Technology Collaboration Programme
by IEA

2021

WAVE ENERGY DEVELOPMENTS HIGHLIGHTS

OES OCEAN ENERGY SYSTEMS

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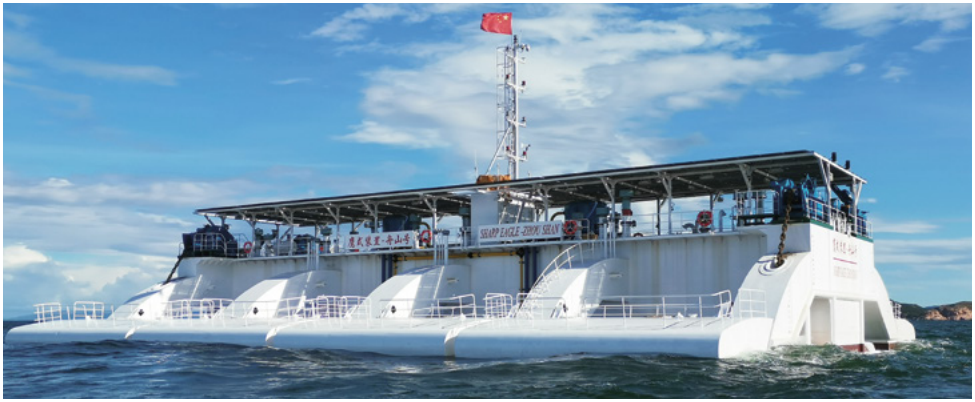
ADVANCES IN WAVE ENERGY

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

MARKETS

- Due to an impressive worldwide resource, wave energy devices are designed to be installed in large arrays to **provide utility-scale power**.
- The technology can be designed to meet the energy and water needs of **island and coastal communities**.
- Wave energy can help to meet the requirements of **ocean industries that are moving further offshore**, such as aquaculture, mining and oceanographic research.
- And it can be integrated into **hybrid systems** that might include wind, solar, and energy storage.

TECHNOLOGY HIGHLIGHTS



Courtesy: Guangzhou Institute of Energy Conversion (GIEC)

1.
MW-LEVEL WAVE ENERGY DEMONSTRATION FARM BUILT IN CHINA

Wanshan 1 MW Wave Energy Demonstration Project

Since 2017, a MW-level wave energy demonstration project developed and designed by Guangzhou Institute of Energy Conversion (GIEC) of the Chinese Academy of Sciences (CAS) has been progressing with governmental support.

GIEC formed a consortium with a group of companies including China Southern Power Grid and China Merchants Heavy Industry and in 2020 completed the first 500 kW unit "Zhoushan" which was deployed successfully at open sea. The construction of the second 500 kW unit "Changshan" has been completed in 2020 and will be deployed to open sea test in 2021.

This project is based on the "Sharp Eagle" technology, a wave energy converter with a hinged double floating body using a semi-submersible barge, developed by GIEC since 2011.

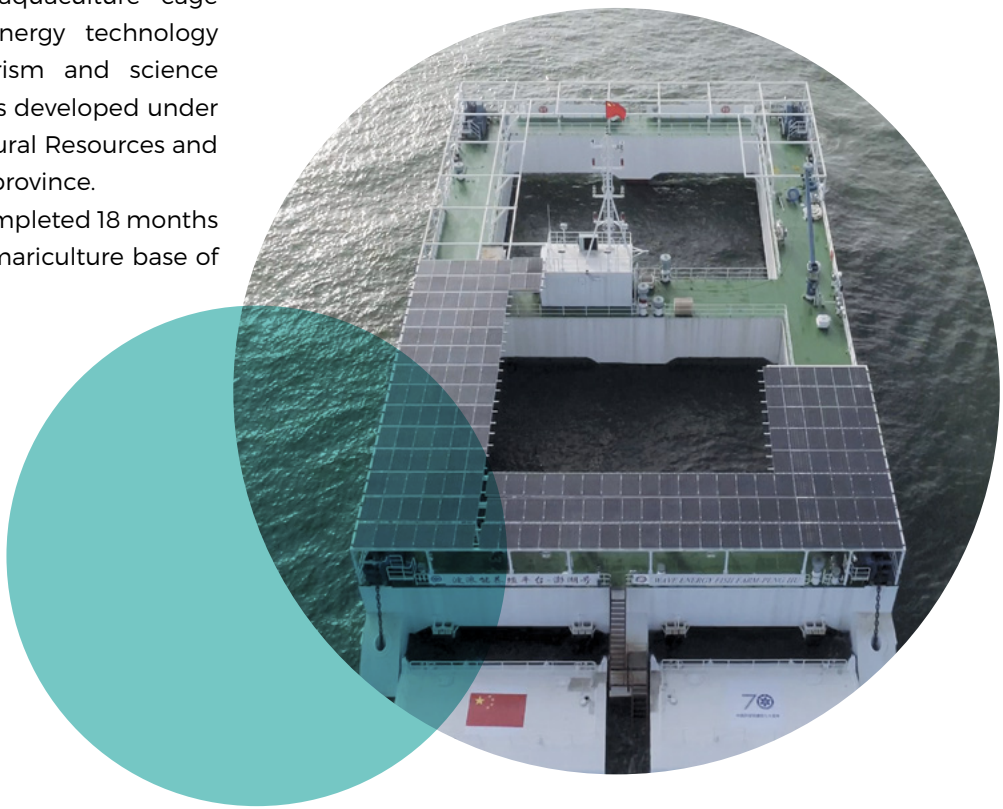
This demonstration project will make Wanshan Island become an important demonstration test site for wave energy technology in China.

2.
FIRST SEMISUBMERSIBLE OPEN SEA AQUACULTURE POWERED BY WAVE ENERGY

Wave Energy Aquaculture Cage “Penghu”

Guangzhou Institute of Energy Conversion (GIEC) successfully built an offshore aquaculture cage with the Sharp Eagle wave energy technology with aquaculture, offshore tourism and science popularization. This prototype was developed under the support of the Ministry of Natural Resources and local government of Guangdong province.

As of December 2020, Penghu completed 18 months of demonstration operation in a mariculture base of Zhuhai city.



Courtesy: Guangzhou Institute of Energy Conversion (GIEC)

3.
WAVE SWELL ENERGY
CONNECTED INTO KING ISLAND GRID

Wave Swell Energy

Wave Swell Energy (WSE) has successfully deployed its UniWave200 wave energy power generator at King Island, Tasmania, on January 10, 2021.
This 200 kW wave energy plant will provide electrical energy into the local grid, operated by Hydro Tasmania, The project received $4 million funding from the Australian Renewable Energy Agency.
Based on the concept of an oscillating water column (OWC), WSE's technology resembles an artificial blowhole that allows waves to enter a hollow chamber that is open underneath the waterline. The motion of the waves in the chamber displaces the air above, driving a turbine and thereby generating electricity.

Courtesy: Wave Swell Energy

Courtesy: Ocean Energy

4.
OCEAN ENERGY BUOY TOWED ACROSS THE PACIFIC FROM OREGON TO THE USA NAVY TEST SITE IN HAWAII

Ocean Energy

Ocean Energy constructed a 500 kW Ocean Energy Buoy which was towed across the Pacific to the U.S. Navy's Wave Energy Test Site (WETS) in Hawaii. The device is ready and waiting for its deployment in the open sea for testing.

The project has been co-funded by both Sustainable Energy Authority of Ireland (SEAI) and the U.S. Department of Energy (DOE). Prior stages of this project have been completed with financial support from SEAI, the Marine Institute, Enterprise Ireland and the European Commission funding programmes. The prior stage included several deployments at the Galway Bay Quarter Scale test site in Ireland during which the device accumulated over 24,000 hours of open water testing.

Courtesy: National Institute of Ocean Technology (NIOT)

5.
WAVE POWERED NAVIGATIONAL BUOY GUIDING SHIPS IN THE CHANNEL OF KAMARAJAR PORT, CHENNAI

NIOT Wave powered navigational buoy system

The wave powered navigational buoy developed by NIOT is being operated in the navigational channel of Kamarajar Port, Chennai for oceanographic measurements and navigational aid. This wave energy device consists of floating body with and oscillating water column (OWC) equipped with an impulse turbine and a generator.
The buoy was launched in November 2017 and since then, then has been successfully demonstrated for longer periods at all weather conditions in Kamarajar Port.
The technology has been transferred to the industry and four more of such buoys are on the anvil to be financed by the Andaman and Nicobar Islands administration.

6.
DIGITAL TWIN TECHNOLOGY APPLIED TO PERFORM SMART OPERATION AND MAINTENANCE AT JEJU ISLAND WAVE POWER PLANT

Yongsoo OWC Pilot Plant

Yongsoo OWC Pilot Plant (500 kW) is a bottom-standing Oscillating Water Column type wave energy converter. It was installed at 1.2 km away from the coastline of Jeju Island, South Korea in 2016. The plant is 37 m long and 31 m wide, equipped with two axial-flow impulse turbines and two 250 kW generators, and grid-connected by the 22.9 kV AC underwater cable. The Ring-type impulse turbine of which KRISO has its own patent right was equipped with 1.8 m diameter, 26 rotor blades, and fixed guide vanes. The power generator facility has received the final approval of electricity connection to the national grid from the Korea Electrical Safety Corporation. The plant is currently under the trial run.

The Digital Twin technology is being applied for the wave energy plant to perform smart operation and maintenance. The annual energy production will be increased by forecasting the peak wave power input for the rated power control system from the turbine input digital model. The operation and operation cost will be decreased by predicting the optimal maintenance timing from prognosis health monitoring based on the component fault digital model.

Courtesy: KIOST

Courtesy: EVE

7.
WAVE POWER PLANT OPERATING SUCCESSFULLY SINCE 2011 WITH OVER 2.1 GWH OF ELECTRICITY DELIVERED TO THE GRID

Mutriku Wave Power Plant

Mutriku Wave Power Plant, integrated in an existing breakwater at Mutriku harbour, a coastal village in the Spanish Basque Country, has been connected to the grid since July 2011. Until September 2020 the plant has supplied to the grid over 2.1GWh of electricity.

This plant consists of 16 oscillating water column (OWC) units, each equipped with a Wells turbine and electrical generator of 18.5 kW, yielding a total installed capacity of 296 kW. This facility is now available as a test site providing developers with a unique opportunity to test new concepts in air turbines, generators, control strategies and auxiliary equipment.

This plant makes the town of Mutriku a world reference in wave energy, attracting regional and international tourism and represents for the country an opportunity to develop both the industry and the field of knowledge creation. More than 7,500 people have already visited this facility.

8.
MAKING USE OF WAVE ENERGY POTENTIAL IN PORT BREAKWATERS

SINN Power

Wave power developer SINN Power GmbH has been developing a project in a breakwater at the port of Iraklio, Greece. It now consists of several wave energy module prototypes, each equipped with up to eight self-developed generators with integrated power electronics, the SINN PowerTrain 3.4. The wave energy modules were put back in operation a few weeks after storms hit the site in early 2020.
The company announced plans to upgrade the modules' powertrains. Additionally, the company installed an Ocean Hybrid Platform (OHP) in the port of Iraklio, which features the possibility to combine wave, wind and solar power converters.

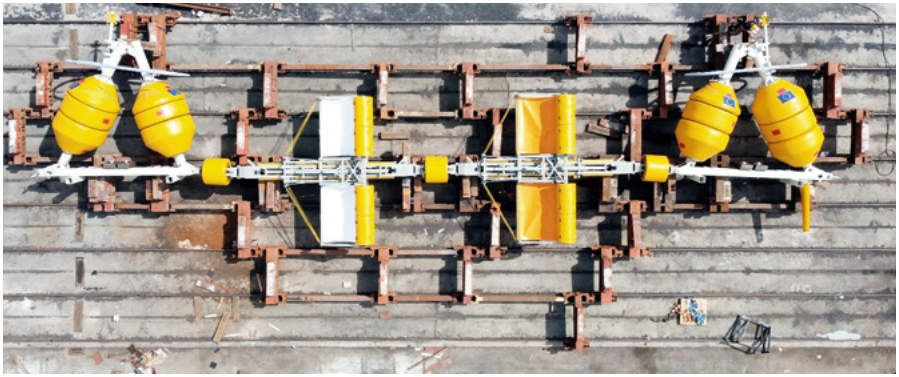
Courtesy: SINN Power

9.
SECOND OFFSHORE SUCCESSFUL TEST PHASE OF TORDENSKIOLD

Crestwing

Tordenskiold was towed back in Frederikshavn after the second offshore test phase (February-November 2020) near the Hirsholm Islands. For a total of 14 months, data has been collected regarding the plant's capacity and efficiency. The Danish Consulting Engineering Company, NIRAS A/S, has analyzed and compared the offshore data with previous pool tests data. Next step to test the durability of the mooring system and the hinges of Tordenskiold in a more challenging wave environment in the North Sea of Hanstholm, and to further develop the PTO and generator system.

Courtesy: Crestwing



Courtesy: Wavepiston

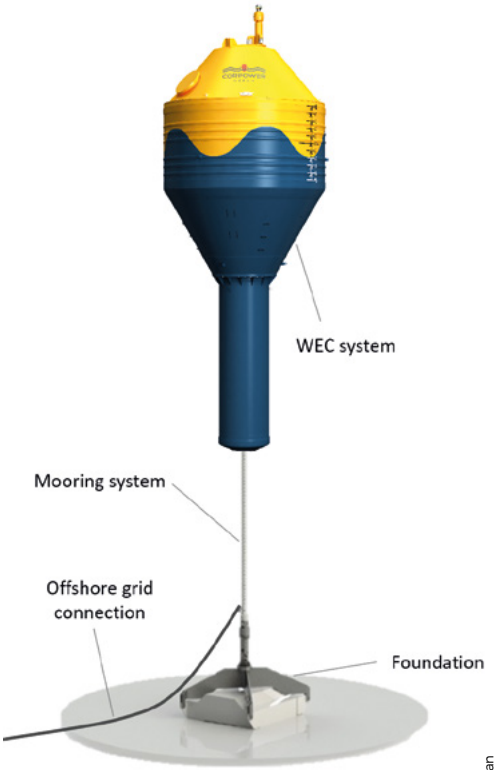
10.
DANISH TECHNOLOGY ACHIEVED AN IMPORTANT MILESTONE AT THE OCEANIC PLATFORM OF THE CANARY ISLANDS (PLOCAN)

Wavepiston

A full-scale demonstration system started to be tested at the Oceanic Platform of the Canary Islands (PLOCAN), Gran Canaria. It consists of a single unit with 24 energy collectors (length 200 m, width 8 m). Going for full scale demonstration the Danish company Wavepiston reaches a new milestone in its development.
The system comprises a chain of wave energy collectors stretched between two anchored buoys. The plates of the collectors move when waves roll along the system, pumping pressurised sea water into a pipe leading to a turbine or a reverse osmosis system, in order to obtain energy or desalinated water.
The first short test string with two energy collectors attached have been assembled in the Port of Las Palmas Gran Canaria and has been installed at the test site at Plataforma Oceánica de Canarias, being now ready for the first round of testing.

11.

AFTER SUCCESSFUL TESTS IN SCOTLAND WITH A HALF-SCALE DEVICE, CORPOWER IS NOW BUILDING IN PORTUGAL THE FIRST OF A PILOT ARRAY



Courtesy Corpower Ocean

CorPower Ocean

This Swedish company CorPower Ocean has been developing a compact wave energy device.

The project **HiWave-5** is CorPower's flagship demonstration project designed to prove the survivability, performance and economics of a grid-connected array consisting of four full scale devices.

The first phase of this project is a single device full scale C4 wave energy converter and next phase will be a pilot array with three additional C5 devices. During 2020 the manufacture of the C4 wave energy modules was initiated.

This technology uses a light buoy from composite material, a pre-tension mooring line and a very interesting breakthrough called the wave spring that allows the device to operate efficiently over a wide range of wave frequencies when the wave spring is turned on and very transparent to storm waves when the wave spring is turned off.

Courtesy: AW-Energy

12.
FIRST-OF-A-KIND 350 KW WAVEROLLER
A NEW MILESTONE ON THE ROAD FOR COMMERCIALISATION

The Finnish company AW-Energy Ltd deployed the First-Of-A-Kind 350 kW WaveRoller in Peniche, Portugal during the autumn 2019 and connected the device to the Portuguese national grid.
During the time the floating platform was submerged, the technicians have monitored performance continuously by remote control and carrying out tests to adjust the system and improve operation. Performance was in accordance with expectations.
The WaveRoller device operates in near-shore areas, anchored to the seabed, at depths between 8 and 20 meters. Depending on tidal conditions it is mostly or fully submerged.
AW Energy has created several types of units in the last decade and tested them on the seabed at Almagreira Beach, Portugal. This deployment was an important milestone.

Courtesy: Mocean Energy

13.
WAVE ENERGY DEVICE WITH A GOAL TO BRING POWER TO SUBSEA OIL AND GAS

Mocean Energy

Mocean Energy is manufacturing their *Blue X prototype* to be tested at EMEC in Orkney; the project is funded through the Wave Energy Scotland's Novel Wave Energy Converter (NWEC) programme. The device is an hinged raft: two hulls connected by a single revolute joint parallel to the wave crests. Wave forcing and the bodies' dynamic responses cause a relative motion about the hinge, which drives a PTO producing electricity.

Blue X will be used to demonstrate power to real subsea equipment. Mocean Energy's innovation is in the geometry – using AI-optimisation to design hull-shapes that significantly increase performance.

14.
WAVEGEM PLATFORM DEVELOPED AS AN AUTONOMOUS HYBRID ENERGY PRODUCTION SYSTEM
DESIGNED TO SUPPLY MARITIME APPLICATIONS OR REMOTE ISLANDS

GEPS Techno

GEPS Techno's hybrid WAVEGEM platform, combining solar and wave energy, has been tested at SEM-REV site in France.
The platform converts wave energy into electricity using the float's movements to create a closed circulation of seawater through a low speed turbine.
This type of platform is intended for oil and gas, marine renewable energy, mining and aquaculture sectors.
Wavegem platform, a hybrid (wave, solar) autonomous energy production system designed by GEPS Techno has reached 18 months of offshore testing since August 2019.

Courtesy: GEPS Techno

15.
INDUSTRY PARTNERS JOIN FORCES TO DEVELOP THE ACADEMIC ISWEC PROJECT TESTED IN THE ADRIATIC SEA

ISWEC (Inertial Sea Wave Energy Converter)

The ISWEC is a point-absorber wave energy converter based on the gyroscopic technology, suitable for mild climate seas such as the Mediterranean. A first full-scale prototype of 100 kW was moored 800 m from the coast of Pantelleria in 2016 and more recently another pilot project has been put into operation in the Adriatic Sea off the coast of Ravenna. This project originally developed by the Polytechnic of Turin has been realized in partnership with the Italian energy company, Eni. In October 2019, a number of Italian companies joined forces to launch a joint project to convert ISWEC into an industrial scale power plant.

Courtesy: Polytechnic of Turin

Courtesy: Slow Mill Sustainable Projects

16.
DUTCH SLOW MILL DEMONSTRATE THE ABILITY TO GENERATE POWER FROM NORTH SEA WAVES

Slow Mill Sustainable Projects

Slow Mill Sustainable Projects, a Dutch company designed a novel wave energy device for the moderate wave climate of the North Sea and in 2020 tested a prototype 4 km of the coast of Texel island.

UPCOMING DEVELOPMENT PLANS

DEVELOPERS PREPARING NEW DEPLOYMENTS

Carnegie Clean Energy

Carnegie Clean Energy has been actively progressing its Digital Development Pathway, a development project to significantly improve the performance and reduce the cost of the CETO technology. Carnegie has also developed and validated a machine learning based wave predictor that allows CETO (and other applications) to accurately forecast waves before they arrive which supports intelligent control. Carnegie has also been progressing prototype demonstration plans at its private wave energy research facility in North Fremantle, Western Australia.

Bombora Wavepower

The Australian wave energy developer Bombora Wavepower received a Marine Licence for the deployment and testing of 1.5 MW mWave wave energy converter technology off the coast of Pembrokeshire, Wales. In 2018, Bombora secured a £10.3 million Welsh European Funding Office grant to support this project. Bombora's team have been designing and fabricating a full-scale 1.5 MW mWave prototype in Pembrokeshire. In July 2020, the full scale 'cell module' structure, a key component part of the 75-meter-long subsea mWave, was transported to the assembly workshop. The project is scheduled to be deployed in 2021.

WELLO OY

The Finnish wave energy developer WELLO OY is planning to test PENGUIN2 at BiMEP. The device started in autumn 2020 the travel from Scotland to the Port of Bilbao, close to BiMEP, but bad weather conditions forced to suspend the towing and wait

to spring for better sea conditions. The device is expected to be at BiMEP in Spring and will start its two-year test campaign.

AWS Ocean Energy

AWS Ocean Energy has developed a fully submerged pressure differential wave energy device named the 'Archimedes Waveswing'. The company was awarded £3.4m from the Wave Energy Scotland programme to develop a prototype to be deployed and tested in Orkney. AWS has been working closely with EMEC through 2020 in preparation to begin testing in 2021. The technology was tested offshore Portugal in 2004 and since that time, the Waveswing has been refined and developed.

Oscilla Power

Oscilla Power has been developing the Triton wave energy converter. The company is currently completing construction of their first commercial-scale system, the Triton-C, a 100kW wave energy converter which is expected to be tested in Hawaii during 2021. This system is being constructed in Seattle at the Snow & Company shipyard. The development of the Triton-C has been substantially funded through the US Department of Energy's Water Power Technologies office (DOE WPTO), who have committed over $5 Million to date towards its design, development and construction.

SBM Offshore

SBM Offshore's wave energy converter - WEC S3® - is planned to be tested in the sea, offshore Monaco. The manufacturing process of the prototype is in progress. The prototype is a 'floating rubber tube', 60m long and 1.2m in diameter. The WEC S3® converts the kinetic energy from waves directly into electricity using Electro Active Polymers (EAP).

Columbia Power Technologies, Inc. (C·Power)

The SeaRAY autonomous offshore power system provides in-situ power, energy storage, and real-time data and communications support that will advance the marine economy toward a future of autonomous, connected and resident technologies. It is designed to support unmanned offshore activities and equipment, including subsea vehicles, sensor packages, and operating equipment. Sea trials are planned to take place during the year at the Navy's Wave Energy Testing Site in Hawaii. The company also continues developing their MW-scale device called StingRAY,

EXOWAVE

With funding from the Danish EUDP programme, Exowave will demonstrate an innovative wave energy converter in combination with a desalination system. The Exowave wave energy converter also known as oscillating wave surge converter, extracts the kinetic energy from the ocean waves through bottom-hinged flaps. The demonstration offshore is planned to take place in late summer 2021 in the North Sea at the north west coast of Denmark at DanWEC test site.

www.ocean-energy-systems.org