

## A TECHNOLOGICAL ASSESSMENT OF THE WAVE ENERGY CONVERTER

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**Abstract:** Global demand for energy increases annually, at the same time as the demand for carbon-free, sulphur-free and NO<sub>x</sub>-free energy resources grows considerably. This is manifested in the research for newer sources like biomass and shale gas as well as the renewable energy resources like solar, wind, geothermal and hydraulic energy.

Wave energy is also a form of renewable energy which has not fully been exploited technically and economically. However, it is beyond doubt that the demand for wave energy will soon increase as fossil energy resources are depleted and environmental concerns gain more importance.

The electrical energy to be supplied to the grid shall be produced from the wave energy whose conversion can basically be carried out by three classes of systems:

- i. Systems that exploit the motions or shape deformations of their mechanisms involved, being driven by the energy of waves passing.
- ii. Systems that exploit the weight of the seawater stored in a reservoir or the changes of water pressure by the oscillations of wave height,
- iii. Systems that convert the wave motions into air flow.

This study is aimed for a general survey of the systems and classification of the wave energy converters based on their types and functionality, as well as investigating their state-of-the-art.

**Keywords:** Wave energy, wave converter, type of converter, assessment of converter.

### INTRODUCTION

Global demand for energy increases annually, whereas the demand for carbon-free, sulphur-free and NO<sub>x</sub>-free energy resources grows considerably. Nowadays there is a great need for the research for newer sources like biomass and shale gas as well as the renewable energy resources like solar, wind, geothermal and hydraulic energy. Scientists and engineers as well as leaders in renewable energy sector have the thought that wave energy is also a form of renewable energy which has not fully been exploited technically and economically.

The wind generated by solar energy creates so-called wind-waves consisting of huge amounts of energy. The total theoretical wave power resource in the oceans is estimated between 1-10 TW, whilst the average electrical power consumption of the world accounts for approx. 2 TW.

#### **Wave – Wind Relations and Wave Characteristics**

The wind velocity profile expands over several kilometres as seen in Figure 1, thus a wind turbine and/or farm exploits only a tiny sublayer of that. In contradiction to wind, most of the wave energy flux is concentrated near the sea surface; hence a wave farm at the sea surface can absorb a large part of the wave energy flux (Fig. 1 and 2).

Waves are formed by winds blowing over the sea and ocean surface, which make the water particles adopt circular motions. Wave energy occurs due to the movements of these water particles near the surface of the sea. This motion carries kinetic energy, the amount of which depends on the speed, duration and unchanged direction of the wind, the length of sea, over which it blows (fetch), the water depth, sea bed conditions and interactions with the tides. The stronger the wind and the longer the distance over which it blows, the larger the waves and the more energy they carry. This energy can be harvested from waves in terms of the following characteristics:

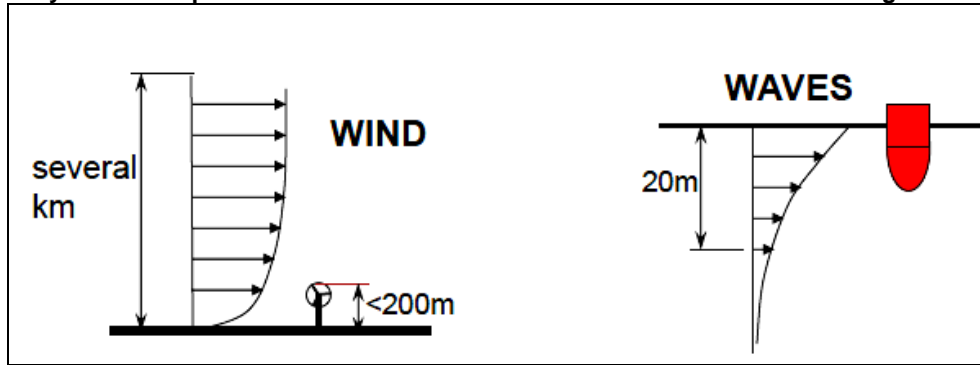


Figure 1. Comparison of the velocity profiles of the wave and wind [1]

- a) The waves possess the potential energy due to gravity, and so the movements of the water from a higher to a lower potential energy position yield its share, and
- b) Additionally they have the kinetic energy produced by the actual movement of the waves and create the other share in wave energy.

For exploiting wind energy, wind turbines are worldwide deployed, whereas a major change and/or difference in the design and manufacturing of the wind turbines is worldwide not visible. However the state of the art in wave energy systems is very different, since many various wave energy converters (WECs) were designed and manufactured as prototypes due to complex interactions between coastal- near shore - offshore waves and devices [1-3].

In exploiting wave energy, the aim always is to extract energy from the ocean and/or sea waves as much efficiently and safely as possible with the cheapest investment and operating costs as well as with producing maximum economic return through so-called WECs of different types. However, it is technically and economically an uncontroversial problem to meet the expectations to design and produce a commercially viable wave energy converter (WEC), because the following principle design challenges for WECs should be overcome:

- i. Ocean renewable energy technologies tend to be very intermittent in their power output if the electric energy obtained by these technologies are transmitted and synchronized in consumer locations. The WECs can extract significant amounts of energy when the waves encounter them directly and continuously, which however is usually not always the case. As a result, the traditional wave energy techniques do not produce energy continuously.

- ii. It is still unable to economically store wave power.
- iii. Wave energy technologies produce electricity at a very low frequency which does not match high voltage grid connections on land.
- iv. Survivability of the WECs in storm conditions has been a key obstacle of ocean technologies in the past, present and near future.

Most sea-based energy generating technologies are hampered by several factors such as design-based weakness and/or construction-based shortcomings. As a result, many of the WECs and these generators have been very expensive to manufacture and maintain. Some WECs eliminate these problems by keeping most of the costly electrical components on-shore where they are protected from the vast marine environment and can be easily serviced. This technique is an alternative to that with grid connection by undersea cabling [4]. As another measure for improving continuous power supply, certain types (Type 1a-b, Table 1) of the WECs can also supply energy by pumping seawater into a coastal reservoir at a suitable height above the calm water level, running through a channel into a hydropower turbine for solving the general problem of fluctuating output in wave energy [4].

Since the seas and oceans are open to the wind, they are richer in wave energy than the closed seas; further the west coasts of the continents have a higher wave energy value compared to their east coasts because of the Coriolis forces. However, it was turned out that setting up WEC plants in the open seas and oceans contains important problems regarding economic and technical aspects as above-mentioned. In conclusion despite any drawbacks, one reaches suitable results if the WEC plants are deployed in coastal and/or nearshore areas in shallow waters.

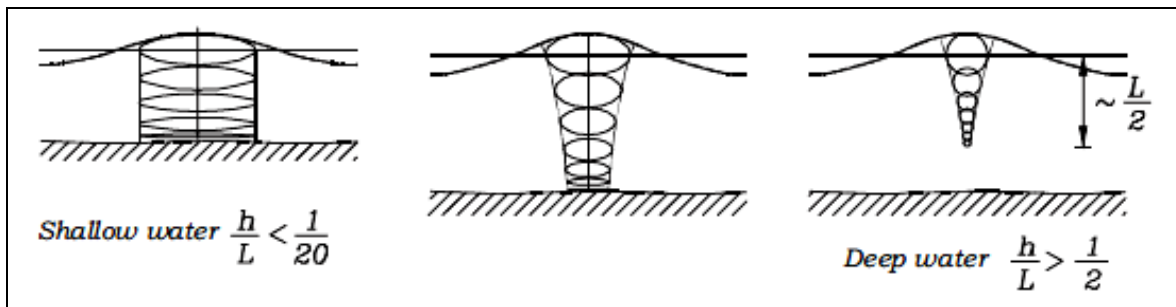


Figure 2. Movement of water molecules according to the water depth [6]

Wave energy devices convert wave energy into electricity through a power take-off system that is usually a turbine such as Pelton, Wells/HydroAir/Dennis–Auld and Kaplan turbines driven by pressurized oil, air and water, respectively. Wave energy converters can be divided into different types of classifications, e.g., The European Marine Energy Centre classifies them into nine classes<sup>1</sup>; attenuators (A; 19%), point absorbers (B; 39%), oscillating wave surge converters (C; 8%), oscillating water column systems (D; 15%), overtopping and terminator converters (E; 11%), submerged pressure differential devices (F; 1,6%), bulges (G; 2%) and rotating mass (H; 4%) as well as the group “others” (I; 0%)<sup>1</sup> (Table 1) [5]. The information on the WECs analysed in this study was obtained from original websites of each corresponding companies and the reports on their tank and/or sea tests according to the company list given by the EMEC’s website as to 25<sup>th</sup> March 2015. The data in Table 1 refer to the last development stages of the systems to respective time. If all of the various concepts of the WECs registered by the EMEC should be investigated elaborately, a conclusion can be reached that the technological modelling of the EMEC is both inappropriate and non-systematic. This argumentation is proven through non- and misclassification as well as classification of the devices under the group “others” by the EMEC [5]. One of the aims of this study is to present the classification failures of the WECs of the “wave developers” prepared by the EMEC in a web-site list, which were to be reclassified and further a new classification was arranged as seen in Table 1. The other aim of the study is to assess the technological state of the art of the wave energy converters designed and/or produced for utilizing wave energy.

<sup>1</sup>The new classification in Table 1 was used.

### ASSESSMENT OF THE WAVE ENERGY CONVERTERS

After examination of all the WECs listed by the EMEC, the following information was obtained:

- i. 17 % of devices could not be classified (31).
- ii. 28% of converters were misclassified (51).
- iii. 13 % of devices were arranged under "unknowns or not-classified" (24), which should never be performed in such a classification.

This structuring needs more systematic order that can contain all various types of the WECs presented and not presented in the list of the EMEC. As initial recommendation, all the WECs designed and/or produced should principally be classified as follows (Fig. 3):

Type 1 of the WECs consisting of point absorbers, attenuators and wave surge converters as well submerged pressure differential devices defines systems generating solid body motions and/or solid body deformations using wave energy, which drive mostly Pelton turbines by a hydraulic mechanism.

Type 2 being composed of overtopping devices indicates systems creating seawater storage in a reservoir above the calm water level which drives low head (Kaplan) turbines.

Type 3 consisting of oscillating water column converters specifies systems exploiting oscillation of water columns in one or more chambers in which air columns are pressurized which drive Wells/ HydroAir /Dennis Auld turbines. In this study, these types are categorized into two subsystems: a) Systems tethered on the seafloor, b) Systems floating with the reference point of the motion, which are slack and/or taut moored to the seafloor as seen in Figure 3.

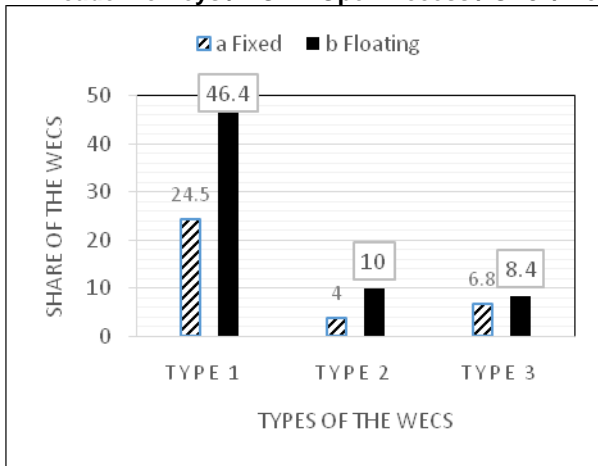


Figure 3. New classification of the WECs given by the EMEC in Table 1

As above-mentioned, wave energy, unlike wind energy far above the ground, increases the concentration at the free water surface as seen in Figure 1 and 2. In the depth of one-half of the wave length in deep water the movement of water molecules does not exist. Whereas in transitional water ( $1/2 > \text{Depth}/\text{Wave length} (h/L) > 1/20$ ) the movement of water molecules decreases partially to the depth, it remains unchanged in shallow water (Fig. 2). Thus, all WECs must principally be deployed as floating at or directly under the free sea surface in both deep and transitional waters; nevertheless they can be arranged at the free sea surface as well on the seabed in shallow waters. Since formerly "most" of all devices had been very expensive in manufacturing and maintaining, large offshore WECs were designed and their prototypes were produced in order to reduce energy unit costs. Although low costs reached in energy production using these systems had provided a very big advantage, these costs increased significantly due to the offshore deployments of the WECs raising the costs of power transmission to the land and the ones of maintenance as well repair. Furthermore, it was also very difficult to protect these systems against severe storms. Therefore, it began to be designed and tested versions of the small onshore/nearshore WECs after 2000-2010. Some of those reached in pre-commercialization stage. If the Table 1 is analysed, it is seen that the projects and works have progressed in this direction. 21 of WECs were commercialised, whereas 34 of those are still in full scaled prototype testing stage. 107 WECs are undergone for small scaled prototype testing stage whilst 32 devices are still in design stage.

Since the "fixed" systems (Type 1a, 2a and 3a) are "tethered on the seafloor or onshore" generally, they have higher capacity in case of the survivalability than those of "floating system" (Type 1b, 2band 3b). For some of the both systems, additional measures have been developed "under storm conditions" such as pulling-down / up or lifting and fixing the mechanisms. However, costs of production, installation, maintenance and repair of these devices are higher than those not-having these mechanism. The taut mooring for floating systems also has the advantage of taking up less space in the sea per buoy, as opposed to slack moored buoys, and provides more energy to be harvested per square mile of sea.

Although the "fixed" devices (Type 3a) functioning according to oscillating water column principle (OWC) are costly in terms of construction and installation, they are cost-efficient regarding maintenance and repair expenditures and can better withstand heavy storms. The floating OWC devices (Type 3b) are somewhere between the fixed OWC ones (Type 3a) and the devices functioning with water weight or its pressure (Type 2b) in terms of properties above-mentioned.

In technologies of most WECs, the capacity factor is similar to the wind energy systems between 0.3 – 0.40, which amounts to be possibly larger in the southern hemisphere due to smaller seasonal variations. At the present stage of the technology development, the unit cost of electricity from waves averages still between wind and large photovoltaics [1].

Even in oceans where wave potential is significantly better than in open seas, the net present value of wave energy converters is still negative under current market conditions [7]. The reason for this is that the wave energy is still in its research and development phase with a few of technologies at the pre-commercial and commercial phase [8]. It can be stated that there are over 1000 wave energy conversion techniques patented in Japan, North America and Europe [2]. High capital costs coupled with low wave resources currently make wave energy conversion in the offshore and at deeper water locations of 100 m depth unfeasible. Generally, WEC plants being deployed in near-shore sites reduce both the cost and power losses in the cable bringing power back to shore, as well they provide considerable reduction in installation and maintenance costs [9].

A unique system in which existing offshore wind and wave technologies are combined into a single modular structure, can deliver cost-effective and competitive renewable energy system with minimal impact on the natural environment. They

should be integrated into the design of next-generation offshore wind foundations. This technique reduces capital costs by sharing offshore infrastructure such as foundations, cabling and grid connection. Combining wave energy generation with offshore/onshore wind devices reduces the intermittency of the output power from the co-located wind-wave farm. Since this technique enables long term, sustainable cost reduction, offshore/onshore wind development can move into deeper waters, further offshore.

All types of utilizing renewable energies especially combining offshore/onshore wind energy turbines with convenient wave energy converters protrude as ideal solution which should be playing an increasingly important part in the energy landscape of industrialized nations and developing economies alike. However, delivering reliable and consistent electricity of renewable energy that can compete with conventionally-generated electricity is still the real challenge.

Hitherto, no system of technology appears to be dominant unlike the wind energy turbines. From the technological state of the art, development and applications as well as economic trends, the conditions are similar to wind energy technologies in the 1980s. Except for a small number of cases, there is no experience of maintenance, reliability and survivability under extreme conditions in open-seas for more than one year. The most advanced technologies are still before the pre-commercial stage, because the design and development of a wave energy system is too complex and detailed. Only through a staged project development approach, where actual performances and operation of a device are measured and observed experimentally at a sufficiently large scale and in a sufficiently long term as well where complete system designs are developed, built and tested, both the device and its actual cost of energy can be assessed so far so precisely.

## CONCLUSIONS AND FUTURE RECOMMENDATIONS

Hitherto, wave energy is the only renewable energy source that is not commercially exploited. Numerous designs and concepts exist and most are in early development stage with limited knowledge concerning the actual costs and expenses and/or ability to operate and survive in the harsh environment of oceans and seas.

Furthermore the systems of the WECs can be very complex in design, non-linear in performance and include numerous cost and/or legal uncertainties such as grid integration and legal processes as well permitting. In real sea conditions, predictions of numerical energy analyses on capacity factors of the WECs can be off by over 40%. Until prototypes are designed, built and tested for a sufficiently long time, ones will not know the true cost of energy or not be able to reliably forecast methods of cost reduction. For the short time, the following recommendations can be mentioned:

- Caisson breakwaters for harbour protection can be combined with energy production from waves using the technology of the oscillating water column with air turbines (%15<sup>2</sup>) and attenuators (%39<sup>2</sup>) (Type 1a and 3a). This is to be carried out in coastal areas of low wave energy content.
- Point absorbers and attenuators as well wave surge converters (%66<sup>2</sup>, Type 1a and 1b), which should be designed and mass-produced as simple and cost-efficient as possible, could be deployed in onshore/near shore by keeping most of the costly electrical components on land.
- The WECs above-mentioned can be utilized by pumping the seawater into a coastal reservoir at a suitable height above the calm water level, running through a channel into a hydropower turbine.
- Further it is appropriate to build and install sufficiently large overtopping devices (%15<sup>2</sup>) at coastal areas (Type 3a) or to deploy near shore (Type 3b), especially where the population density and industrialization level is low.
- For providing extensive exploitation of wave energy, large farms of the WECs should be planned as it is the case in other energy systems like wind energy.
- Combination of the WECs as much as possible with offshore/onshore wind power plants should be investigated intensively.

The traditional wave power companies are still challenging with obtaining a continuous power supply, and it seems that the existing technologies do not have the abilities to reach high energy conversion rates and therefore cannot just yet become competitive with burning fossil fuels especially at these currently low oil prices.

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<sup>2</sup> Total share of the WECs in Table 1

Table 1. WECs and company names presented by the EMEC’s website as to 25<sup>th</sup> March 2015

Company	Device name	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in
40 South Energy	R115	1b	B/F!	None				2013
Able Technologies LLC	Electric Generating Wave Pipe	1b	B	B		2009		
AeroVironment Inc.	Eel Grass	1a	B	B	2013			
Aker Solutions ASA		1a	A/C	None		2014		
Aker Solutions ASA		1b	A/C	None		2014		
Alba TERN	Squid	1b	B	A		2014		
Applied Technologies Company	Float Wave Electric Power Station	1b	B	B		2011		
Aquagen Technologies	Surge Drive	1a	B	B	2011			
Aqua-Magnetics Inc.	Electric Buoy	1b	B	B		2012		
Aquamarine Power	Oyster 800	1a	C	C			2015	
Atargis Energy Corporation	Cycloidal WEC (CycWEC)	2a	E!	I		2012		
Avium AS	Yeti Cluster System	1b	H/I	I			2014	
Atmocean Wave Energy	Atmocean	1b	B	None				2016
AW Energy	WaveRoller	1a	C	C			2012	
AWS Ocean Energy	AWS III	3b	D	E		2011		
Balkee Tide and Wave Electricity Generator	TWPEG	1b	B	C/E	2010			
BioPower Systems Pty Ltd	bioWave	1a	C	C/E			2015	
Blue Power Energy		1a	B	B		2014		
Bombora Wave Power	Bombora	3a	D!	F		2015		
Brandl Motor	Brandl Generator	1b	B	B	2007			
Caley Ocean Systems	Wave Plane	2b	E	I			2013	
Carnegie Wave Energy Ltd.	CETO 5	1a	B	B			2014	
Checkmate Seaenergy UK Ltd.	Anaconda	2b	G	G		2012		
College of the North Atlantic	SARAH Pump	1b	B	F		2006		
Colombia Power Technologies	StingRAY	1b	A/B	A/B		2012		2016!
Colombia Power Technologies	Direct Drive Rotary WEC	1b	A/B	None		2011		
Coppe/UFRJ and TractebelEnergia	Clean Energy from Waves	1a	A/B	None			2012	
CorPower Ocean AB	CPO2	1b	B	B	2012			
Costas Wave	Costas Wave	2a	E!	E		2013		
Costas Wave	Costas Wave	2b	E!	E	2013			
Daedalus Informatics Ltd.	Wave Energy Conversion Activator	3a	D	C	2013			
Calvin College	Wave Powered Water Pump	1a	B	No data			2005	
Del Buoy	D. B. Wave Powered Desalination	1b	B	B				1989
DEXAWAVE A/S	DEXAWAVE Convertor	1b	A	A		2011		
Eco Wave Power	Power Wing	1a	A!	I				2014
Eco Wave Power	Wave Clapper	1b	A!	I				2014
EcleCentarle de Nantes	SEA REV	1b	H	D			2010	
Ecomerit technologies Centipod		1b	A	A	2010			
Ecotricity	Searaser	1a	B	B		2014		
ELGEN Wave	Horizon Platform	1b	B	B	2013			
Embley Energy Ltd	Sperboy	3b	D	B/D		2001		
Etymol Ocean Power SpA	Etymol WEC Alpha Series	2b	G	I			2014	2022

Company	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in
Euro Wave Energy		1a	B	B	2008			
eze - Sea Power Generator		1a	A/C	No data		2013		
eze - Offshore Sea Power Generator		1b	A/C	No data	2010			
FlanSea	Wave Pioneer	1a	B	B		2013		
Float Inc	Rho Cee	3b	D	B		2009		
Floating Power Plant	Poseidon-Wave wind hybrid	1b	A	A		2012		
FOBOX AS	FO3	1b	B	D		2004		
Fred Olsen Co. Ghent U.	SEEWEC	1b	B	B			2009	
Fred Olsen Ltd	The B1 Buoy	1b	B	A		2008		
Fred Olsen Ltd	Wavehub	1b	B	None			2014	
Fred Olsen Ltd	BOLT Lifesaver	1b	B	None			2012	
G Edward Cook	Syphon Wave Genertator	2a&2b	E	A		2008		
G Edward Cook	Floating Wave Genertator	1b	A	F		2007		
GraysHarbor Ocean Energy Comp.	Titan Platform	3a&3b	D	D	2009			
GasNaturalFenosa	OWC	3a	D	D	None			
Greencat Renewables	Wave Turbine	1b	A	A		2013		
Greenheat Systems Ltd.	GentechWaTS	1b	D	I	2014			
Grey Island Energy Inc.	SeaWeed	1b	A	None		2014		
Group Captain SM Ghouse	FreeFloatingWEC	3a	D	A	2010			
Gyrodynamics Co Ltd.		1b	H	None		2008		
GyroWaveGen	GyroWaveGen	1b	H	I		2013		
Hann-Ocean	Drakoo B	2a	E	B				2012
Hann-Ocean	Drakoo R	2b	E	B				2012
Havkraft	Evolver (Havkraft WEC)	3a	D	D	2013			
HidroFlot SA	Hidroflot	1b	B	B		2007		
Hydrocap Energy SAS	Seacap	1a	B	B		2013		
IHC Tidal Energy	Wave Rotor (Breakwater)	2a	E!	I		2012		
IHC Tidal Energy	Wave Rotor (Floating)	2b	E!	I		2012		
Independent Natural Resources	SEADOG	1a	B	B			2007	
Indian Wave Energy Device	IWAVE	1b	B	B	2007			
Innova Foundation	Penwest	1b	H	None		2013		
Intention AS	Intention Offshore WEC	1b	B	I			2012	
JAMSTEC	Mighty Whale	3b	D	E				2003
Jospa Ltd.	Irish Tube Compressor	2b&3b	G/D	I		2010		
Joules Energy Efficiency Services Ltd.	TETRON	1b	B	B		2007		
Joules Energy Efficiency Services Ltd.	Wave Train	1b	B	D		2013		
Kinetic Wave Power	PowerGin	2b	E	E		2008		
Kneider Innovations	Wave Energy Propulsion	1b	A	A		2005		
Korean Ins. of Ocean Science and Tech.	KIOST	2b	E	None		2010		
Korean Ins. of Ocean Science and Tech.	KIOST	1b	C	None		2013		
KN Ocean Energy Science&Development	KNSWING	3b	D	None		2013		
Laminaria	Laminaria	1a	C	None		2012		
Lancaster University	WRASPA	1a	C	None		2006		
Lancaster University	Seaweaver	1a	C	None		2010		
Lancaster University	PS Frog	1b	H	B		2005		
Langlee Wave Power	Langlee System	1b	C	C			2013	
Leancon Wave Energy	Multi Absorbing WEC	3b	D	D		2008		
Limerick Wave Ltd.	Seapower Platform	1b	A	None		2013		

M3 Wave LLC	DMP Device	3a	F!	F		2014		
M4 Wave Power	M4	3a	A	None		2014		
Marine Energy Corporation	Wave Catcher Barge	1b	B/I	B/I	2013			
Marine Energy Corporation	Wave Catcher with round pontoons	1b	B/I	B/I	2012			

Company	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in
Marine Hydroelectric Company		1a	B	None		2006		
Marine Power System	WaveSub	1b	B	B		2014		
Marine Power Tech. Pty Ltd.	Energy Island	3b	D	None		2014		
MartiferEnergia	FLOW FutureLife in OceanWaves	1b	A	A		2010		
Orecon Ltd.	MRC Orecon	3b	D!	No data			2011	
Motor Wave	Motor Wave	1b	A	B		2006		
Mururan Institute of Technology	Pendulor	1a	C	I				For years
Navatek Ltd.	Navatek WEC	1b	A	A		2007		
NEMOS GmbH	NEMOS	1a	B	I		2014		
Norvento	Wavecat	2b	E	None	2008			
Norwegian University of Science a. Tech.	CONWEC	1a	B	B		2000		
NualgiNanobiotech	Rock n Roll WE Device	1b	A/B	A/B	2013			
Ocean Electric Inc.	Wave Platform	1b	B	B	2014			
Ocean Energy Industries Inc.	WaveSurfer	1b	B	B			2012	
Chinese Academy of Science (GIEC)	Floating Duck	1b	A	A			2012	
Chinese Academy of Science (GIEC)	Eagle	1b	A	A			2014	
Ocean Energy Ltd.	Ocean Energy Buoy	3b	D	D		2010		
Ocean Harvesting Technologies AB	Ocean Harvester	1a	B	B		2010		2016
Ocean Harvesting Technologies AB	Collector Hub System	1a	B	B	2013			
Ocean Hyropower Systems Ltd.	OHS Wave Energy Array	1b	B	B			2014	
Ocean Motion International	OMI Combined Energy System	1b	B	B		2013		
Ocean Power Technologies	Autonomous Power Buoy	1a&1b	B	B			2013	
Ocean Rus Energy	Ocean 3 / 160 7 640	1b	H	H				2013
Ocean Wave and Wind Energy	Wave Pump Rig	1b	B	B		2001		
Ocean Wave and Wind Energy	OWWE Rig	2b	E	E	2005			
Oceanlinx	blueWAVE	3b	D	D				2013
Oceanlinx	greenWAVE	3a	D	D				2011
Oceanlinx	ogWAVE (Remote control app.)	3b&3a	D	D				2014
OceantecEnergias Marinas SL	Oceantec Energy Convertor	1b	A	H		2008		
Offshore Wave Energy Ltd (OWEL)	OWEL WEC	3b	D	C		2012		
Oscilla Power Inc.	Magnetostrictive WE Harvester	1b	B	B			2014	
OWC Power AS	OWC Power	3a	D	D			2014	
OWC Power AS	OWC Power	3a	D	D			2014	
OWEC Ocean Wave Energy Company	OWEC Ocean WEC	1a	B	B		2013		
Phil Pauley Innovation	Solar Marine Cells	1b	B	I	2011			
Pelagic Power AS	W2Power	1b	B	B		2009		
Pelamis Wave Power	Pelamis	1b	A	A				2008!
PerpetuWave Power Pty Ltd.	Hybrid Float	1b	A	A		2013		
PIPO Systems	APC-PISYS	1a	B	None		2012		
PolyGen Ltd.	Volta WaveFlex	1b	C	C		2014		
Pontoon Power	Pontoon Power Converter	1b	B	A		2012		



Portsmouth Innovation Ltd.	WAVESTORE	2b	E	E		2012		
Protean Energy Ltd.	Protean	1a	B	B		2013		
Pure Marine	DUO WEC	1b	B	None		2012		
WET-NZ New Zealand	WET-NZ Device	1b	A/B	B		2013		
Purenco AS	The Fisherman WEC	1a	B	B		2011		
Renewable Energy Pumps		1a	B	B	2013			
Resen Energy	Resen Waves LOPF buoys	1a&1b	B/I	B/I				2013
Resolute Marine Energy Inc	SurgeWEC	1a	C	C			2013	
Company	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage III	At full scaled prototype testing stage III	At commercializing stage in
RTI Ocean Wave Energy	RTI Ocean WEC	3a	D	None		2013		
RTI Ocean Wave Energy	RTI Ocean WEC	3b	D	None		2013		
SARA Inc.	MHD WE Conversion	1a	B	I		2008		
SDE	SDE	1a	C	C				2010
Sea Carpet		1a	F	No data		2014		
Sea Energies Ltd.		3b	D	None		2014		
Sea Power Ltd.	Sea Power Platform	1b	A	A		2014		
Sea Wave Energy Ltd (SWEL)	Waveline Magnet	1b	A	I		2014		
Seabased AB Wave Power Tech.	Linear Generator	1a	B	B			2015	
Seamax Energy	Triton	1a	B	I		2012		
SeaNergy	Turbo Outburst Power/Top Desalination System	1a	F	F				2012
Seatricity		1a	B	B			2015	
Seavolt	Wave Rider	1a	B	No data	2007			
Seawood Designs Inc.	SurfPower	1a	B	B		2012		
SDK Marine	SDK Marine Wave Turbine	2a	E	D		2014		
SDK Marine	SDK Marine Wave Turbine	2b	E	D		2014		
Sigma Energy	MD wave power converting device	1b	B	None		2013		
Snapper Consortium	Snapper	1a	B	B		2011		
Spindrift Energy	Spindrift Energy Device	2b	B	B		2011		
SRI International	Electroactive polymer artificial muscle technology	1b	B	I		2007		
Tecnalia	PSE-MAR	1b	A	A		2011		2013!
The CyanWave WEC	CyanWave4	2b	E	None		2013		
Tremont Electric	nPower WEC	1b	B	B	2011			
Trident Energy Ltd.	PowerPod Linear Generator Power	1b	B	B	2013			
University of Edinburgh	Salter's Duck	1b	A/C	A		1980		
VERT Labs		1b	B	None		2012		
Wave Energy AS	Seawave Slot-Cone Generator	2a	E	E		2007		
Vigor Wave Energy AB	Vigor WEC	2b	G	A		2014		
Voith Hydro Wavegen	Limpet	3a	D	D				2000
Vortex Oscillation Technology Ltd.	Vortex Oscillation Technology	2a	!	A	2005			
Wave Dragon	Wave Dragon	2b	E	E			2011	
Wave Energy Centre (WavEC)	Pico Plant	3a	D	D			2008	
Wave Energy Tech. Inc.	WET EnGen	1a	B	B		2010		
Wave Energy Technology New Zealand		1b	A/B	B		2013		
Wave Star Energy ApS	Wave Star	1a	A/B!	B		2013		
Waveberg Development	Waveberg	1b	A	A			2012	
WaveBob Ltd.	WaveBob	1b	B	B			2012	
Waveenergyfyn	Crestwing	1b	A	A		2009		
WavElectricInc	WE 10 / WE 50 / WE 125	1a&1b	B/H!	H		2012		

WavePiston	WavePiston	1b	A!	A		2013		
WavePlane Production	WavePlane	2b	E	E		2010		
Waves 4 Power	WaveEL-Buoy	1b	B	B			2012	
Waves Ruiz		1b	C	None		2014		
Wavetube		2b	E/B!	None		2013		
Wello OY	Penguin	1b	H	H			2014	
Weptos	WEPTOS WEC	1b	C/I	I			2015	
Wind Waves and Sun	WaveBlanket	3b	D!	I	2007			
Yu Energy Corp.	Yu Oscillatting Generator (YOG)	1a	C	C	2009			
Yu Energy Corp.	Yu Oscillatting Generator (YOG)	1b	C	C	2009			

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