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ALTERNATIVE MARKETS FOR OCEAN ENERGY

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Water desalination plant at Agatti Island (Courtesy: NIOT)

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CONTENTS

FOREWORD

Yann-Hervé De Roeck
Chairman of the IEA-OES

Ocean energy is a dynamic and fast-growing sector of the blue economy. There are a number of sectors of the blue economy that depend on access to consistent and reliable energy, including offshore aquaculture, ocean observation, marine robotics and offshore data centers. These offshore applications will require new energy approaches. Ocean energy can provide solutions to support a variety of ocean-based activities. Also, remote coastal and island communities are exploring options to reduce dependence on single sources of fuel and water, while seeking their energy independence and sustainability. Combining several activities in the same marine space can be also a viable option to meet economic, social, and environmental goals.

The **IEA-OES International Vision for Ocean** Energy recognises that there are several ways in which specific synergies exist within varying industries, leading to a range of transfers from other industries into the ocean energy sector. Furthermore, most ocean energy technologies are being developed to generate electricity for the grid, while at the same time considering direct power for other blue growth activities like aquaculture or the production of fresh water from seawater by desalination.

In this brochure six examples are presented of these synergies. Stakeholder interviews conducted by IEA-OES show that small islands present a compelling argument for the exploitation of their ocean energy resource potential, and the importance of engaging local communities and local authorities in a dialogue that highlights these projects as a platform for job creation and social improvement. Energy problems faced by many islands and coastal regions can be solved by harnessing the available renewable energy resources of the sun, wind and ocean to supply electricity and freshwater. The idea of multi-use of the sea can be an efficient allocation of compatible activities in the same ocean space providing socio-economic and environmental benefits. Ocean energy and offshore aquaculture can achieve effective complementary advantages: the Penghu semi-submersible aquaculture platform in China is showing a new form of offshore aquaculture supported by green energy. Offshore applications, such as data science platforms, can also benefit from access to reliable power. The robustness and reliability of these projects have to be proven with sea trials before commercialization of the technologies is possible and governmental support will be needed, but the examples show the value of ocean energy to other blue growth sectors.

This brochure presents a series of interviews discussing potential applications and markets for marine energy technologies beyond grid-connected power generation markets, where ocean energy may hold a unique value proposition:

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

Three low temperature thermal desalination (LTTD) plants were built in the Kavaratti, Minicoy and Agatti Islands in the Union Territory of Lakshadweep in India, for water desalination. The Kavaratti plant was commissioned in the year 2005 and the other two in 2011. These projects were funded by the Ministry of Earth Sciences (MoES), Government of India. Following the success of these plants, the island administration is now setting up such plants in 6 more islands.

Wave powered desalination plant in Cape Verde

Ocean waves are an abundant and consistent source of clean renewable energy that can be harnessed to power desalination plants. Resolute Marine have chosen to focus their initial efforts on developing projects in Cape Verde because it has a relatively small population spread across a nine-island archipelago which means that building a large, centralized desalination plant is not a viable option.

CalWave XNode Ocean Science Platform

CalWave was the winner of the Ocean Observing Prize launched by the US Department of Energy, in which competitors submitted novel concepts and ideas to integrate ocean observing sensors and platforms with marine energy systems. CalWave xNode is a technology platform providing any offshore operation access to reliable power and data.

Penghu semi-submersible aquaculture platform powered by wave energy

The Government of China has launched financial support for the application of ocean energy in aquaculture in 2016. In June 2019, GIEC deployed for sea trials the first semi-submersible aquaculture platform Penghu driven by wave energy. To date, Penghu has completed 24 months of demonstration operation in aquaculture base of Zhuhai city. The Penghu semi-submersible aquaculture platform has provided a new form of offshore aquaculture supported by green energy. GIEC has completed the design of several models to meet different user needs, and signed some commercial orders for the platform.

Multiple-use of ocean space and multi-use platforms

The MUSICA project aims to create a one-stop trial solution to address the energy problems faced by many islands and coastal regions. MUSICA's Multi-Use Platform will reduce the need for importing expensive and harmful fossil fuels by harnessing the available renewable energy resources of the sun, wind and waves to produce an autonomous, readily available supply of electricity and freshwater. The Greek island of Oinousses was selected as a trial for this multipurpose floating offshore platform.

Blue Growth Farm multipurpose platform

Blue Growth Farm project is a hybrid wind-wave-aquaculture concept on a multi-functional offshore platform. It is a research project funded by the European Commission under the framework of the Horizon 2020 programme. The project is co-ordinated by RINA Consulting, based in Genoa, and has partners in Cyprus, France, Italy, Scotland and Spain. A 1:15 scale prototype platform was deployed in the open sea at the Natural Ocean Engineering Laboratory of the Mediterranean University of Reggio Calabria.

DESALINATION PROJECTS USING OCEAN THERMAL GRADIENT IN INDIA'S LAKSHADWEEP ARCHIPELAGO

Dr Purnima Jalihal
Head of Energy and Fresh Water Department
National Institute of Ocean Technology (NIOT)
India

With the support of the Ministry of Earth Sciences (MoES), the National Institute of Ocean Technology (NIOT) was responsible for the planning, design and installation of low temperature thermal desalination (LTTD) plants for water desalination in the Lakshadweep archipelago.

Three low temperature thermal desalination (LTTD) plants were built in the Kavaratti, Minicoy and Agatti Islands in the Union Territory of Lakshadweep, for water desalination. Can you please describe, for the general public, in simple words, how an LTTD plant works?

The LTTD process is very simple. We all know water boils on the stove under atmospheric pressure at 100ºC. If the pressure is reduced sufficiently, it can boil even at 28ºC, i.e. the temperature of seawater surface. In the LTTD process, warm seawater surface is passed through a vessel under vacuum and it vaporizes instantaneously. The vapor is condensed using deep sea cold water. The continuous cycle keeps working throughout the year giving good quality drinking water.

Could you please provide details about each of these three projects (e.g. capacity, population of the islands, water requirements, data of installation/start of operation)? And how have been these projects financed?

Each of the plants at Kavaratti, Agatti and Minicoy are of 100m^3/day of fresh water capacity. The population of Kavaratti is around 10000 and the other two are slightly lesser. The Kavaratti plant was commissioned in the year 2005 and the other two in 2011. All these projects were funded by the Ministry of Earth Sciences (MoES), Government of India.

Which entities were responsible for their planning, design and are now involved in the day-to-day operation?

National Institute of Ocean Technology (NIOT) under MoES was responsible for the planning, design and installation. The plants have been handed over to the island authorities for operation and maintenance after NIOT operated them for two years and trained the local people.

Water desalination plant at Kavaratti Island
Courtesy: NIOT

Desalination plants are energy intensive hence ocean energies could be used to meet the power requirements.

The development of these projects involves a wide variety of risks, including technical, regulatory and financial. Could you describe which are the most critical ones you have encountered/are encountering and how could they be overcome?

The islands are remote and do not have any infrastructure or industries. The local population has low education levels. Transportation of equipment and material is very difficult. The islands are very small hence only one island has an airstrip. Travel is only by ships and inter-island transport is by smaller vessels. Additionally, during May to August is the rainy season or the southwest monsoons when barges & vessels cannot sail due to rough weather. Lack of local resources and transportation and logistics are the most difficult issues to deal with while working in the islands.

Water desalination plant at Agatti Island
Courtesy: NIOT

How has been the engagement with the local communities and with regional authorities? What can you say about the impact this business has on jobs and prosperity in the local area?

The main positive impact is that the health of the islanders has improved due to the clean water from the desalination plants. This has led the authorities to consider more such plants which can be useful for furthering tourism in these beautiful islands.

Water desalination plant at Minicoy Island
Courtesy: NIOT

Following the success of the existing plants are there any other projects on the pipeline? The islands in the Indian Ocean as other remote islands are often challenged to meet their energy needs; getting energy from the mainland is expensive. How do you see prospects for ocean energy in the context of these islands? What would you say to encourage other nations to explore the potential of ocean energy for the production of clean potable water?

Following the success of these plants, the island administration is now setting up such plants in 6 more islands. The islands have a diesel generator-based power grid and hence there is certainly a case for ocean energies. Since NIOT has successfully used the ocean thermal gradient to produce freshwater, the next effort is towards generating power from the ocean thermal gradient known as Ocean Thermal Energy Conversion or OTEC. The next plant will be self-powered i.e. water will be generated using OTEC power, not diesel generators. This plant can pave the way towards diesel displacement and help the fragile ecosystem of the islands and also would be a step towards a scaled up OTEC plant. Desalination plants are energy intensive hence ocean energies could be used to meet the power requirements. Wave energy, OTEC and tidal energy can all be used in conjunction with desalination for clean water using green energy.

WAVE POWERED DESALINATION PLANT IN CAPE VERDE

Mr. William Staby
Co-founder and CEO
Resolute Marine
USA

Resolute Marine is nearing the completion of the site characterization studies for their first wave powered desalination plant in Cape Verde with financial support provided by the African Development Bank. Resolute Marine is collaborating with IMAR, the national marine institute, Electra, the national water and electric utility, and Biosfera, a local Environmental NGO, to perform the necessary feasibility studies at the site, on the island of Sao Vicente.

Resolute Marine's mission is to significantly improve access to water for coastal populations and industrial/agricultural operations using wave energy technology as a source of power. Can you describe your technology and recent developments?

Our wave powered desalination plants comprises three primary systems that must be carefully coordinated to produce freshwater reliably and at an attractive cost.

The 100% offshore system is the wave energy converter and for that, we've chosen to develop a type of WEC known as an Oscillating Wave Surge Converter (OWSC) which is a bottom-mounted hinged flap that extends from the seabed to the ocean surface. The flap is connected to the power take-off (PTO) system and as the flap moves back and forth in response to waves passing overhead, energy is transferred to a series of rotary pumps. The rotary pumps pressurize seawater and send it ashore in low-pressure pipes where the reverse osmosis desalination system does the actual work of producing freshwater.

The 100% onshore system is the reverse osmosis desalination plant. Here the pressurized seawater is passed through a series of filters before being introduced to the pressure vessels which contain spiral wound membranes that separate freshwater (permeate) from the solutes (mainly chloride and sodium) which is typically called "brine" because of its higher salt concentration. Reverse osmosis desalination processes are very well known and, while the configuration of a desalination plant will vary according to the chemical composition of the ambient seawater, there is very little technical risk inherent in the onshore desalination plant.

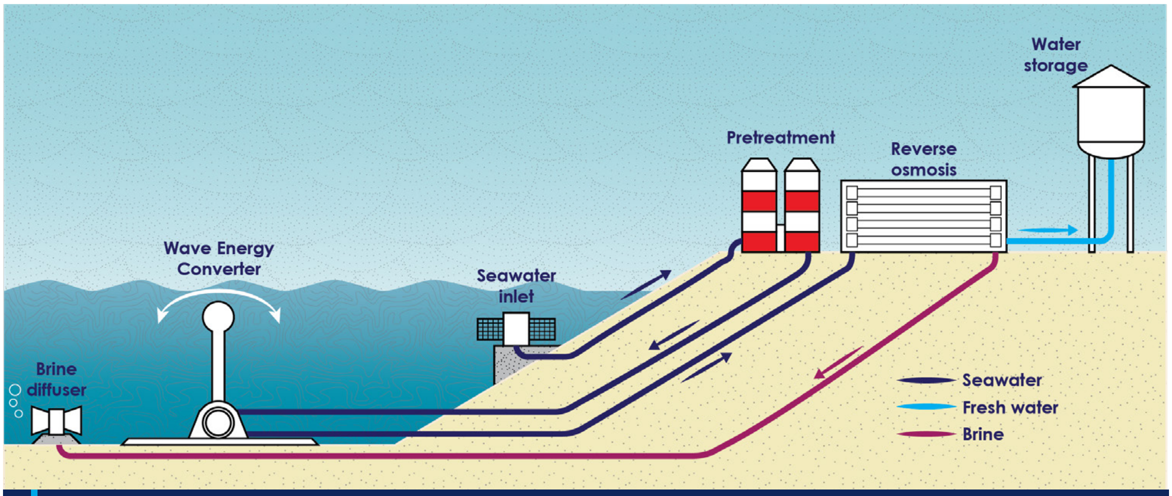
The third major system has both onshore and offshore components and is the hydraulic "circuit" which couples the offshore WEC with the onshore desalination plant. Our choice of an OWSC as the power source was driven by the need to keep the distance between offshore and onshore components to a minimum which would favor WEC types that can operate and survive in shallow water.

Without a doubt, the biggest technical challenge we've faced is getting all three systems to operate as efficiently and reliably as possible given the variability in the wave resource. The innovations we've come up with have, however, helped immensely. The first is the notion of directly powering the reverse osmosis process with pressurized seawater rather than generating and storing enough electricity to run the entire plant. The second innovation is a PTO system that operates with seawater as the fluid power medium rather than oil-based hydraulic fluids. The third innovation is the development of a control system that "orchestrates" everything, i.e., keeps the WEC system operating at or near optimal power output while ensuring that the dynamics of the hydraulic circuit are managed such that the desalination plant is maximizing water production while minimizing wear and tear on critical components.

In terms of recent developments, the most important is that, thanks to the generous financial support provided by the African Development Bank, we're nearing the completion of the site characterization studies for our first commercial project in Cape Verde.

The development of these projects involves a wide variety of risks, including technical, regulatory, and financial. Could you describe which are the most critical ones you have encountered/are encountering and how could they be overcome?

In ranking risks, in my opinion, it's a two-way tie between technical and financial risk which is a classic "chicken and egg" dilemma, i.e., financial capital is needed to retire technical risk, but financial capital is only available when technical risk has been mostly eliminated. While this may be true, it oversimplifies the problem because a third factor, commercial risk, can have a strong influence on the perception of financial and technical risk. One need only look at Tesla, or any other of the emerging EV manufacturers, to understand how the commercial potential of EVs lowered the perception of financial and technical risk for investors and unlocked billions in investment capital as a result. This is a key reason why we chose to apply our efforts to freshwater production which, for a variety of reasons, we believe has lower commercial risk than electricity production. Our challenge now is to prove this by demonstrating that our wave-powered desalination system can form the foundation of a profitable, scalable, and sustainable business.



Resolute Marine's wave energy system for desalination
Courtesy: Resolute Marine

In addition, to further mitigate financial risk and hasten the commercial and technical validation of our technology, we're focusing our fundraising efforts on investors who, despite the presence of technical risk, are willing to support the development of a product and enterprise that can help solve a global humanitarian crisis that is the direct cause of the death of millions of people every year.

How has been the engagement with the local communities and with regional authorities? What can you say about the impact this business has on jobs and prosperity in the local area?

Our business development efforts always include engaging local communities and government officials in a dialog that highlights our activities as a platform for job creation, co-creation of intellectual property, capacity building and social improvement.

In Cape Verde, we're collaborating with IMAR, the national marine institute, Electra, the national water and electric utility, and Biosfera, a local Environmental NGO, to perform the necessary feasibility studies at the site of our first project on the island of Sao Vicente. We currently have a full-time employee in Cape Verde who helps coordinate and manage all our activities and we have also employed student interns from two of Cape Verde's leading universities.

As part of our commitment to local capacity building, we have helped IMAR apply for funding from the African Development Bank to purchase equipment and implement a training program to conduct bathymetric surveys and wave energy assessments. Biosfera will benefit from technology transfer related to conducting water quality assessments and we believe that Cape Verde can serve as a manufacturing hub and staging area for our further business development efforts on the African continent.

Today more than 1 billion people lack access to clean and safe drinking water and the World Commission on Water predicts the situation will dramatically worsen in the next 20 years unless clean water supplies increase by about 50 percent and access is more evenly distributed.

To mitigate any effects associated with the displacement of the indigenous fishery from the area occupied by our wave energy converters, we are seeking funding to conduct a halieutic study to identify new fishing grounds that can replace the traditional fishing grounds that are becoming overfished.

What would you say to encourage governments to explore the potential of ocean energy for the production of clean potable water?

We're focusing our development activities on developing countries and island nations where water scarcity is a major contributor to the vicious cycle of poverty, conflict, disease, and death in which many of them are trapped. According to the United Nations Development Program ("UNDP"), today more than 1 billion people lack access to clean and safe drinking water and the World Commission on Water predicts the situation will dramatically worsen in the next 20 years unless clean water supplies increase by about 50 percent and access is more evenly distributed. If these new supplies are not made available, by 2025 an estimated 4 billion people – one-half of the world's population – will be living under conditions of severe water stress.

Resolute Marine' wave energy converter
Courtesy: Resolute Marine

It is generally accepted that desalinating seawater on a massive scale is the only viable means of alleviating the World Water Crisis. Oceans cover over 70% of the earth's surface and 97% of all water is saline (undrinkable). Approximately 38% of the world's population lives within 100 kilometers of a coastline and, therefore, if made available, desalinated seawater is within easy reach to millions of people who desperately need it.

Ocean waves are an abundant and consistent source of clean renewable energy that can be harnessed to power desalination plants. Wave energy has energy density factors that far exceed either wind or solar and, therefore, wave-powered desalination systems should be considered alongside other renewable energy technologies when planning the implementation of desalination projects.

We have chosen to focus our initial efforts on developing projects in Cape Verde because it has a relatively small population spread across a nine-island archipelago which means that building a large, centralized desalination plant is not a viable option.

Approximately 84% of Cape Verde's 530,000 inhabitants have access to a water distribution network but constant water shortages create stressful living conditions for the entire population. Cape Verde's renewable water availability is only 537 m^3 per person per year, the second lowest of any country in sub-Saharan Africa, and it will need to supply an additional 1,100 m^3/person/year to meet the minimum standards set forth by the World Water Organization (1,700 m^3/person/year).

Cape Verde is reliant upon desalination to provide 85% of its fresh water needs and 100% of its desalination plants are powered by diesel-electric generators which create noise and pollution and generate social, environmental and economic risks associated with buying diesel fuels, transporting them over long distances and storing them for later use. We believe that this is one of many motivating factors for the investment community we are aiming to attract as long-term business development partners.

CALWAVE XNODE OCEAN SCIENCE PLATFORM

Mr. Marcus Lehmann
Co-Founder and CEO
CalWave Power Technologies Inc.
California
USA

CalWave xNode is a technology platform providing any offshore operation access to reliable power and data. CalWave was the winner of the Ocean Observing Prize launched by the US Department of Energy, in which competitors submitted novel concepts and ideas to integrate ocean observing sensors and platforms with marine energy systems.

Can you please describe your concept?

The CalWave xNode is enabling the Ocean Internet of Things by providing access to power and data offshore. The xNode is a versatile, adaptable, and resilient ocean observing platform with built-in power generation. It is lightweight and low cost, resilient for storm survivability, and easily stores, ships, and deploys. The xNode facilitates and improves a range of existing and novel offshore missions.

A standard baseline ocean science sensor suite ensures that every mission maximizes data collection and cross-functional interest. The modular scientific payload compartments can be equipped independently and configured easily in the standardized hull.

In addition to providing remote power and data offshore, the xNode stands out through innovative features such as a digital twin, autonomous shelter/survival functions, on-board edge computing, and a lightweight and compact size enabled by an inflatable hull.

What was your motivation to develop this concept?

In 2017 as a follow up to the US Wave Energy Prize that had the goal to identify wave technologies that can become cost competitive with other utility scale renewables, CalWave was awarded a contract from the U.S. Department of Energy to demonstrate a scaled version of our MW level xWave™ technology in open water.

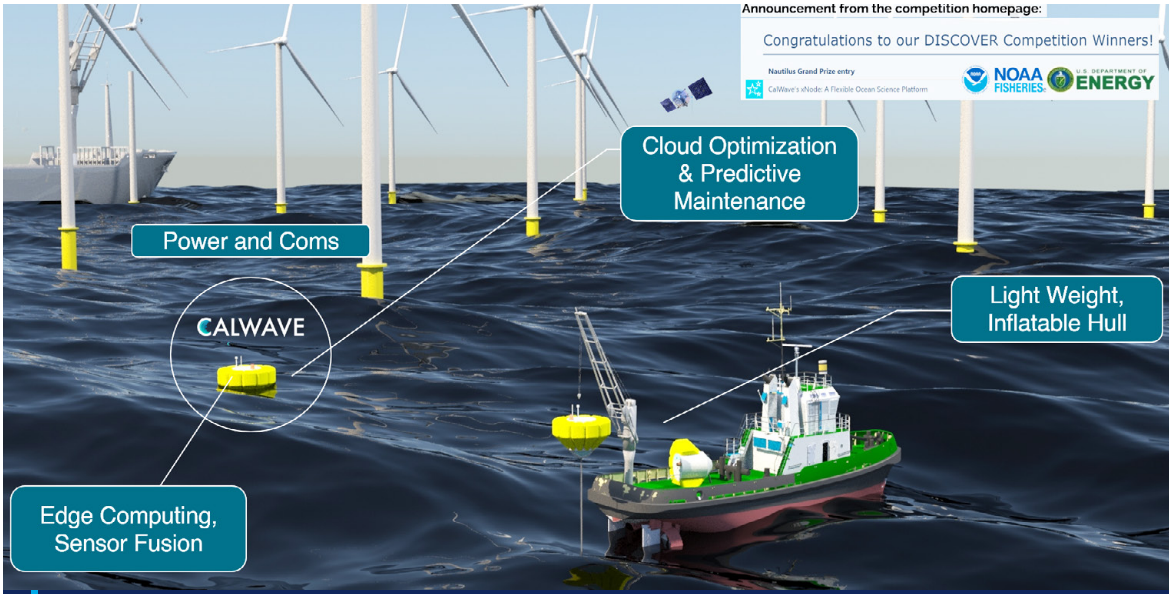
Next to these, our team participated in the early workshops of the US DOE that lead to the Powering the Blue Economy (PBE) initiative and further advanced our interest in solutions for the blue economy.

Since then, our team has designed, built, and tested critical subsystems and elements such as our drivetrain (power take off unit, or PTO) suitable for our open ocean demonstration scheduled for Q3 2021 in San Diego, CA. Together with our development partners at UC Berkeley, Sandia National Laboratory, and NREL, we've built a hardware in the loop test facility to validate the overall performance of our PTO, optimize advanced control strategies, and obtained numerical models for simulations.

This PTO, is now a mature subsystem we can utilize for lower power units specifically designed for end-users of the blue economy, such as the xNode.

How do you see your project moving forward?

Our team has continued to conduct customer discovery to narrow down specific use cases and requirements, such as continuous power needs that inform the onboard energy storage capacity, types and dimensions of sensors that



XNode Ocean Science Platform using wave energy
Courtesy: CalWave

allow dimensioning of the variable payload compartment.

After our open ocean demonstration of the xWave™ architecture in 2021, we are planning to offer the xNode as a stand-alone product line to the market in the near future.

Next to that, CalWave is planning to demonstrate the X100 at PacWave in Oregon the coming years. The X100 is the 100 kW product line of the xWave™ architecture that is scalable to MW levels. The xWave class is operating fully submerged and next to performance, incorporates critical load management features. These are essential features for MW level wave farms that operate for 20 years+ as standalone wave farms or collocated with offshore wind farms.

Are you also looking for other market applications for your wave energy concept? And if so, why do you consider your technology appropriate for these markets and which benefits in particular you see?

Our xNode is a technology platform providing any offshore operation access to reliable power and data. We've received interest from operators of offshore aquaculture farms, navigational aid systems, long term monitoring stations of remote environmental stations, disaster recovery first responders and other remote micro grids. Having continuous power and data connectivity on the surface via satellite is the critical missing piece needed to enabling permanent offshore operations, such as resident AUVs or ROVs.

Next to that, we are offering a version of the xNode called the HydroNode. It will deliver fresh water to remote coastal communities, providing a rapidly deployable and easily operated and maintained system for locally generated desalinated water to support disaster relief. Here we can pair with an existing or integrated RO system for wave powered desalination.

With this product line, our team is currently contesting in the U.S. DOE Waves to Water Prize that will host at sea testing at Janett's Pier in North Carolina in the final stage of the competition in 2022.

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The main value of wave power for ocean observation platforms is its high energy density relative to wind and solar. That means with the same weight of a device and space, wave power can generate more power as the energy density is up to 20-60 times denser compared to other renewables.

The development of these projects involves a wide variety of risks, including technical, regulatory and financial. What do you anticipate to be the main barriers to integrate wave energy technology in ocean observation platforms at large scale and how could they be overcome?

There are existing ocean observation platforms available today using energy storage technology (fuels and/or batteries) and renewables such as solar and micro wind turbines.

The main value of wave power for ocean observation platforms is its high energy density relative to wind and solar. That means with the same weight of a device and space, wave power can generate more power as the energy density is up to 20-60 times denser compared to other renewables (annual average wave power densities range from 20-60 kW/m of coast line) .

The main motivation to use renewables for ocean observation platforms is that we can remove the frequency of human intervention for refueling. Thus, the critical barrier to prove the value proposition of wave power technology for ocean observation is ease of deployment, robustness, and reliability. This barrier is overcome by sea trials often carried out at pre-permitted test sites such as here in the U.S. WETS in Hawaii or PacWave in Oregon.

Advanced sensor technology and digital tools, including our digital twin that enables predictive maintenance can further improve reliability going forward.

If support measures are put in place to overcome those barriers, can you identify the responsible stakeholders for delivering solutions, such as, governments, supply chain, research sector, etc and what would be the expected improvement in terms of your project pipeline and cost reduction that could be achieved?

As mentioned, testing at sea in the same environment and depth as our end-users is critical which test sites can support. Next to that, accelerated life-time testing of critical subsystems and components will accelerate the commercial adoption of new technologies. We've seen similar key enabling test facilities in the wind industry where blades are tested for fatigue and generators for controls in large dyno test stands.

Cost is certainly a consideration for all end-users, so support mechanisms to achieve higher production volume for new solutions can help quickly bring the initial cost down. This allows for wider adoption and even more cost reductions due to volume. In summary, mechanisms that help to get the ball rolling overcoming the initial inertia (or the first 10-50 units) are important. This support can come in form of loan guarantee programs or e.g. financial incentives to end government or private sector end-users.

WAVE ENERGY PROJECTS AND AQUACULTURE – CHINA

Mr. Peng Wei
Deputy Director
National Ocean Technology Center (NOTC)
Ministry of Natural Resources (MNR)
China

In June 2019, the first semi-submersible aquaculture platform Penghu was deployed to sea trail. The platform can provide 60kW of wave energy power supply, 15,000 m³ of aquaculture water, living space for 20 people, 300 m³ of storage space, and several equipments (e.g. fish monitoring, water monitoring, fish transmission, ice making, sea water desalination).

Can you please provide details on the ocean energy projects that have been implemented and tested in islands in Chinese waters?

China has made great progress in green and sustainable energy actively implementing a strategy to reduce carbon emissions and has always focused on islands as a key application field of ocean energy and given constant attention. As early as the 1990s, China began to explore the application of ocean energy in islands, and successively developed several island ocean energy test power stations. Since 2010, China has successively launched a series of wave energy and tidal current energy island demonstrations and test projects in Shandong, Zhejiang, Guangdong and Hainan, and has gradually formed the Guangdong Wanshan Islands Wave Energy Demonstration Zone and Zhejiang Zhoushan Islands Tidal Current Energy Demonstration Zone. In recent years, with the successful application in island power supply and agriculture, the application domain of wave energy is gradually broaden in China. In 2017, to further accelerate the large-scale application of wave energy in island areas, China launched the "Wanshan 1 MW Wave Energy Demonstration Project". At present, two 500 kW wave energy prototypes "Zhoushan" and "Changshan" have been constructed and deployed to sea trials. In 2022, China's first MW-level wave energy demonstration project will be put into demonstration operation.

The development of these projects in islands involves a wide variety of risks, including technical, regulatory and financial. Could you describe which are the most critical ones you have encountered/ are encountering and how could they be overcome?

Ocean energy has a unique advantage over other renewable energy in islands, but it also faces a more complex operating environment and greater risk. From the implementation of those ocean energy projects, and what I know of, I think the main risks are the following three aspects: the reliability of ocean energy devices in complex sea status, the affordability of ocean energy in islands, and the policy and regulation of ocean energy projects.

Ocean energy devices in island areas face a more complex and harsher operating environment than near shores, especially facing the challenges of extreme sea conditions such as typhoons. How to ensure the reliability of ocean energy devices and survivability under extreme sea conditions are key issues that need to be solved for the successful application of ocean energy in island areas. In this regard, the test site will play a vital role. By establishing a complete set of real-time testing evaluation system for ocean energy devices, to prevent immature ocean energy devices from entering the next stage, the test site will effectively reduce the technical risks applied in island areas of ocean energy.

At present, the cost of ocean power is still high. In island areas, compared with mature wind power, photovoltaic and fossil energy (considering transportation and environmental costs), the economy and market competitiveness are still weak. The cost of power generation is directly related to the maturity of the technology and the scale of development. China is promoting the large-scale application of ocean energy in island areas and driving the optimization and upgrading of equipment with scale to promote the reduction of development costs. We make full use of the advantages of many additional products driven from ocean energy development and utilization, and explore the comprehensive utilization and development model of "ocean energy +" to further boost the economic efficiency of ocean energy. In addition, we also hope to use electricity prices and tax preferential policies to attract more private enterprises to enter the ocean energy sector to improve their market competitiveness.

As a new promising renewable energy, ocean energy is still in its infancy in terms of policy and regulation system construction. In 2021, the large-scale of ocean energy has been included in the 'the 14^{th} Five-Year Plan for National Economic and Social Development and the Long-Range Objectives Through the Year 2035', which is the highest level planning document in China, ensuring the development of China's ocean energy at the national policy level. In the next step, we will further facilitate the use of ocean energy in islands in terms of policies and systems.

Ocean energy has a unique advantage over other renewable energy in islands, but it also faces a more complex operating environment and greater risk. From the implementation of those ocean energy projects, and what I know of, I think the main risks are the following three aspects: the reliability of ocean energy devices in complex sea status, the affordability of ocean energy in islands, and the policy and regulation of ocean energy projects.

Penghu semi-submersible aquaculture platform
Courtesy: NOTC

In particular, for the project combining wave energy and offshore aquaculture – Penghu semi-submersible aquaculture platform - could you please describe how this initiative started, how it works and what are the power requirements for the aquaculture farm?

China has a huge market with big potential and wide prospect in agriculture industry. In recent years, China's aquaculture industry has been transforming to higher quality and green development. In order to promote the application and development of ocean energy in a wider range, China has launched financial support for the application of ocean energy in aquaculture in 2016. In 2017, Guangzhou Institute of Energy Conversion (GIEC) was supported to develop a power supply system driven by wave energy for offshore cages based on the Sharp Eagle WEC technology.

In June 2019, the first semi-submersible aquaculture platform Penghu was deployed to sea trail. The platform can provide 60 kW of wave energy power supply, 15,000 m^3 of aquaculture water, living space for 20 people, 300 m^3 of storage space, and it is equipped with automatic bait casting, fish monitoring, water monitoring, fish transmission, ice making, sea water desalination equipment and other production equipment. To date, Penghu has completed 24 months of demonstration operation in the aquaculture base of Zhuhai city, successfully completed multi-season breeding of various species such as golden pomphrey and grouper, and achieved good demonstration effect and economic benefits.

The Penghu semi-submersible aquaculture platform has provided a new form of offshore aquaculture supported by green energy. GIEC has completed the design of several models to meet different user needs and signed some commercial orders for the platform.

In your view ocean energy is a viable energy source for the future expansion of the offshore aquaculture?

The aquaculture industry plays an important role in the marine economy. Over the years, the aquaculture industry has developed vigorously, and many coastal countries have built various types of aquaculture platforms in the bay. Due to the worse circulation of water in the bay, the excessive breeding density is easy to cause marine environment pollution.

Considering the sustainable development and marine environment protection, the aquaculture will develop into deeper, farther and open sea area, and energy supply will be the primary problem to be solved. According to the previous project demonstration experience, a 50-100 kW wave energy device can meet all the power requirements of the offshore aquaculture cage (10,000-20,000 m^3) supplied with 100~150 kWh, which could provide electricity for the larger-scale aquaculture farm through array deploying.

The wave energy technologies will improve anti-wave and survivability of the offshore aquaculture cage in complex sea conditions, in general, ocean energy and offshore aquaculture could achieve effective complementary advantages. I believe that ocean energy could and will become a viable energy source to promote the development of offshore aquaculture in the future, and it has been successfully verified in China.

Considering the sustainable development and marine environment protection, the aquaculture will develop into deeper, farther and open sea area, and energy supply will be the primary problem to be solved. According to the previous project demonstration experience, a 50-100 kW wave energy device can meet all the power requirements of the offshore aquaculture cage (10,000-20,000 m^3) supplied with 100~150 kWh, which could provide electricity for the larger-scale aquaculture farm through array deploying.

MULTIPLE-USE OF OCEAN SPACE AND MULTI-USE PLATFORMS

Dr. Gordon Dalton
Senior research fellow
Plocan
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MUSICA which stands for "Multiple Use of Space for Island Clean Autonomy will pilot a floating offshore platform" is a recent European-funded project, coordinated by the University College Cork in Ireland. This project is seeking to accelerate the roadmap to commercialisation of Multi-Use Platform (MUP) and Multi-use of Space (MUS) combination for the small island market. The Greek island of Oinousses was selected as a trial for this multipurpose floating offshore platform.

What is the goal of MUSICA project? And who is involved in this initiative?

Many islands face a unique set of challenges posed by climate change and the pressing need for decarbonization. Island communities suffer from high energy prices, due almost exclusively to their reliance on costly imported fossil fuels, and their comparative lack of space and resources. The Greek island of Oinousses for example has 0% RES, and Islanders pay 3 times the land rate for grid electricity. Moreover, the quality and reliability of the electricity is poor. Oinousses has no local water source, with 30% of the island water produced by a desalination plant powered by diesel.

And yet, island communities such as Innousses have a potential abundance of natural energy sources if they can tap into them. The MUSICA project aims to create a one-stop trial solution to address the energy problems faced by many islands and coastal regions. MUSICA's Multi-Use Platform will reduce the need for importing expensive and harmful fossil fuels by harnessing the available renewable energy resources of the sun, wind and waves to produce an autonomous, readily available supply of electricity and freshwater.

MUSICA will provide a full suite of Blue Growth solutions including:

- Three forms of renewable energy (RE) (wind, PV and wave), providing high RES penetration and competitively affordable electricity.
- Innovative energy storage systems on the MUP, will provide all required storage for power on the island and platform, as well as electrical output smoothening (compressed air storage and batteries).
- Smart energy system for the island, including: demand response, modelling and forecasting based on high flexibility services from distributed generation.

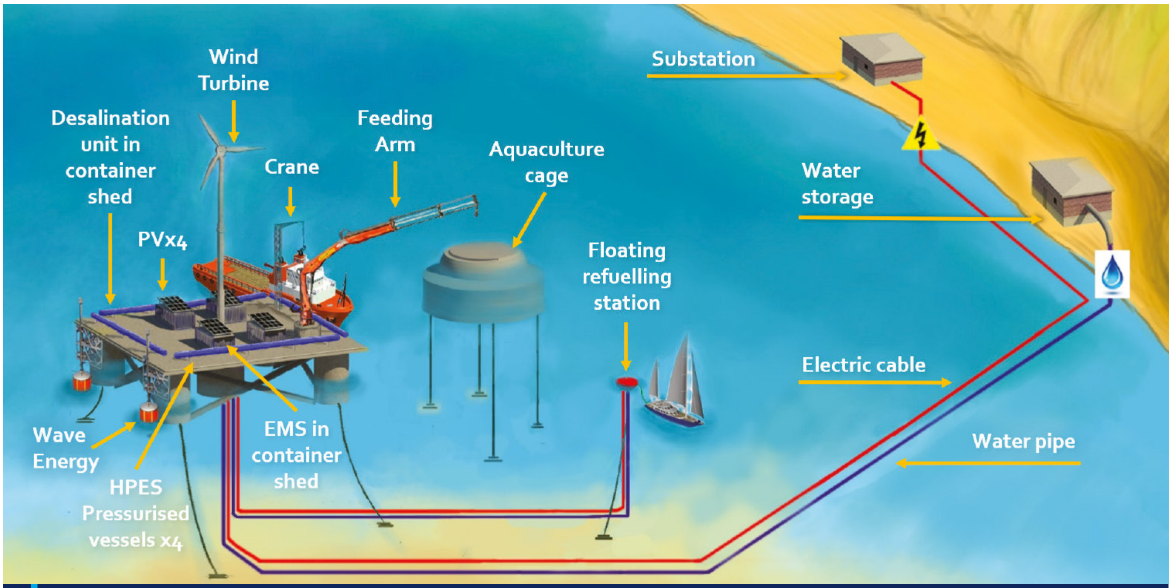

Illustration of MUSICA platform
Courtesy: MUSICA

- Desalinated water made by desalination unit on the MUP powered by RES providing 1000m³ fresh water for a water stressed island.
- "Green" support services for island's aquaculture production.

Ultimately, MUSICA is seeking to create the means by which island communities can transition to clean and renewable energy sources and gain energy autonomy, and, in doing so, accelerate the roadmap to commercialisation of our Multi-Use Platform (MUP) and Multi-use of Space (MUS) combination for the small island market. In doing so, we hope we can provide a de-risk for future operators and investors, by providing real plans to move beyond trialing and into mass market commercialisation.

MUSICA is a consortium comprised of 15 partner organisations; University College Cork (Coordinator), Heriot-Watt University, University of the Aegean, Municipality of Chios, University of Malta, Coral Ltd, International Consortium of Research Staff Associations, Network of Sustainable Greek Islands, Platforma Oceania de Canarias, Innosea, Aquabiotech Ltd, NeoDyne Ltd, SinnPower Gmbh, INSB Class International Classification Society, Forkys.

The island of Oinousses in Greece was selected as a trial for this multipurpose floating offshore platform. How has been the interaction with the local stakeholder's community? What can you say on the expected impact this business may have on jobs and prosperity in the local area?

The project is committed to a full and frank engagement across the Quadruple Helix. Transparency is key, particularly if we are to foster the necessary buy-in from the local community. We have relied heavily on RRI (Responsible Research & Innovation) methods to fully integrate with the QH to gain societal acceptance and support and to harness any potential interest into tangible community involvement. We've done so through a series of public engagement activities, including workshops and surveys. We are seeking to conduct at minimum three Oinousses Public engagement and transferable skills training workshops for the full range of QH stakeholders.

We believe strongly in the project's potential for job creation. That's why, in addition to the Workshops, we are also looking at the possibility of facilitating further information sessions on topics such as the economic benefits of the MUP, particularly around the potential for the creation of primary and secondary employment (such as construction and operational jobs, fish farming and eco-tourism).

During this last decade, the ideas of co-location and integration were highly supported by the European Union within The Oceans of Tomorrow and Horizon 2020 programmes. MAREI lead a previous European project – MARIBE – dealing also with the combination of ocean energy and other sectors. Would you like to mention any key lessons from your experience in these projects involving different sectors? what are the key challenges?

MARIBE, which was coordinated by the same coordinator of MUSICA, conducted 9 case studies on real MUS/MUP combinations, assessing their technical viability, business plans, financial viability, and risk. It demonstrated that combining Blue Growth (BG) sectors, which are currently struggling to exit the "Valley of Death", with more established sectors, makes their overall value proposition more attractive.

There has been much skepticism of the value of combining which today has favored the more established BG sectors (e.g. fixed offshore wind) which are continuing to thrive having proven they can achieve low LCOE EC targets. MUP wave and wind platforms have had numerous FP7 funding to explore technical and financial viability.

MUSICA
Multiple Use of Space for Island Clean Autonomy
www.musica-project.eu

The limitations analysis by combination can be reduced to those special and relevant problems that can appear in some specific combinations. These limitations refer mainly to environmental and social perception issues, but also to different technology development stages between sectors.

The projects were not successful in enabling IP derived from the projects to progress to commercialization, however, which subsequently reduced the European Commission's confidence in MUS/MUP.

The limitations analysis by combination can be reduced to those special and relevant problems that can appear in some specific combinations. These limitations refer mainly to environmental and social perception issues, but also to different technology development stages between sectors.

- **Environmental limitations.** Some sectors can produce a harmful impact on the environment. And some other sectors' viability depends on the quality of this same environment. The co-existence of both can, in this case, result problematic. An example of this problem appears in the combination of aquaculture and oil and gas exploitation. Though actual systems for oil and gas to limit the spills, the risk for these to happen, persist and represents a serious limitation for aquaculture production.

- **Social perception.** There are some blue growth and blue economy sectors that can be seen as prejudicial by society. Oil and gas is associated with spills and environmental impacts, and aquaculture is in some cases seen as a rival sector by traditional fisheries. Any sector planned to be developed with any of these two cases can be also seen as problematic by local societies, affecting the political decisions related to permissions and possible subsidies and help.
- **Financial assessment.** The sectors analysed in this project are planned to experiment an important expansion in the next years, but nowadays are mainly under no full development. Due to this, it is difficult to perform realistic cost and benefit analyses just for one sector. Doing this type of analysis to assess the commercial and financial viability of the projects of two or more sectors combined will result even more difficult.
- **Technical maturity.** Some of the sectors analysed are in a very low TRL stage. This means that lot of research and development work must still be done. The aim to merge two sectors with very different stages can be problematic for the more advanced sector, limiting its development and even making it impossible. The obvious uncertainties existing in early steps of technology can contaminate.
- **Production requirements.** Energy sectors (wind, wave) need some weather and environmental requirements that could mean the impossibility of development of other sectors. For example, if high waves are required for energy production and its economic viability, these high waves could be harmful for the survivability of the cages used in aquaculture. The compatibility of environmental requirement cannot be taken as given and require a cautious approach
- **Wave energy and aquaculture.** This is a recurrent combination analysed (it has appeared in all four basins). For aquaculture, wave height and current speed are key constraints, both physically and with respect to animal welfare. But wave energy requires a minimum wave height in order to present viability. The combination of these two sectors can be problematic in this sense: the minimum requirements for waves can be translated into an important barrier for aquaculture. The use of submergible cages can be a possible solution, but its development is still in the early stages and is facing technical difficulties.

Combining large-scale wave energy with offshore wind (either MUP or MUS) will never fully compare financially with large-scale offshore wind by itself and there is no EC market where offshore wind itself will not be a competitor. The large-scale wave energy sector will consistently require EC support in the medium term. Combining wave with more established wind, reduces the risk for wave development, enables learning, and conforms to EU MUS and MUP directive.

Maribe identified that small niche MUS/MUP offerings are very attractive even at pilot scale. Both of the high ranking Maribe small-scale projects displaced diesel, one from desalination, the other from aquaculture operations. The wind-driven desalination project is financially viable from all the economic benchmarks investigated, while it also addresses a very high societal challenge (water scarcity and salification, and associated socio-economic challenges).

Maribe only explored floating wind with desalination but further evaluations can be expanded to include other renewables (e.g. wave and solar PV for example) in the most promising business models. Maribe case study evaluations of projects combining aquaculture with ocean energy showed them to have good financial

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The mature aquaculture sector assisted de-risking the less mature ocean energy by ensuring good financial returns for the combined projects. Aquaculture benefits from using green powered electricity thereby increasing its public image. Incorporating ocean energy is also relatively easy for aquaculture, and increases its position within the MSP directives, leasing/licencing etc.

performance, and they attracted high panellist/consortium ratings. The mature aquaculture sector assisted de-risking the less mature ocean energy by ensuring good financial returns for the combined projects. Aquaculture benefits from using green powered electricity thereby increasing its public image. Incorporating ocean energy is also relatively easy for aquaculture, and increases its position within the MSP directives, leasing/licencing etc.

The EWW MUP concept case study was a wind power floating desalination platform in the Aegean. The EWW market and business case was rated by MARIBE as very strong and EWW was the highest rated project overall in MARIBE. Based on MARIBE results, EWW MUP technology was selected as the basis for MUSICA innovation.

MUSICA is the logical follow-on from the MARIBE SoA review and is the best route to commercialisation of the MUP/ MUS concept, balancing operator and investor risk, and acceleration of progress.

In your view, multiple-use of space or multi-use platforms have viable economic futures? If so, what is needed now to make it commercially viable in the future?

Maribe has identified a range of MUS and MUP combinations that have the potential to be economically viable at 3rd phase of commercial deployment. The results should give confidence to the EC to pursue a policy to promote appropriate MUS and MUP combinations both in the Strategic Energy Technology Plan (SET-Plan) and continued funding for MUS and MUP in H2020.

The EC's drive to promote Multiple-use of space (MUS) (an important part of the Marine Spatial Planning directive) and multi-use platforms (MUP) has been justified by the positive outcomes from the Maribe evaluation.

Maribe recommends three EC driven initiatives:

1. The first, is further CSA Maribe type projects to continue explore the financial viability of MUS/MUP and provide further business accelerator support to a host of projects.

2. The second is to recommend that the EC set aside a pot of funding for the next stage of future EC funding calls in BG. Blue Growth projects would range from small autonomous projects to larger-scale prototype machines and combinations. The funding would enable pilot deployments, and explore financial instruments for large-scale roll-out of the projects.

3. Maribe also recommends that further exploration should be conducted into the feasibility of tapping into regional infrastructure fund, EIB and public-private partnership funds to fund large budget pilot projects (outside the scope of H2020 funds) and ultimately commercial projects.

BLUE GROWTH FARM MULTIPURPOSE PLATFORM

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Italy

Blue Growth Farm (BGF) project is a hybrid wind-wave-aquaculture concept on a multi-functional offshore platform. In this research project a floating version of the Italian REWEC 3 patented solution for fixed installations (breakwater) is proposed, based on the Oscillating Water Column (OWC) principle.

What is the main goal of the BlueFarm project? Which entities are involved and what is their key role in the project?

The Blue Growth Farm project, funded by the European Commission under the framework of the Horizon 2020 programme (GA n.774426, *www.thebluegrowthfarm.eu*), aims at designing an environmentally friendly multi-purpose offshore platform, which accommodates an industrial aquaculture system within a rectangular-shaped concrete caissons-based platform.

This infrastructure includes a wind turbine and a set of wave energy converters, producing renewable energy for own operations, thus making the infrastructure energetically independent. By integrating and suitably engineering the aquaculture and renewable energy production systems, this efficient, cost-competitive, and environmentally friendly multi-purpose offshore platform design is well suited for applications in the open sea, within territorial waters (< 12 nautical miles). This endeavor is participated by the Blue Growth Farm Consortium, composed of 13 partners from 5 different European countries.

In the Blue Growth Farm project, the Italian company **RINA Consulting**, part of RINA group, acts as Project Coordinator, and it is responsible for the system integration, the overall control and automation, the surveillance and security design, structural health monitoring, data transmission and control by remote. The Italian SME **Wavenergy.it** is responsible for the design and optimization of the REWEC3 wave energy converter (WEC) integrated into the floating structure, while **Politecnico di Milano** is devoted to the design of the wind turbine scaled model.

The French engineering consulting company **Safier Ingenierie** is responsible for the structural and mooring design of the scaled prototype as well as the full-scale configuration and the Italian company **Fincosit**, specialized in the construction of all types of marine works, is in charge of the construction design and manufacturing of the prototype. The

Spanish SME company **Ditrel Industrial** and **Tecnalia** deal with the electrical connection system.

SAGRO AQUACULTURE Ltd in Cyprus will develop an optimal production programme for the aquaculture unit, to be used as the basis for a full economic appraisal of the aquaculture activity. Chlamys srl (IT), an SME working in the field of R&D and services related to offshore aquaculture takes care of the Environmental Impact Assessment of the Blue Growth Farm project, while the **Scottish Association for Marine Science (SAMS)** develops the assessment of societal views on integrated offshore developments and application of Framework Directives.

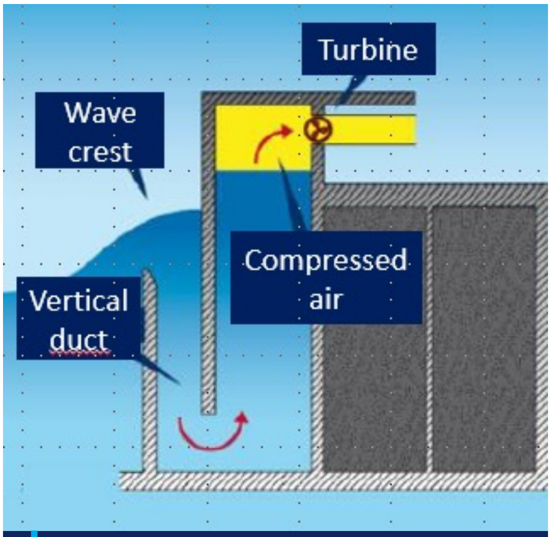
Further, the **University of Strathclyde, Ecole Centrale de Nantes** and the **Italian Natural Ocean Engineering Laboratory** are involved in laboratory and numerical work related to the development of this platform.

Can you please describe to the general public the working principle of the wave energy technology used?

For the Blue Growth Farm, a floating version of the REWEC 3 patented solution for fixed installations (breakwater) is proposed, based on the Oscillating Water Column (OWC) principle. OWC devices are one of the most studied wave energy conversion technologies so far. An OWC consists of an empty chamber opened to the sea surface (see picture) with a power take-off system (e.g. air turbine). Wave action causes the oscillation of the water column inside the chamber, alternately compressing and decompressing the air in the upper part of the chamber. The pressure difference created between the interior of the chamber and the atmosphere forces the air to move in and out of the chamber, driving the air turbine. Due to the bidirectional characteristics of the flow, a special power take-off system is required to harvest the greatest amount of available pneumatic energy per cycle. The most common solution is the self-rectifying air turbine. Among self-rectifying air turbines, Wells (reaction) turbines and impulse turbines, both axial, radial, or the novel biradial, are at the forefront of the developments. The chamber must be designed to ensure near-resonant conditions with the incident waves and, at the same time, to avoid energy losses.

What was the motivation and the driving forces for this initiative?

The further expansion of marine fish farming in coastal waters is limited by a lack of suitable sites, as well as by concerns about pollution, sustainability and, in many cases, missing regulatory issues, and local community opposition. The integration of the different subsystems into one complex infrastructure, the shared use of the asset, and the combination of various offshore energy generation resources make the multi-purpose offshore platform an economic and efficient solution for both offshore renewable energy and the marine fish farming industry.



Wave energy device based on the oscillating water column principle

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For these reasons, the Blue Growth Farm (BGF) project's aim is to propose an efficient multi-functional offshore platform that 1) combines fish production with the generation of renewable energy from wind and waves, 2) operates with advanced automation and remote-control capabilities, 3) provides extra produced electric energy to the grid and sea electric station service to platform shipping operations.

The development of these projects involves a wide variety of risks, including technical, regulatory and financial. Could you describe which are the most critical ones you have encountered/are encountering and how could they be overcome?

Given the nature of the problem it is addressing, key platform design requirements are that it must be able to withstand offshore conditions including wave significant heights of up to 6 m whilst offering the highest standards of fish welfare, efficient use of resources, minimal environmental footprint and visual impact and, at the same time be commercially viable and acceptable to local communities. If all these goals are met, the system should be an attractive option for commercial investors, and much less likely to attract opposition for its deployment from regulators or local communities.

Whilst various designs for offshore fish farming systems have been proposed over the years, so far none have had widespread uptake due to various concerns including their real ability to withstand harsh offshore conditions, unknown and unproven technology, the inherent difficulties in managing units to which access may be limited for long periods, security and, not the least, cost. All of these concerns have been taken into account in the design of the BGF platform. The fish will be grown in floating net pens, much as currently practiced, so the fish farming technology used is well proven. However, rather than being exposed to the open sea, the net pens will be held within a rectangular open-bottomed "pool" formed by floating, prefabricated concrete caissons joined together on site. The caissons, which also act as the collar for the pens, have a draught of 20 m thereby affording the protection of the cage from most of the incident wave energy and currents. Water exchange within the pool is facilitated by surface openings at the aft of the platform which allows the outflow of water upwelling from the bottom of the pool due to the motion of the platform and the effects of sub-surface currents. The large open areas over and within the caissons will be used to house the feed silos, automatic feeding system, and other infrastructures such as a net store, ensiling system and workshop. The design of all these facilities is based on requirements dictated by the fish production programmes which have been developed for three different species (salmon, sea bream and sea bass) at three selected sites within territorial

1:15 scale model of the Blue Growth Farm platform (wind+wave+nets) at Reggio Calabria
Courtesy: RINA

waters in Europe (Mediterranean, Northern Sea, Subtropical Atlantic). Each programme has been tailored to give maximal production from the cage volume available whilst ensuring all environmental parameters remain within set limits for best stock welfare.

A way to de-risk the full-scale (210 m x 162 m) installation investment is by implementation and study of the infrastructure behavior under harsh environmental conditions at different scales. A 1:40 scale model of the selected design was then built and tested in a wave tank trial at the Ecole Centrale de Nantes (FR), to validate the computer model assumptions under well-known and reproducible conditions. A second set of experiments is carried out in the open sea at the NOEL laboratory of the Mediterranean University of Reggio Calabria (IT) on an outdoor 1:15 scale model (11m x 14m) of the platform, integrated with a set of technologies. This study model, which will operate in Reggio Calabria for the next 7 months before its decommissioning, will provide valuable elements of scientific relevance for the NOEL researchers and also for the designers and experts involved in the project and will add knowledge on the aero-hydrodynamic behavior of the platform, of vital importance for optimizing the numerical calculation tools for predicting behavior in full scale.

Parallel to the engineering design work on the platform, the project has also looked at the social acceptance of multi-use platforms by holding workshops and meetings with stakeholders and local communities in two selected locations, Reggio Calabria (Italy), and Islay (on the west coast of Scotland). This interaction has provided valuable information on the key factors that most strongly influence public perception of such offshore systems which could help guide potential investors on how best to win local approval and support for their proposed activities. Regulatory aspects related to the Marine Spatial Framework Directive (MSFD) and its compatibility with Multifunctional Offshore Installations will be investigated, thus contributing to the implementation of the EU Integrated Maritime Strategy, as well as to MSF Directive.

Finally, the business plan is to be sustainable as well to secure the infrastructure future investments. For BGF, the main source of revenues is given by aquaculture production. Nevertheless, fish prices can fluctuate wildly in very short time periods, and this does not help in building reliable revenue streams. On the other hand, at the current stage of design, the Blue Growth Farm infrastructure capital cost is still far from being appealing to investors. Again, making offshore functions in common to existing activities is one way to save both capital and operating costs. For instance, the BGF co-location near offshore wind parks is an opportunity to enjoy the existing electric connection to the land grid (one umbilical cable only), whilst wind turbine and WECs technology can make use of on-site expertise, thus leaving BGF staff to concentrate on aquaculture technologies only. Furthermore, as the production of fish is constrained by the cage volume available, other ways of generating more revenues come from the production of marine microalgae by the aquaculture, health and biochemical industries. Algae could be produced in one specific cage equipped with photobioreactors, lit by LEDs powered by the renewable energy available, in a quasi-automated way. Further potential revenues are today under analysis and being represented by re-use of the concrete-based caissons after the infrastructure end of life in port seabed accommodation or becoming a foundation for new breakwater lines.

How this project can contribute to facilitating the spread of ocean energy technologies in new regions, sectors, markets?

The 2016 Paris agreement and the following related initiatives have pushed countries worldwide to set ambitious targets in terms of cutting greenhouse emissions (in terms of CO_2 equivalent tonnes). To achieve these targets, countries are largely relying on the use of renewable energy sources, transitioning from fossil fuels to these sustainable energy resources. Offshore renewable energy such as offshore wind, wave, current and tidal, is a favorable green energy resource that is plentiful, predictable, and environmentally friendly.

The development of wind energy has been a hot topic in the realm of the blue economy field, especially after the successful operation of Hywind, which is the first full-scale floating offshore wind turbine in the North Sea in 2009. Wave energy is another kind of ocean renewable energy, and much research has been conducted to convert the wave energy into reliable power via wave energy converters (WECs) such as oscillating-water-column (OWC) WEC. These conclusions, together with the need to provide the 2050 world population with increased availability of seafood proteins as never experienced so far, make the BGF initiative one of the best candidates to promote a combined solution to enable the near future planet sustainability.

About IEA-OES:

The **Technology Collaboration Programme for Ocean Energy Systems (OES)** is an intergovernmental collaboration between countries, which operates under a framework established by the **International Energy Agency (IEA)** in Paris.

IEA-OES facilitates:

- Access to advanced R&D teams in the participating countries
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www.ocean-energy-systems.org