)

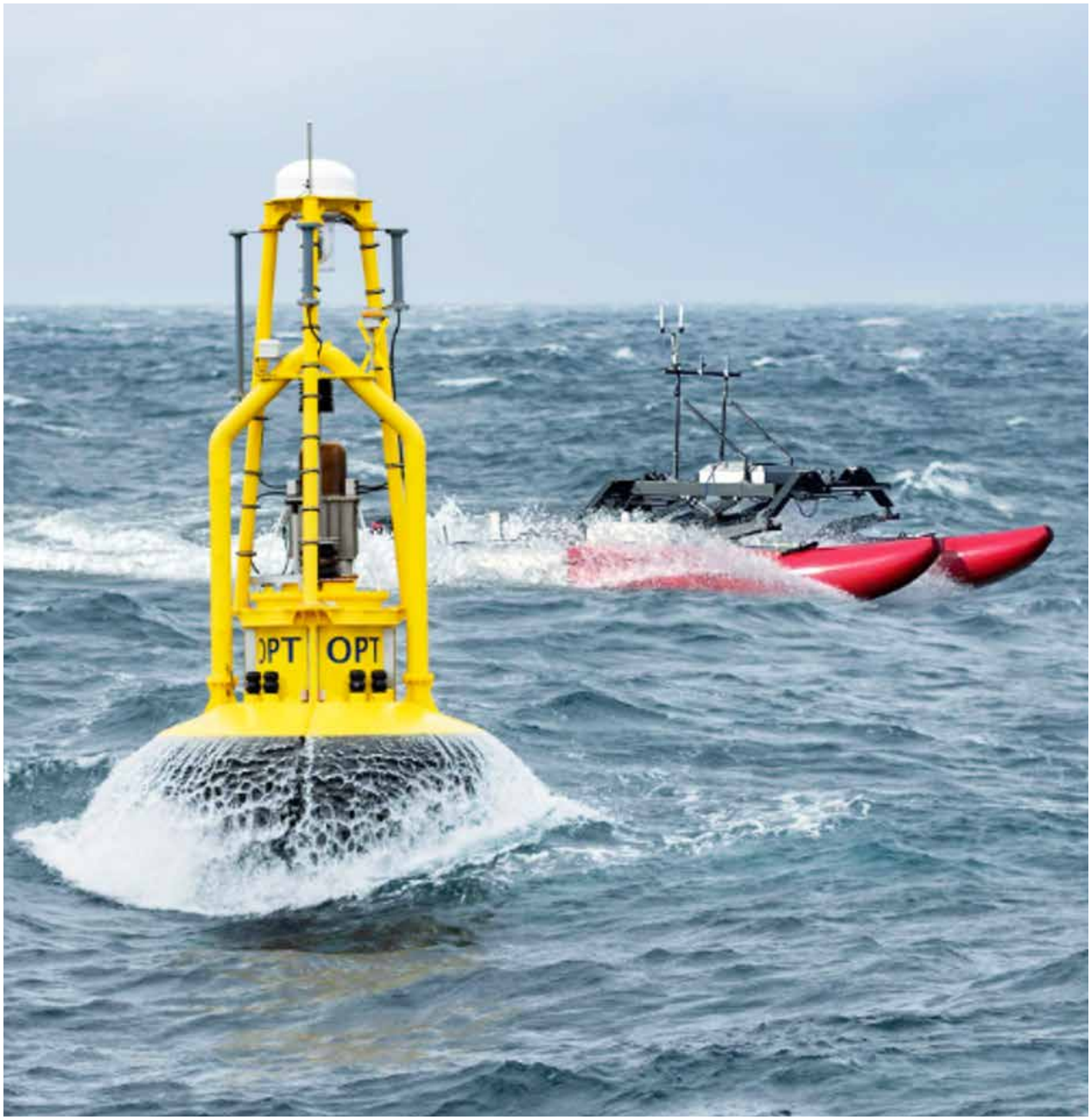
The Polytechnic of Turin developed ISWEC (TRL 7), a pitching point-absorber wave energy converter suitable for mild climate seas such as the Mediterranean. It is based on the gyroscopic technology. Research activities started 15 years ago and led to the development of the technology industrialized by 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. The 50 kW prototype in Ravenna was removed in September 2022 after the conclusion of the test period; meanwhile, at the end of 2022, the installation of a new 250 kW unit was started off Pantelleria.

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 technolo-

Breakwater equipped with the OBREC prototype in the Naples harbour

ISWEC installation



OPT PowerBuoy in the Adriatic Sea

gies 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 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. 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. 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.

The installation in Marina di Pisa

Illustration of the deployed GEMSTAR system

RELEVANT NATIONAL EVENTS

- **22 April 2022 Rome:** BLUE DEAL Open Day. Economy of the sea and ecological transition: the role of marine renewables in Lazio Region.
- **27 April 2022 Livorno:** Blue Days. La transizione ecologica a partire dal mare
- **10 May 2022 Reggio Calabria:** A sea of energy and how to capture it: the sea is large, it is deep and above all it is an inexhaustible source of energy!
- **19-20 May 2022:** European Maritime Day 2022 was hosted in Ravenna.
- **19 September 2022 Trieste:** Sea Days 2022.
- **6 October 2022 Gallipoli:** XXXI review of the sea safeguarding of biological resources and blue economy.
- **21 November 2022 Ravenna:** NOW! Outpost Ravenna for Energy Transition.

Japan

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SUPPORTING POLICIES FOR OCEAN ENERGY

The 4th Ocean Basic Plan (2022-2026) is being studied for the promotion of new ocean energy applications, mainly by the Headquarters for Ocean Policy, with the aim of a Cabinet decision in May 2023. In the current Third Ocean Basic Plan (2018-2022), which was approved by the Cabinet in 2018, it is stated that, with regard to ocean energy such as wave power, tidal currents and ocean currents, efforts should be made to conduct demonstration research and to link this with measures to promote the development of remote islands.

RESEARCH & DEVELOPMENT

The following are some of the large-scale research and development projects currently being implemented in Japan in relation to marine energy.

IHI Corporation conducted a demonstration experiment in the waters of Kuchinoshima Island, Teshima Village, Kagoshima Prefecture, under the 'Ocean Energy Power Generation Demonstration R&D' project of the New Energy and Industrial Technology Development Organisation (NEDO), to investigate the power generation capacity, equipment durability and economic efficiency of an underwater floating ocean current power generation system (horizontal shaft propeller system, 100 kW output: two 50 kW units) in actual sea areas. The demonstration tests were conducted in the waters of Kuchinoshima, Toshima Village, Kagoshima Prefecture, to verify the power generation capacity, equipment durability and economic efficiency of the system in actual sea areas.

Kyuden Mirai Energy Ltd. installed SIMEC Atlantis Energy's 500 kW tidal current generator in Naru Seto, Goto City, Nagasaki Prefecture, as part of the Ministry of the Environment's project to promote the practical application of tidal current power generation technology.

The University of Tokyo and others have conducted research into the practical application of a fixed oscillating water column wave power generator (40 kW output) installed on a breakwater, aiming for higher efficiency, etc., under the Ministry of the Environment's '2000 CO2 Reduction Measures Enhancement Guided Technology Development and Demonstration Project'.

Saga University and others are continuing research on a hybrid system of ocean thermal energy conversion (OTEC) and seawater desalination under the JST International Science and Technology Research Collaboration Programme for Global Issues (SATREPS, Subject name: *Establishment of a sustainable energy system for a low-carbon society by developing innovative OTEC in Malaysia*). Research on a hybrid system of ocean thermal energy conversion and seawater desalination is being carried out in collaboration with Universiti Teknologi Malaysia and others. A 3 kW hybrid OTEC experimental system has been completed and will be installed in Malaysia in 2023 to start research.

Monaco

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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 km^2 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 reduce the greenhouse gas emissions by 55% in 2030 compared to the reference date of 1990 and to achieve carbon neutrality in 2050.

In 2020, the GHG emissions decreased by 32% compared to 1990 (last published data).

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 finance actions in favour of the reduction of the GHG emissions and the energy efficiency, the development of renewable energies and the clean mobility.

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. 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 sea-water 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.

Projects Planned for Deployment

Two new thalossothermal loops connected to seawater heat pumps are under construction. They should supply 3500 homes and eliminate 6ktCO2eq of GHG emissions (approx. 8% of the total emissions of Monaco).

Netherlands

AUTHORS:
J. Reijnders

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 of the North Sea is focused on offshore wind. Special areas have been appointed for offshore wind (3500 MW).

Market Incentives

The generic national subsidy scheme (SDE++, stimulating renewable energy) for 2023 is not yet open. In 2022, the subsidy for the ocean energy options varied from 0.0547 €/kWh to 0.0852 €/kWh, divided into 5 phases. The project probabilities in lower subsidised 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.

Public Funding Programmes

In addition to the feed-in tariff (OPEX subsidy) mentioned above, generic funding programmes (CAPEX subsidy) are available 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 AND DEVELOPMENT

DutchWaters is a collaborative project granted by Top consortia for Knowledge and Innovation (TKI) Delta Technology in 2022. Led by DMEC, DutchWaters developed detailed wave and tidal resource models for the North Sea. The resource analysis resulting from the models is open source providing valuable information for offshore energy farms, coastal protection- / climate resilient infrastructure and the Dutch energy system.

VALID is a H2020 project aiming to develop and validate a novel test platform for wave energy. Technical University Delft is one of the academic partners contributing to the testing methodology offered by providing open-access models, testbeds and improved data management to lower the cost of future wave energy technologies. In 2022 the Technical University Delft launched the Marine Renewable Energies Lab (www.tudelft.nl/ceg/mrel) and joined as a founding member the European Ocean Research and Education Alliance (EOREA).

OceanDEMO is an Interreg North West Europe project targeting multi-device ocean energy installations to prove their technology at full commercial scale. In 2022 Dutch developers SeaQurrent and Oceans of Energy are demonstrating their scaled systems at the Waddensea respectively the North Sea. Both demonstrations are supported by DMEC.

NL-MARINERG-i is a consortium backed by the Dutch Ministry of Economic Affairs and Climate Policy (EZK). It brings together research institutes and test facilities with an aim to accelerate offshore renewable energy research actions. Led by DMEC, the Dutch consortium includes Deltares, Maritime Research Institute Netherlands (MARIN), HZ University of Applied Sciences, Royal Netherlands Institute for Sea Research (NIOZ), TNO, Netherlands Aerospace Centre (NLR), DNW German-Dutch Wind Tunnels, Technical University Delft and Wageningen University & Research. NL-MARINERG-i aims to provide research and test support to achieve technology and commercial support. Within 2022 the project was extended to capitalise on the results by developing blueprints for market applications and developing a corporate partnership program offering the majors insights into the ocean energy sector.

TECHNOLOGY DEMONSTRATION

Operational Projects

Tocardo's Oosterschelde Tidal Power Plant (OTP) consisting of a platform of 5 x T-2, 250 kW Tocardo tidal turbines, continued operations during 2022 successfully. The power plant was visited by the European Energy Commissioner Kadri Simson and a European delegation from the Commission Directorates-General for Energy (DG ENER), Maritime Affairs and Fisheries (DG MARE) and Climate (DG CLIMA).

Slow Mill deployed the very first Dutch-made wave energy converter in the North Sea. The company designed a novel wave energy device for the moderate wave climates. In the summer of 2022 Slow Mill made a trial deployment at a 1:2.5 scale. The company has learned lessons and is now planning a redeployment in 2023 to finalise validation tests. A full-scale wave energy converter including grid connection is projected to harness

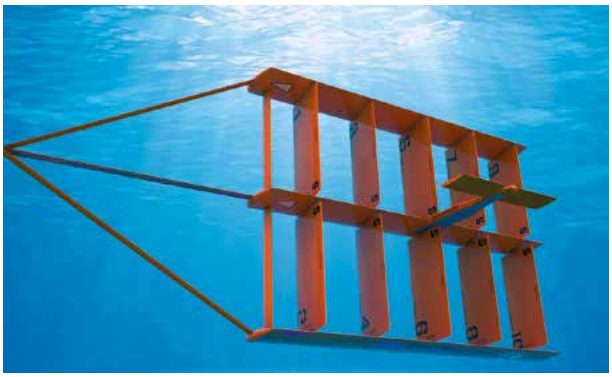
@Tocardo

@Slow Mill

400 kW from North Sea waves and provide electricity for 100 households on the island of Texel.

SeaQurrent is now working towards a demonstration of the fourth kite of its unique patented TidalKite system at Ameland. 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 is converted into electricity in a power take-off system comprising a hydromotor, which in turn drives a generator, generating green electricity. Demonstration of the kite is planned for 2023, following the completion of preparatory works on the test site this year.

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 pilot-installation in the world which has been operating continuously since its beginnings in 2014, with a blue energy production capacity of max 50 kW. The two main potential applications are where a river naturally discharges into the sea or within a desalination process. To further develop and implement this latter application, REDstack joined the HyREward and the INDESAL EU-projects.



SeaQurrent

@REDstack

Planned Deployments

- SeaQurrent TidalKite demonstrator at the Wadden Islands (2023)
- Slow Mill wave demonstrator (40 kW) off the coast of Texel (2023)
- Dutch Wave Power (DWP) off the coast of Flanders or The Hague (2023)
- Tocardo in Eastern Scheldt (further future)
- Several arrays in Afsluitdijk discharge gates (further future)

RELEVANT NATIONAL EVENTS

Offshore Energy Exhibition & Conference (OEEC)

On the 29th and 30th November 2022, 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. During this year's Marine Energy Session policy makers, market players and developers discussed collaboration opportunities for scaling-up marine energy. Other marine energy highlights included the networking reception in the marine energy pavilion together with IRO and NWEA, several round tables on marine energy topics (hosted by DMEC and EWA) and the Marine Energy Alliance end of project conference activities. Several ocean energy developers exhibited at the Dutch pavilion.

Dutch Marine Energy Community Strategic Session

On 23rd of September 2022, DMEC organized a strategic session for the Dutch Marine Energy Community, which includes over 180 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 Dutch Marine Energy sector in 2023 and beyond.

Offshore Experience Den Helder

On the 8th of September the first edition of the Offshore Experience was held in the harbour city of Den Helder. It was organised by the Port of Den Helder, North Sea Energy Gateway, CoP Noordzee and ECHT. The event covered the opportunities and challenges faced by the offshore sector and the blue economy. DMEC, Slow mill, Teamwork Technologies and SeaQurrent were present to showcase how marine energy can contribute directly to the blue economy and sustainable future of the North Sea.

EWA workshop on Adaptive Policies

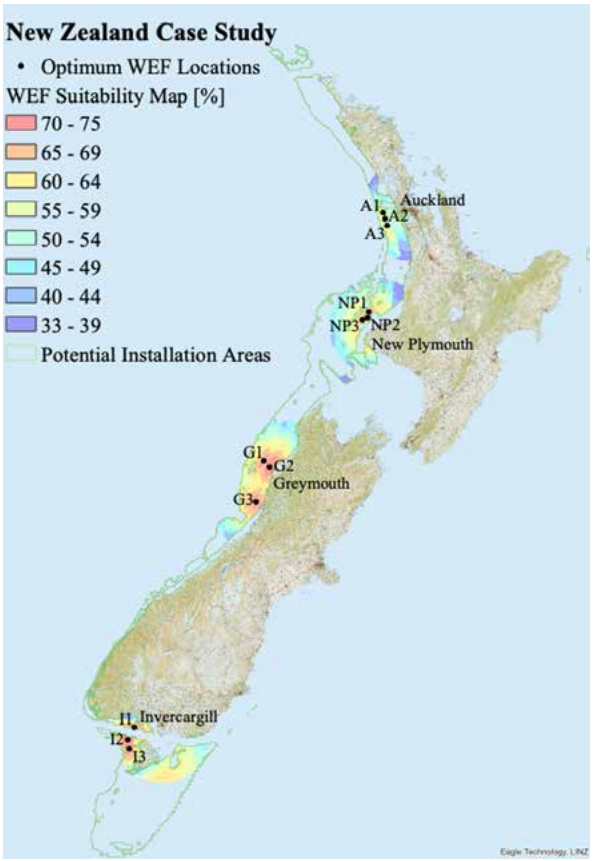
On the 27th of June, Dutch Energy from Water Association EWA organised a validation workshop on adaptive policy interventions to support the implementation of the EU strategy on Offshore Renewable Energy. Policy makers at European, national and regional level discussed the benefits of Offshore Renewable Energy and how the use of Adaptive Policies can help to sustain technology progression and market creation.

New Zealand

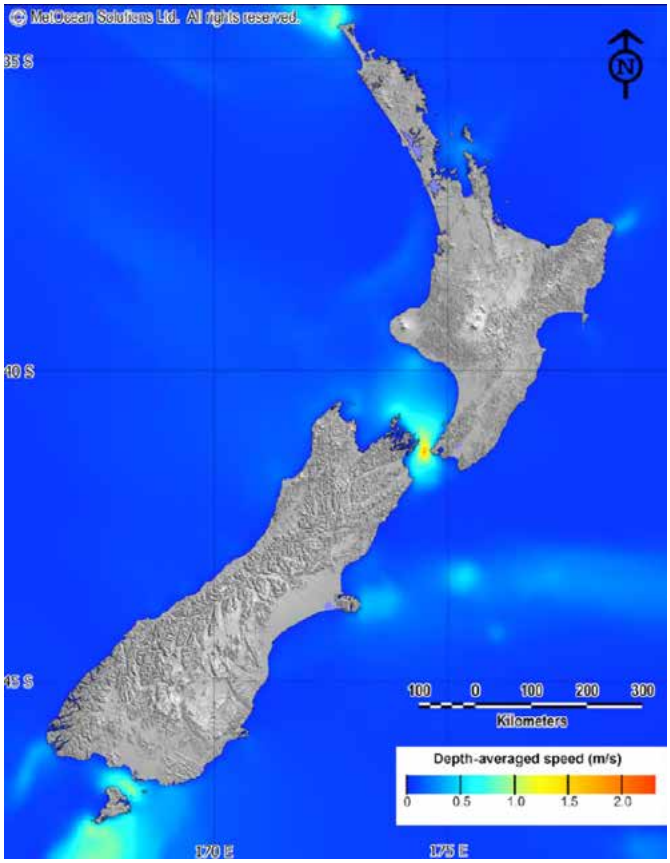
AUTHOR:
Martin Knoche, New Zealand Marine Energy Association

OVERVIEW

New Zealand has one of the best marine energy resources on the planet: over 15,000 km of coastline and the fifth largest Exclusive Economic Zone (EEZ) in the world, in the biggest of all oceans. The Cook Strait alone could provide 5 GW of marine energy. If wave energy along the West Coast and tidal energy in key harbours is included this number is likely to be higher. Areas, where tidal energy is feasible on the North Island, include the Hokianga, Whangarei, Kaipara Harbour, and on the South Island Cook Strait, Tory Channel, French Pass and Fauveaux Channel.



Wave Energy Potential



Depth-Averaged Tidal Current Speeds for Mean Springs Flows. Source: MetOcean Solutions

RESEARCH & DEVELOPMENT

Aotearoa Marine Energy developments include EcoMerit Tech's Aquantis tidal, wave and carbon capture utilisation and storage (CCUS) solutions. They are used for desalination in California and trials in the Gulf Stream, Wales and Scotland.

Key Research Topics

Given NZ's leadership in geothermal and onshore wind, as well as on offshore oil & gas, there is much expertise and capacity to design, build and maintain offshore structures. It is, however, lacking a Marine Energy talent development programme. With EMEC, Heriot Watt University Professor Susan Krumdiek, there is the intention to establish an **Aotearoa Transition Engineering Lab (ATL)** later in 2023. The idea of the Aotearoa Transition Engineering Lab (short: ATL) is to provide independent and transparent feedback on organizations, policies on environmental issues.

Blue Carbon - In terms of Carbon sequestration, the Nature Conservatory, Cawthrone and Victoria University are running very exciting Blue Carbon sequestration projects. The ocean sequesters about 25% of carbon. A big part is done by sea grass. Mangroves can sequester up to four times more than land based trees. Saltmarshes are also potent carbon sinks. Given a rising carbon per ton price, this could constitute a substantial environmental and regional commercial & Blue Job opportunity.

Blue Food & Fertilizer - Commercial fishing in NZ still allows bottom trawling, which is very, very harmful. Aquaculture is done onshore (NIWA at Bream Bay), in Coromandel, Queen Charlotte Sound and spat production in Whangape harbour and Bay of Plenty. CH4 is working on seaweed projects for fertilizer and food production as far as I know. Several iwi are contemplating Blue Carbon or Blue Food projects, driven by their environmental awareness and the "Te mana o Te wai" claim over the NZ waterways & ocean.

Blue Economy - Powering remote, coastal communities, providing potable water via desalination, switching from diesel to renewables, powering ocean, coastal based weather and climate monitoring equipment, are probably key areas. New Zealand is focussing on bespoke, small-scale solutions and not utility-scale projects.

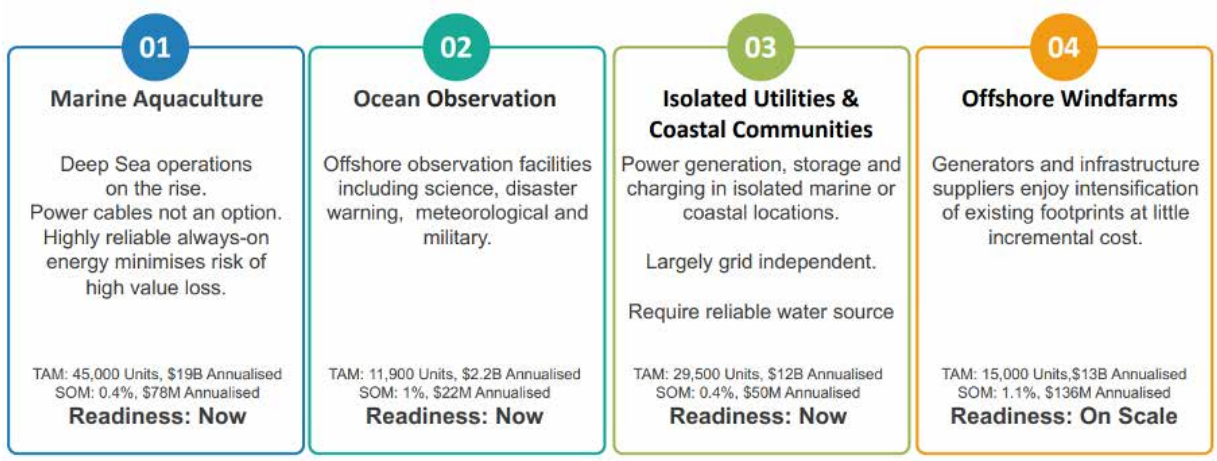
With the big EEZ, the iwi "Te mana o Te wai" claim this is a huge opportunity for environmental, socio-cultural, Blue Jobs, and commercial reasons, but also comes with a huge responsibility to be sustainable, and equitable. There is a conviction that with strong leadership, New Zealand could become a Blue Innovation Global Leader, leveraging its huge competitive, natural, and talent advantages.

Projects Under Development

Azura Wave

The Azura technology was originally developed by the NZ Government Agency Industrial Research (now Callaghan Innovation). The technology was licensed to Taranaki Engineering company EHL in 2013 and has since been tested in Hawaii, funded by US DOE. Azura converts the pitch and roll from waves in hydraulics and from there either into electricity or to power a desalination device using reverse osmosis technology.

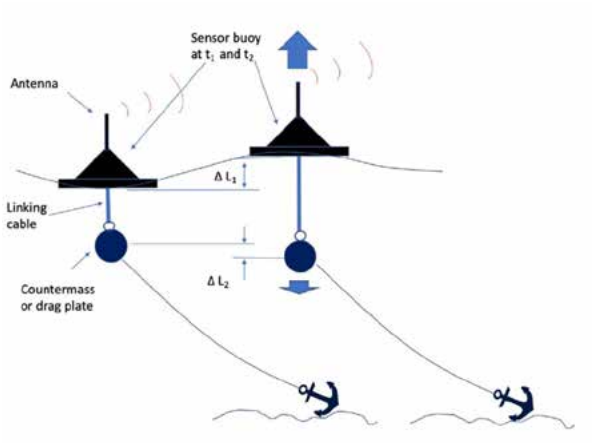
@Azura Wave



AzuraWave's target market opportunities (2022)

Aotea Buoy

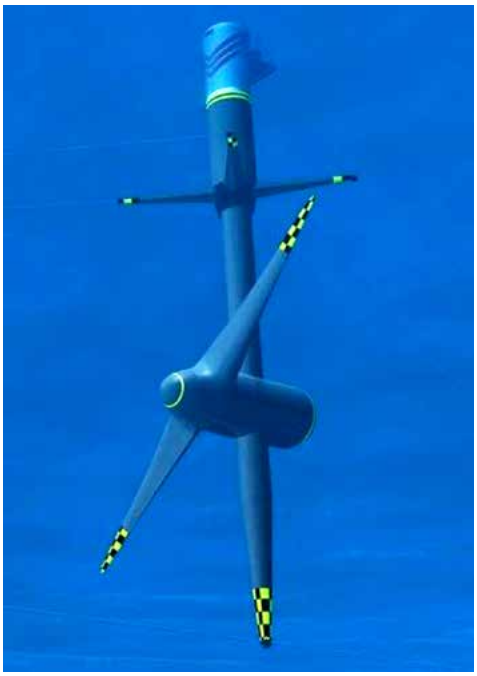
The Aotea Buoy is at proof of concept stage (Feb 2022) and has been developed by University of Auckland. The principle is that the 1 W of power is either generated by a solar panel (first prototype) or later the pitch and roll drive shaft within a magnet. This generates sufficient energy to power the low powered device. It can measure temperature, conductivity, turbidity and in the future Nitrogen, PH, dissolved oxygen and other parameters.



@Aotea Buoy

Aquantis

The Inventor of the Aquantis current and tidal turbine, as well as their wave pods is the octogenarian Jim Dehlsen. He developed his first wind turbine over five decades ago. Ecomerit Tech has been developing ocean energy devices for over ten years. This makes this technology the most advanced marine energy technology co-developed in New Zealand. The smallest Aquantis current turbine has a carbon fiber rotor of 8 m. Aquantis received DOE and UK Government funding in 2021 to deploy their technology in Wales or EMEC.



@Aquantis

Ruka Marine Turbine

The Ruka Marine Turbine (RMT) is a longitudinal water wheel driving a shaft like a wind turbine. The size of the RMT can be scaled to the relevant use case. The RMT can be used in rivers or tidal flows.

Portugal

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OVERVIEW

In 2022, the government announced plans to launch its first auction for offshore wind in 2023, to reach a capacity of 10 GW by 2030. Prime Minister said, "Portugal is strongly committed to putting the blue economy at the heart of its development strategy and will increase investment in research into new technological solutions that contribute to combating climate change." This is an economic opportunity for Portugal to expand the country's existing wind manufacturing industry and take advantage of large ports and shipyards in the area.

Portugal has a 25 MW floating wind project off its Atlantic coast from Ocean Wind and the first wave energy farm of 1.2 MW from Corpower Ocean is under development, with a first device ready to be installed in early 2023.

The European EU-SCORES funded project in which 3 Portuguese entities are involved - EDP, WavEC and INESCTEC - is supporting the discussion of the co-location of different offshore renewable systems and delivering solutions for the interconnected challenges to demonstrate large-scale roll-out of complementary offshore renewable energy source in so-called multi-source energy parks.

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.

The Roadmap for Carbon Neutrality 2050 (RNC 2050) was approved in 2021. In conjunction with the objectives of the RNC 2050, the National Energy and Climate Plan 2030 (PNEC 2030) was developed, which is a key national instrument of national energy and climate policy for the next decade toward a carbon-neutral future. The PNEC (in conjunction with other instruments as the National Strategy for Hydrogen) is intended as well to put Portugal on a path to achieving the goals set in the Roadmap for Carbon Neutrality 2050 (RNC2050), which calls for GHG emissions reductions of 85-90% by 2050 versus 2005 levels, complete decarbonisation of electricity generation and transport, and carbon sequestration to reach carbon neutrality.

In January 2022, the government published the Decree-Law nº15/2022 which establishes the organisation and functioning rules of the National Electric System (SEN). This Decree-Law also established an appropriate legal framework for the Technological Free Zones (ZLT). 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 aims 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. In 2022 the government announced the creation of one Technological Free Zone for marine renewable energies projects located Offshore Viana do Castelo, northern Portugal.

From the 27th of June to the 1st of July 2022, the 2022 UN Ocean Conference was held in Lisbon, with representatives from more than 150 countries. This 5-days conference culminated in the unanimous adoption of the Lisbon Declaration. Under the motto "Our Ocean, Our Future, Our Responsibility", this is the main policy document resulting from the Conference, submitted by the two Presidents of the Conference (Kenya and Portugal). It brings together a set of innovative and science-based actions to halt the rapid decline in the health of the Ocean. Portugal assumed the following commitments, announced in the speech of Prime Minister António Costa:

- Creation of an office for the United Nations Decade of Ocean Sciences for Sustainable Development.
- Ensure that 100% of the maritime space under Portuguese sovereignty or jurisdiction is evaluated in Good Environmental Status and, by 2030, classify 30% of national marine areas.
- Investing in the production of oceanic renewable energies, with a view to reaching 10 GW of capacity by 2030, and in the creation of a pilot area in the Portuguese sea.
- Double the number of start-ups and projects supported by public funds in the Blue Economy.

National Strategy for the Sea 2021-2030

The National Strategy for the Sea 2021–2030, released by the government in 2021, aims 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 centers around 10 objectives, including combatting climate change, decarbonize 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. In 2022, the first report monitoring the National Strategy for the Sea was prepared, presenting statistics for the services and value of the blue economy.

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

Atlantic Strategy Committee (ASC)

Portugal, Spain, Ireland and France are represented in the Atlantic Strategy Committee. The ASC is the governing body of the Atlantic Maritime Strategy adopted in 2011 by the European Commission in response to repeated calls from stakeholders for a more ambitious, open and effective cooperation in the Atlantic Ocean Area. In this context, the Atlantic Action Plan 2.0 was approved aiming to unlock the potential of the sustainable Blue Economy in the Atlantic area while preserving marine ecosystems and contributing to climate change adaptation and mitigation of environmental hazards. The new action plan includes four pillars, one of which is on Marine Renewable Energy. In 2023, Portugal will chair the Atlantic Strategy Committee.

More information:
https://atlantic-maritime-strategy.ec.europa.eu/en/atlantic-strategy-glance/atlantic-strategy

European Marine Energy Board (EMB)

The European Marine Board is the leading European think tank in marine science policy. It provides a platform to advance marine research and to bridge the gap between science and policy. The European Marine Board is a unique strategic pan-European Forum for seas and ocean research and technology. As an independent, self-sustaining, non-governmental advisory body, the European Marine Board transfers knowledge between the scientific community and decision makers, promoting Europe's leadership in marine research and technology.

In 2022, the EMB activity was focused on preparing an update on status and recommendations related to marine renewable energy, highlighting the current knowledge and research gaps in marine science. This publication is expected to be released in 2023. The working group is formed by members from Greece, Ireland, UK, Italy, France, Norway and Portugal (represented by WavEC).

Marine Spatial Planning Policy

National Maritime Spatial Plan (PSOEM)

The Maritime Spatial Plan covers the entire national maritime space, from the baselines to the outer limit of the continental shelf, integrating inland maritime waters, the territorial sea, the exclusive economic zone and the continental shelf, including beyond 200 nautical miles.

The Maritime Spatial Plan (https://www.psoem.pt/) is an instrument for planning the national maritime space and constitutes an essential tool for the policy of the sea. The Plan identifies existing and potential uses/activities and exclusion areas. This plan is also the instrument that allows the attribution of a Permit of Private Use of the National Maritime Space.

In 2022, following the public announcement by the government of their intention to launch a 10 GW offshore wind auction, it was decided to review the PSOEM for the integration of potential areas for offshore renewable energies commercial projects. The definition of these areas also requires the identification of connection points to the electrical grid, as well as the development of grid and port infrastructures and the establishment of the procedures for the offshore renewable energy bids. This is planned to occur in early 2023.

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).

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 toward 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 cooperate 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, monitoring 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.

Other Initiatives

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.

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).

https://bluetechaccelerator.com/

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. Its mission is to accelerate the energy transition in an economical, safe and sustainable way and promote the growth of the blue economy.

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.

Portugal is formally recognised by the National Innovation Agency (ANI) as a Technology and Innovation Centre (CTI). CTIs are entities dedicated to the production, dissemination and transmission of knowledge, aimed at companies and economic value creation, contributing to the pursuit of public policy objectives, within the framework of priority specialisation areas, whether national or of the regions in which they operate.

IST Instituto Superior Técnico

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 and extreme events prediction, met-ocean data statistical modelling, 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.

A new project on ocean thermal energy conversion (OTEC) was initiated in late 2022 with funding from Horizon Europe. The project **PLOTEC** was launched by seven partners across Austria, Italy, Portugal, Spain and the United Kingdom and will run until 2025 with a €3.5M budget. Partners in the project are Global OTEC, Cleantech Engineering Limited, WavEC, The Oceanic Platform of the Canary Islands PLOCAN, Quality Culture, Agru Kunststofftechnik Gesellschaft m.b.H., and University of Plymouth.

The main goal of the project is to design and simulate an **OTEC floating platform** capable of withstanding the extreme weather effects of tropical oceans, with a viable cost model, validated by a scaled demonstration of a structure. The consortium plans to conduct the deployment at the PLOCAN test facility in Gran Canaria in 2024. WavEC is responsible in the project for the assessment and quantification of the environmental and socio-economic impacts of the project.

Below some other key representative projects are presented:

Funded by the Horizon 2020 programme:

- **EU-SCORES** was initiated in September 2021 aiming 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 wind farm 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.
- **OceanSET** had 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 were 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. The project was concluded in 2022.
- **LIFTWEC**, coordinated by the Queen's University of Belfast, focus on the development of a novel type of wave energy converter - LiftWEC - based on the exploitation of lift forces generated by wave-induced water velocities. WavEC has been contributing to the identification of promising configurations of the LiftWEC concept that may minimise environmental impacts and ensure social acceptance. It was initiated in 2019 and will run until 2023.

Funded by the European Maritime and Fisheries Fund (EMFF):

- **SAFEWAVE** addresses 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. The Portuguese company Hidromod is also partner of the project. The project will come to a close in 2023.

Funded by the European programme INTERREG Atlantic Area:

- **BLUEGIFT** supports 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 run until the end of 2022.
- **PORTOS** – Ports Towards Energy Self-Sufficiency: 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), started in 2019 and its extension to 2023, with additional activities and partners (two additional case study ports and three technology developers) was recently granted.

Projects with funding from the European Regional Development Fund (ERDF):

- **ATLANTIDA** – *Platform for the monitoring of the North Atlantic Ocean and tools for the sustainable*

exploitation of the marine resources: aims the 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.

- **Ocean3R –** *Reduce pressures, restore and regenerate the NW-Portuguese ocean and waters:* aims the development of solutions to reduce pressures on marine and freshwater ecosystems, and to restore and regenerate degraded habitats along the northwest coast of Portugal. Within the project, the supply of electricity from marine renewables to offshore facilities is being considered. The project is led by CIIMAR.

Funded by the European ERA-NET - European Research Area networks:

- **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 FEUP and INEGI, responsible for scaled physical and numerical modelling activities, performance improvement and optimisation to reduce the LCOE.
- **EVOLVE** aims to model future energy generation, taking in consideration supply and demand scenarios, from distribution to balancing and storage/back-up. This allows to evaluate 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 has been leading the planning of energy mix scenarios, through metocean data, characterization of the different ocean energy resources and identification of demand and supply patterns. It was initiated in 2021 and will be concluded in 2023.

Funded by the National Foundation for Science and Technology (FCT):

- **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.
- **SAGE MIT Portugal Project** is a project conducted by Instituto Superior Técnico with funding from the MIT Portugal Programme through FCT, 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. In 2022, *Instituto Superior Técnico* built and dry-tested a 2.2 kW PTO system for off-grid OWC wave energy converter in a project funded by the Portuguese Foundation for Science. The research built upon the successful experience of the H2020 OPERA project and incorporated new aerodynamic, mechanical, and electrical designs in response to the requirements of stand-alone systems. Applications for this technology include autonomous remote sensing and vehicle battery charging. Further research includes wet-testing in IST's Spar-buoy OWC.

2.2 kW PTO system for off-grid OWC wave energy converter at IST

TECHNOLOGY DEMONSTRATION

Test sites

Portugal has a **Pilot Zone at Viana do Castelo** set up by the government in 2018, with an area of 47 km², at 85-100 m water depth where Portugal's first floating offshore wind project, WindFloat Atlantic (25 MW) occupying an area of ca. 11 km², became fully operational in July 2020.

In 2022, by Decree-Law No. 15/2022, of January 14, the government created a **Technological Free Zone (ZLT)** to be located offshore Viana do Castelo, for the testing and demonstration of new technologies and innovations in a real environment. Later in the year, the government submitted for public consultation the delimitation of the ZLT area (ca 20 km²) inside the limits of the previous Pilot Zone. This area, still under consultation, will be managed by the General Directorate for Energy and Geology (DGEG).

At Aguçadora, there is a test site with an area of 3,3 Km², at 45 m water depth, for research and demonstration projects, where the Swedish developer Corpower is developing their HiWave-5 flagship wave energy project. This area is managed by *Companhia de Energia Oceânica*.

Planned Deployments

CorPower Ocean

During 2022 CorPower Ocean Lda has continued to expand its operations and the team of experts within composites development and manufacturing. The 'Hi-Wave-5' wave energy array demonstration project of the coast of Aguçadoura in northern Portugal has seen the necessary infrastructure, for the first converter installation, achieve readiness level, with the UMACK® anchor and new submarine power export cable installation. The on-land substation refurbishment and upgrade has also been completed. Out of the on-land operations, in the port of Viana do Castelo, the first composite hull has been fabricated and tested and was later integrated with the power-take-off, mooring rod and tidal regulator system. A severe battery of tests was done to prove the reliability of the system before deployment. The HiWave-5 project aims at having four operational devices demonstrating them on a "wave farm", delivering electricity to the grid with certification of availability and performance. In early 2023, the first full-scale unit 'C4' will be deployed, taking the technology from TRL 6 to TRL 7.

© CorPower Ocean

CorPower C4 WEC in Viana do Castelo. © CorPower

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

Atlantic International Research Centre (AIR Centre)

The Atlantic International Research Centre (AIR Centre) is an international collaborative organization that promotes an integrative approach to space, climate, ocean and energy in the Atlantic. The AIR Centre is focused on understanding how the Atlantic and its ecosystems are changing, developing transversal tools and strategic solutions to be applied both locally and globally.

The AIR Centre is the outcome of a long process of scientific diplomacy called Atlantic Interactions, which is an ongoing intergovernmental initiative to unleash the full potential of the Atlantic Ocean for society. The 1st Atlantic Interactions International Workshop (New York City, United States of America, June 2016) was driven by the Portuguese Government and initiated a systematic process of scientific diplomacy. This was followed by five High-Level Industry-Science-Government-Dialogues and other scientific and policy workshops under the title of "Atlantic Interactions". The formal establishment of the AIR Centre was achieved as a conclusion of the 2nd High-Level Dialogue on Atlantic Interactions (Florianopolis, Brazil, November 2017). It was acknowledged that the AIR Centre would become a multilateral networked organization, in association with national and international scientific and research infrastructures. The AIR Centre was legally formed in April 2018 as a non-profit association with headquarters in Terceira Island, Azores, and facilities in Lisbon (Portugal).

RELEVANT NATIONAL EVENTS

WavEC Annual Seminar in 2022 was organized on November 10th in collaboration with the Embassy of Spain in 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 the public and private sectors.

All presentations are available at WavEC website:
https://www.wavec.org/en/events/wavec-seminar-2022

Republic of Korea

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OVERVIEW

The Ministry of Oceans and Fisheries (MOF) set a target for a carbon dioxide reduction by 2050 of 2.3 million CO2 from the ocean energy sector. Many R&D projects are being carried out to support this ministry's carbon-neutral target and ocean energy commercialization. Korea Research Institute of Ships and Ocean Engineering (KRISO) has successfully demonstrated the performance of 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. 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 was installed near the existing Uldolmok Tidal Power Pilot Plant at the end of 2022, and the field test will be carried out in early 2023. The first ocean energy technical standard, harmonized from IEC TS 62600-1, was submitted to the Korea Agency for Technology and Standards and will be registered in 2023 as the Korean Industrial Standards.

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 September 2022 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 for 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 Energy 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. In contrast, the value of REC for wave energy is not given at this moment, and it is expected to be set by analysing the actual power output data from the demonstration project of WEC in the Mook-ri power plant and Yongsoo OWC Pilot Plant. The first REC was issued for the Uldolmok Tidal Power Pilot Plant in 2022 based on the records to generate electricity from tidal current energy.

Public Funding Programmes

MOF provides public funding for ocean energy R&D programs, including demonstration projects, and 17.6 million USD was invested in developing ocean clean energy technologies and tidal energy systems in 2021. In 2022, a new R&D program was launched for developing green hydrogen production technology using ocean energy, and the total budget for three R&D programs was 7.8 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. The Korean Agency for Technology and Standards (KATS) is Korea’s representative national standardization body to develop and manage technical standards. In 2021, the Korea Electric Association (KEA) was designated as the Cooperation Organization for Standards Development (COSD) in the ocean energy sector for standardization activities to setting domestic standards. KIOST and KRISO are participating in this new project to develop national standards and collaborate strongly with KCL, KEA, and KATS. For developing the national standards, the technical specifications published by IEC/TC114 were basically harmonized. In addition, the project is confirming whether it is applicable in Korean and Asian environments. The standardization activities are expected to lead the advancement of ocean energy technologies in connection with existing R&D accomplishment, and technical standards and certification systems can activate the ocean energy industry.

TECHNOLOGY DEMONSTRATION

Projects in the Water

Mook-ri OWC plant

In the 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 the Mook-ri small port in Chuja Island, and the generation performance was successfully evaluated in 2022. This project was selected as one of the 2022 National R&D Excellent Accomplishment 100 by the Ministry of Science and ICT. This demonstration plant adopts the OWC wave power generation method. The armor blocks on the front of the sloped breakwater in the 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

Overview of Mook-ri OWC Plant © KRISO

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.

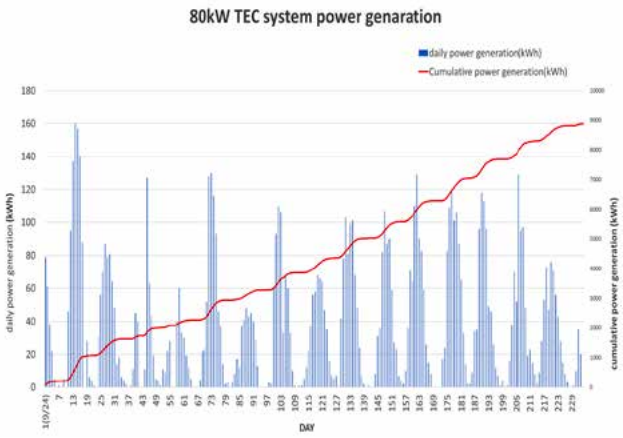
The Mook-ri OWC plant will be operated by KRISO and private enterprises to study various topics such as (1) the correlation of wave condition with power output, (2) output variability of OWC WEC system according to tidal level in the real sea, (3) optimization of control strategy to maximize power output under fluctuating wave conditions, (4) the effective ESS charging and discharging method, (5) continuous measurement and analysis of field noises by operation of WEC, (6) the safety and durability of caisson structures for WEC.

KRISO-Wave Energy Test Site (WETS)

The KRISO-Wave Energy Test Site (WETS), located in the western part of Jeju Island, has been in operation since 2019. KRISO-WETS has 5 test berths, including the **Yongsoo OWC** pilot plant, two in 15 m, one in 40 m, and one in 60 m water depth. Each berth has a 4.5 MW maximum output capacity and 5 MW capacity in total, and it is considered to increase the capacity to meet the requests from floating offshore wind developers. Dry-mate type connecter, ADCP and buoy type wave measurement instrument and onshore and offshore substations are provided. Several small projects were conducted using the test site, such as wave energy devices developed by Jeju University. in 2020, a digital twin for WEC by KRISO. And also, this test site will be used for testing floating offshore wind and green hydrogen production projects. Unmanned underwater vehicles, radars, and floating lidars are being tested using this facility. By conducting more test projects, it will come closer to operating this facility without additional financial support from the Korean government.

One of the open-sea test sites, **Uldolmok Tidal Power Pilot Plant**, is under operation, and it consists of a vertical axis tidal turbine with three helical blades, a power converter, a PMSG, and SCADA. The rated water speed is 3.68 m/s, and the rated output is 80 kW. From 14 September 2021 to 15 May 2022, 8.88 MWh of electricity was generated from this small tidal power plant, and 20 RECs (Renewable Energy Certificates) were officially issued by the Korea Energy Agency. Even though the amount of RECs is not big, it becomes a significant milestone in ocean energy development as the first REC from ocean energy in Korea.

Projects at the KRISO-WETS © KRISO



Uldolmok Tidal Power Pilot Plant and Power Output Records © 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 the 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 on the island. This hybrid system was manufactured and is being installed at the front side of the existing Uldolmok Tidal Power Pilot Plant, and KIOST plans to test its performance under open sea conditions in early 2023.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

A second-term 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. The 6th annual joint workshop was held in September 2022 as an in-person and remote hybrid meeting. Twelve presentations were made in tidal, wave, and ocean thermal energy converters and technical standardization activities.

6th Ocean Energy Joint Workshop

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 5.6 million as per data provided by Department of Statistics Singapore in 2022. In 2015, Singapore pledged to reduce its Emissions Intensity (EI, or GHG emissions per unit of GDP) by 36% from 2005 levels by 2030 and stabilise emissions with the aim of peaking around 2030. In 2022, Singapore raised its climate ambition to achieve net zero emissions by or around mid-century. To enable this transition to a low-carbon future, Singapore will raise the carbon tax levels progressively from 2024. Carbon tax will be raised to $25/tCO2e in 2024 and 2025, and $45/tCO2e in 2026 and 2027, with a view to reaching $50-80/tCO2e by 2030. Singapore's low-carbon transition will have three thrusts.

- To transform our industry, economy, and society,
- Harness emerging technologies as they mature
- Pursue and leverage international collaborations.

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 Re-

newable 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 which actively involves in 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

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.

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 Singapore Government awarded $55 million to support 12 research, development and demonstration projects on low-carbon energy technology solutions. Government is also prepared to spend more than the estimated S$1 billion in carbon tax revenues collected in the first five years, to help companies invest in energy- and carbon-efficient technologies. The Maritime and Port Authority of Singapore (MPA) has partnered up with several major industry players with a $300m decarbonisation fund to boost decarbonisation efforts in the maritime industry.

RESEARCH & DEVELOPMENT

ERI@N, supported mainly by the EDB, 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, micro grids, 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 deployment of offshore renewable technologies specific to the tropics, where unique technology challenges exist. It advances the 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. ERI@N is also actively contributing towards marine energy standards adoption and development as part IEC TS 62600.

TECHNOLOGY DEMONSTRATION

Test Sites

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 50 m 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 the 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.

TCOMS – Ocean basin Facility

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.

MW testing facility at EPGC

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 explore pre-competitive R&D opportunities in energy sector for future micro grids.

Renewable Energy Integration Demonstrator Singapore

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 local supply chain's marine energy resource mapping guidelines of new regions, such as our neighbouring 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 towards 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 attraction. 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 picnic spots in addition to the governmental facilities. Currently, the islands use diesel power generation and water transported by 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 large number of tourists every year. Presently, deployment of renewables and water generation system 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" test bed 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-size 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

Southern Islands of Singapore

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 focused on test-bedding renewable energy and energy storage systems such as high-efficiency solar panels and solar deployment on pipe racks and storage tanks. The Energy Market Authority (EMA) and JTC, with support from Enterprise Singapore (Enterprise SG), have awarded three projects under the $6 million grant to test-bed floating renewables on Jurong Island.

Singapore also announced plans to import up to 4 GW of low-carbon electricity by 2035, with the first Request for Proposal to import up to 1.2 GW beginning by 2027. Singapore also announced plans to import 100 MW of low-carbon electricity from Pulau Bulan, Indonesia and up to 100 MW of hydropower under the Laos PDR-Thailand-Malaysia-Singapore Power Integration Project.

Jurong Island, Singapore

Floating Solar Deployment

- Singapore has switched on a 45-hectare solar photovoltaic (PV) farm that floats in the island's Tengeh Reservoir. This offsets 7% of PUB's annual energy needs.
- 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.
- Aurecon has been appointed by PUB, Singapore's national water agency, to carry out preliminary engineering design and feasibility studies for the proposed 100 MWp and 44 MWp large scale floating solar photovoltaic (PV) systems at Lower Seletar Reservoir and Pandan Reservoir.
- Keppel Infrastructure's subsidiary Keppel Energy Nexus was awarded 6 million grant to test bed offshore floating solar in Jurong island coast of Singapore.
- Keppel Infrastructure, through its applied technology innovation arm, KepInfra Energy Transition Centre (KETC), National University of Singapore, through its Solar Energy Research Institute of Singapore (SERIS), and Nanyang Technological University (NTU), through its Energy Research Institute @ NTU (ERI@N) have signed a Memorandum of Understanding (MOU) for a joint-study on the technological and economic feasibility of developing a first-of-its-kind floating hybrid renewable energy system (RES) for operations in Singapore.

Electrification of Ships & Electricity Imports from other ASEAN countries

- MPA on Mar 2022 announced a $300 million, 2050 maritime decarbonisation blueprint. One of its aims is the electrification of Singapore's harbour craft, with the whole fleet to run on electricity and/or net zero fuels by 2050.
- Keppel O&M working with DNV, the Energy Research Institute @ NTU, Eng Hup Shipping, Envision Digital, Surbana Jurong, and the Technology Centre for Offshore and Marine, Singapore undertake efforts to test, trial, and operationalize end-to-end solutions for the electric harbor craft.
- Singapore has made several announcements regarding plans to decarbonise its energy sector. Chief among them is its plan to import 30% of its electricity from low-carbon or renewable sources such as from neighbouring ASEAN countries.

60 MW Floating Solar in Tengah Reservoir

Workshops on Tidal Current Extractable Energy: Modelling, Verification and Validation

The main goal of this workshop is 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 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. There were attendees from various international tidal energy working teams from all over the world such as France, Sweden, USA, UK, Germany, India, Australia, Indonesia, China, Philippines and Singapore.

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 15th edition of SIEW 2022 addressed on theme of "A Resilient and Sustainable Energy Future", highlighting how to secure, diverse and resilient energy supply even as the world undergoes an energy transition. Singapore and IRENA co-hosted a High-Level Forum at SIEW, with the theme "Realising Green Energy Financing and Decarbonisation Opportunities for a Net-Zero Future". The forum focused on these key areas:

- Scaling Decarbonisation Technologies
- Fostering Green Financing Leadership

SIEW 2022 also had Roundtable sessions focused on the following:

- **Charting the ASEAN Energy Security and Climate Resilience** - The discussion included the efforts to achieve the aspirational target for increasing the component of renewable energy to 23% by 2025 in the ASEAN energy mix, including by increasing the share of RE in installed power capacity to 35% by 2025, reducing energy intensity by 32% in 2025 based on 2005 levels, and expand regional multilateral electricity trading, strengthen grid resilience and modernisation, and promote clean and renewable energy integration.
- **Integrating Battery Energy Storage Systems to Support a Clean Energy Future: Public and Private Sector Perspectives** - Experts shared BESS implementation case studies in the United States. By providing operational and planning insights in distinct market settings across the United States, speakers will highlight how BESS can benefit the Asia region. In particular, speakers will focus on lessons learned from these U.S. use cases and discuss leading practices that East Asia Summit (EAS) members can consider minimizing the barriers to implementation and maximize the benefits of BESS
- **The Role of Nuclear Energy in ASEAN Decarbonisation and Its Implications for Regional Nuclear Cooperation** - This roundtable aimed to assess the viability of nuclear energy as a decarbonisation strategy in ASEAN, the safety issues and challenges for the regulators, and the suitability of advanced nuclear technologies such as SMRs in the region.
- **Achieving our Net Zero Strategy through Technology** – Achieving "net zero" requires investing and enhancing the pace of change across the energy landscape to reduce greenhouse gas emissions. Focusing on the five key pillars of Energy Efficiency, Electrification, Renewables (with a focus on geothermal), Fuel Diversification and Carbon Capture, this Roundtable brought together leading industry and academic leaders who will put forth various strategy and projects covering a comprehensive and integrated net-zero approach.
- **The Role of Energy Imports to support Singapore's Decarbonisation Goals** - This roundtable session provided a strategic and holistic exposition of essential consideration of energy imports in meeting Singapore's decarbonisation ambitions, through a fundamental top-down analysis from a technical, commercial/regulatory/market as well as from an environmental, social, and governance (ESG) and geopolitical perspectives.

Spain

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SUPPORTING POLICIES FOR OCEAN ENERGY

National Strategy

Following the adoption in December 2021 of the "*Roadmap for the Development of Offshore Wind and Ocean 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, the Spanish government has been developing a new legal framework for the licensing of renewable marine energy plants. This legal framework has not yet been approved.

In order to speed up the development of the new regulatory framework, the government is exploring the possibility of promoting legislative sandbox to promote research projects nimbly while considering how best to adapt legislation for a rapid licensing process without undermining the process guarantees for all parties involved.

In the field of maritime spatial planning, the mandatory strategic environmental study of the Maritime Spatial Planning Plan was completed at the end of the year, therefore it is expected the plan to be finally approved in short term.

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 to start the tender calendar for the next five years.

The above mentioned Order TED/1161/2020 stablishes a tender of 20 MW every two years focused on "Other Technologies", where ocean energy is included, reaching 60 MW for 2025.

Public Funding Programmes

As part of the Recovery, Transition and Resilience Plan, the Spanish government is working on a support line called "**Renmarinas Demos**".

In preparation for that funding programme, Order TED/1204/2022 of 2 December 2022 laying down the regulatory bases for the programme to grant investment aid for pilot projects and testing platforms and port infrastructure for marine renewables, published under the Recovery, Transformation and Resilience Plan (RENMARINAS DEMOS Programme), financed by the European Union, NextGenerationEU.

Subsequently, the First Call was published by Resolution of 21 December 2022, of the Governing Council of the Institute for Energy Diversification and Saving (IDAE).

This aid programme was already foreseen in the "*Roadmap for the Development of Offshore Wind and Ocean Energy in Spain*" of December 2021 and in the PERTE for Renewable Energies, Renewable Hydrogen and Storage (ERHA).

The Basque Energy Agency (EVE) launched a new call of its "Demonstration and validation of emerging marine renewable energy technologies" programme in 2022. As previous calls, the programme has a budget of €2.5M for a maximum of 3-year duration projects.

RESEARCH & DEVELOPMENT

EUROPEWAVE

The 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 2022 have been:

– Contract Execution of the 7 Phase 1 projects:

- 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

– Phase-Gate (down-select) process between of Phase 1 Contractors

– Selection of the 5 successful Phase 2 proposals:

- Mocean Energy Ltd: Blue Horizon 250
- IDOM Consulting, Engineering, Architecture SAU: MARMOK Atlantic
- CETO Wave Energy Ireland Ltd: ACHIEVE
- Arrecife Energy Systems SL: Trimaran
- AMOG Consulting Limited: Sea-Saw WEC
- Commencement of contract execution of Phase 2 projects
- Communication and Dissemination activities (EuropeWave 1st Annual Event, Side-Event at ICOE 2022…)

TURBOWAVE

The Basque Energy Agency (EVE) 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 3 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.

After calling the Preliminary Market Consultation, EVE issued the Call for Tender Documentation for the TurboWave initiative on the 27th December 2022.

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 2022, test rigs have been upgraded for a first-of-a-kind practical implementation of the novel testing methodology on three critical components. In Spain, TECNALIA, IDOM and BiMEP work together in the analysis of electric generator failure.

More information: https://www.validhtp.eu/

ELBE Eurocluster

The European cluster alliance ELBE (European Leaders of Blue Energy), led by the Basque Energy Cluster, has been selected by the European Commission as a "Eurocluster" initiative for offshore renewable energy. This Eurocluster is part of the European Commission's Industrial Strategy, structured around 16 priority industrial ecosystems, one of which is the "Renewable Energy Industrial ecosystem".

The ELBE Eurocluster alliance gathers seven European leading clusters: Pôle Mer Méditerranée (France), Offshore Vast (Sweden), Energy Cluster Denmark (Denmark), GCE Node (Norway), Blue Cluster (Belgium), Pomeranian Offshore Platform (Poland) and BEC, as the coordinator of the alliance. Over the next 3 years, the clusters in the alliance will carry out joint activities to support European SMEs in the sector around networking, innovation, adopting new technologies, training, and internationalisation.

SEETIP Ocean

The SEETIP project, funded under the Horizon Europe programme, supports the activities of both the European Technology and Innovation Platform for Ocean Energy (ETIP Ocean) and the SETPlan Ocean Energy Implementation Working Group (OE-IWG). TECNALIA is leading, in collaboration with Ocean Energy Europe and the University of Edinburgh, the Work Package on Research, Technology, Development and Innovation, where a series of webinars and workshops will be organised to enable knowledge sharing and the Strategic Research and Innovation Agenda for the sector will be updated based on the latest technical developments.

JRL-ORE

The Joint Research Laboratory on Offshore Renewable Energy has been active for 5 years. Based on the Basque Country, the JRL-ORE is a scientific community composed of around 60 researchers from TECNALIA, BCAM and UPV/EHU. It seeks to strengthen the research links between the parties in order to take advantage of synergies between them in the agreed scientific and technological areas. It aims to increase the level of the research results in terms of their impact in the business world and society in general.

More information: https://jrl-ore.com/

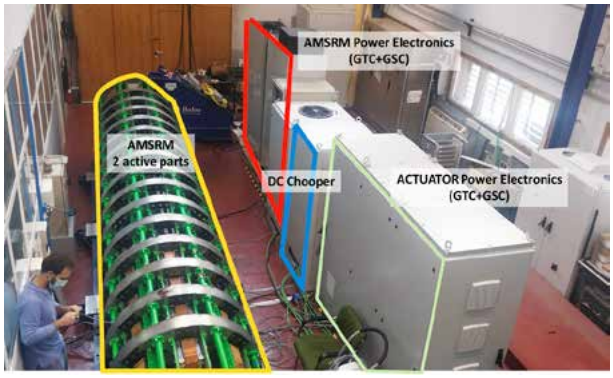
Project SEA TITAN

The European project SEA TITAN: Surging Energy Absorption Through Increasing Trust and Efficiency (Horizon 2020, grant agreement No. 764014) has finished in 2022. The project has been coordinated by the Spanish company WEDGE GLOBAL and it has involved 8 companies (WEDGE, CORPOWER, CENTIPOD, HYDROCAP, OCEM, COLUMBUS, ENGIE and EDP CNET) and 3 non-profit organizations (CIEMAT, WAVEC and UNE).

The objective of the project was to develop an optimized cross-cutting power take-off (PTO) with application to multiple systems through collaboration with multiple wave energy developers and industrial partners with a strong track record on technology. CENTIPOD, HYDROCAP, CORPOWER and WEDGE GLOBAL were the companies in charge of providing the frame conditions to design a modular, adaptative and scalable PTO based on the technology of Azimuthal Linear Switched Reluctance Generator.

A complete prototype of the new design of PTO was fabricated, including the linear generator, power electronic converters and control platform. The complete novel prototype of PTO was tested in laboratory environment, emulating real conditions by means of a hardware-in-the-loop scheme with 8 different scenarios corresponding to the conditions related to the different technology developers involved. Complete information of the performance of the new PTO (force limits, efficiency map, thermal behaviour and mechanical vibrations) was obtained from these experimental tests.

More information: https://seatitan.eu/



SafeWAVE

The project started on October 2021 and will run until September 2023. During summer 2022 some environmental monitoring activities continued, and several documents on public education and engagement strategy, consenting, and marine spatial planning were produced as project deliverables. Co-funded by the European Climate, Infrastructure and Environment Executive Agency (CINEA) and launched in November 2020, the SafeWAVE - *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 projects in EU.

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.

More information: https://www.safewave-project.eu/

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 (wave and tidal) in Orkney, UK; SEENEOH (hydrokinetic and tidal) in Bordeaux, France; SmartBay (wave and floating wind) from Galway, Ireland; Centrale Nantes/ SEM-REV (wave and floating wind) in Nantes, France; PLOCAN (wave and floating wind) in the Canary Islands; WavEC (wave and floating wind) in Portugal; and BiMEP (wave and floating wind) in Spain.

TECHNOLOGY DEMONSTRATION

Existing Open Sea Test Sites

Marine Corrosion Test Site "El Bocal"

The main objective of this facility is to test, study and analyze, in realistic conditions, coatings and materials used in the marine industry, such as renewable energy devices (wind, tidal, wave, etc.), ships, oil & gas structures, etc., with improved corrosion, degradation, and erosion properties and marine growth. In order to achieve this objective, the Marine Corrosion Test Site (MCTS) *"El Bocal"*, an unique place for testing new coatings and components under realistic marine conditions, has been developed by CTC.

The MCTS *"El Bocal"* is located at the shoreline of the Cantabria coast, few kilometers away from Santander city, in an idoneous site with an easy access for testing and monitoring activities. This facility is placed in open water so that specimens to be tested are subjected to real offshore environment. For this reason, the corrosion and biofouling conditions are similar to the ones a typical offshore structure faces along its life cycle.

MCTS El Bocal Location and Environment

MCTS El Bocal Corrosion Environment

HARSHLAB

HarshLab component and testing laboratory has been commissioned in Bimep Area in June 2022. This new version of HarshLab allows testing and trials of new materials and developments for the offshore industry, in a real environment and under controlled conditions. In addition to the traditional test areas for testing samples (splash, immersion and atmospheric), it will be connected to the electrical and communications network thanks to a dynamic cable that will connect it to BiMEP's underwater electrical grid in 2023, which will allow testing equipment in operation, data collection and subsequent analysis, as well as facilitating the handling of loads through the hydraulic crane on the main deck.

The new laboratory measures 8.5 m in diameter by 7 m in height and has a usable deck area of 120 m^2, which gives it greater testing capacity. On the other hand, thanks to the renewed features of this new version of the laboratory, it also has the capacity to test anchoring elements, submarine cable connectors, or in the seabed itself, up to 65 m deep. Last but not least, some additional features have been included, such an underwater modem to communicate submerged elements with the surface; its own weather station; and an underwater ROV (Remotely Operated Vehicle) to perform remote inspections.

More info at: https://harshlab.eu/

BiMEP

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.

PLOCAN

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.

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.

Projects in the Water

Mutriku Wave Power Plant, the first multi-turbine wave energy facility in the world, has been integrated in BiMEP infrastructure, being now a second facility of BiMEP. The plant was connected to the grid in July 2011, and in 2022 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). The total energy generated since the start of the plant is almost 2.8 GWh.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

TECNALIA has contributed to the OES Task 12 “Performance Metrics International Framework for Ocean Energy” supporting the organisation of a Funders Summit and disseminating the Evaluation Framework and the joint publication with IEC/IECRE “Supporting ocean energy technology development and commercialisation”.

RELEVANT NATIONAL EVENTS

Relevant Event in 2022

ICOE-OEE 2022

This year, the Basque Energy Cluster (BEC) together with Ocean Energy Systems (IEA-OES), in collaboration with Ocean Energy Europe (OEE) have come together to combine a unique reference event, ICOE-OEE 2022, bringing together the global ocean energy sector in the Basque Country. During October 18-20, the Kursaal Congress Center brought together more than 600 attendees from all over the world. The delegates were able to attend more than 20 sessions in an ambitious program that included the participation of 150 speakers from the main companies, R&D agents and public institutions that lead the sector. In addition, in parallel, project consortia, companies and entities had the opportunity to hold up to nine side events in which they shared progress on different projects and initiatives underway.

The technical sessions were completed with an exhibition area at full capacity and more than 80 posters. This exhibition area, in which more than 50 companies and institutions participated, was the meeting and networking point for all attendees. The significant Basque presence grouped under the ‘Wave Energy Basque Country’ brand stood out in this space, with the participation of EVE, BiMEP, the companies IDOM, AEROBLADE, DITREL and GALEA, as well as the technology centers TECNALIA and AZTI.

The possibility of professional connection and networking in the exhibition area was completed with a specific B2B (Business-to-Business) event organized by SPRI and Basque Trade & Investment, as representatives in the Basque Country of the European Enterprise Network, through of which more than 125 meetings were closed in which around 100 delegates from more than 16 countries participated.

The event had 17 sponsors, whose participation and support facilitated the celebration of the event and the high level of both technical and organizational quality. Among these, the Basque Energy Entity/Energiaren Euskal Erakundea (EVE) stands out as the most important sponsor of the event, within the platinum category. In addition, among the sponsors, there were other Basque companies such as BiMEP as a silver sponsor, IDOM and DITREL as bronze sponsors, SPRI-GV as a sponsor of the ‘Tech Trail’ and Euroregion as a collaborator. On the international side, it is worth mentioning the national pavilions of Canada and Wales, with gold sponsorship, as well as the Scottish pavilion with silver sponsorship.

Relevant Event Planned for 2023

EWTEC 2023

The city of Bilbao will host European Wave and Tidal Energy Conference in 2023 (3-7 September) organised by the University of the Basque Country (https://ewtec.org/ewtec-2023/)

Sweden

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OVERVIEW

In 2022, Swedish ocean energy developers continued to move closer to commercialization. For example, Minesto completed commissioning of the Dragon 4 (100 kW) tidal power plants in Vestmannasund, Faroe Islands and the results verified commercial performance. Next steps are to run a mini array with the two Dragon 4 units operating in parallel and to install a utility-scale Dragon 12 in 2023. Corpower installed the first commercial-scale UMACK anchor, to support the HiWave-5 demonstration, in Aguçadoura, Portugal, and the C4 wave energy converter (WEC) power take off (PTO) completed a rigorous one-year on-land testing program in Stockholm in which the data confirmed that the C4 is meeting its target metrics. Ocean deployment of CorPower's C4 WEC will take place in early 2023. Novige continued to develop and test their WEC prototype, NoviOcean2 (NO2), both onshore in a test rig and offshore, in the Stockholm archipelago. The offshore testing matched simulations and the system worked as expected. In the EU funded LIFE NOVIOCEAN project Novige is working on development and subsequent offshore testing of a pre-commercial 500 kW pilot unit (NO500). Ocean Harvesting Technologies successfully completed a test rig project for the InfinityWEC Power Take-Off with control system at scale 1:10 and has started preparations for sea trials at scale 1:3.

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 2022, over 20 R&D projects were running, covering topics such as reliability & survivability, anchoring systems, material improvements, wave prediction, WEC and tidal power device array optimizations, co-location of multiple power conversion technologies, environmental studies and salinity gradient power potential.

SUPPORTING POLICIES FOR OCEAN ENERGY

National Strategy

In 2016, the government together with several other political parties agreed on a long-term bipartisan energy policy for Sweden. The agreement included a target of 100 percent renewable electricity production by 2040 and no net emissions of greenhouse gases in the atmosphere by 2045. The target of 100% renewable electricity production by 2040 was taken as a decision by the Riksdag (the Parliament of Sweden) in 2018. This target does not exclude the existence of nuclear power and following the election in the autumn 2022, when the new Government took office, the focus of the national energy politics has changed to 100% fossil free electricity

production. In 2018, a new Climate Policy Framework Act was introduced, 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 published Sweden's integrated national energy and climate plan, which presents how Sweden contributes to reaching the European Union's goals in renewable energy and energy efficiency by 2030. Ocean energy is one of many areas included in Sweden's national maritime strategy, which identifies areas where action is needed to promote a sustainable development in the Swedish maritime sector. This strategy was enacted in 2015 by the Ministry of Enterprises, Energy and Communications. In February 2022, the Government adopted three marine spatial plans for its territorial waters and Exclusive Economic Zone. Marine spatial planning will form the basis for governmental agency and municipal decisions regarding the most appropriate usage of a marine area. To date, no specific area has been designated for ocean energy usage.

Market Incentives

The current long-term Swedish energy policy relies on economic policy instruments, which are technology neutral, and include a carbon tax, international emissions trading and a renewable electricity certificate system. However, renewable electricity production developments commissioned beyond the end of 2021 are not eligible to receive electricity certificates. 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, www.energimyndigheten.se), 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, www.vr.se), which is tasked with funding fundamental research and research infrastructure for a wide range of topics.
- Swedish Innovation Agency (VINNOVA www.vinnova.se), 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 programme was started. The programme ends in 2024 and has a total budget of around 10,2 MEuro. 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

No additional calls are planned within the ocean energy programme but ocean energy projects can apply for funding within other existing programmes such as, for example, Framtidens elsystem[23], Pilot- och demonstrationsprojekt[24], Verifiering av innovation med kund[25] and Utveckla en affärsidé[26].

The Swedish Energy Agency is also involved in the Clean Energy Transition Partnership[27] (CETPartner-

23 https://www.energimyndigheten.se/forskning-och-innovation/forskning/elsystem/framtidens-elsystem/

24 https://www.energimyndigheten.se/forskning-och-innovation/stod-till-affarsideer-test-och-lansering/testa-en-innovation/pilot-och-demonstrationsprojekt/

25 https://www.energimyndigheten.se/forskning-och-innovation/stod-till-affarsideer-test-och-lansering/testa-en-innovation/verifiering-med-kund/

26 https://www.energimyndigheten.se/forskning-och-innovation/stod-till-affarsideer-test-och-lansering/utveckla-en-affarside/

27 https://cetpartnership.eu/

ship), which is a collaboration between national/regional funding organisations in European Members States and Associated Countries that aims to accelerate the energy transition.

RESEARCH & DEVELOPMENT

Swedish companies, universities and institutes have been involved with several research and development projects during 2022, see examples below.

Deep Green Tether

The unique tidal and ocean current power plant Deep Green, developed by Minesto, has been demonstrated in the Faroe Islands (DG100) and Wales (DGU). The functionality of the powerplant is verified and the commercial potential confirmed. Analysing these results, the tether (anchoring system) is identified as a critical area of improvement to further utilise the potential of the technology and reach a commercial breakthrough. The tether includes the power cable for electricity distribution, counterforce to the lift force of the wing, communication, connectors, and hydrodynamic fairings. In this project Minesto will develop a new tether for the Minesto powerplant and demonstrate it in real operating conditions.

De-Risk PTO by control of marine biofouling and corrosion (DERISK)

The project aims to study the effects of marine growth, corrosion and wear and validate solutions for the piston rod and sealing system within wave energy devices. Tests were carried out in accelerated forms in lab environments as well as in field environments at Kristineberg Center for Marine Research and Innovation, Sweden, CorPower test facility in Stockholm, Sweden, WavEC´s test site in Portugal and PLOCAN, Canary Island, Spain. The project's final aim is to establish methodology for multi-degradation testing. Project partners are RISE Research Institutes of Sweden and CorPower Ocean.

DUAL Ports project

The DUAL Ports project was an Interreg project that finished in 2022. This project aimed to reduce carbon dioxide emissions from ports by examining the possibility of ports operating 100% of renewable energy. The project contributed to developing and building up knowledge about the completely renewable system and its operation, which aligns with Europe's and local climate goals. Uppsala University's part of the project was to explore the possibilities of using offshore wind and wave power as a part of the energy supply to develop and test an energy management system that enables the combination of different renewable energy sources to the port's energy system.

European Scalable Offshore Renewable Energy Source (EU-SCORES)

The EU-financed project EU-SCORES will demonstrate the combination of offshore wind with wave and offshore floating PV parks. These multi-source parks will use offshore space more efficiently and balance the electricity grid to achieve a resilient and cost-effective 100% renewable energy system. Among the project partners are CorPower Ocean and Uppsala University. The project will include ocean demonstration of two 2nd generation full-scale CorPower WECs and collection hub. Uppsala University leads the task on grid infrastructure planning, electrical power management, and power quality from the multi-source parks.

Evaluation of WaveMove's energy relevance in North Sea installations

OE systems develops a wave energy converter called WaveMove, which is a terminator wave energy solution that works in water depths from 30m - 200m. The purpose of this project is to evaluate the energy relevance, via marine analyses, of the wave energy system WaveMove in places that are interesting for potential customers. OE Systems are planning for wave tank testing of their wave energy system in scale 1:25 in late 2023 in Gothenburg, Sweden, together with clients.

Harvesting of Blue energy using Swedish natural and artificial resources

The main goal of this project is to evaluate the potential of salinity gradient power (SGP) as a sustainable energy source in Sweden based on the existing natural and artificial resources. In 2022, a salinity gradient map for Sweden based on natural resources was prepared. The total theoretical SGP potential was estimated to be approximately 2610 MW from 87 estuaries. A lab scale Reverse Electrodialysis (RED) setup has been installed at Lund University and a pre-pilot scale RED setup has been installed at Umeå University. This project is a collaboration between Umeå University and Lund University.

Hull-Material for Wave Energy Converters (WECHULL)

The main objective of the WECHULL project is to develop and validate two types of innovative materials, composite (CorPower Ocean) and concrete (Ocean Harvesting Technologies), to be applied to hulls for wave energy devices. The overall concept of the WECHULL project is based on accelerated hybrid testing of the materials through establishing loads though slamming analysis, material screening process, testing of critical sections of the hull and integrating the results in a full-scale simulation. Project partners are RISE Research Institutes of Sweden, RISE SICOMP, CorPower Ocean, Ocean Harvesting technologies, KTH Royal Institute of Technology and I-Tech AB.

Kite array: Optimization of tidal power arrays

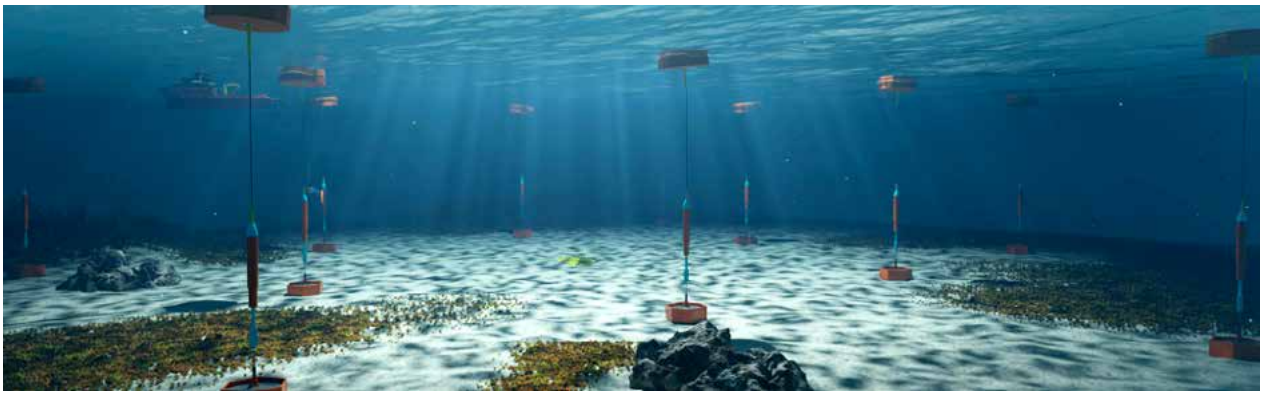
The purpose of this project is to contribute to knowledge of how the arrangement of several tidal power plants in arrays can be designed, taking power output and interactions between the power plants into account. In 2022, the model that is used for calculations has been validated against observations provided by Minesto. The project is a collaboration between University of Gothenburg and Minesto.

Multiple cluster scattering theory and collaborative control for wave power optimization

This project addresses the problems of achieving high efficiency and competitive costs in large-scale wave power farms with new approaches to modelling and optimizing large-scale wave power systems. A multiple cluster scattering theory has been developed and validated, and a time-domain model for a farm is under development. This will be coupled to a machine learning control method to enhance the performance of the farm. The project is being carried out by Uppsala University.

Ocean Harvesting Technologies / InfinityWEC

Ocean Harvesting Technologies AB develops a wave energy converter called InfinityWEC. During 2022, the InfinityWEC wave energy converter has been upgraded with an innovative solution that uses hydrostatic pressure to provide a constant pre-tension force in the PTO instead of a hydraulic cylinder with gas accumulators. A test rig project for the InfinityWEC PTO with control system at scale 1:10 was successfully carried out and completed in March 2022. A case study for Lundin Energy Norway evaluating the feasibility of a possible wave farm installation for an oil and gas platform was completed in May 2022 and showed promising results.



Visualization of InfinityWEC devices in the sea. © Ocean Harvesting Technologies

OESA project

The OESA project was an Interreg project that finished in 2022. The initial objective of this project was to realize a transnational Pilot Accelerator Programme by promoting a new Scale-up Service Offer, accelerating the deployment of five ocean energy pilots and engaging relevant stakeholders to stimulate greening of North Sea region. In this project, Uppsala University actively collaborated with three technology developers, Seabased Group (Norway), Floating Power Plant (Denmark), and Nemos (Germany) and also with other organizations, namely Aalborg University (Denmark), SSPA (Sweden), and ORE Catapult (UK).

Robotized dry testing of wave energy converters

In this project a novel dry test rig concept for wave energy converters was developed and evaluated at Uppsala University. An industrial robot manipulator is here used as wave emulator, providing full 6-Degrees-Of-Freedom (6-DOF) motion for testing wave energy converter power take-off units on-shore. The purpose of the project is to achieve a general and cost-efficient setup with full motion flexibility and high motion accuracy for realistic scaled force and power experiments. In 2022, a full-scale demonstrator of the test rig concept was evaluated together with the LRTC wave energy converter prototype from Uppsala University.

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. The project is being carried out by KTH Royal Institute of Technology in collaboration with Ozone Tech Systems AB.

Uppsala University / development of a marine current power converter

During 2022, experiments have been carried through at the test site for marine current power in Söderfors, Sweden. The marine current power converter, of 7.5 kW, has successfully been connected to the local power grid and power has been fed into the grid. Data for the whole system, including turbine, generator and electricity system, has been registered. Additionally, hydrodynamic simulation models have been used to further develop the turbine. The grid connection has also been modelled and studied in lab environment to better understand the observations from the test site.

Verification through Accelerated testing Leading to Improved wave energy Designs (VALID)

The EU-financed VALID project is developing and validating a new test 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). VALID assembles the full value chain required from methodology and platform development (AVL, Aquatera), technology development (Corpower, IDOM, Wavepiston), LCOE (Julia F Chosaz Consult Engineering) to certification bodies (RINA-C) in order to develop an integrated solution with support from research and technology organisations (RISE, Tecnalia, Bimep) and academia (Aalborg University, TUDelft, DTU).

Wave Energy Converters – integration of tribological design principles

The main goal of this project is to enhance the development and implementation of wave energy converter (WEC) technology by integrating tribological principles into the WEC design work. During 2022, research has been conducted in close collaboration with participating WEC developers. The project is being carried out by KTH Royal Institute of Technology in collaboration with Axel Christiernsson International AB, Corpower Ocean AB, Novige AB and Nynas AB.

TECHNOLOGY DEMONSTRATION

Existing Open Sea Test Sites

Lysekil test site – Lysekil, Sweden

The Lysekil wave energy research test site in Sweden is operational. It has 11 wave energy converters of a total of 260 kW installed and grid-connected. During 2022 there have been no specific activities at the test site apart from the related development by Uppsala University of a new type of measurement system integrated in a 1 m buoy.

Testbed for Marine Materials - Fiskebäckskil, Sweden

The testbed for materials in marine environment was inaugurated in 2021 and offers development, testing and verification of antifouling systems, corrosion protection and environmental assessment. The testbed for materials in marine environment is located at the Kristineberg Marine Research and Innovation Center in Fiskebäckskil (Skaftö), Sweden. The facility gathers expertise, laboratory resources and field infrastructure.

Kristineberg Marine Research and Innovation Center in Fiskebäckskil, Sweden. © RISE

Projects in the Water

Minesto - Vestmannasund, Faroe Islands

In summer 2022, Minesto successfully completed commissioning including satisfactory electricity production and verification of all core functionality with the new Dragon 4 (100 kW) tidal power plant in Vestmannasund, Faroe Islands. The kite generated first electricity to grid right “out of the box” and the commissioning plan was executed as planned. The commissioning results verified commercial performance and are fully in line with simulation results. Since its successful commissioning, the second Dragon 4 unit has been producing electricity throughout October and November and has delivered record-breaking results in terms of total electricity generated, peak performance, and energy conversion at large. To enable a mini array of both systems in parallel, a second foundation, subsea cable and onshore interface were installed in December 2022. The subsea infrastructure is ready for a second kite installation.

Deployment of the first Dragon 4 powerplant in Vestmannasund, Faroe Islands. © Minesto

Novige – Stockholm archipelago, Sweden

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. During 2022, Novige has continued to further develop and test their smaller scale NO2 prototype. Improvements have been made and testing of the system has been performed both in their test rig at KTH, Stockholm, and offshore. The NO2 prototype was deployed for three months in the spring of 2022, in the Stockholm archipelago. The system worked as expected, basically with no problems of significance. The most important result was that the offshore testing matched Novige's own and third-party simulations to the point.

Novige's NoviOcean, NO2, deployed in the Stockholm archipelago. © Novige

Planned Deployments

CorPower - Aguçadoura, Portugal

HiWave-5 is CorPower's flagship demonstration project which will bring their wave technology to a bankable array product offering between 2020 and 2025. The project is designed to prove the survivability, performance and economics of a grid-connected 1.2 MW array consisting of four commercial scale devices at the Aguçadoura site in Northern Portugal. Product certification is provided by DNV and independent validation of device performance by EMEC and WavEC. The HiWave-5 project is implemented in two stages:

- Stage 4 (2020-2022): Demonstration and prototype certification of single device at full commercial scale called the "C4 WEC". Stage 4 takes the technology from TRL 6 to TRL 7.
- Stage 5 (2022-2024): Demonstration and type-certification of a pilot array with three additional full commercial scale WECs called the "C5 WEC". The C5 WEC is an improved version of the C4 from Stage 4 by taking in all learnings from Stage 4. Stage 5 takes the technology from TRL 7 to TRL 8.

The C4 WEC Power Take Off (PTO) completed a rigorous one-year on-land testing program in Stockholm, that started in September 2021 and was completed in August 2022. Following successful dry testing, the C4 PTO was transported from Sweden to Portugal. CorPower Ocean has teamed up with composite experts to develop its first commercial-scale hull in Viana do Castelo (Portugal), completed in 2022. Following the completion and successful factory-acceptance testing of the C4 composite hull and the delivery of the C4 PTO to Viana do Castelo, the steps of WEC system integration have been performed. The system integration includes mating the PTO with the composite hull to form the main WEC unit and connecting up the mooring system and tidal regulation unit to the C4 WEC. After completing the C4 WEC system integration, a rigorous Pre-Deployment Check (PDC) program was initiated as a final step to confirm functions and key requirements before bringing the system quay-side for ocean deployment.

In early 2022, CorPower, in the HiWave-5 project, completed substation and site preparation work to secure a reliable grid connection between the offshore site and the on-land substation located in Aguçadoura, Portugal. CorPower Ocean and Maersk Supply Services installed a 6.2 km subsea export cable for the HiWave-5 Project. The cable was successfully connected into the on-land substation in June 2022. The 100-tonne cable was installed using the Maersk Achiever vessel to provide power and data connection to the site. CorPower Ocean, Maersk Supply Service and Dieseko successfully installed the first commercial-scale UMACK anchor, to support the HiWave-5 demonstration in June 2022.

Developed by a European consortium of experts led by CorPower Ocean, the UMACK technology provides a step-change improvement to the vertical holding capacity of pile-type anchors. It offers significant reductions to cost and carbon footprints compared to both monopiles and gravity foundations and can support offshore installations such as marine energy devices, floating wind and aquaculture.

In early 2023, CorPower's C4 WEC will be towed to the Aguçadoura site and installed with local service vessels, following successful completion of the on-land pre-deployment check (PDC) program in Viana do Castelo.

Minesto

Minesto is planning deployment of a second Dragon 4 kite in Vestmannasund, Faroe Islands, which will make it possible to run a mini array with two Dragon 4 units operating in parallel. The development of Minesto's utility-scale power plant Dragon 12 (1.2 MW) made significant progress during the year. Installation of the Dragon 12 is planned for 2023. In December 2022, Minesto signed collaboration agreements for Project Development in Nusa Tengara Barat (NTB) region, Indonesia.

Novige

After a final run in COAST Lab wave tank, Plymouth, in spring 2023, Novige is planning to install their NO2 prototype long-term by a small island close to Stockholm. The off-grid island will be powered by a combination of solar and wave energy. It will be a long-term test but also a showcase for visitors coming to see Novige in Stockholm. 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, of 500 kW, over a 4-year period.

Since the start of this project, Novige has performed extensive simulation work. Novige, together with experts in ship design, are currently exploring the possibility of reusing carbon fiber rotor blades from decommissioned wind turbines for constructing the float. Regarding ocean deployment, the plan is to start a longer period of ocean testing of the float and moorings within two years and thereafter to integrate the PTO with the float a year later. Location for the ocean testing has not

Corpower C4 PTO in dry-test rig in Stockholm. © Corpower

UMACK anchor in Viana do Castelo. © CorPower

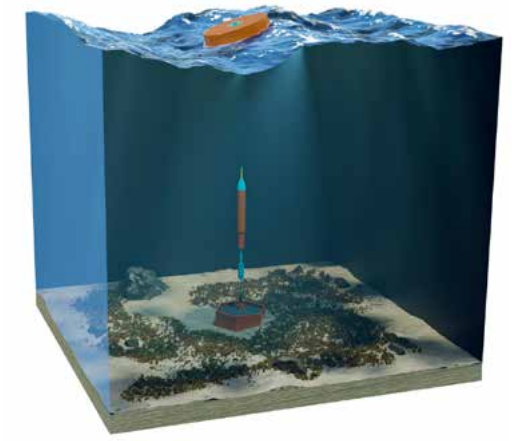
Dragon 4 - Lifting. © Minesto

Novige's NoviOcean, NO2. © Novige

yet been decided but the BIMEP test site is an option that is being explored.

Ocean Harvesting Technologies (OHT)

During 2022 Ocean Harvesting has started preparations for sea trials of InfinityWEC at scale 1:3, to be performed off the west coast of Sweden. The sea trial project, to validate the performance in a real sea environment, is planned to be conducted between February 2023 and June 2025. Results will be used to further develop and improve the full-scale system with regards to energy yield, system efficiency, availability, and ultimately affordability.



Visualization of InfinityWEC device in the sea.
© Ocean Harvesting Technologies

Uppsala University – Lysekil test site, Sweden

A new type of measurement system integrated in a 1 m buoy has been developed during 2022. The measurement system consists of an inertial measurement unit (IMU) and a force load cell. All measurements are synchronized in time, which allows to measure both 6 degrees of freedom motion of the buoy and the force in connection line simultaneously, which is essential, for example, for active control in offshore conditions. The buoy will be installed in 2023 for long term offshore testing at the Lysekil test site in Sweden.

Waves4Power - MoU signed with the Indonesian national power company

In 2022 Waves4Power participated in Business Acceleration Program Indonesia, a programme managed by Business Sweden and financed by the Swedish Energy Agency, aiming at making Swedish technologies available on the Indonesia market. Through the program Waves4Power has established a local representation in Indonesia and contacted potential customers for their WaveEL™ wave energy system. The work on the Indonesian market resulted in a MoU between Waves4Power and PLN (Perusahaan Listrik Negara, the Indonesian national power company) aiming at a definitive agreement to install 150 MW of wave power in the next five years.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

Viable Seas – A Swedish collaboration platform for a sustainable blue economy

Viable Seas is the open Swedish partnership founded in December 2022 to accelerate the transition to a sustainable blue economy. It will unite partners in the vision Viable Seas and a sustainable blue economy with the joint mission to mobilize actors and facilitate co-creation of new sustainable blue solutions for a transformation to a sustainable society. Viable Seas is an intermediary that unite actors, link initiatives and systems to create shortcuts between people, resources and markets. They unite Swedish actors to international partnerships where Swedish strengths contribute to a transformation to a sustainable blue economy while simultaneously strengthening Swedish competitiveness.

International cooperation within marine tribology initiated

KTH Royal Institute of Technology, Sweden, and Ghent University, Belgium, have initiated a collaboration within marine tribology. The aim of the collaboration is to develop an international platform within this area and to include wave energy developers.

UK

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OVERVIEW

The UK's position as a leading nation in the global effort to slow climate change has now become synonymous with our position as one of the leading nations in the research, innovation and development of the ocean energy sector. The value of this position has only been emphasised in light of Russia's ongoing illegal invasion of Ukraine, with the UK looking to further develop renewable energy technologies, such as wave and tidal, that can complement and strengthen the existing domestic energy mix. The maturation of the sector continues to move at pace, with tidal stream looking to move from single device deployment to arrays and the wave sector seeing increased tank testing and deployment of prototypes. With regards to the policy landscape, recent government energy strategies, both at a UK and devolved level, make explicit reference to the untapped potential of the ocean energy sector for energy generation and energy security. This is only bolstered by the success of market pull mechanisms such as the Contracts for Difference scheme, which has delivered increased sectoral confidence as a number of device developers were granted contracts. Across the UK, industry, academia and government continue to tie the ocean energy sector to net-zero ambitions, energy security strategies and the Just Transition. However, there is still a pressing need for a reduction in the overall costs of ocean energy to ensure the sector becomes competitive with more mature renewable technologies, there is reason to believe that both wave and tidal energy have a vital role to play in the future of UK energy production.

Tidal Stream

2022 was a pivotal year for the tidal sector, both with regards to achieving long-term funding support and the continued progression of several key technology developers:

- The UK government awarded Contracts for Difference (CfDs) to the tidal sector for the first time, with a total of 40.82 MW of tidal energy projects granted contracts at a strike price of £178.54/MWh.
- Orbital Marine Power have continued to help lead the sector, with their current flagship device, the O2, having been in continuous operation since 2021 and reporting a peak power of 2.5 MW.
- In February 2022, Nova Innovation announced the award of an Option Agreement from Crown Estate Scotland to develop a 15 MW tidal array at Yell Sound, Shetland – the company's largest array to date. This site has the potential to meet over a third of household electricity demand in Shetland.
- The Scottish government's draft energy strategy, released in early 2023, outlines the vast potential of tidal stream technology and plans to consult across government on ambitions for realising its potential.

Wave

Wave energy continues to move from strength to strength, with concerted efforts to continue its drive towards higher TRLs and overall commercialisation:

- Wave Energy Scotland (WES) continues to drive wave energy R&D activity in the UK and to build confidence in the sector's technology. In 2022, WES concluded its Novel Wave Energy Converter (NWEC) programme with AWS Ocean Energy's 16 kW Archimedes Waveswing wave energy converter becoming the second participant to deliver its open-sea testing project.
- Mocean Energy continue to advance their technology towards commercialisation and have recently collaborated with energy storage company Verlume to showcase an operational renewable remote power system, showcasing their Blue X wave energy converter.
- In preparation for Phase 3 of the Europewave Programme, which will see prototype wave energy converter systems deployed for 12 months, Europewave has reserved a berth at EMEC's Billia Croo test site from 2022 to 2025.
- The Scottish government's draft energy strategy, released in early 2023, recommends continued support for Wave Energy Scotland and suggests that an appropriate target for wave energy could be the testing of up to four wave energy convertors (250 kW each) at European Marine Energy Centre (EMEC) by 2027.

SUPPORTING POLICIES FOR OCEAN ENERGY

National Strategy

The design and implementation of energy policy within the UK is made more complex by the presence of the different devolved administrations in Wales, Scotland and Northern Ireland, all of whom have differing levels of autonomy with regards to the decision making processes within their own borders. This is further complicated, as each nation currently has a different majority ruling party, each of which has its own unique vision regarding the role that renewable energy sources should play in the national energy mix.

Energy policy within the UK is the responsibility of the Department for Business, Energy and Industrial Strategy (BEIS). Within the UK, energy policy is largely devolved to the Northern Ireland Executive, yet it is only partially devolved to Wales and Scotland. However, the ability to enact policy that is designed to tackle climate change, through policy levers such as the promotion of renewable energy, energy efficiency and electricity generation and transmission development are fully devolved matters, allowing the devolved governments some powers in governing the overall energy mix.

United Kingdom

2022 represents a critical moment in the UK's journey towards Net Zero. Despite facing a turbulent year domestically, the UK remains one of the few nations with credible emissions targets in line with the long-term goals of the Paris Agreement. The UK remains committed to achieving its legislatively bound target of Net Zero emissions by 2050 and is largely supported by a sound policy framework that addresses the challenge with the requisite scale and pace. Renewable uptake in general across the UK is growing steadily and the role of both solar and wind as the foundation of our new Net Zero energy system is now clearly defined. However, it is becoming increasingly clear that UK energy policy must ensure that a diversified and resilient energy mix is created. To this end, there is now a growing consensus that wave and tidal energy resources can help to underpin and strengthen our national energy mix.

In light of the need to reach Net Zero and at the same time address heightened concerns regarding energy security, a number of high-level policy documents published by the UK government emphasise the importance of exploiting all of the potential sources of renewable energy across the UK:

- The "Net Zero Strategy: Build Back Greener", published in 2021, aims to keep the country on track for meeting the UK carbon budgets, the 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 net zero targets.
- The publication of the British Energy Security Strategy (BESS) has seen the UK double down on its commitments to Net Zero, which will be achieved in part through the increased provision of renewable energy resources. The BESS also highlights the need to aggressively explore tidal energy as a future source of clean energy and the potential importance of funded collaboration with international partners.
- The Environmental Audit Committee has also set out plans for how the UK can accelerate the transition away from fossil fuels and secure energy supplies that tackle the energy affordability, security and sustainability crises. This report calls for a greater focus on the potential of tidal energy to contribute to the UK's long term energy security baseload all year round.
- The UK government is also planning to hold a Review of Electricity Market Arrangements (REMA), with consultation currently ongoing. This is particularly relevant for the future of the CfD scheme and the role it would play in a revamped electricity market.

The ocean energy sector can also draw confidence from a strong ongoing relationship with the European Union and our continued ability to successfully bid into the Horizon Europe program, with the UK government announcing an extension to the Horizon Europe Guarantee scheme until 2023. Not only will this ensure that successful applicants receive the full value of their funding at their UK host institution for the lifetime of their grant, but it will also help to ensure strong international collaboration opportunities for UK research, despite the uncertainties associated with Brexit.

Wales

In 2022, the Welsh government released its Net Zero Strategic Plan, detailing their commitment to embed a response to the climate and biodiversity emergencies in everything that they do. Like the UK, the Welsh government is legislatively bound to achieve net zero by 2050, compared to 1990 levels, however it has also set the ambitious target of achieving net zero within the public sector by 2030. In addition to this, there are targets for Wales to meet 100% of its electricity demand from Welsh renewable electricity sources by 2035, of which at least 1.5 GW of this capacity will be locally owned, excluding heat pumps. These ambitious targets rely heavily on ensuring that the expansion of the renewable energy sector in Wales continues to accelerate and benefit from targeted support. The Welsh Government remains committed to unleashing the energy potential contained in Welsh waters and has underlined their desire to see Wales established as the location of choice for tidal stream developers and their subsequent supply chains. The Welsh government has consistently stated its commitment to providing strong policy support for the ocean energy sector, with an aim of capturing at least 10% of the potential tidal stream and wave energy off the Welsh coastline by 2025. There is a strong belief that Wales has the potential to be a world leader in the ocean energy sector, both as a developer and demonstrator of domestic technology and as an exporter of ocean energy, technology and skills. This aim is bolstered by the confidence shown in the Welsh ocean energy sector, both nationally and internationally. Current European Regional Development Fund (ERDF) grants support a number of projects aimed at establishing Wales as a centre for ocean energy production. This includes the Marine Energy Test Area (META) and Morlais project demonstration zone, as well as technology developers such as Bombora, Minesto, Nova Innovation and Marine Power Systems.

The responsibility for coordinating the research and development of the ocean sector in Wales lies largely with Marine Energy Wales (MEW), the industry-led stakeholder group representing the wave, tidal and floating offshore wind industries. 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, the cumulative investment and spend in Wales by the ocean energy sector is approximately £159 million, with £13.7 million worth of that investment coming in 2022. Research is the most heavily invested area, with £4.6 million spent across Welsh academic institutions such as Bangor University, Swansea University and Cardiff University. The Welsh supply chain has also seen investment totalling £3.7 million, as companies begin to respond with confidence to the emergence of clearer business opportu-

nities, underpinned by government funding. The MEW 2022 State of the Sector report indicates that in the last year alone, there has been an increase of 188 full time employees working in the ocean energy sector.

Major developments with benefits for ocean energy in Wales announced in 2022 include:

- Marine Energy Wales has received its longest ever funding package from the Welsh Government, having been awarded a three-year grant worth £150,000 a year to support their work until 2025.
- The Morlais project in Anglesey, North Wales, will benefit from £31 million of funding in what is likely to be the last large grant from the EU's regional funding program, with the aim of establishing Wales as the location of choice for tidal stream developers.
- As part of the fourth CfD allocation round Magallanes Renovables has been awarded a 5.6 MW contract at a strike price of £178.54/MWh, which will be deployed at the Morlais project.
- The construction of a new supersize slipway at the Port of Milford Haven waterway has begun, providing maximum flexibility in the deployment and recovery of ocean energy devices, a key step in the development of green growth across the region.
- Swansea-based ocean energy developer Marine Power Systems, has signed up to deliver a multi-megawatt wave energy commercial scale-array at EMEC, booking two berths from 2025 to 2026.
- Australian Bombora Wave Power mWave energy device is entering its final test and assembly phase, as it prepares to validate its 1.5 MW device.

Scotland

The Scottish Government has committed to achieving net zero emissions of all greenhouse gases by 2045. In December 2020, the Scottish Government updated its Climate Change Plan, reflecting the increased ambition of the targets set by the Climate Change (Scotland) Act 2019. Scotland's transition to net zero is supported by the Scottish Government's vision for the future of the energy sector and includes a target for the equivalent of 50% of the energy for Scotland's heat, transport and electricity to come from renewable sources by 2030.

In January 2023 the Scottish Government published a draft Scottish Energy and Just Transition Plan which presents a vision for Scotland's decarbonised energy system and the collective actions needed to deliver this. It suggests a potential ambition to deliver at least 20 GW of additional low-cost renewable electricity capacity by 2030, which could help to generate the equivalent of around 50% of Scotland's current total energy demand. An outline vision for ocean energy is included as part of the draft Plan, and as part of the consultation the Scottish Government is seeking views on the introduction of a specific level of ambition for wave and tidal energy and the near-term supportive actions required to build on the achievements of Scotland's ocean energy sector to date.

Scotland's ocean energy sector continues to make substantial progress as both tidal and wave energy continue the journey towards commercialisation. In 2022, Scottish companies Simec Atlantis Energy and Orbital Marine Power secured the majority of support provided from the fourth allocation round of the UK Government's CfD funding mechanism. This will deliver a substantial increase in installed capacity from tidal stream over the next five years. The Scottish Government, together with industry itself, continues to advocate for long-term certainty for the ocean energy sector through the CfD and will closely monitor developments relating to the fifth allocation round, due to take place in 2023. A number of Scottish developers, including Nova Innovation and Sustainable Marine, made further progress in 2022 in exporting their technology and expertise to the emerging global market for tidal stream energy.

Through the Wave Energy Scotland (WES) programme, wave energy technology from both Mocean Energy and AWS Ocean Energy have been successfully deployed and tested in real sea conditions in Orkney (EMEC). WES is working with the Basque Energy Agency and Ocean Energy Europe to deliver EuropeWave, a European programme which mirrors and builds on the WES competitive development approach to further propel wave energy towards commercialisation.

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 (CES) is a public corporation that holds responsibility for the licensing of renewable energy generation in Scotland's offshore waters. All profit generated by CES is returned to the Scottish Government and capital is reinvested in the Scottish Crown Estate, with a record £15.7 million

returned in the 2021/22 financial year to aid in public spending and Scotland's green economic recovery. A major highlight for CES in 2022 was the support that they provided to the hugely successful leasing round for ScotWind, resulting in a total of 20 seabed agreements totalling 27.6 GW of potential energy generation.

Marine Energy Council (MEC)

Since its formation in 2018, the UK Marine Energy Council (MEC) has facilitated collaboration between, and represented the interests of, leading wave and tidal technology 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. The MEC have also played an active role in helping to guide the formation of the upcoming CfD AR5, ensuring that the long-term support required for commercialisation of the ocean energy sector continues.

In 2022, the BEIS Select Committee invited the MEC to present evidence to its inquiry into the Government's plans to decarbonise the UK's power supply sector, in line with government targets to achieve a fully decarbonised power sector by 2035. A summary of the MEC's contributions are as follows:

- The MEC welcomed the leadership showed by the government in establishing a tidal stream ring-fence in the CfD AR4 and called for increased clarity on future support.
- The MEC highlighted that the industry is well-aware that ongoing ring-fenced support, establishing a 1 GW tidal energy target for 2035 and easing the consenting process will all be essential for the potential of wave and tidal energy to be fully realised.
- The MEC sought to underline the importance of strong policy frameworks that reflect accurately the benefits of the different renewable technologies that exist within the current energy mix and emphasised their importance to energy security and a cost-effective energy system.

https://www.marineenergycouncil.co.uk/

Market Incentives

The **Contracts for Difference (CfD)** scheme is the UK government's flagship programme 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 four allocation rounds (AR) which have seen a number of different renewable energy technologies compete in auctions for a contract. Historically ocean energy technologies have struggled 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. However, following on from the government's announcement in 2021 that there would be a separate £20 million ring-fenced fund available solely for the use of the tidal stream sector, AR4 has delivered a major milestone, with four CfD contracts being awarded to tidal energy projects. A total capacity of 40.82 of MW tidal energy were granted contracts at a strike price of £178.54/MWh:

- Orbital Marine Power won two separate CfDs totalling 7.2 MW for tidal energy deployments at EMEC's Fall of Warness site.
- Simec Atlantis secured 28 MW to further develop the MeyGen tidal array.
- Magallanes was awarded 5.6 MW for a tidal energy project located at the Morlais Project in Wales.

In December 2022, the parameters of AR5 were set with plans to move from three auction pots to two, reflecting the success of the CfD scheme in helping to bring down the per unit cost of offshore wind, which was previously in its own auction pot. There will now be an auction pot reserved for established technologies, and a second auction pot reserved for newer projects, larger than 5 MW, such as wave and tidal stream. In AR5, the administrative strike price for tidal stream energy projects has been set at £202/MWh, while the wave energy projects stand at £245/MWh.

Public Funding Programmes

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 (BEIS).

www.ukri.org

The Engineering and Physical Sciences Research Council (EPSRC)

The EPSRC is the main funding body for engineering and physical sciences research in the UK, investing in various fields such as chemistry, energy, engineering and materials and physics. The EPSRC funds and co-invests with industry, at both national and international levels, helping to deliver advanced research facilities and resources for engineering and physical sciences, including wave test facilities and tidal tank testing. From 2017 until 2022, EPSRC funding for the offshore renewable energy sectors amounted to over £55 million and covers a range of technology push policy support mechanisms, such as the Centre for Doctoral Training (CDT), Fellowships, Managed Activity, Standard Grants and Programme Grants.

https://www.ukri.org/councils/epsrc/

Innovate UK

Innovate UK is the UK's primary innovation agency, which provides funds and support to help businesses grow by developing and commercialising new products, processes, and services. Innovate UK is part of the UKRI and provides services for UK-based companies in all sectors and industries, from pre-start-up to large multinationals. Innovate UK is a key delivery body for the Government's innovation strategy for the UK to be a global hub for innovation by 2035.

www.gov.uk/government/organisations/innovate-uk

Wave Energy Scotland (WES)

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 have driven the development of novel wave energy devices, power take-off systems, control systems, quick connection systems and materials. The headline achievements of 2022 were the deployment of the AWS Waveswing device in Scottish waters and demonstration of three mechanical and electrical quick connectors which are attracting interest in other offshore sectors, most notably floating offshore wind. WES has to date awarded £50 million through 132 contracts, including 300 organisations from 18 countries.

www.waveenergyscotland.co.uk/

RESEARCH & DEVELOPMENT

Key R&D Institutions

Supergen Offshore Renewable Energy (ORE) Hub

The Supergen ORE Hub was established in July 2017 with an initial £5 million of funding from the EPSRC, and a subsequent second award of £4 million 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 2022 are as follows:

- The Supergen ORE Hub Fourth and Autumn Annual Assemblies took place both virtually and in person from 18 – 20 January 2022 and 28 – 30 September 2022 respectively, bringing together over 675 delegates between the two events.
- The Supergen ORE Hub had awarded almost £3,000,000 to 30 projects at UK institutions through its flexible funding scheme, designed to support ambitious research in offshore renewable energy.
- The Supergen ORE Hub has awarded an additional £150,000 to 37 projects at UK institutions through its Early Career Researcher fund, targeted at supporting and developing existing research activities, or developing ECR career skills further.
- 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.
- The Supergen ORE Hub attended both COP26 and COP27, which included the launch of a briefing paper on the role of offshore renewable energy in delivering net zero, a video highlighting the role of offshore renewable energy research in mitigation climate change.

https://supergen-ore.net/

Offshore Renewable Energy (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. In 2022, as part of the Interreg funded TIGER project, the ORE Catapult produced the following report, "*Cost Reduction Pathway of Tidal Stream Energy in the UK and France*". This report emphasises the rapid decrease in LCOE experienced by the tidal stream sector, from an estimated £300/MWh in 2018 to an awarded CfD strike price of £178/MWh in 2022, a reduction of almost 40%. The report also predicted, that with adequate and targeted support, that the LCOE could be reduced further, with estimates of £84/MWh by 2035, £60/MWh by 2042 and £50/MWh by 2047, with various associated socioeconomic benefits.

https://ore.catapult.org.uk/

Key R&D Projects

EVOLVE

Although the implementation of renewable energy technologies is accelerating across Europe, providing a consistent and stable supply of power from variable energy sources like wind is a key challenge. The EVOVLE project, funded by Scottish Enterprise, Swedish Energy Agency and the Portuguese Foundation for Science and Technology (FCT), aims to quantify how ocean energy can not only supply power to our electricity grids, but also enable a more diverse energy mix and cost-effective matching of energy supply and demand. The project aims to develop an understanding of the system benefits of ocean energy within future high-renewable power systems, using the analysis of production, supply and demand profiles and credible future energy supply scenarios. As the project draws to a close, the key findings show that including a higher proportion of wave and tidal energy within our future electricity mix consistently results in higher renewable energy dispatch for the same total of renewable energy availability.

SELKIE

Launched in 2019, SELKIE is a €5.2 million project 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 and Gavin and Doherty Geosolutions. Since its inception, this project has focussed on developing a streamlined commercialisation pathway for the ocean energy industry by establishing a cross-border network of developers and supply chain companies in Ireland and Wales. In early 2022, SELKIE launched a tank testing call for Irish and Welsh developers and have since had three developers complete SELKIE funded tank testing at the Lir National Ocean Test Facility. The project is scheduled for completion in May 2023.

https://www.selkie-project.eu/

Enabling Future Arrays in Tidal (EnFait)

EnFAIT is a flagship €20 million EU H2020 project led by Nova Innovation and supported by ORE Catapult, running since 2017. It aims to demonstrate development, operation and decommissioning at the world's first offshore grid-connected tidal array of up to six 100 kW turbines, with the aim of accelerating cost reductions and providing a step change in the lifetime cost of energy for tidal power. Following successful demonstration in 2020 of Nova's first direct drive turbine, *Eunice*, activity in 2022 has focused on building two additional direct drive turbines, turbines 5 (*Grace*) and 6 (*Hali Hope*). By December 2022 the array had achieved a world record performance of 60 months of continuous monthly power output to the grid. No negative effects on marine life have been recorded in over 11 years of environmental monitoring at the site.

https://www.enfait.eu/

Marine Energy Alliance (MEA)

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 €7.2 million and is supported by Interreg North West Europe, who provide €4.3 million of ERDF funding. The project was extended to March 2023 with funding from the 2nd Call for Capitalisation with an additional €0.7 million of ERDF funding, with the aim of establishing a business plan on how to sustain the alliance. The MEA partners (DMEC, EMEC, MaREI, Centrale Nantes, Exceedence, Innosea, Marin, University of Edinburgh, and Navingo) supported 41 SMEs / marine energy technology companies to progress their technical and commercial maturity level up the TRL stages, with the overall goal of reducing the risk of device failure in subsequent demonstration phases.

Tidal Stream Industry Energiser (TIGER)

Led by ORE Catapult, the TIGER project is an ambitious €48.4 million project running from October 2019 until 31 July 2023. With the European Regional Development fund contributing €32.8 million of the overall funding, the project falls within the category for low-carbon technologies of the Interreg France (Channel) England Programme. So far, the TIGER project has installed nearly 4 MW of new turbine capacity, supported consenting at tidal sites Ramsey Sound, Raz Blanchard and PTEC and provided new infrastructure at Paimpol-Bréhat, with over 75 new designs in development. The project has also provided evidence to the Marine Energy Council to inform the case for subsidy support for tidal stream in the UK. Across the Channel, data from TIGER and subsequent support to French developers Hydroquest and Sabella, has led to ADEME starting discussions around a French Feed in Tariff. 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.

https://interregtiger.com/

Marine Energy Engineering Centre of Excellence (MEECE)

MEECE is a collaboration between Offshore Renewable Energy (ORE) Catapult and the universities of Swansea, Cardiff, Bangor and Cardiff Metropolitan. MEECE also works closely with the Marine Test Area (META) which comprises a series of pre-consented test sites in the Milford Haven Waterway. MEECE is a project led by ORE Catapult, and funded by ERDF (through the Welsh European Funding Office WEFO). One of MEECE's main activities is to support Welsh SMEs to demonstrate and validate their innovations. MEECE cannot give out grants, but can use its funding to deliver small innovation projects on behalf of SMEs at no or very low financial cost to the SME involved. MEECE is more than just a single project, it is also the brand under which ORE Catapult operates in Wales. The Wales 'team' delivers the Milford Haven Energy Kingdom project and is developing a pipeline of projects that will continue beyond the end of the ERDF-funded MEECE project. MEECE is also one of four projects that make up the Pembroke Dock Marine City Deal project.

https://www.meece.org.uk/

Effective Lifetime Extension in the Marine Environment for Tidal Energy (ELEMENT)

ELEMENT is a €5 million EU H2020 project led by Nova Innovation alongside an international consortium of 10 members. 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 of December 2022, the team is optimising turbine performance using real-time ADCP data in Shetland and preparing for the deployment of Nova's RE50, 50 kW turbine, in the Étel estuary, Brittany.

https://element-project.eu/

Collaborative Offshore Renewable Energy Subsea Systems (COSS) research accelerator

Led by the University of Plymouth and the Offshore Renewable Energy (ORE), the COSS will tackle some of the key engineering challenges to accelerating the roll-out of new technologies in wave, tidal stream and floating wind. This new facility will be focused around the hydrodynamics of floating offshore structures, offshore engineering and control systems. It will comprise a suite of advanced engineering facilities for use by academic researchers, industry and businesses working in collaboration with the University and ORE Catapult staff. These laboratory facilities will be augmented by access to test rigs located across the South West, the real seas trials site Smart Sound Plymouth, and include access to national test facilities operated by ORE Catapult across the UK.

Wave Energy Scotland (WES)

2022 saw a number of projects achieving significant milestones in the WES stage gate research, development, and innovation programmes. AWS Ocean Energy completed construction of their Waveswing device, and successfully deployed at EMEC. After seeing favourable results in early operation and analysis, AWS returned to the water for further testing later in the year. The 2021 award of £1.8 million to Apollo Offshore Engineering, Blackfish Engineering Design and Quoceant was rewarded in 2022 with the full-scale demonstration of three technologies for quick connection and disconnection of wave energy converters. These promise to help reduce operating costs, improve the safety of offshore deployment and ultimately lower the overall cost of wave energy, with opportunities for transfer into floating wind. WES, in partnership with EVE and Ocean Energy Europe, announced five successful projects for Phase 2 of EuropeWave, a 3-phase programme co-funded by the European Commission which will lead to the deployment of three wave energy converters in Scotland (EMEC) and the Basque Country (BiMEP). WES continued to build international and sector collaborations, letting a contract with OWC Ltd. to investigate the benefits of sharing infrastructure, services and supply chain with the rapidly growing floating offshore wind sector. This project is expected to identify attractive technical and economic benefits for wave and wind, which will be investigated through further collaborative activity in 2023.

https://www.waveenergyscotland.co.uk/

OceanDemo

OceanDEMO, a €12.85 million project led by EMEC and supported by DMEC, SmartBay, Ocean Energy Europe and Ecole Centrale de Nantes, provides funding to developers of ocean energy renewable technologies to test their products or services in real sea environments, specifically targeting multi-machine ocean energy installations. To date, OceanDemo has supported the demonstration programmes of many tidal and wave energy companies. In 2022, OceanDemo supported the live sea testing and demonstration of AWS Waveswing at EMEC and saw California-based tidal energy developer Aquantis, Inc sign up to test its Tidal Power Tug, also at EMEC. Ocean Demo is funded by Interreg North-West Europe.

http://www.oceandemo.eu/

Forward-2030

In 2022, Orbital Marine Power and partners commenced the design phase of the €26.7 million FORWARD-2030 project set up to deliver the accelerated commercial deployment of floating tidal energy. The FORWARD-2030 project consortium received €20.5 million of grant support from the European Union's H2020 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 feature

a range of cost reduction innovations, and be coupled with a hydrogen production and battery storage facility at EMEC.

https://forward2030.tech/

MAXBlade

Awarded in 2022 and launched at the University of Edinburgh's FastBlade test facility in early 2023, MAXBlade is a €10 million project funded by the European Union and UKRI. The project aims to investigate the performance and full lifecycle of tidal turbine blades from fabrication to decommission, embedding a circular economy element in their design. Working with tidal technology company Orbital Marine Power, the project will implement longer blade designs, increasing the swept area and reducing the overall cost of tidal energy. Innovations from MAXBlade will be integrated with findings from its sister project, FORWARD2030, to enable large-scale production of Orbital's O2 turbine technology. MAXBlade is led by TechnipFMC and includes Orbital Marine Power, Marasoft, TECNALIA, Edinburgh University, EMEC, Laborelec and European Composites Industry Association. It is supported by Edinburgh Innovations, Edinburgh University's commercialisation service.

SEETIP Ocean

SEETIP Ocean is a multi-partner project, coordinated by Ocean Energy Europe, involving the University of Edinburgh, Wave Energy Scotland and a number of European partners, with the aim of enhancing the cooperation and collaboration of stakeholders both inside and outside the European ocean energy sector. SEETIP Ocean is a €788,254 project funded by the European Commission.

TECHNOLOGY DEMONSTRATION

Existing Open Sea and Blade Test Sites

European Marine Energy Centre (EMEC)

Established in 2003 and now entering its twentieth year of operation, EMEC is the world's leading centre for testing and demonstrating wave and tidal converters. EMEC is the world's only accredited test facility for ocean 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. Throughout 2022, EMEC has continued to monitor, maintain and evaluate its Billia Croo wave test site, reviewing the position and condition of subsea cables and any changes to site topography and geology. This increased understanding of site characteristics will provide invaluable assistance to prospective developers as they prepare to deploy. In 2022 alone, Marine Power Systems (MPS) booked out two berths for the testing of a multi-megawatt wave energy array in 2025/26; the PelaGen wave energy converter will be deployed on a modular floating platform, PelaFlex; and EMEC announced the launch of a €19.6 million project WEDUSEA, co-funded by EU Horizon Europe and In-

EMEC preparing wave rider buoy for deployment © EMEC

novate UK, culminating with a two-year grid-connected demonstration of OceanEnergy's OE35 WEC at their Billia Croo wave test site. Having played a substantial role in arguing for the creation of a ring-fenced CfD pot in AR4 to support the tidal sector, EMEC is pleased to see many of their sector colleague's benefit, with Orbital Marine Power having been awarded two CfDs totalling 7.2 MW for tidal energy deployments at the Fall of Warness test site.

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 and this year welcomed 34 delegates from 17 different ocean energy test centres.

https://www.emec.org.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 has the potential to be England's first multi megawatt tidal stream power generation project. In recent years PTEC has moved decisively to ensure that it is well prepared to build upon increased interest and investment in the tidal sector, securing key consents for onshore and offshore activities and an updated grid connection offer. In late 2022, PTEC entered into a 20-year seabed lease from the Crown Estate, enabling the site to move into the final stages of development. In 2022, PTEC agreed a partnership with Orbital Marine Power to deliver up to 20 MW of tidal energy, opening up opportunities for future CfD bids in AR5 and beyond.

https://perpetuustidal.com/

Morlais

The West Anglesey Tidal Demonstration Zone, referred to as the Morlais project, encapsulates 35 km² of seabed 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. Having secured the planning permission from Welsh Government, a marine licence from Natural Resources Wales and funding from the Welsh European Funding Office, the infrastructure works to enable the export of electricity generated from tidal stream devices in the Morlais project to the Scottish Power Energy Network infrastructure commenced in early 2022. This work will be completed in the second half of 2023.

https://www.morlaisenergy.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, this series of 8 non-grid-connected sites is suitable for a range of wave and tidal component, sub-assembly, scale and full-scale device tests. Currently operational on the META sites are a tidal turbine designed by Swansea University and the MEECE buoy which is supporting various component tests, including a novel mooring damper.

https://www.marineenergywales.co.uk/meta/

FastBlade

Based in Rosyth, Scotland FastBlade is an innovative research facility that uses regenerative hydraulic technology to allow high-quality, low-cost accelerated testing of composite and metal structures including tidal blades, composite bridge sections and carbon fibre aircraft wing boxes. Developed by the University of Edinburgh, the facility will use a Digital Displacement regenerative hydraulic actuation system to reduce the energy requirements of fatigue testing. Officially opened in May 2022, the FastBlade test site will provide support to numerous projects, including both the MAXBlade and Forward2030 tidal energy projects.

https://www.fastblade.eng.ed.ac.uk/

FaBTest

FaBTest is a 2.8 km2 non-grid connected pre-consented nursery test site consisting of three test berths situated within Falmouth Harbour. The relatively sheltered location of the bay from the west allows for ocean energy converter concept devices and components to be tested, whilst being occasionally exposed to more significant weather from the east. As a result, FaBTest provides a step in the device development process, between tank testing and demonstration deployment.

https://www.fabtest.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 2022.

Tidal Stream

MeyGen

The MeyGen project, established in 2010 in the Pentland Firth, is the largest planned tidal stream project in the world. With consent currently awarded for 86 MW, and the option to develop up to 398 MW, the MeyGen project is split into 4 phases of delivery. In operation since 2018, MeyGen Phase 1 comprised of the installation of four 1.5 MW turbines that, as of October 2022, have delivered over 45 GWh of renewable electricity available for export into the local Shetland distribution network. Phase 1 incorporated two different turbine technologies, Simec Atlantis Energy's AR1500 and Andritz Hydro Hammerfest AH1000 MK1. MeyGen Phase 2 plans to deliver an additional 28 MW of tidal energy generation capacity with a target commissioning date of 2027. This will be enabled by the successful award of a CfD in AR4 for 28 MW at a strike price of £178.54/MWh, a transformational moment for the project, that will ensure that MeyGen delivers the world's first commercial scale tidal array.

https://saerenewables.com/tidal-stream/meygen/

SIMEC Atlantis deployed at MeyGen © SIMEC Atlantis

Magallanes Renovables

Spanish tidal developer Magallanes Renovables' second-generation tidal turbine device, the ATIR, was successfully re-deployed at EMEC in 2021. The testing of the ATIR has been supported by the Horizon 2020 Fast Track to Innovation Ocean_2G project, and the Interreg Ocean DEMO and MaRINET2 projects, part of the EU's H2020 research and innovation programme. Magallanes was one of three tidal turbine developers to receive a CfD in the UK government's most recent round of auction, successfully bidding for a 5.6 MW contract awarded at a strike price of £178.54/MWh. This important milestone will see Magallanes look to deploy their first commercial deployment at the Morlais project in Anglesey, Wales, bringing long-term jobs, opportunities and socioeconomic benefits to the region for a number of years.

https://www.magallanesrenovables.com/

Magallanes Renovables ATIR © Magallanes Renovables

Minesto

Swedish marine energy developer Minesto has had a physical presence in Hollyhead, Wales since 2015, where it has been testing and validating its first commercial-scale system, the 0.5 MW Deep Green 500 device, along with other technologies. This site, known as Hollyhead Deep, already includes an Agreement for Lease for a 10 MW installation, a state-of-the art assembly hall and a highly skilled commissioning and operations team. There are long-term plans to see this site transformed into a large-scale 80 MW array with the potential to be a world-leading tidal energy generation site. In 2022 Minesto launched a detailed plan for large-scale build-out of tidal energy arrays in the Faroe Islands, outlining four new verified sites that would supply 40% of the nation's growing electricity consumption. This long-term goal will be underpinned by the deployment of the 100 kW Dragon 4 tidal energy converter in Vestmannasund, Faroe Islands. At the close of 2022, Minesto's Dragon 4 tidal energy converter had recorded new record levels of energy production and a second unit had been successfully installed, operating in parallel to double production capacity.

https://minesto.com/projects/holyhead-deep

Orbital Marine Power

The company continued to put its flagship device, the O2 turbine, through its paces at EMEC's Fall of Warness tidal test site as part of a long-term demonstration programme. The O2 features a range of innovations focussed on driving down the cost of tidal stream energy, including twin 20 m rotor diameters - the largest swept area on a single tidal energy converter to date, pitching hubs for floating tidal energy and a 'gull wing' leg retraction system to allow low cost, onsite access to the entire generating unit. In July 2022, Orbital was awarded two CfDs in the UK AR4 process. This will support the delivery of 7.2 MW of new tidal stream energy at EMEC and once grid connected will power up to 7,200 homes. Orbital also secured new investment from the Scottish National Investment Bank and individuals via the Abundance Investment platform to finance the ongoing operation of the O2, the company's 2 MW+ floating turbine. These debt facilities will be serviced by the long-term sale of electricity from the turbine, forecast at around 100 GWh, delivered to the UK grid or hydrogen electrolysers over its project life.

https://orbitalmarine.com/

Orbital Marine Power's O2 turbine © Orbital Marine Power

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 M100 turbines to be installed, bringing the overall installed capacity to 0.6 MW. In 2022 Nova Innovation built three 100 kW direct drive turbines: two have been shipped for deployment in Bluemull Sound, Shetland, and one has been exported to the company's Nova Tidal Array in Petit Passage, Canada. In addition, a 50 kW demonstrator turbine will be deployed by Nova Innovation in France in 2023 under the ELEMENT project. Also in 2022, Nova Innovation developed a feasibility study for a 7 MW tidal array in the Larantuka Strait in Indonesia in the InnovateUK funded FLITE project, and has developed tools and techniques to reduce the cost of tidal turbine deployment and recovery in the BEIS-funded CREATE project. The company also signed a grant agreement for the UpTEMPO project, in which they will develop and demonstrate their next-generation tidal turbine. This project will be funded under the UK Treasury Guarantee, having been successful in winning funding under the EU European Innovation Council (EIC) Accelerator programme.

https://www.novainnovation.com/

Nova M100-D tidal power turbine © Nova Innovation

Wave

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 Novel Wave Energy Converter (NWEC) 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, where it 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. The next step is to deploy Blue X along with subsea equipment to demonstrate reliable power and communications in a real-world ap-

Mocean Energy Blue X device at EMEC © Mocean Energy

plication, further the development of the Blue Horizon technology through the EuropeWave programme, and commercialise the small-scale product lines for launch in 2024-25.

https://www.mocean.energy/

Bombora Wave Power

Australian wave energy developer Bombora Wave Power has established its key operations in Pembrokeshire, Wales and is currently progressing the 1.5 MW mWave™ Pembrokeshire Demonstration Project supported by ERDF funding through the Welsh Government. This project has progressed at pace throughout 2022, beginning its final test and assembly phase before ocean deployment. In 2022 it was also announced that Bombora Wave Power had received an investment of £3.54 million from Japanese shipping company Mitsui O.S.K. Lines Ltd., to further commercialise its technology and grow its presence and supply chain capabilities in the region. Bombora has continued to engage with global Engineering, Procurement, Construction and Installation (EPCI) contractor TechnipFMC on the InSPIRE project, with the aim of developing a combined floating offshore wind and wave foundation device, incorporating Bombora's mWave™ technology. As part of the EuropeWave Programme, Bombora has successfully completed tank testing of a floating foundation system suitable for implementation into the InSPIRE project.

https://bombora.com/

AWS Ocean Energy

2022 has been another exciting year for AWS Ocean Energy, with successful at-sea testing of its 16 kW Archimedes Waveswing wave energy prototype at EMEC's test site in Scapa Flow, Orkney, UK. AWS is also in the process of completing a study expected to confirm the feasibility of large-scale multi-absorber wave energy platforms based on the Waveswing technology. These platforms will address the fundamental challenge of scale, and the practicality of offshore maintenance, both of which are essential to the delivery of affordable utility scale power. The development of Waveswing was the recipient of a £3.4 million grant from the WES programme, highlighting another successful instance of industry collaboration. The successful testing of AWS's device at EMEC's Scapa Flow test site has proven the key technology sub-systems necessary to allow the concept to work at real-world scale. AWS is now looking for partners to participate in the development and demonstration of a 2 MW multi-absorber pre-commercial prototype, whilst also pursuing other exciting opportunities for deployment of smaller systems in remote applications.

https://awsocean.com/

Sea tests of the AWS Ocean Energy © AWS Ocean Energy

Projects Planned for Deployment

It is hoped that the success of the CfD AR4 will provide the basis for a number of future tidal energy projects, with Orbital Marine Power, Simec Atlantis and Magallanes aiming to deliver an additional combined total of 40.82 MW of tidal energy generative capacity by 2027 at the latest. Moving forward, there is also hope that there will be continued and sustained innovation in the design and application of financial mechanisms that support the development of the ocean energy sector. As this chapter highlights, the successful collaboration of government, industry and academia has helped to deliver a thriving ocean energy sector, which is well positioned to move from strength to strength. The application of bespoke and tailored funding packages, guided and shaped by knowledge exchange at the highest level, can only help to accelerate the commercialisation of the wave and tidal sectors.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

This is a non-exhaustive list of examples of different bilateral/regional cooperation initiatives involving the UK

Clean Energy Transition Partnership (CETP)

The CETP programme is a transformative Research, Technological Development and Innovation (RTDI) program, designed to accelerate clean energy transition through annual funding calls. The CETP exists as an international collaboration involving 32 countries and over 50 funding agencies, supported through the Horizon Europe R&I programme. Within Scotland, Scottish Enterprise leads and delivers the programme on behalf of Scottish Government, Highlands and Islands Enterprise and South of Scotland Enterprise. The CETP programme made up to £6 million available for support, with projects being awarded on a competitive basis. The programme closed in November 2022.

https://cetpartnership.eu/

European Energy Research Alliance (EERA)

The UK continues to chair the European Energy Research Alliance (EERA) Ocean Energy Joint Program (JP), providing the UK the opportunity to continue to guide and assist in the development of the H2020 and now Horizon Europe European funding and work programmes. Comprising of 9 full participants and 4 associate partners, the EERA Ocean Energy JP has identified areas of research, based on existing research roadmaps, which are considered critical for meeting the necessary requirements for the successful growth of the industry.

https://www.eera-set.eu/

International Energy Agency (IEA)

The UK was a founding member of the International Energy Agency in November 1974 and has maintained a close relationship since then, utilizing its position of leadership to strengthen energy security, spur economic development and advocate for the implementation of cleaner forms of energy.

https://www.iea.org/

RELEVANT NATIONAL EVENTS

Relevant events for the ocean energy sector that took place in the UK in 2022 include:

- **18 - 20 January**, Supergen ORE Hub Annual Assembly, virtual
- **22 - 23 March**, Marine Energy Wales Conference, Llandudno
- **3 May**, Wave Energy Scotland Annual Conference, Edinburgh
- **11 - 12 May 2022** – All-Energy, Glasgow
- **25 May**, Scottish Renewables Marine Conference, Edinburgh
- **1 - 7 September**, Orkney Science Festival, Orkney
- **29 September**, Supergen ORE Autumn Assembly, Oxford

The UK will also be hosting a series of important events in 2023:

- **21 - 22 March**, Marine Energy Wales Conference, Swansea
- **9 - 10 May**, All-Energy, Glasgow
- **25 May**, Scottish renewables Marine Conference, Edinburgh

USA

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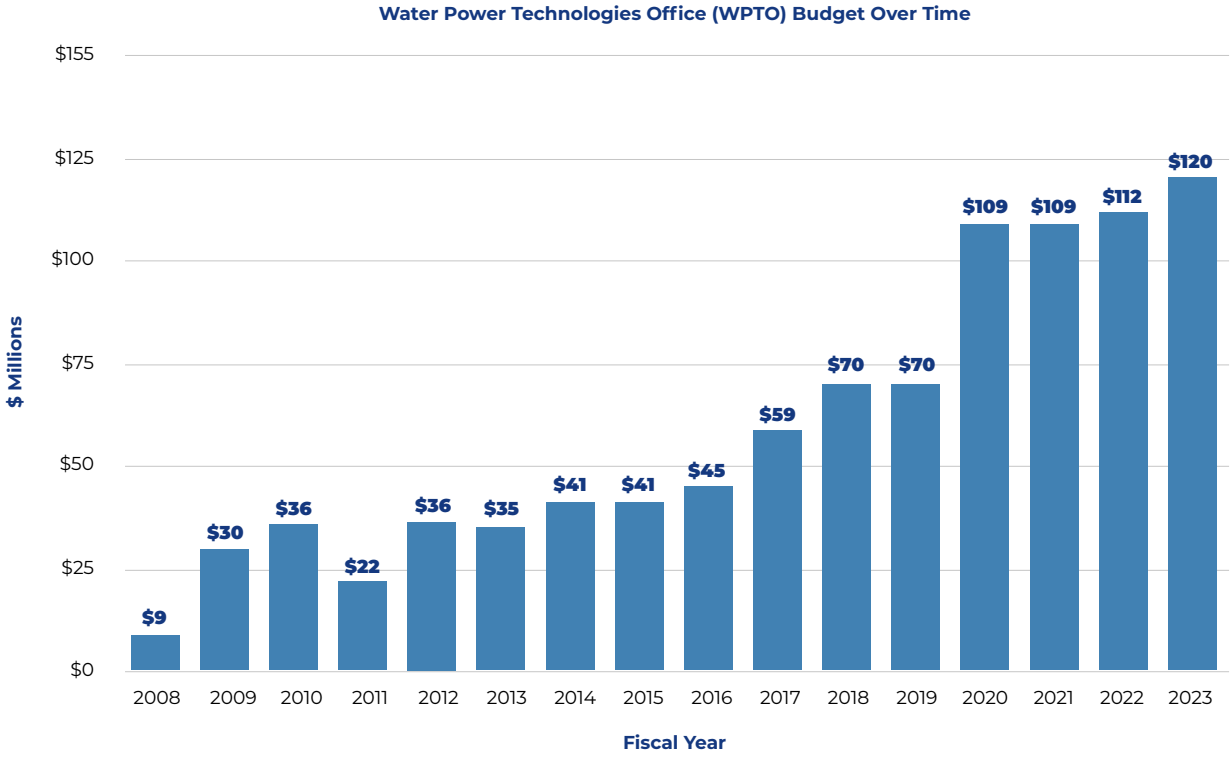
OVERVIEW

Ocean energy experienced record U.S. budget support in 2022. The U.S. Department of Energy's (DOE) Water Power Technologies Office (WPTO) has received increased U.S. government appropriations for ocean energy in recent years from its initial establishment in 2008. WPTO's Marine Energy Program is authorized by the U.S. Congress to fund research, development, demonstration, and deployment activities in support of technologies harvesting energy from waves, tides, ocean, and river currents; free-flowing waters; and differentials in salinity, pressure gradients, and water temperature, including ocean thermal energy conversion. For the current fiscal year (FY) 2023, the U.S. Congress granted WPTO's Marine Energy Program its largest annual budget to date with a record $120 million (an increase of $8 million compared to FY 2022). This does not include the $110.4 million in Bipartisan Infrastructure Law funding, passed at the end of 2021, for WPTO-led marine energy activities. These increased resources are helping the program make a significant impact on ocean energy development in the United States.

During calendar year 2022, six wave energy projects were deployed for testing in open water. Further, $25 million was awarded in 2022 for projects to advance research, development, and demonstration of wave energy technologies, and of which several are expected to deploy at the PacWave South test site in 2024 or 2025. Three wave energy developers also prepared to install and test their devices at the U.S. Navy's Wave Energy Test Site (WETS) in Hawaii. Meanwhile, tidal energy developer Verdant Power successfully decommissioned its project site with valuable lessons learned related to installation, operations, and maintenance.

In addition to device testing and demonstration, WPTO continued to support industry-, university-, and national laboratory-led research and development (R&D) projects. In 2022, projects focused on a range of topics including advancing environmental monitoring systems and instrumentation, and new materials innovation with distributed embedded energy converter technologies. Additionally, the Waves to Water Prize and the latest stage of the Ocean Observing Prize (both part of WPTO's Powering the Blue Economy™ initiative) were completed in 2022, delivering technologies with potential to support coastal communities and the blue economy.



Note: This graph shows annual appropriations and enacted funding only. This graph does not reflect the $110.4 million of funding from the Bipartisan infrastructure Law for WPTO-led marine energy activities.

WPTO year-on-year marine energy budget

SUPPORTING POLICIES FOR OCEAN ENERGY

National and Program Strategy

WPTO's Marine Energy Program supports a broad portfolio of research activities to strengthen the body of scientific and engineering knowledge and boost industry efforts to develop and operate marine energy technologies at all scales. To detail the office's research, development, demonstration, and commercial activities for the coming years, WPTO developed its Multi-Year Program Plan (MYPP), which was released in 2022 and serves as an operational guide to help the office effectively manage and coordinate its activities, as well as communicate its mission, goals, and plans to ocean energy stakeholders and the public. The MYPP also details how these efforts are important to meeting the nation's energy and sustainability goals.

In 2022, the program provided funding to advance the design, fabrication, and testing of ocean energy conversion devices, including demonstrations of wave, current, and tidal power technologies for grid and off-grid applications. The program also dedicated resources for more foundational, crosscutting research like controls and advancements in materials and manufacturing while also continuing a robust testing program to provide technical assistance to marine energy developers.

Over the last few years, WPTO has also expanded the Powering the Blue Economy initiative, which focuses on potential applications for marine energy at smaller scale power generation In 2022, WPTO concluded two prizes under its Power the Blue Economy initiative: the Waves

to Water Prize to advance wave energy-powered desalination technologies and the Ocean Observing Prize to support the building and testing of devices to power ocean-observing technologies. Additionally, the office increased funding for foundational research efforts to better understand the potential for other blue economy applications like aquaculture and marine carbon dioxide removal and monitoring, reporting, and verification.

While managing its research and development portfolio, WPTO also contributed to national ocean policy efforts such as the Ocean Climate Action Plan (OCAP). OCAP, which is led by the White House's Office of Science and Technology Policy and the Council on Environmental Quality on behalf of the interagency Ocean Policy Committee, is intended to help guide and coordinate the federal government's and civil society's future actions to address ocean, coastal, and Great Lakes-based mitigation and adaptation solutions to climate change. OCAP will summarize planned federal, ocean-based climate actions and their benefits, identify gaps in knowledge and its application to emerging ocean-climate issues, and recommend actions to advance the effectiveness of the nation's response to the impacts of climate change.

Market Incentives

In August 2022, the Inflation Reduction Act of 2022, H.R.5376, was passed with significant impacts for clean energy tax credits. One provision extended and modified credit for electricity produced from certain renewable resources, also referred to as a production tax credit. A clean energy investment tax credit was also created for eligible clean energy investments. Marine and hydrokinetic energy technologies were included as eligible for both tax credits. Additionally, through the Bipartisan Infrastructure Law, Section 242 provides funding for up to $0.017/kWh for marine energy projects once operating. WPTO aims to encourage developers to take advantage of these credits to help set up a viable business model for ocean energy companies and/or site developers.

Public Funding Programmes

Prior to the passing of the Inflation Reduction Act, the U.S. passed another historic piece of legislation for U.S. clean energy. In November 2021, U.S. President Biden signed the Infrastructure Investment and Jobs Act, H.R.3684, into law. The $1.2 trillion deal, commonly called the Bipartisan Infrastructure Law (BIL), is a transformative investment in U.S. clean energy infrastructure and jobs. The law provided $62 billion for DOE to stand up 60 new programs, including 16 demonstration and 32 deployment programs, and expand funding for 12 existing research, development, demonstration, and deployment programs, including WPTO's Marine Energy Program. WPTO received $110.4 million in new funding from BIL for marine energy and has already announced its intentions to use $45 million of this amount to support tidal and current energy demonstration site development. The office anticipates the funding opportunity will be released in spring 2023.

One of the key changes at DOE as a result of the BIL was the creation of the Office of Clean Energy Demonstrations (OCED). OCED was set up to help bridge the gap between R&D (including earlier-stage R&D led by WPTO) and later-stage demonstration and deployment activities necessary to validate technologies in real-world conditions and provide confidence they work as intended. OCED received about $27 billion in funding from the BIL and the Inflation Reduction Act for clean energy demonstration and research hubs focused on next-generation technologies needed to achieve the U.S. goal of a net-zero economy by 2050. This included $1 billion for demonstration projects in rural or remote areas.

In 2022, WPTO released a funding opportunity using annual appropriations titled Marine Energy Systems Innovation at Sea. This opportunity will invest in wave-powered technology innovation and R&D for seawater desalination and a feasibility assessment for an ocean current test facility. This announcement builds off WPTO's previous investments in desalination, and the new projects will focus on coastal and island resilience and incorporate end-user needs assessments. Previous WPTO-supported research demonstrated the

feasibility of small, modular, wave-powered desalination systems through theoretical studies, laboratory testing, and short-duration, at-sea testing like through the Waves to Water prize. This funding opportunity focuses on innovation of wave energy converters (WECs) for nearshore environments across diverse coastal conditions through long duration, at-sea testing and operations (i.e., two weeks to six months) and component/sub-system technology development and testing.

To address the key challenge of testing to validate all scales of ocean energy technologies, in 2022 WPTO continued to support the Testing Expertise and Access for Marine Energy Research (TEAMER) program, which helps accelerate technology testing in collaboration with U.S. universities and national laboratories by providing developers with access to ocean energy testing facilities and capabilities across the country. As of January 2023, TEAMER has provided more than $10 million worth of technical support across 101 marine energy projects. Though all facilities in the TEAMER network are U.S.-based, both U.S. and non-U.S. developers are eligible to apply and for technical support through TEAMER.

DOE also continued its efforts with other government agencies to advance safety and environmental sustainability. For example, DOE and the U.S. Department of the Interior's Bureau of Safety and Environmental Enforcement previously issued a funding opportunity for up to $40 million over a five-year period for the operation and maintenance of the Ocean Energy Safety Institute (OESI 2.0) to support additional improvements in safety and environmental sustainability in offshore energy exploration and production. In 2022, the OESI team worked in collaboration with Texas A&M University in the United States to develop key roadmaps for offshore oil and gas, offshore wind, and ocean energy technologies.

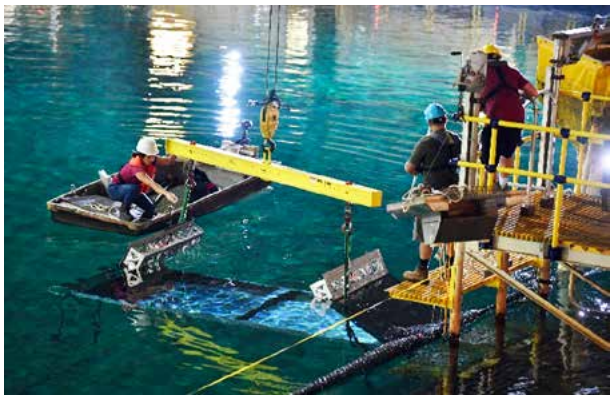
Other Funding and Technical Assistance Mechanisms

In addition to large, multimillion dollar funding opportunity announcements, WPTO offers a variety of funding and technical assistance opportunities to advance marine energy technologies. For example, the previously mentioned TEAMER program is the U.S. flagship program providing technical support in ocean energy.

Additionally, WPTO continues to invest in small businesses through the U.S. government-wide Small Business Innovation Research (SBIR) and Small Business Technology Transfer programs. The program aims to increase private-sector commercialization of innovative technologies and encourages participation by women- and minority-owned small businesses. WPTO participates in the SBIR program and makes funding available for ocean energy companies on an annual basis. In 2022, WPTO invested $14.6 million in SBIR projects, including $12 million in new funding to advance projects selected in the previous year.

WPTO's Seedlings and Saplings Program is a mechanism to fund promising, potentially high-impact research ideas from DOE's national laboratories, encouraging and incentivizing researchers to broaden their thinking about research pathways. From FY 2020 to FY 2022, WPTO funded 98 ocean energy-focused seedling and sapling projects across six national labs, leading to new lab-led areas of research and bringing in new researchers and projects that span analytical studies to building and testing prototypes. To date, the office has provided about $11 million to ocean energy seedlings and saplings projects, investing nearly $5 million of this amount in FY 2022.

Prizes and competitions enable WPTO to tap into the ingenuity and creativity of innovators nationwide. These unique, low-barrier to entry, funding mechanisms bring together a diverse community of researchers, innovators, students, and other partners to address energy challenges in the hydropower and ocean energy industries. As mentioned, WPTO recently concluded two prizes focused on wave energy technologies, the Waves to Water Prize and the Ocean Observing Prize.



WPTO and the National Oceanic and Atmospheric Administration recently announced the winners in the latest phase of the Ocean Observing Prize, which challenges competitors to develop solutions that use ocean energy to power hurricane-monitoring systems. © National Renewable Energy Laboratory

Additionally, WPTO's annual Marine Energy Collegiate Competition has helped hundreds of undergraduate and graduate students gain experience and connections in the fields of ocean energy and the blue economy.

In addition to the R&D activities led by WPTO, DOE's Advanced Research Projects Agency-Energy (ARPA-E) has also supported and invested $35M towards marine energy in recent years. ARPA-E funds short-term, technology-focused, applied R&D across a variety of energy topics with a goal of creating real-world solutions to important problems in energy creation, distribution, and use. Currently, several ocean energy companies have active projects under ARPA-E's Submarine Hydrokinetic And Riverine Kilo-megawatt Systems program for tidal energy. Through this program, ARPA-E seeks to identify new technical pathways to design economically competitive hydrokinetic turbines for tidal and riverine currents.

RESEARCH & DEVELOPMENT

In 2022, WPTO funded six wave energy technologies to test in open water, more than in any previous years, while also supporting several device development projects which are expected to test in open water in 2023. In addition to this record-level support for open-water testing, WPTO furthered R&D efforts led by industry, university, and national laboratory partners to provide the enabling research and tools needed to prepare devices for open water.

Numerous universities, private companies, organizations, nonprofits, and national laboratories lead ocean energy research in the United States. Collectively, these institutions offer 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): the Atlantic Marine Energy Center, Hawai'i National Marine Renewable Energy Center, Pacific Marine Energy Center, and Southeast National Marine Renewable Energy Center. Notably, of the $110.4 million of BIL funding provided to the Marine Energy Program, Congress designated $40 million for the NMRECs. WPTO also supports additional universities and students through competitive funding opportunities, prizes, TEAMER, the Marine Energy Collegiate Competition, and the Marine Energy Graduate Student Research Program.

DOE's national laboratories possess unique testing instrumentation, expertise, and facilities capable of addressing large-scale, complex R&D challenges. WPTO partners with six of these laboratories to support R&D in ocean energy and hydropower. This includes Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory, Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories. Numerous additional R&D institutions in the United States work on ocean energy technologies, such as the U.S. Naval Research Laboratory, U.S. Navy Office of Naval Research, and the Marine Environmental Laboratories operated by the National Oceanic and Atmospheric Administration.

In December 2022, DOE announced $10.5 million for ocean energy projects at five national laboratories. This included $2.7 million for nine marine energy saplings projects covering key programmatic priorities such as foundational R&D and removing barriers to testing as well as $8.7 million for 11 new marine energy projects across four topic areas focused on providing power at sea, microgrids for remote coastal communities, powering ocean-observing devices in partnership with the Woods Hole Oceanographic Institution, and an environmental monitoring campaign for future DOE ocean energy deployments.

WPTO also supported environmental monitoring programs and instrumentation deployments as part of the international collaboration and work underway through the International Energy Agency-Ocean Energy Systems Task 4 Working Group. The group is focused on the assessment of environmental effects and monitoring efforts for ocean energy, and it disseminates information on the latest science through its State of the Science Report.

This year, a major accomplishment from WPTO's environmental monitoring portfolio was the robust environmental monitoring and validation of a wave energy device tested off the coast of California. Integral Consulting, working with PNNL, deployed the NoiseSpotter® alongside CalWave Power Technologies' deployment of its xWave wave energy device. The NoiseSpotter is a cutting-edge acoustic monitoring sensor system that classifies and provides accurate location information about sounds related to ocean energy installations. The environmental interaction data collected during the deployment will be made available in a public report and showed no significant concerns to the local marine wildlife or ecosystem.

Also, alongside CalWave's xWave device, PNNL's Triton Underwater system collected acoustic measurements for underwater noise tracking of marine mammals in the area. Notably, this deployment used the International Electrotechnical Commission's TS 62600-40 standard, which provides uniform methodologies to consistently characterize the sound produced by the operation of ocean energy converters.

The NoiseSpotter® acoustic monitoring sensor system ready for deployment. © Integral Consulting and Pacific Northwest National Laboratory

TECHNOLOGY DEMONSTRATION

In 2022, six WPTO-funded wave energy devices began and concluded in-water tests, a new record for the United States. This includes the four teams that deployed their small, modular, wave energy-powered desalination systems off the coast of the eastern United States during the final stage of the Waves to Water Prize. All devices successfully produced water as designed. NREL researchers also deployed their own wave-powered desalination device, the Hydraulic and Electric Reverse Osmosis (HERO) WEC, twice during the year with the first deployment designed to prepare the crew to safely install and deploy prototypes during the prize competition.

Tidal energy projects also continued to progress from technology readiness levels 5-6 to 7-8 as evidenced by Verdant Power's project in New York City, as well as Ocean Renewable Power Company's optimization of its RivGen Power System for deployment in 2023.

Triton system deployed on the seabed in February 2022. © Scripps Institution of Oceanography

NREL's HERO WEC device is taken out for an ocean deployment in August 2022 off the coast of Nags Head, North Carolina, with the help of the Coastal Studies Institute. © Coastal Studies Institute

The laydown area for Ocean Renewable Power Company's RivGen project on Millinocket Stream in Maine in December 2022. @ ORPC

Existing Open-Water Test Sites

In 2022, construction continued on the PacWave South test site, a grid-connected, and pre-permitted wave energy testing facility in the United States off the coast of Oregon. Drilling was completed and conduit was placed onshore and offshore for all berths, ready for electric cables to be installed. At Driftwood Beach State Recreation Site, the project team installed a vault that will provide access to the cables, resurfaced the parking lot above the vault, and made other improvements to return the site to its original condition.

The University of New Hampshire, which leads the Atlantic Marine Energy Center, offers a tidal energy site installed under the Portsmouth Memorial Bridge where small prototype turbines can be installed and tested. In addition, the Coastal Studies Institute's Jennette's Pier project, located in the Outer Banks of North Carolina, has been developed as a scaled test site specifically for wave energy prototype testing.

Through a cooperative effort between DOE and the U.S. Navy and with the support from Hawai'i Natural Energy Institute and the Hawai'i National Marine Renewable Energy Center, the Wave Energy Test Site (WETS) hosts companies seeking to test their pre-commercial WEC devices in an operational setting, enabling them to advance their device's technology readiness level.

Projects in the Water

In 2022, CalWave concluded its open-ocean wave energy pilot after 10 months of continuous operation off the coast of San Diego in California. The device, which was deployed in September 2021, survived two extreme storms, required no interventions, and remained operational for 99% of its time deployed. Performance and operational lessons learned are informing the next scaled device, which will be deployed at the PacWave South test site.

CalWave Power Technologies concluded its xWave wave energy device deployment off the California coast in July 2022. © CalWave

A project team led by Ocean Motion Technologies deployed a prototype wave energy converter that can generate power from passing waves created by boat wakes. This test, which also took place off the coast of California, successfully demonstrated that power can be harnessed from waves as small as those created by boats. By generating power from waves of this size, this test showed greater versatility and environments in which ocean energy devices could be used to harness power.

In January 2022, tidal energy developer Verdant Power successfully decommissioned its project site with valuable lessons learned related to installation, operations, and maintenance. Over six months of continuous operation, Verdant Power's tidal energy TriFrame™ system achieved over 99% availability while generating 210 MWh. While deployed, the tidal turbines provided clean energy to Con Edison's distribution grid, powering homes and businesses in Manhattan, New York.

Further work at the University of New Hampshire's tidal turbine test site focused on preparing, executing, and collecting data from a tidal turbine the university deployed.

Projects Planned for Deployment

Three wave energy developers plan to deploy devices at WETS in Hawaii. Oscilla Power and C-Power completed fabrication and onshore testing and shipped their devices (the Triton-C and SeaRAY autonomous offshore power system, respectively) to WETS for installation. Sensors (3G-AMP) developed by the University of Washington were integrated with the Oscilla device to collect environmental data. Meanwhile, the BioSonics perimeter detector measurements will be deployed alongside the SeaRAY autonomous offshore power system.

In addition, Ocean Energy's OE35 buoy has completed hull repairs and is waiting on weather windows to install and continue testing at WETS.

SPECIFIC INITIATIVES FOR INTERNATIONAL COOPERATION

Relevant international initiatives:

- IEA OES ExCo, Tim Ramsey (delegate) and Elaine Buck (alternate), DOE
- IEA OES OES-Environmental, Samantha Eaves, DOE
- IEA OES Performance Metrics, Elaine Buck, DOE
- UMERC University Maine Energy Research Community, Samantha Eaves, DOE, and Henry Jeffrey, international liaison

RELEVANT NATIONAL EVENTS

- **March 30–April 5, 2022**; Waves to Water Prize DRINK Finale, Nags Head, North Carolina
- **April 5–7, 2022**; Water Power Week; Washington D.C.
- **May 23–25, 2022**; ARPA-E Energy Innovation Summit; Denver, Colorado
- **May 23–27, 2022**; Marine Energy Colligate Competition; Virtual
- **June 7-20 2022**; Ocean Observing Prize BUILD Contest Tank Testing; Bethesda, Maryland
- **July 18–29, 2022**; WPTO Peer Review Program; Virtual
- **September 13–15, 2022**; Ocean Renewable Energy Conference, the University Marine Energy Research Community (UMERC), and the Marine Energy Technology Symposium; Portland, Oregon

5.
Appendices

APPENDIX 1

Membership of the Executive Committee

CABINET 2022

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	**Professor Irene Penesis** University of Tasmania	**Professor Christophe Gaudin** The University of Western Australia
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	**Ms.Evdokia Tapoglou** Joint Research Center
France	**Dr. Yann-Hervé De Roeck** France Energies Marines	

Germany		**Mr. Jochen Bard** Fraunhofer Institute for Energy Economics and Energy Systems Technology
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	**Ms. Jae-ok Roh** 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. Jos 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. Yago Torre-Enciso** BIMEP - Biscay Marine Energy Platform	**Ms. Dorleta Marina** Simply Blue Energy Ltd
Sweden	**Mr Tobias Walla** 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** Pacific Northwest National Laboratory

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	
44	10 - 11 March 2022	Online meeting	
45	29 – 30 June 2022	Online meeting	
46	17 October 2022	San Sebastián	Spain

About the International Energy Agency (IEA)

The IEA works with governments and industry to shape a secure and sustainable energy future for all.

IEA Technology Collaboration Programmes

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 breadth of the analytical expertise in the Technology Collaboration Programme is a unique asset to the global transition to a cleaner energy future.

These collaborations involve over 6 000 experts worldwide who represent nearly 300 public and private organisations located in 55 countries, including many from IEA Association countries such as China, India and Brazil.

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