SPOTLIGHT ON OCEAN ENERGY

20

20 PROJECTS
+
5 POLICY INITIATIVES

OES OCEAN ENERGY SYSTEMS

iea Energy Technology Network

April 2018

INDEX

INTRODUCTION

ABOUT OES

The Technology Collaboration Programme on Ocean Energy Systems, known as OES is an intergovernmental collaboration between countries, which operates under a framework established by the International Energy Agency in Paris. OES was founded by three countries in 2001 and has grown to its present 25 members, which provide 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.

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.

OCEAN ENERGY POTENTIAL

The ocean energy sector provides significant opportunities to contribute to the production of low carbon renewable energy around the world. Utilization of ocean energy resources will contribute to the world's future sustainable energy supply. Ocean energy will supply electricity, drinking water and other products at competitive prices, creating jobs and reducing dependence on fossil fuels. It will reduce the world energy sector's carbon emissions, whilst minimizing impacts on marine environments.

The OES Vision for International Deployment of Ocean Energy estimated a global potential to develop 748 GW of ocean energy by 2050. Deployment of ocean energy can provide significant benefits in terms of jobs and investments. The global carbon savings achieved through the deployment of ocean energy could also be substantial. By 2050 this level of ocean energy deployment could save up to 5.2 billion tonnes of CO_2.

THE OCEAN ENERGY POTENTIAL IS BASED ON **THE FOLLOWING ENERGY RESOURCES LOCATED IN OUR OCEANS:**

TIDAL ENERGY

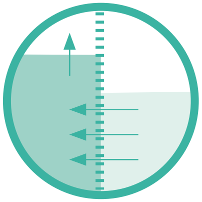
Tidal energy is derived by height changes in sea level, caused by the gravitational attraction of the moon, the sun and other astronomical bodies on oceanic water bodies. The potential energy (tidal range) of the difference in the height of water at high and low tides can be captured wit tidal barrages, while the kinetical energy from the moving water of the tide (tidal currents) can also be captured using different tidal current energy converters mainly based on tidal turbines deployed in arrays, similarly to wind farms but underwater.

OCEAN AND RIVER CURRENTS

Ocean currents are the constant flows of water around the oceans. These currents always flow in one direction and are driven by wind, water temperature, water salinity and density amongst other factors. They are part of the thermo-haline convection system, which moves water around the world.
Similarly, river currents are available in all continents all year long and can be used for energy generation. Both ocean and river current energy technologies are being developed to capture this kinetic energy with most concepts being also based on water turbines deployed in arrays.

WAVE ENERGY

Waves are created by the action of wind passing over the surface of the ocean. Wave heights and thus energy are greatest at higher latitudes, where the trade winds blow across large stretches of open ocean and transfer power to the sea swells and west-facing coasts of continents tend to have better wave energy resources.
There are number of diverse wave energy converter (WEC) concepts being developed, most of them being intended to be modular and deployed in arrays to capture the kinetic and potential energy from ocean waves and convert it to electricity or pumping water for different uses.



SALINITY GRADIENT

Seawater is approximately 200 times more saline than fresh river water, derived from rain, snowmelt and groundwater, which is delivered to the coast by major rivers. The relatively high salinity of seawater establishes a chemical pressure potential with fresh river water, which can be used to generate electricity. Salinity gradient power thus has its greatest potential at the mouths of major rivers, where large volumes of fresh water flow out to sea. There are two technologies being developed to convert this energy into electricity: pressure retarded osmosis (PRO) and reverse electrodialysis (RED).

OCEAN THERMAL

Ocean thermal energy arises from the temperature difference between near-tropical surface seawater, which may be more than 20º C hotter than the temperatures of deep ocean water, which tends to be relatively constant at about 4º C. Bringing large quantities of this cold seawater to surface enables a heat exchange process with the warmer surface waters, from which energy can be extracted. Ocean Thermal Energy Conversion (OTEC) is a technology to convert this energy resource into electricity or other uses.

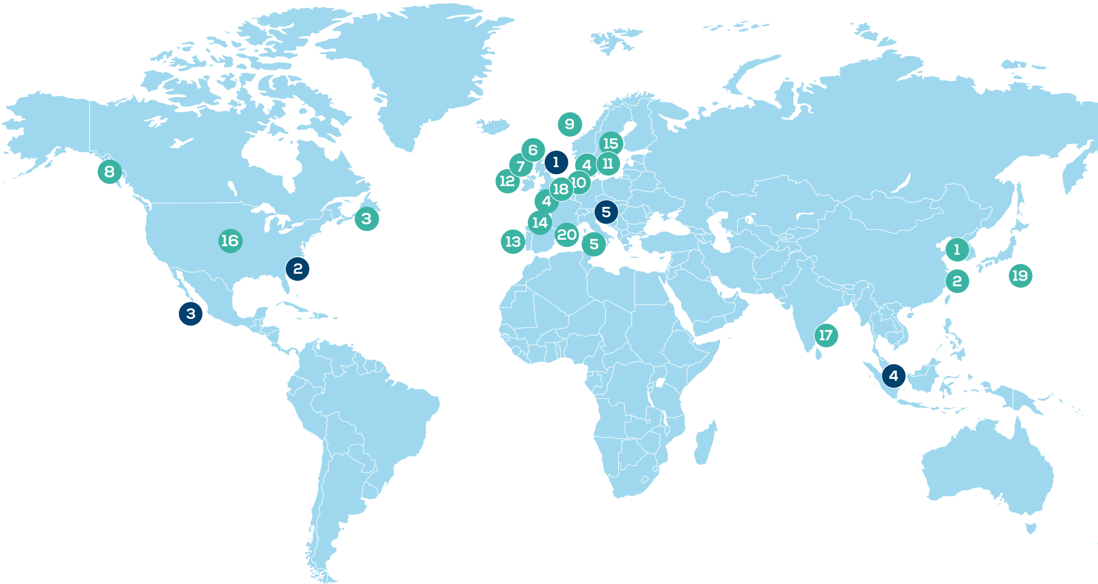
Other uses of ocean energy

Ocean energy can also be used for activities other than electricity generation or in combined hybrid systems that enhanced the overall systems efficiency. There are many technologies being explored for producing drinking water through desalination, supplying compressed air for aquaculture, hydrogen production by electrolysis or sea-based air conditioning.

SPOTLIGHT

ON 20 OCEAN ENERGY PROJECTS
AND 5 POLICY INITIATIVES

This report provides insights of 20 ocean energy projects and 5 policy initiatives on the OES member countries. These projects are good examples of the intense activity of this emerging sector but there is a much larger number of relevant projects being developed world wide not included in this report.



Projects

1. Korea	Sihwa Tidal Power Plant	Tidal
2. China	LHD Tidal Current Energy Demonstration Project	Tidal current
3. Canada	Cape Sharp Tidal Project	
4. France	SABELLA D10 Tidal Turbine	
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14. Spain	Oceantec MARMOK A-5 Project	
15. Sweden	Seabased Sotenäs Project	
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18. Netherlands	Blue Energy Reverse Electrodialysis Project	Salinity Gradient
19. Japan	Okinawa OTEC plant	OTEC
20. Germany	StEnSea project	Other uses

You can find more information on other projects at OES interactive GIS map available on our website.

Initiatives

1. UK	Wave Energy Scotland
2. USA	Wave Energy Prize
3. Mexico	Cemie-Océano
4. Singapre	SEAcORE
5. European Commission	OCEANERA-NET

01

Sihwa Tidal Power Plant Project

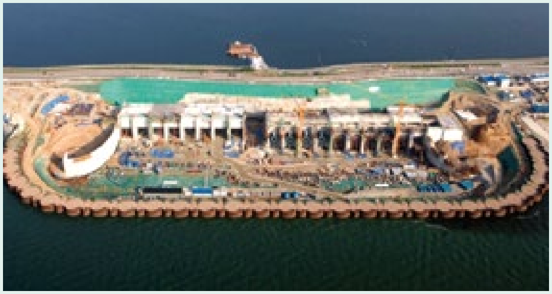
South Korea

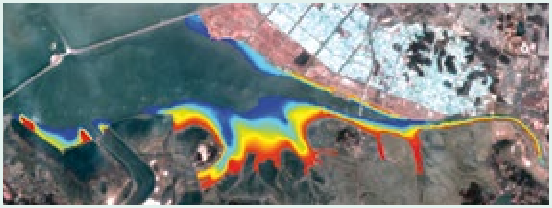
FACTS AND FIGURES

Lake Sihwa is a man-made lake constructed from June 1987 to January 1994 originally planned for supplying water to an agricultural and industrial area, but after the completion of the embankment, severe water contamination appeared. In 2002, the Korean government approved a plan called K-Water for constructing a tidal power plant to improve water quality of the lake by regular exchange and circulation of seawater while harvesting renewable energy.

The turn-key based project was started in 2004 and completed in December 2011 with the installed capacity of 254 MW (10 units of one-way bulb turbine-generator of 25.4 MW unit capacity) and 8 sluices with an opening of 15x 12m each, generating 553GWh of electricity per year.

In addition to the electricity generation, the project has rapidly improved the water quality and the species diversity of Lake Sihwa. Concretely, the organic content in the sediment decreased from 8% to 1-2% between 2009 and 2013 and the number of species of benthos increased from 83 to 232 between 2005 and 2014.





Aerial view of construction of Sihwa TPP (top) and restored tidal flat after operation of Sihwa TPP (down)

Details about the project

Project Type	Commercial project
Technology name	K-Water Tidal Power Plant
Technology type	Tidal barrage
Technology developer	K-Water
Energy source	Tidal Range
Location	Gyeonggi Bay (South Korea)
Status	Operational
Project Capacity	254 MW
Website	http://tlight.kwater.or.kr

02

LHD Tidal Current Energy Demonstration Project

China

FACTS AND FIGURES

This tidal current demonstration project is being developed near Xiushan island by the LHD Technology. So far, two vertical axis LHD Tidal Current turbines have been installed (of 400 kW and 600 kW respectively) on a bottom-standing platform and connected to the grid in August 2016. By the end of June 2017, the electricity generated had accumulated more than 200 MWh. Overall, the project is planned to install a total of 7 turbines resulting in 3.4 MW of installed capacity.

One innovative aspect of this project is the modular design of the bottom-standing platform which facilitates installation and maintenance, with the equipment being accessible from the surface. The bottom-standing platform is 70 meters long, 20 meters high and weighs 2,500 tons.

LHD Technology has received 45 million RMB of funding by the SFPMRE (Special Funding Plan for Marine Renewable Energy) to move forward with the second phase project, and two new 300 kW turbines will be installed and tested on the platform in July 2018.

LHD demonstration project (top left), modular vertical-axis turbine (right) and the platform (left down)

Details about the project

Project Type	Technology Demonstration
Technology name	LHD Tidal Current Energy
Technology type	Vertical-axis turbines; Bottom-standing structure
Technology developer	LHD Technology
Energy source	Tidal Current
Location	Xiushan island, Zhejiang province (China)
Status	Operational
Project Capacity	3.4 MW

03

Cape Sharp Tidal Project
Canada

FACTS AND FIGURES

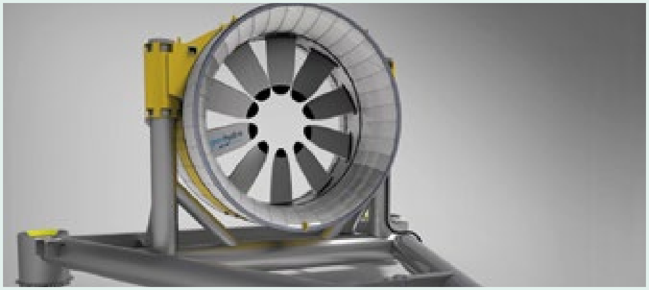
Cape Sharp Tidal is a joint venture between Emera Inc. and OpenHydro, a Naval Energies company, aiming to deploy a fully grid-connected 4 MW in-stream tidal demonstration project in the Minas Passage, offshore of Nova Scotia, Canada.

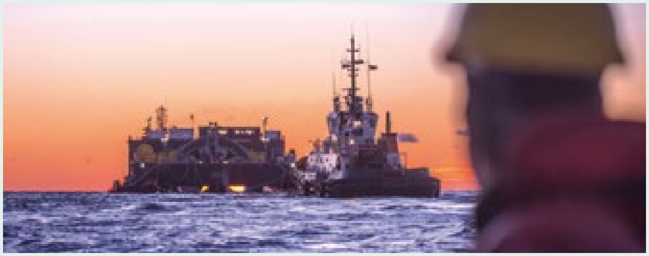
The tides in the Bay of Fundy are some of the most powerful in the world. What is learned from deploying in-stream tidal turbines in Nova Scotia's waters will change global understanding of how to safely, responsibly and economically generate renewable energy.

The Cape Sharp Tidal project uses OpenHydro's Open-Centre Turbine. It has a simple design with four key components: a horizontal axis rotor, a magnet generator, a hydrodynamic duct and a subsea gravity base foundation. The turbine base sits directly on the seabed floor, out of the way of ships, and without drilling.

Cape Sharp Tidal has partnered with leading scientists and experts, universities and companies around the world to ensure energy creation is balanced with protecting oceans and wildlife.

This demonstration project has potential to be one of the world's largest multi-megawatt arrays of interconnected tidal turbines, providing energy to more than 1,000 customers in Nova Scotia. Subject to regulatory approvals, the development has the potential to grow through subsequent demonstration phases to commercial development in the future.





Cape Sharp Tidal turbine (top) and during deployment operation (down). Courtesy: Cape Sharp Tidal

Details about the project

Project Type	Technology Demonstration
Technology name	OpenHydro open-centre turbine
Technology type	Open-Centre Turbine; Horizontal axis
Technology developer	OpenHydro
Energy source	Tidal current
Location	Fundy Ocean Research Center for Energy (FORCE)
Status	Operational; under testing
Project Capacity	4 MW
Website	http://www.capesharptidal.com

04

SABELLA D10 Tidal Turbine

France

FACTS AND FIGURES

SABELLA installed their full scale 1 MW SABELLA D10 turbine in Fromveur Passage (Iroise Sea, Britany) in June 2015. After the grid connection in September 2015, this was the first tidal turbine to have fed electricity to the French grid (on Ushant island).

During the 12 months of testing, the system demonstrated a perfect mechanical behaviour during the winter in the Northern Atlantic Ocean (over 13 meters swell) and the qualification of the electrical signal by the grid manager, as well covering up to 15% of Ushant's remote grid needs. Also, neutral environmental impacts were confirmed.

The 10-meter diameter horizontal axis turbine weights of 400 tonnes and uses a gravity-based foundation. Some of the innovative aspects of this technology are a ruggedized design to operate in the harsh offshore conditions (with a direct drive permanent magnet generator and no pitch nor yaw systems) and a dedicated system to deploy and recover only the turbine while leaving the support structure on the seabed for turbine maintenance.

This project was supported by the French Environment and Energy Management Agency (ADEME) and the Brittany Council under the Invest for the Future and ERDF programs.

D10 device installation (top) and recovery of the turbine (down).
Courtesy: SABELLA

Details about the project

Project Type	Technology Demonstration
Technology name	D10-1000
Technology type	Horizontal axis turbine; gravity-based foundation
Technology developer	SABELLA
Energy source	Tidal current
Location	Fromveur Passage, Iroise Sea, Brittany (France)
Status	Completed
Project Capacity	1 MW
Website	http://www.sabella-d10.com

05

GEM “the Ocean’s Kite”

Italy

FACTS AND FIGURES

GEM “Ocean’s Kite” technology has been developed by a public/private consortium involving the University of Naples “Federico II” and Seapower Scrl.

After experimental tests in a towing tank at the University of Naples, the first GEM prototype was deployed in the Venetian Lagoon, demonstrating the correspondence of the system behaviour to the models. For this prototype, the 100 kW turbine rating was downscaled to 20 kW, being lagoon maximum current speed of 1.5 m/s. A full scale prototype of 200 kW at 2.5 m/s water current is expected to be deployed in the Strait of Messina in 2018.

Some innovative aspects of GEM technology are that it uses two contra-rotating turbines driven by slow-moving water flows, namely river, tidal or water currents, which are mounted on a floating system linked to the seabed by means of a tether allowing self-orientation, avoiding expensive submarine foundations. Releasing the anchorage cable also allows the system to pop-up for easy maintenance.

3D representation of GEM project (left) and installation of 100 kW prototype (right). Courtesy: Seapower

Details about the project

Project Type	Technology Demonstration
Technology name	GEM
Technology type	Horizontal axis turbine; floating system
Technology developer	Seapower Scrl in consortium with the University of Naples Federico II
Energy source	Tidal current
Location	Venice lagoon (Veneto, Italy)
Status	Completed
Project Capacity	20 kW
Website	http://www.seapowerscrl.com/ocean-and-river-system/gem

06

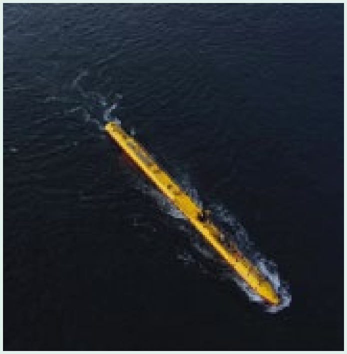
Scotrenewables Floating Tidal System
UK

FACTS AND FIGURES

The SR2000 floating tidal system, developed by Orkney based company Scotrenewables and with 2MW installed capacity, was first commissioned in December 2016 at the European Marine Energy Centre (EMEC) in the Orkney Islands. A 250 kW prototype (the SR250) had previously done a two-year test programme also at EMEC.

This floating system is suitable for use with a range of anchoring systems to suit most seabed types. The SR2000 uses components with demonstrated reliability from other sectors such as oil and gas and offshore wind. The hull of the device contains most of the components of the turbine, while the two retractable rotors are designed to make installation and maintenance simpler.

Scotrenewables is working with a number of industrial and academic partners as part of the EU-funded Floating Tidal Energy Commercialization (FloTEC) project. The aim of the project is to advance the SR2000 technology while reducing the LCOE. Scotrenewables' shareholders include ABB, DP Energy, Fred Olsen, Total and the Scottish Government. The project has also been supported by Scottish Enterprise funding.

Turbine during load out from fabrication yard (left) and operational turbine (right). Courtesy: Scotrenewables

Details about the project

Project Type	Technology Demonstration
Technology name	SR2000
Technology type	Horizontal axis turbine; Floating system
Technology developer	Scotrenewables
Energy source	Tidal current
Location	EMEC, Orkney Islands (UK)
Status	Operational
Project Capacity	2 MW
Website	http://www.scotrenewables.com

07

Shetland Tidal Array

UK

FACTS AND FIGURES

The Shetland Tidal Array has been developed by the Scottish tidal energy company Nova Innovation with support from the Belgian energy investor ELSA. It consists of an array of three Nova M100 100 kW turbines. The first turbine was installed in March 2016 and the third turbine installed in February 2017. The devices are installed in the Bluemull Sound in the Shetland Islands north of Scotland. This project was the world's first offshore tidal array.

The Nova M100 is a bottom fixed, two bladed tidal turbine, building on the earlier generation 30kW Nova 30 device, which was successfully deployed in 2014. The turbine has been built using established off the shelf parts where possible, which improves reliability. The turbine's design employs a modular system meaning full power plants can be shipped around the world using standard shipping containers and trucks.

To date the project has achieved 80% Scottish supply chain content with 25% of the project expenditure staying in Shetland. Nova Innovation has been awarded a Horizon 2020 grant from the European Commission to extend the array to six turbines and will work with a number of industrial and academic partners as part of the 'Enabling Future Arrays in Tidal' (EnFAIT) Horizon 2020 project. Nova Innovation is now working on developing projects in Wales.

Nova M100 during assembly (left) and under operatio (right); (courtesy: Nova Innovation Ltd.)

Details about the project

Project Name	Shetland Tidal Array
Project Type	Commercial project
Technology name	Nova M100
Technology type	Bottom fixed tidal current turbine
Technology developer	Nova Innovation
Energy Source	Tidal current
Country and site	UK, Shetland Islands (Bluemull sound)
Status	Operational
Project Capacity	300 kW
Website	https://www.novainnovation.com/tidal-array

08

Water Wall Turbine

Canada

FACTS AND FIGURES

WET Energy manufactures and operates its Water Wall Turbine system to extract electrical energy from fast moving tidal and river stream currents for use in remote, off-grid coastal communities. WWT systems are designed to serve energy demand up to 5 MW.

In 2016, WWT installed a 1 MW floating system at Dent Island, British Columbia. With its floating design, the WWT Energy system operates on the water's surface, permitting easy access for maintenance or repair, and greatly reducing the deployment/retrieval work.

A key advantage of WWT technology is its proprietary Microgrid, which counts with energy storage and is able to manage multiple sources of energy, including variable renewable energy resources but also diesel generation, and adapt to changing load demands.

WWT ocean power plant and land based microgrid with energy storage.

Details about the project

Project Type	Technology Demonstration
Technology name	Water Wall Turbine (WWT)
Technology type	Horizontal axis turbine; floating system
Technology developer	WWT - WET Energy
Energy source	Tidal current; River current
Location	Dent Island, British Columbia (Canada)
Status	Operational
Project Capacity	1 MW
Website	www.wwturbine.com & www.wetenergy.ca

09

Deep River Power Plant

Norway

FACTS AND FIGURES

Deep River is developing a modular container-based power plant with an horizontal axis Darius type. The container can be towed to site and installed with a top and bottom sections that include ballast tanks. The system is then fitted in a jacket or anchored.

After the first pilot test carried out in Nemunis River (Lituania), several changes have been made in order to optimize the turbine efficiency, with the goal to deliver 100 kW at 2.5-3 m/s of current speed.

The technology has been developed by the Norwegian company Deep River AS in cooperation with other suppliers and with the support from Innovation Norway and the Research Council.

Pilot turbine is installed in test barges (left) and optimized design with a Darius turbine (right).

Details about the project

Project Type	Technology Demonstration
Technology name	Deep River
Technology type	Horizontal axis turbine (Darius); bottom mounted
Technology developer	Deep River AS
Energy source	Tidal current; River current
Location	Nemunis River, Klaipeda (Lituania)
Status	Completed first phase
Project Capacity	100 kW
Website	www.deepriveras.com

10

Laminaria Wave Energy Converter

Belgium

FACTS AND FIGURES

Laminaria (Belgium) has developed a surge and pitch-based point absorber without mechanical end-stops, using a Drum Power Take Off (PTO) system for energy conversion. The device has a ground-breaking storm protection system: load management strategy results in a submergence of the device in relation to the actual sea state and ensures continuous nominal electricity production.

A 1:5 scale prototype was tested in real sea conditions, 1 km offshore of the Belgian cost, and survived a storm with significant wave heights (Hs) of up to 2.7 m (corresponding to wave heights of 13.5 m Hs in full-scale conditions) in March 2015. A 1:30 scale tank testing campaign has been done in November 2017 for successful validation of the storm protection system in environmental conditions similar to the ones occurring at Billia Croo.

A first full-scale device is planned to be deployed at EMEC in summer 2018, as part of the LAMWEC funded project by OCEANERA-NET and FORESEA of Interreg North-West Europe.

1:5 scale model of the Laminaria WEC while testing the height adaptation (top left), before open ocean testing (right) and during testing (down left).

Details about the project

Project Type	Technology Demonstration
Technology name	Laminaria Wave Energy Converter
Technology type	Surge and pitch based point absorber
Technology developer	Laminaria NV
Energy source	Wave energy
Location	European Marine Energy Centre (EMEC)
Status	Under development
Project Capacity	200 kW
Website	www.laminaria.be

11

Resen Waves Smart Ocean Buoy

Denmark

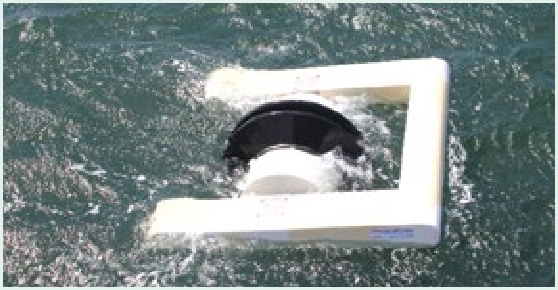
FACTS AND FIGURES

RESEN WAVES (Denmark) has developed a small scale commercial 300 to 600 W buoy which can operate in full ocean exposure. It is specifically designed to provide continuous electric power and real-time data communication to instruments and machinery in the oceans. Customers can monitor their instruments worldwide on demand.

The low weight buoy consists of a U-shaped float and a water proof cylindrical drum which contains all mechanical and electronic systems. The mooring line, which is wrapped around the cylindrical drum, is tension moored to the seabed. When the buoy is either pushed or lifted up and down by the waves, the drum is turned forth and back and drives the generator directly. An electric motor, inside the drum controls the pre-tensioning of the mooring line, compensates for tidal variation and pulls the buoy underwater in stormy conditions. The buoy was released for sales in April 2017 and is a standard off the shelf product.

The plan is to scale the buoys in incremental steps for specific commercial applications and eventually reach MW scale, by cost optimizing the buoy in each incremental step and by selling buoys.

In total 2,8 M€ have been invested from early tank testing in 2011/12 at Aalborg University to open sea testing in the Bay of Biscay and Nissum Bredning. The project has been funded by ForskEl, ForskVE, EUDP, Innovationsfonden and RESEN WAVES.



Smart buoy in operation (top) and during transit to the site in Nissum Bredning (down). Courtesy: Resen Waves

Details about the project

Project Type	Technology Demonstration
Technology name	Smart Ocean Buoy RW-06-0.3kW
Technology type	Point Absorber
Technology developer	RESEN WAVES
Energy source	Wave energy
Location	Nissum Bredning /Helligsø (Denmark)
Status	Completed
Project Capacity	0.3 kW
Website	http://www.ResenWaves.co

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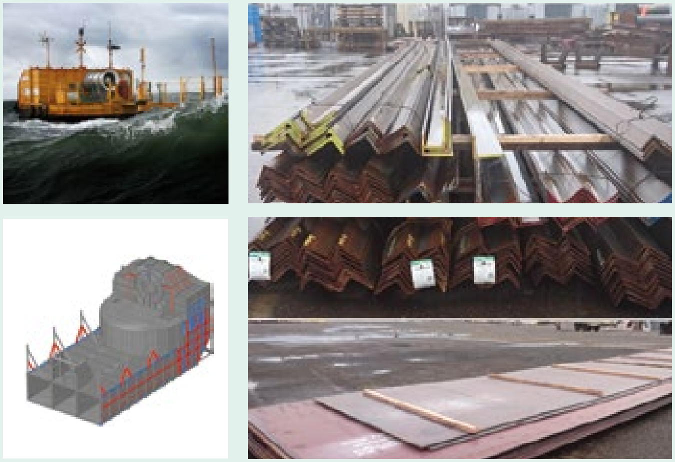
OceanEnergy OE35 Buoy
Ireland

FACTS AND FIGURES

The OE35 Buoy is an oscillating water column (OWC) device, with duct length of 35 m, developed by the Irish company OceanEnergy. The OE35 Buoy will be deployed for one year, beginning in Q4 of 2018, at the US Navy's Wave Energy Test Site (WETS) in Hawaii. The demonstration project is part of a USD$12 million project part-funded by the Sustainable Energy Authority of Ireland, through the Prototype Development Fund grant support scheme, and the US Department of Energy's office of Energy Efficiency and Renewable Energy (EERE).

For the demonstration project at WETS the OE35 Buoy will have a power capacity of 500 kW. The power generation system will use the bi-directional HydroAir turbine developed by Dresser Rand (a Siemens business). After the completion of testing at WETS the OE35 Buoy will be transported to the European Marine Energy Centre (EMEC) in Scotland, re-powered to 1 MW capacity and deployed there for another 12 months. The wave energy converter is currently being built by Vigor, a century old United States marine and industrial fabrication company, at their facility in Portland Oregon under a USD$6.5 million contract.

A quarter scale version of the device, the OE12 Buoy (12 m duct length), has previously accumulated over 24,000 hours (3 years) of in-ocean testing at the SmartBay test site in Galway Bay (Ireland).



OE12 Buoy device in operation at Galway Bay Test Site (left), structural model of the OE35 Buoy under construction at Vigor (down left) and Steel material at Vigor for construction of the OE35 Buoy (right). Courtesy: OceanEnergy

Details about the project

Project Type	Technology Demonstration
Technology name	OE35 Buoy
Technology type	Floating Oscillating Water Column device
Technology developer	New Wave Technologies Ltd., trading as OceanEnergy
Energy source	Wave energy
Location	US Navy Wave Energy Test Site (WETS) Hawaii
Status	Development; device under construction
Project Capacity	500 kW - 1 MW
Website	www.oceanenergy.ie

13

Waveroller

Portugal

FACTS AND FIGURES

WaveRoller® is a near-shore underwater wave energy device, utilizing a hinged panel anchored to the seabed. The energy is stored in specifically built accumulators part of the submerged device. The concept is developed by the wave energy pioneer AW-Energy (Finland), active since 2002.

The company plans to deploy a 350 kW device in 2018, which will operate under a commercial grid connection license, supplying renewable electricity to hundreds of local homes in Peniche, Portugal. This project follows previous tests of three 100 kW prototypes, with over 5000 operational test hours and more than 1000 hours of data samples between 2012-2014. This has lead WaveRoller to receive the first Technology Qualification certificate from Lloyd's Register in the field of ocean energy. Located in a NATURA 2000 protected area, the project has successfully completed extensive environmental studies and monitoring activities.

The project is financed by private investors, Tekes (the Finnish Funding Agency for Innovation) and a bank loan from the European Investment Bank (EIB) and operates under full CAR-EAR insurance coverage supplied by a Class-A insurance company Pohjola. AW-Energy has other ongoing projects in four continents.

WaveRoller® 3 x 100 kW demonstration in Peniche in 2012 (top) and new panel for the commercial size 350 kW unit (down). Courtesy: AW-Energy

Details about the project

Project Type	Technology Demonstration
Technology name	WaveRoller
Technology type	Oscillating wave surge converter (OWSC)
Technology developer	AW-Energy
Energy source	Wave energy
Location	Praia de Almagreira, Peniche (Portugal)
Status	Under construction
Project Capacity	350 kW
Website	http://aw-energy.com

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Oceantec MARMOK A-5 Project

Spain

FACTS AND FIGURES

Oceantec Energias Marinas is currently testing a 30 kW prototype of their floating Oscillating Water Column (OWC) technology (called Marmok A-5). The system includes two air turbines to generate electricity from the air pumped in and out of an air chamber inside the buoy by the action of the waves. Some of innovative aspects of the technology are the efficient turbine design, the latching and predictive control, a shared mooring system and an elastomeric mooring tether reducing peak loads at the hull-mooring connection.

The prototype was deployed at Bimep since October 2016 and connected to the grid in December 2016 and has overcome two winters in open waters of the Atlantic without mishaps. Before the offshore tests, the company previously tested the turbines at the Mutriku wave power plant (located onshore).

The project is supported by the Basque Energy Agency under a Pre-Commercial Procurement Contract, and testing activities in the sea are part of the European project OPERA coordinated by TECNALIA. OPERA, "Open Sea Operating Experience to Reduce Wave Energy Cost" will collect and share two years of open-sea operating date. Oceantec Energías Marinas was promoted by the Spanish R&D centre TECNALIA and Iberdrola.


Oceantec device towed to bimep (left) and under operation (right).
Courtesy: Oceantec

Details about the project

Project Type	Technology Demonstration
Technology name	MARMOK A-5
Technology type	Floating Oscillating water column (OWC)
Technology developer	Oceantec Energías Marinas
Energy source	Wave energy
Location	Biscay Marine Energy Platform (BiMEP), Basque Country (Spain)
Status	Operational; under testing
Project Capacity	30 kW
Website	http://www.oceantecenergy.com

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Seabased Sotenäs Project

Sweden

FACTS AND FIGURES

This project, developed by the Swedish company Seabased and supported by the Swedish Energy Agency and Fortum (a multinational power utility from Norway), includes 36 small wave energy converters connected to the grid via a low voltage marine substation and a 9.5 km long submarine cable.

The systems were deployed at Sotenäs in December 2015 and connected to the grid in January 2016. Seabed technology, using small point absorbers driving linear electric generators, had been previously tested at the Uppsala University research facility outside Lysekil (Islandsberg).

While the designed capacity of the project Phase 1 was 1 MW, actual measurements, calculations and extrapolations have indicated a higher potential generation, closer to 3 MW.

Seabased wave energy converters (top) and low voltage marine substation (down) under installation at Sotenäs. Courtesy: Seabased

Details about the project

Project Type	Demonstration project
Technology name	Seabased L12
Technology type	Point absorber
Technology developer	Seabased
Energy source	Wave energy
Location	Sotenäs, Sweden
Status	Operational; under testing
Project Capacity	1 MW
Website	http://www.seabased.com/en

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Columbia Power Technologies Wave Energy Generator

USA

FACTS AND FIGURES

Columbia Power Technologies (US) is developing a large-diameter, direct-drive generator for wave energy converters. The company is currently testing the system at the National Wind Technology Center (NWTC), part of the National Renewable Energy Laboratory (NREL) with the financial support from the U.S. Department of Energy.

NWTC's 5-MW dynamometer facility, originally designed for the wind industry, is able to mimic ocean waves with back and forth oscillation. These lab tests will demonstrate reliability and feasibility of the generator at lower cost than if doing open-ocean testing. After the generator tests, Columbia Power plans to install the generator on their StingRAY wave energy converter for ocean demonstration testing in Oahu, Hawaii, at U.S. Navy's Wave Energy Test Site (WETS).

Representatives from Columbia Power Technologies, NREL and project partners at NWTC facilities at the project start (left), generator connected to the 5 MW dynamometer (right). Courtesy: Mark McDade, NREL

Details about the project

Project Type	Technology Validation
Technology name	StingRAY PTO system
Technology type	Permanent magnet generator
Technology developer	Columbia Power Technologies
Energy source	Wave energy
Location	National Wind Technology Centre, Boulder, Colorado (US)
Status	Operational; under testing
Project Capacity	500 kW
Website	http://columbiapwr.com

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Wave Powered Navigational Buoy

India

FACTS AND FIGURES

The National Institute of Ocean Technology in India has developed a Navigational Buoy powered with an Oscillating Water Column (OWC) system. The system comprises the floating body (buoy), a small 100 W turbine and generator assembly and battery charging electrical system.

The system was deployed at Kamarajar port in Chennai during September- November 2017 and the electricity generated was used for powering a beacon lamp and a few sensors housed in the navigational buoy. Before the final deployment, the turbine was tested in an air flow test rig at IIT-Madras and sea field trials were done on a Backward bent ducted buoy (BBDB). Current work in progress is focused on technology transfer to the industry.

The floating OWC system at port prior to its deployment (left) and the system deployed in position (right)

Details about the project

Project Type	Technology demonstration
Technology name	Wave-powered navigational buoy
Technology type	Floating Oscillating Water Column (OWC)
Technology developer	National Institute of Ocean Technology (NIOT)
Energy source	Wave energy
Location	Kamarajar port, Chennai (India)
Status	Operational; under testing
Project Capacity	100 W
Website	https://www.niot.res.in

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Blue Energy with Reverse Electrodialysis Project

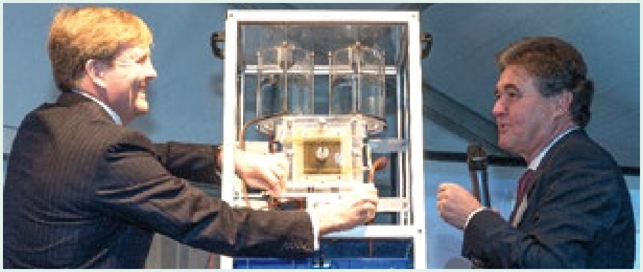
Netherlands

FACTS AND FIGURES

REDstack has developed their Reverse Electrodialysis (RED) technology to convert the difference in salt concentration between two water solutions into clean electricity. One of the key advantages of the technology is that it provides 24/7 energy production as water runoff is not dependent on atmospheric conditions (unlike other variable renewable energy sources). The technology has different applications such as rivers mouths where rivers flow into the sea, in industrial processes, in desalination and storage in salt gradients.

A pilot-installation with 50 kW capacity was installed in 2014 on the Afsluitdijk, a major causeway in the Netherlands running from Den Oever on Wieringen in the Netherlands. Since then the plant has survived winter storms and heavy weather conditions. The company is working on a upscaled demo-pilot of 1 MW capacity in 2020.

The project has been appointed as National Icon by the Dutch Government (consideration: breakthrough technology) and supported by the Dutch Government and the Province of Fryslân. The company is currently cooperating with the company FujiFilm and Wetsus water-technology institute.



Pilot-installation for Blue Energy in the Netherlands (top), opened by H.M. King Willem-Alexander (down)

Details about the project

Project Type	Technology Demonstration
Technology name	Reverse Electrodialysis (RED) technology
Technology type	Reverse Electrodialysis
Technology developer	REDstack BV
Energy source	Salinity Gradient
Location	Afsluitdijk (The Netherlands)
Status	Operational
Project Capacity	50 kW
Website	www.redstack.nl

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Okinawa OTEC plant

Japan

FACTS AND FIGURES

This innovative project aims to demonstrate the efficient combination of power production from ocean thermal energy conversion (OTEC) and the use of deep seawater for other uses to improve the economics of the system as a whole. The "Kumejima Model" integrates OTEC and the use of seawater to supply small communities with energy, water, and food in a self-sufficient manner.

Towards this goal, the project has upgraded the existing OTEC facility in the Okinawa Prefecture Deep Sea Water Research Institute (ODRC) to supply the demand for seawater on Kume Island and test the "Kumejima Model" at small scale. The OTEC plant started operation in April 2013 and the construction of Post-OTEC Seawater Use pipelines was completed in March 2017, allowing for the first time the use by nearby industries of both Post-OTEC deep seawater and surface seawater.

The Implementation of this project is supported by the Okinawa Prefecture has been outsourced to a consortium of three companies: IHI Plant Construction Co., Yokogawa Solution Services Co. and Xenesys Inc.

Okinawa Prefecture Deep Sea Water OTEC Demonstration Facility. Courtesy: Okinawa Prefecture

Details about the project

Project Type	Technology Demonstration
Technology name	Kumejima Model
Technology type	OTEC + Seawater use
Technology developer	IHI Plant Construction Co., Yokogawa Solution Services Co. and Xenesys Inc.
Energy source	Ocean Thermal Energy; Other uses
Location	Kume Island, Japan
Status	Operational
Project Capacity	100 kW
Website	http://otecokinawa.com/en

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StEnSea project

Germany

FACTS AND FIGURES

The StenSea project - *Storing Energy at the Sea* - is a novel pumped hydro energy storage system using the pressure in deep water to store energy in a hollow concrete sphere. It was invented and promoted by Prof. Luther and Prof. Schmidt Böcking and developed and tested by Fraunhofer IWES and Hochtief Solutions AG, with funding from the Ministry of Economic Affairs and Energy.

It is the first worldwide prototype test in a relevant environment, at 1:10 scale.

The removable technical unit holds all electric components including the supervisory control and data acquisition system. Preliminary tests of all components and subsystems have been done in the laboratories of the Hessian Biogas Research Center (HBFZ) in Bad Hersfeld from May until October 2016. The installation and four weeks test operation with predefined test schedule were carried out from November to December 2016.

The prototype has been recovered and transported to the Test Center for Smart Grids and Electromobility in Kassel. A proposal for the follow-up project with a 1:3 scaled prototype in the ocean in ongoing.

StEnSea Protype during the installation (top) and under operation (down)

Details about the project

Project Type	Technology Demonstration
Technology name	StEnSea
Technology type	Pumped Hydro Energy Storage System
Technology developer	Fraunhofer IWES, Hochtief Solutions AG
Energy source	Potential Energy
Location	Lake Constance, Überlingen
Status	Tests completed, prototype recovered
Project Capacity	11 kW
Website	https://www.iee.fraunhofer.de/en/projekte/search/laufende/stensea.html

SPOTLIGHT ON 5 POLICY INITIATIVES IN OCEAN ENERGY

OES countries are implementing a number of policies to support the development of ocean energy and harvest their unique ocean energy resources. This section summarizes a few national strategies, funding programs and market incentives, test sites and R&D centres supporting the development of ocean energy projects.

NATIONAL STRATEGIES FOR OCEAN ENERGY

As of year-end 2017, 9 of the 25 OES member countries had specific ocean energy targets on their national action plans. Action plans or roadmaps are intended to set out an agreed vision for the ocean energy sector. These plans usually outline the actions required by both private and public sectors to facilitate the development and deployment of ocean energy technology. Some of these roadmaps are technology focused providing a guide for mobilising national efforts down a deployment pathway towards a target.

R&D FUNDING PROGRAMS

Some of the policy actions proposed in the action plans are 'technology-push' mechanisms, typically in terms of capital grants, financial incentives or prizes, that encourage research and innovation in ocean energy and the development of the first demonstration projects. One example is **Wave Energy Scotland (WES)**, a research, development and innovation programme established in 2014 by the Scottish Government, which aims to develop cost competitive wave energy technology in Scotland. WES supports innovation calls, strategic projects and industry engagement and collaboration activities. So far WES has supported 150 organizations in 56 projects with an investment of 24.6 million pounds.

Another example of national initiative for wave energy is the **Wave Energy Prize** developed by the U.S. Department of Energy (DOE). This 18-month design-build-test competition catalyzed a major technology leap in wave energy converters (WECs) to reduce the cost of wave energy. Ninety-two teams registered for the prize; 20 teams were selected for 1/50-scale tank testing and nine finalist teams were selected for 1/20-scale tank testing. The competition set a threshold of doubling the energy capture per structural cost of 2014 state-of-the-art designs and four teams—AquaHarmonics, CalWave Power Technologies, Waveswing America, and Oscilla Power—exceeded the threshold, and the top three teams received a monetary

1 Wave Energy Scotland

Sponsor: Scottish Government

Type: R&D&I Programme

Projects to date: 56

Investment: £24.6 million

www.waveenergyscotland.co.uk

2 Wave Energy Prize

Sponsor:
U.S. Department of Energy

Type: Public Prize Competition

Projects to date:
92 entrants; 9 finalists; 3 winners

Prize amount: US $2.25 million

waveenergyprize.org

prize. The grand-prize winning team, AquaHarmonics, demonstrated a five-fold increase in energy capture per structural cost. DOE partnered with the U.S. Navy on the competition, with final tests occurring in Carderock, Maryland, at the nation's most advanced wave-making facility.

MARKET DEPLOYMENT POLICIES

As of year-end 2017, several countries have introduced "Market push" mechanism to incentive the development of the first commercial ocean energy projects. 7 countries (UK, The Netherlands, Denmark, France, Italy, Canada and Japan) have adopted feed-in policies (FIT) making this the most widely adopted regulatory mechanism to promote ocean energy in the OES member countries. In UK, the support scheme for wave and tidal energy is based on "Contracts for Difference (CfD)" auctions introduced in 2014 replacing the Renewable Obligations system in the UK. Tradable green certificates are used in four countries (Belgium, Norway, Sweden and Korea). In Korea, the Tradable Renewable Energy Certificates (REC) supplement the Renewable Portfolio Standards (RPS) policy. The United States relies particularly on tax incentives to support renewables like the Business Energy Investment Tax Credit (ITC) in general.

OCEAN ENERGY TEST SITES AND R&D CENTRES

The development of R&D centres, open water testing facilities and specific consented areas for the deployment of ocean energy projects is key to enable practical experience in the installation, operation and maintenance of ocean energy projects. These activities also help streamlining procedures and ensuring collaboration among the different players. In 2012, a workshop in Dublin launched by OES brought together open-water test site operators and device developers to exchange information and experience on all aspects of planning, development, operation, and usage of open-water test facilities. The aim of this workshop was to identify improvements in the capabilities of these facilities for the mutual benefit of the ocean energy industry. This collaboration activities continued in the following year with the lead of the European Marine Energy Centre (EMEC). In November 2017, the OES Executive Committee approved the organization of a workshop in 2018 with key test centre organisations to build up a detailed work programme.

One example of a national R&D Centre is the **Mexican Innovation Centre on Ocean Energy (CEMIE-Océano)** created in 2014 joining efforts from academia and industry. The Centre has been focusing on the development of technological roadmaps, and definition of priority topics for scientific research and technological development in the country, as well as capacity building. It will be granted for up to 348 million pesos, over a period of four years. Together, the Sustainable Energy Fund, institutions and participating companies will contribute with a total investment of 374 million pesos. Another example is **SEAcORE, the**

As of year-end 2017, several countries have introduced "Market push" mechanism to incentive the development of the first commercial ocean energy projects.

3 CEMIE-Océano

Sponsor: Mexico

Type: R&D Centre

Investment: Up to 348 million pesos, over a period of four years

CEMIE-Océano

http://cemieoceano.mx

Southeast Asian Collaboration for Ocean Renewable Energy, which is a technical working group for offshore renewables under the Association of Southeast Asian Nations (ASEAN) Centre for Energy (ACE). It is an initiative under the Energy Research Institute @ Nanyang Technological University (ERI@N) which is envisioned to become a platform for exchange amongst stakeholders (academe, industry, and government) to facilitate adoption of ocean.

OTHER POLICIES

There are other policies being implemented by OES member countries. There is a consensus that it is necessary to streamline and accelerate the consenting processes by removing excessive administrative and cost burdens. Regulatory and administrative policies and frameworks, such as consenting, environmental impact and planning procedures, can simplify the process of deploying technology by clearly instructing developers on how to secure consent for a project. Some policies have been implemented to reduce administrative barriers such as: i) One-stop-shop approach, e.g. one responsible authorisation agency acting as a single point of contact for dealing with consents. Ii) Marine Spatial Planning (MSP) in order to coordinate decisions on the uses of marine resources, iii) Guidance and advice on consenting of ocean energy device deployments and iv) Ocean testing facilities at different scales, providing grid infrastructure and equipment to measure the resource.

One good example of cross-country coordination to help address the research and innovation challenges for ocean energy is **OCEANERA-NET.** This program, promoted by the European Commission, brings together a network of European national and regional funders and managers of research and innovation programmes in the field of ocean energy. The objective of OCEANERA-NET is to coordinate funding programmes between European countries and regions to support research and innovation in the ocean energy sector.

4 SEAcORE

Sponsor: Singapore

Type: Technical working group

Projects to date: 3 (in 2017) with investment totally around $500K

https://blogs.ntu.edu.sg/seacore

5 Oceanera-NET

Sponsor: European Commision

Type: Funding coordination program

Projects to date: 7 (2014) and 6 (2016)

Investment: €17 million (for 2017 call)

http://oceaneranet.eu

TEST SITES IN OES MEMBER COUNTRIES

	TEST SITE NAME	LOCATION
BEGIUM	Ostend wave energy test site	Harbour of Ostend
CHINA	National small scale test site	Weihai, Shandong Province
	Zhoushan tidal energy full scale test site	Zhoushan, Zhejiang Province
	Wanshan wave energy full scale test site	Wanshan, Guangdong Province
CANADA	Fundy Ocean Research Centre for Energy (FORCE)	Bay of Fundy, Nova Scotia
	Canadian Hydrokinetic Turbine Test Centre (CHTTC)	Winnipeg River, Manitoba
	Wave Energy Research Centre (WERC)	Newfoundland & Labrador
DENMARK	DanWEC	Hanstholm
	DanWEC NB	Nissum Bredning
FRANCE	SEM-REV, wave and floating offshore wind test-site	Le Croisic
	SEENEOH estuarine and ¼ scale tidal site	Bordeaux
	Paimpol-Brehat, tidal site	Bréhat
IRELAND	Galway Bay Marine and Renewable Energy Test Site	Galway Bay
	AMETS	Belmullet, Co. Mayo
KOREA	K-WETEC (Korea Wave Energy Test and Evaluation Centre)	Jeju
MEXICO	Port El Sauzal	Ensenada, Baja California
	Station Puerto Morelos	Puerto Morelos, Quintana Roo
NORWAY	Runde Environmental Centre (REC)	Runde Island
PORTUGAL	Pilot Zone	Viana do Castelo
NETHERLANDS	Oosterschelde	Eastern Scheldt barrier
	Tidal Test Centre (TTC)	Den Oever
	BlueTec floating platform	Texel Island
	REDstack	Afsluitdijk
SPAIN	BIMEP	Basque Country
	Mutriku Wave Power Plant	Basque Country
	Oceanic Platform of the Canary Islands (PLOCAN)	Canary Islands
SWEDEN	The Lysekil wave energy research test site	Lysekil
	Söderfors research site	Dalälven
UK	EMEC	Orkney, Scotland
	Wave Hub	Cornwall, England
USA	U.S. Navy Wave Energy Test Site	Kaneohe Bay
	Pacific Marine Energy Center – North Energy Test 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 Field Research Facility	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

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For more information on Ocean Energy Projects and
Policy Initiatives check out our latest Annual Report at:
https://report2017.ocean-energy-systems.org

OES OCEAN ENERGY SYSTEMS

iea Energy Technology Network

www.ocean-energy-systems.org