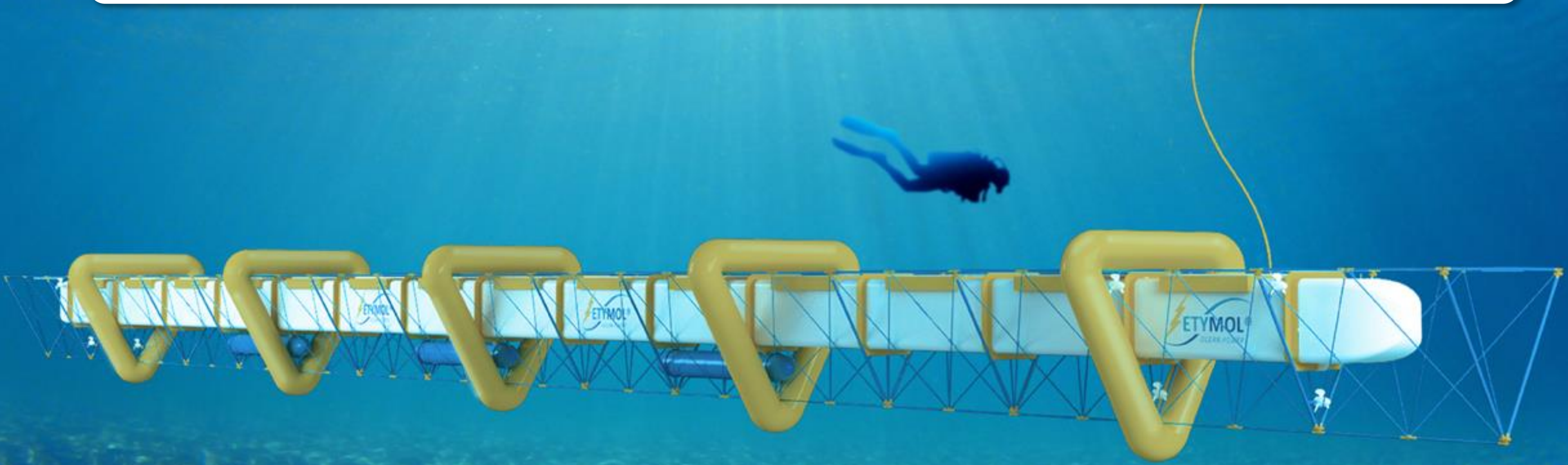
ETYMOL TECHNOLOGY OVERVIEW - YEAR 2018



CON EL APOYO DE:

ETYMOL® OCEAN POWER

INSTITUTO INTERNACIONAL PARA LA INNOVACIÓN EMPRESARIAL

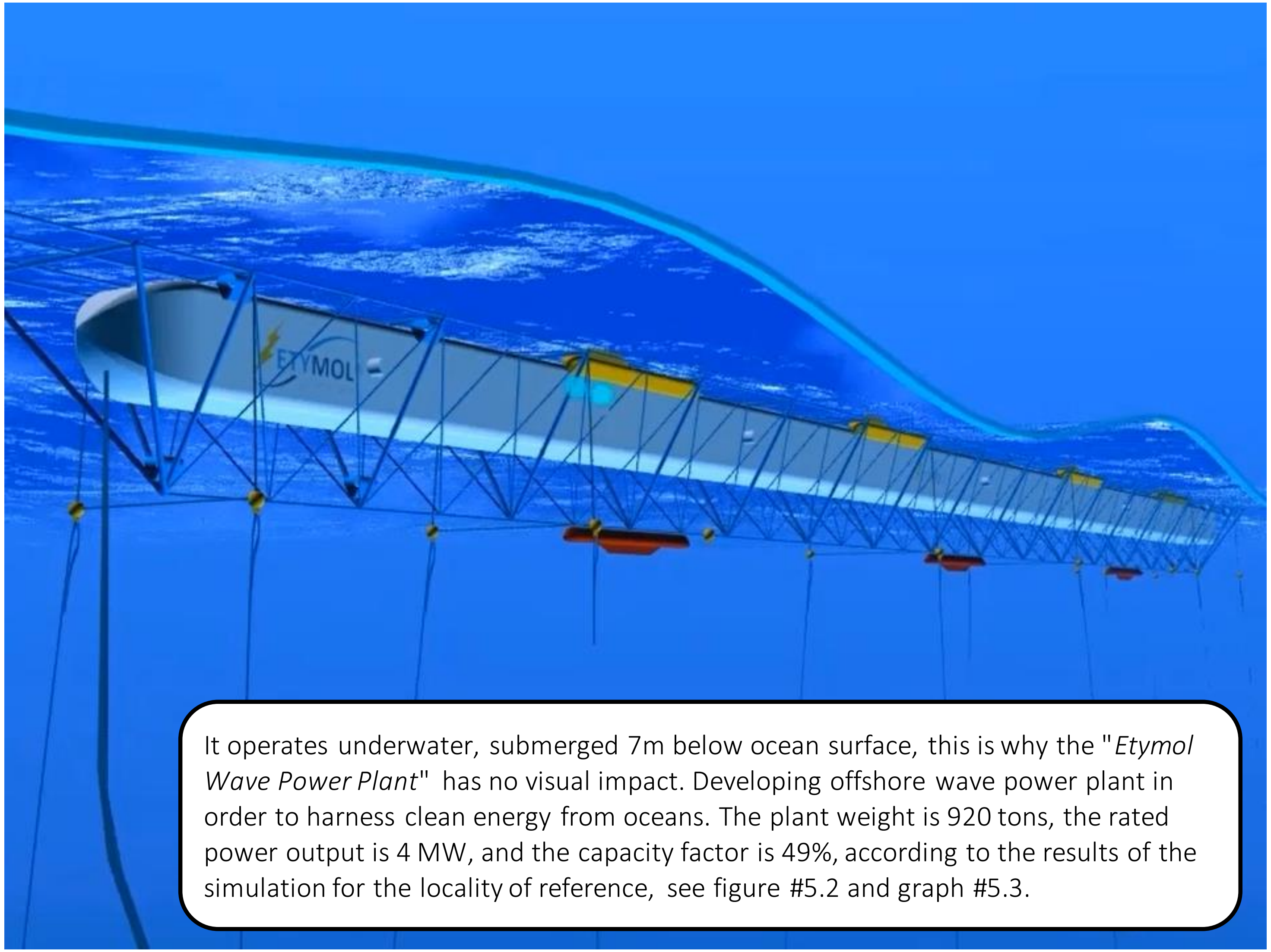
Ing. Lorenzo Sáenz M.

e-mail: saenz@etymol.com

1. INTRODUCTION

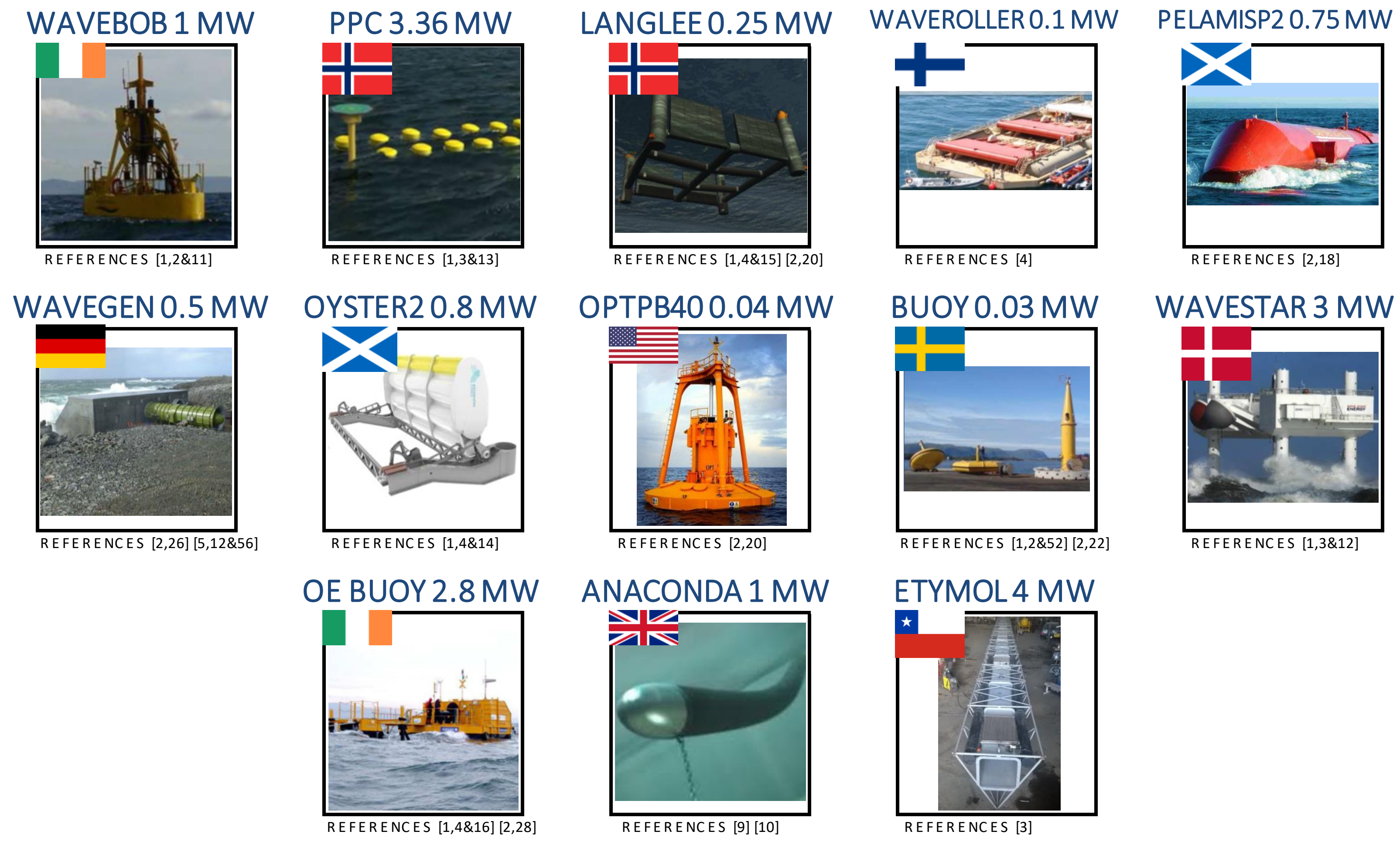
The "Etymol Wave Power Plant" is an energy converter based on a submarine vessel. It has a low initial investment and operational cost in comparison to a fossil fuel power generation, or any other electric power generation system. The unique features are: operation below sea surface in deep-water. The Etymol technical cost efficiency is explained by it is a third-generation wave energy converter, see page 40.

Figure 1.1 "*Etymol 4 MW Model Wave Power Plant*".



1. INTRODUCTION

FIGURE 1.2 Selection of Thirteen WEC´s. The source document is indicated below of the image of the each WEC.



This technical note is partially based on the presentation made by Etymol in “Monthly Ademar Meeting” - www.ademar.cl - held on 7 April 2016. The technical note´s objective is to introduce the “*Etymol Wave Power Plant*” technology and to highlight its strengths in comparison to the other *WEC* Technologies. This technical study produced the updated data base carried out in January 2018 by Etymol.

ETYMOL® OCEAN POWER

1. INTRODUCTION

This report has been divided into the following sections:

2. ETYMOL TECHNOLOGY AND WORKING PRINCIPLE

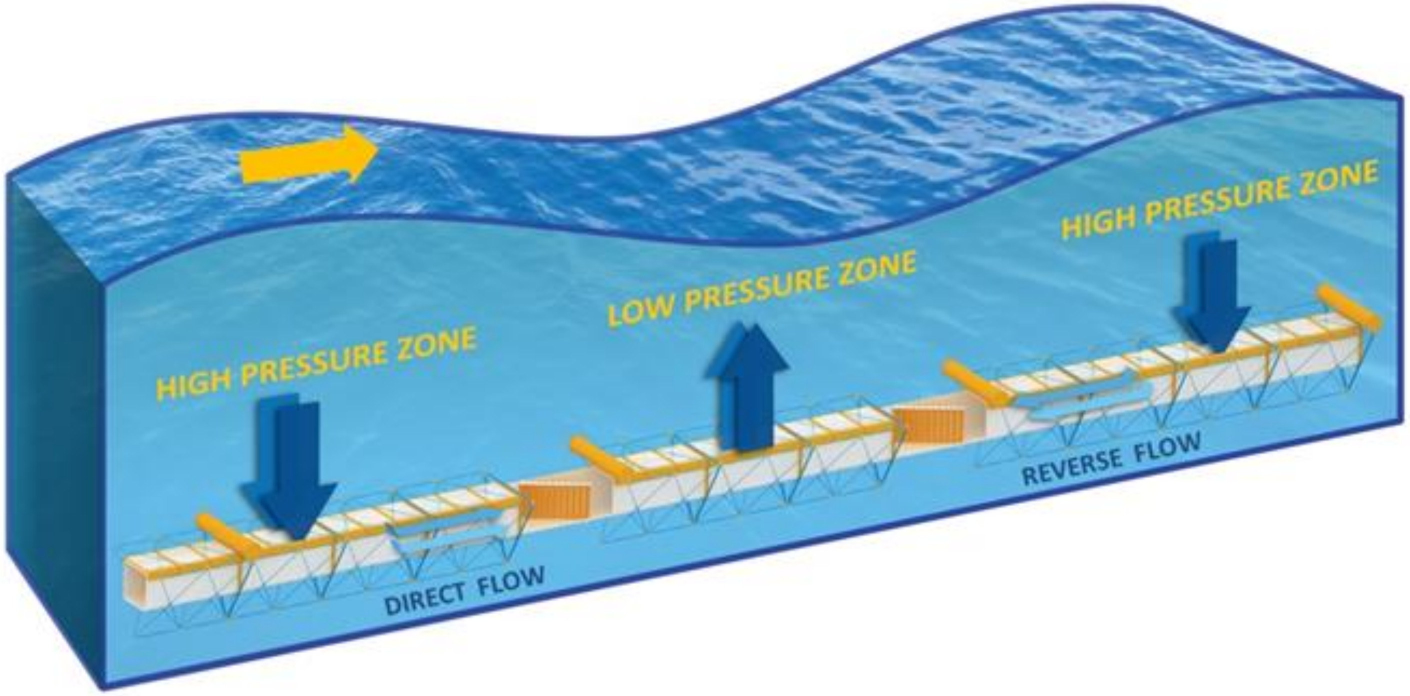
Figure 2.1 "*Etymol 4 MW Model Wave Power Plant*".

The main advantages of "*Etymol Power Plant*" technology are the following:

- *LARGER LIFESPAN*: It works protected, 7 meters submerged, offshore in deep waters.
- *HIGHER ENERGY-EFFICIENCY*: Working principle based in the absorption of the wave of pressure in order to drive a seawater flow in a natural and direct way. This working principle is highly energy-efficient, because it works driving the pressure wave across the WEC vessel hull turning it naturally and directly into kinetic energy without any moving parts.
- *HIGHER COST-EFFECTIVE SOLUTION*: It has no moving parts in the energy conversion process itself.

2. ETYMOL TECHNOLOGY AND WORKING PRINCIPLE

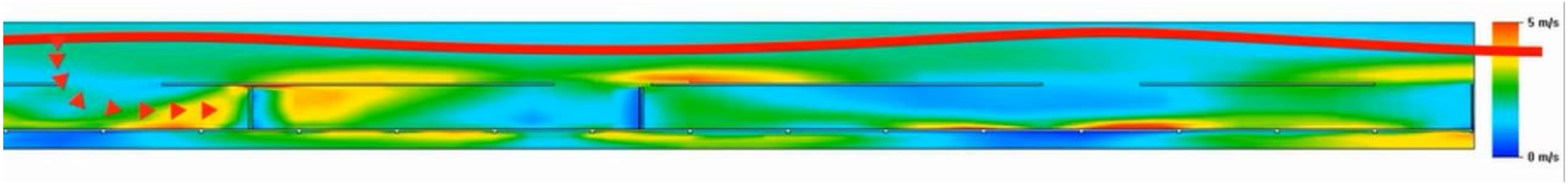
Figure 2.2 Etymol working principle. Not to scale.



- The difference between *high* and *low-pressure zones* generates a seawater flow inside the structure.
- There is a flow in the wave direction (“*Direct Flow*”) and a flow in the opposite direction (“*Reverse Flow*”), both of which reach up to *2 m/s* speeds.
- Every *60 m*, inside the structure, there are vertical axis turbine arrays that generate electricity.

2. ETYMOL TECHNOLOGY AND WORKING PRINCIPLE

Figure 2.3 "*CFD*" simulation of the *"Etymol 4 MW Model Wave Power Plant"* is developed, in the *"Frequency Domain"*.



The engineering process is divided in two technical studies, which include technical notes, calculation reports and logs, technical drawings and description for two different models of *"Etymol 4 MW Model Wave Energy Plants"* and *"Etymol 1 MW Model Wave Energy Plants"* , see figures *#2.3, #2.4 and #2.5*.

2. ETYMOL TECHNOLOGY AND WORKING PRINCIPLE

Figure 2.4 Power Take Off "*CFD*" simulation of the "*Etymol 4 MW Model Wave Power Plant*".

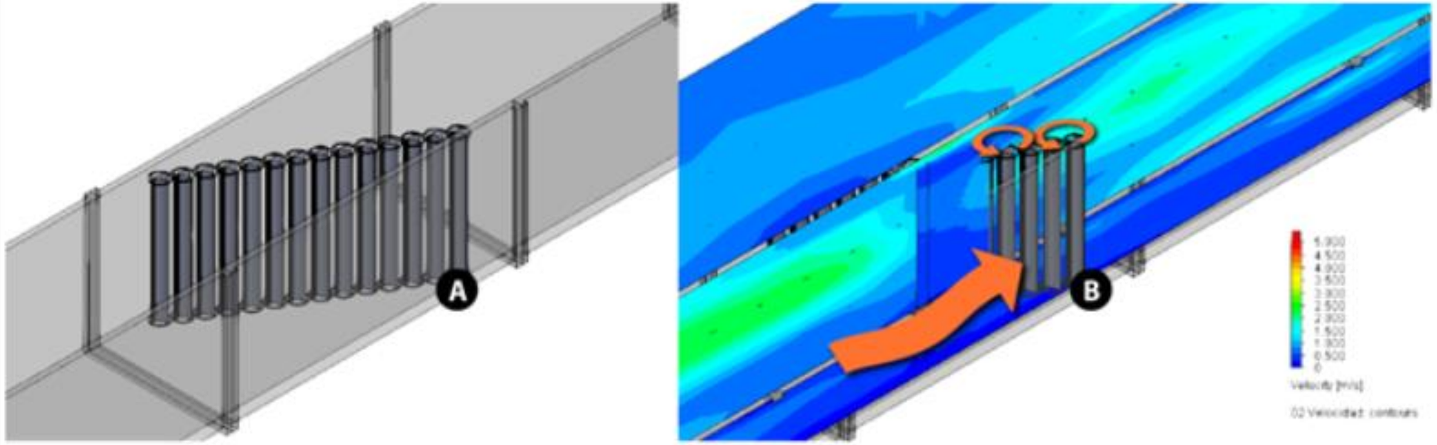
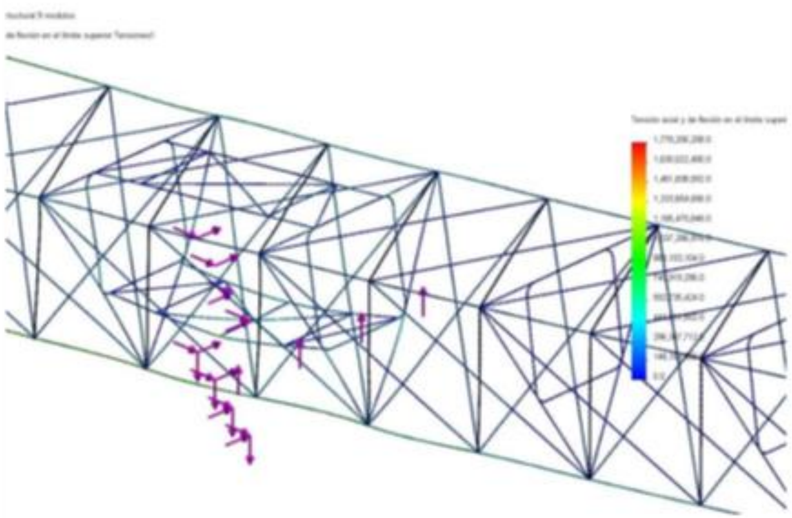
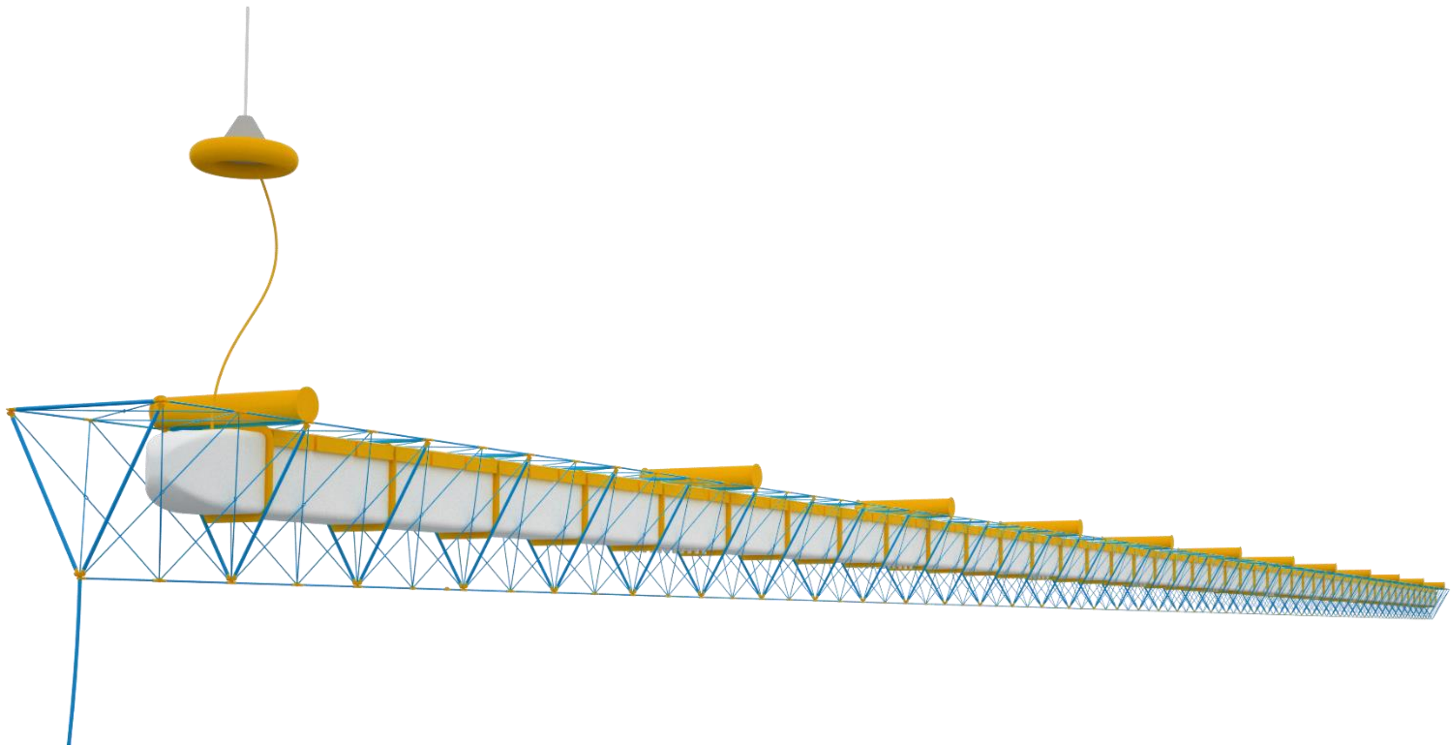


Figure 2.5 "*FEA*" simulation of the "*Etymol 4 MW Model* Wave Power Plant" is developed for the structural stress analysis.



3. PROJECT PROGRESS AND ETYMOL TECHNOLOGY READINESS LEVEL

Figure 3.1 *"Etymol 4 MW Model Wave Power Plant".*



The International Search Report of the "*European WIPO Search Office*" (www.wipo.int), qualifies the *Etymol's third patent application WO2015192258A1* with A's, maximum standard for industrial applicability and novelty for our patent application.

ETYMOL® OCEAN POWER

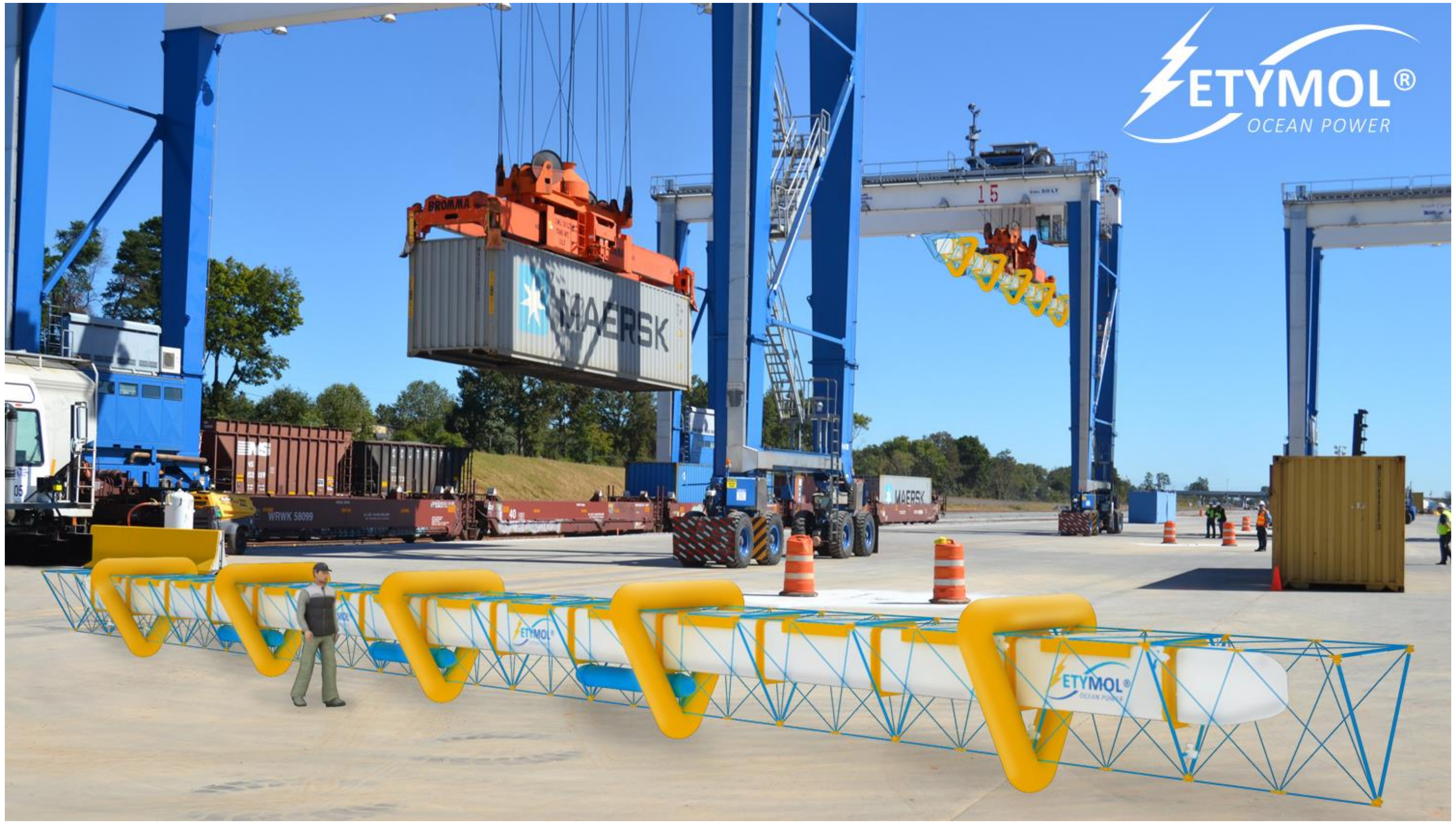
3. PROJECT PROGRESS AND ETYMOL TECHNOLOGY READINESS LEVEL

Figure 3.2 *“Etymol 1:5 Scale Model Wave Power Plant”*, "*Power Take Off*" testing, water tank trial of the "*Axial Turbine*", "*WEC Vessel*" testing and "*Damper Gates for Seawater Entrance*" testing. In the photography testing, the "*Damper Gates*" position is closed.

Etymol has the proven experience of developing and building a wave energy project. The prototype components have been proved in see deep water, in lakes and in the towing tank of the “*National Hydraulics Institute*”. Calculations of *KPI*, *OPEX* and *CAPEX* were achieved by a team of Civil engineers and technicians coming from *Chile's* top universities and with more than *20 years* of professional experience each.

3. PROJECT PROGRESS AND ETYMOL TECHNOLOGY READINESS LEVEL

Figure 3.3 *"Etymol 1:5 Scale Model Wave Power Plant".*



According to the state of maturity of a technology or *"Technology Readiness Level"* (*TRL*), references [2,12], the *ETYMOL Technology* has reached a *TRL-5 level*, having already built a *"Etymol 1:5 Scale Model Wave Power Plant"*, ready to be used in the *towing tank*, which is scheduled in the near future. This test will certify this project as a *TRL-6 stage*.

ETYMOL® OCEAN POWER

4. STATE OF THE ART AND WEC CLASSIFICATION

The aim of this study is to estimate the mean annual power absorption of the *“Thirteen WEC´s Selection”* with different working principles. It is necessary to define *“WEC-KPI”* in order to simplify the *WEC* State of the Art Study and to establish a way to measure *energy-efficiency*. The *“WEC-KPI”* is calculated as a quotient from the *WEC´s* weight and the average annual power produced by a specific *WEC* and for specific site. The *“WEC-KPI”* is a characteristic mass per absorbed energy [*ton/MW*].

Table 4.1 Full power matrix for "*Etymol 4 MW Model Wave Power Plant*", Scatter sheet for *latitude 41°25'N, longitude 8°50'W, Portugal*.

WAVE'S SIGNIFICANT HEIGHT METERS		WAVE'S SIGNIFICANT PERIOD SECONDS: 7 (7.6-6.4)	8.2 (7.6-8.8)	9.4 (8.8-10)	10.5 (10-11)	11.6 (11-12.2)	12.8 (12.2-13.4)	14 (13.4-14.6)
0.5	[0.25-0.75]	0.18%	0.33%	0.23%	0.08%	0.02%	0.02%	0.00%
		1,710	1,197	869	664	515	395	305
1	[0.75-1.25]	1.37%	2.89%	2.87%	1.42%	0.35%	0.76%	0.00%
		2,043	1,429	1,038	793	615	472	365
1.5	[1.25-1.75]	2.52%	4.87%	5.02%	3.48%	1.83%	2.13%	0.18%
		2,758	1,930	1,402	1,071	830	637	492
2	[1.75-2.25]	2.08%	3.96%	4.08%	3.71%	3.02%	2.64%	0.96%
		3,370	2,358	1,713	1,308	1,014	778	601
2.5	[2.25-2.75]	0.94%	2.56%	3.10%	2.82%	2.64%	2.00%	1.91%
		3,624	2,536	1,842	1,407	1,091	837	647
3	[2,75-3.25]	0.18%	1.30%	2.26%	2.13%	1.91%	1.24%	1.85%
		4,000	3,632	2,639	2,015	1,563	1,199	926
3.5	[3.25-3.75]	0.00%	0.43%	1.24%	1.52%	1.39%	0.76%	1.11%
		4,000	4,000	4,000	4,000	3,319	2,546	1,967
4	[3.75-4,25]	0.00%	0.00%	0.50%	0.99%	0.99%	0.54%	0.66%
		4,000	4,000	4,000	4,000	4,000	4,000	4,000
4.5	[4,25-4.75]	0.00%	0.00%	0.18%	0.54%	0.61%	0.41%	0.54%
		4,000	4,000	4,000	4,000	4,000	4,000	4,000

WEC Model	Etymol 4 MW	
Rated Power Output	4,000	kW
Average Annual Power	1,964	kW
Capacity Factor	49	%
Average Annual Hs	2.4	m
Average Annual Ts	10.7	s

PROBABILITY SCALE

0%-0.2%	0.2%-0.8%	0.8%-1.5%
1.5%-2.5%	2.5%-8%	8%-100%

ETYMOL® OCEAN POWER

4. STATE OF THE ART AND WEC CLASSIFICATION

Depending on the level of *energy-efficiency*, *WEC´s industry* falls into the tree following categories:

- ***FIRST-GENERATION WEC:*** It is very *energy-inefficient WEC´s* category, since *WEC-KPI* is greater than *10,000 ton/MW*.
- ***SECOND-GENERATION WEC*:** It is low *energy-efficient WEC´s* category, since *WEC-KPI* is greater than *1,000 ton/MW* .
- ***THIRD-GENERATION WEC*:** It is the only profitable *WEC* generation, since *WEC-KPI* is lower than *1,000 ton/MW*.

Figure 4.2 An example of the "*First-Generation WEC*": "***PELAMIS P2 0.75 MW***"

FIRST-GENERATION WEC
WEC-KPI > 10,000 ton/MW

Figure 4.3 An example of the "*Second-Generation WEC*": "***WAVESTAR 3 MW***"

SECOND-GENERATION WEC
WEC-KPI = 1,000 @ 10,000 ton/MW

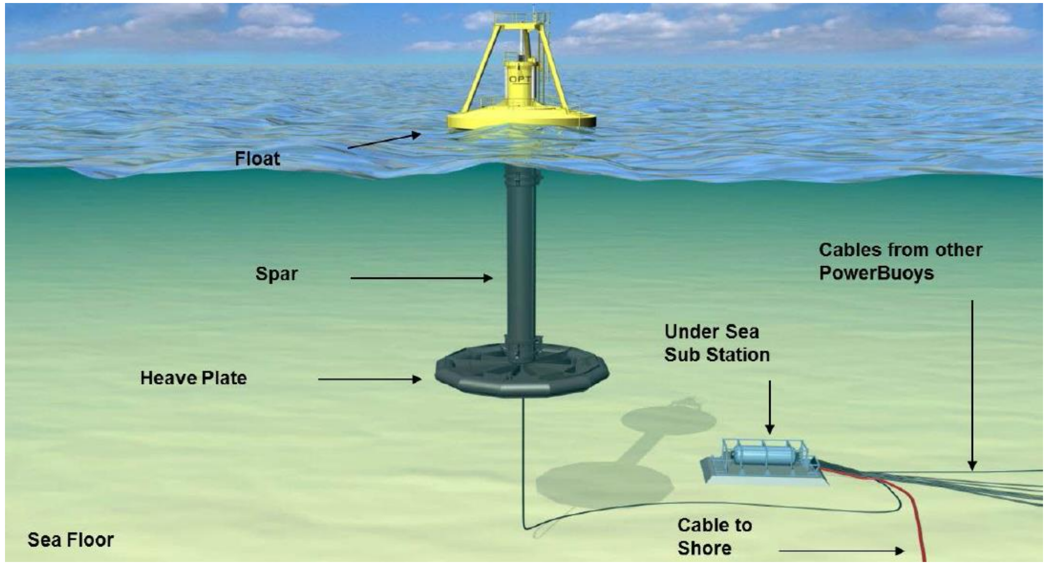
Figure 4.4 An example of the "*Third-Generation WEC*": "***ANACONDA 1 MW***"

THIRD-GENERATION WEC
WEC-KPI < 1,000 ton/MW

ETYMOL® OCEAN POWER

4. STATE OF THE ART AND WEC CLASSIFICATION

Figure 4.5 An example of *WEC-KPI* calculation



Note: The reference for power and weight WEC data is “The Ocean Power Technologies Inc.” website – 2016: www.oceanpowertechnologies.com/powerbuoy, “The average annual output power from a single OPTPB40 40 KW Model, site dependent, 9 kW to 15 kW. The OPTPB40 weight is 114,220 kg”. Other references [2,20]. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portugal*. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

Figure is a view of the *"OPT PB40 Model" WEC*. Its weight is *114,220 kg* and Its power rated is *40 kW*. As for *OPT PB40* Model *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portugal,* the *WEC capacity factor* has a value estimated at around *30%*. Thus, its *average annual power* is *12 kW* (*40kW x 30%*). As for this *WEC*, an example of a *WEC-KPI* calculation method is as follows:

$$\text{WEC-KPI} = \frac{\text{Weight of WEC structure } [ton]}{\text{average annual power } [MW]}$$

⇩

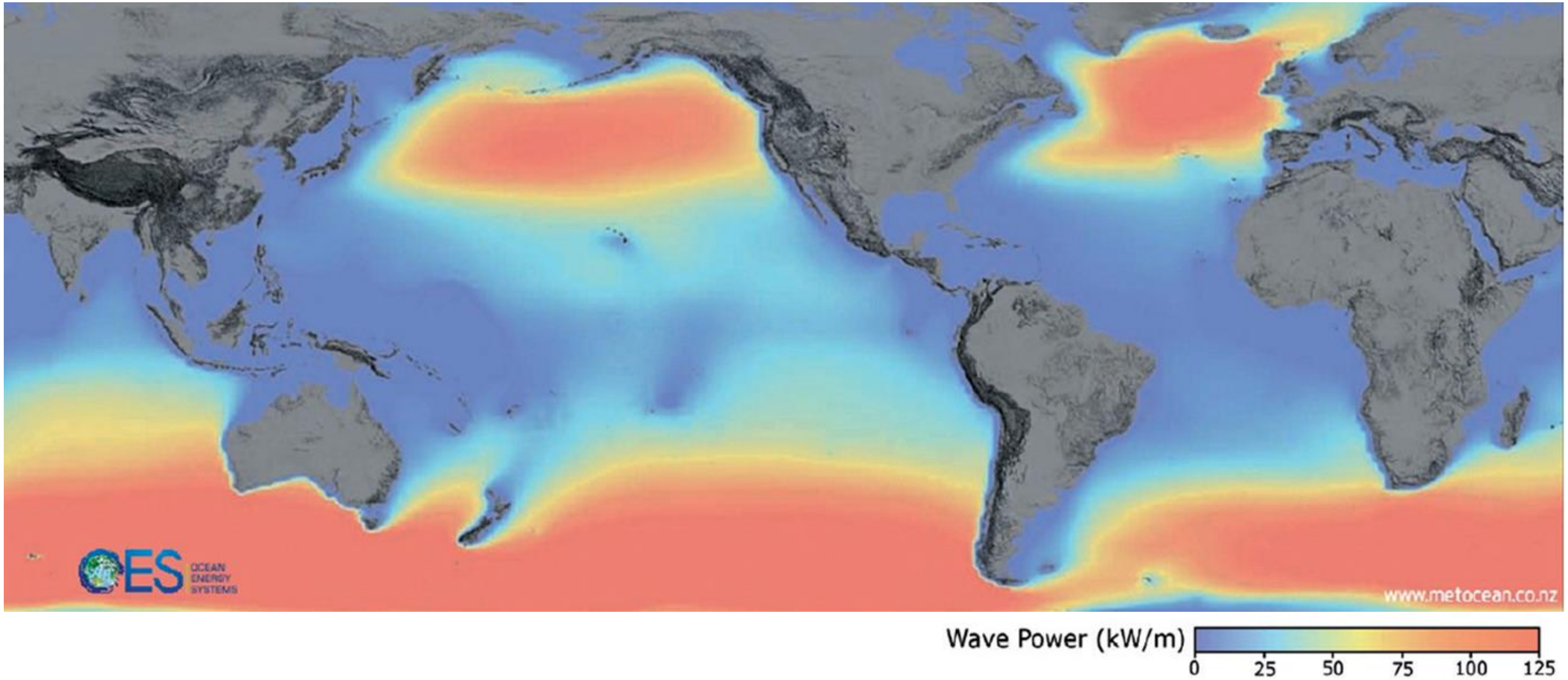
$$\text{WEC-KPI} = \frac{114\ [ton]}{0.012\ [MW]}$$

⇩

$$\text{WEC-KPI} = 9{,}500\ \frac{ton}{MW}$$ ⇨ *SECOND-GENERATION WEC*

4. STATE OF THE ART AND WEC CLASSIFICATION

Graph 4.6 *Global annual mean wave power density*. The units of the *Wave Power Density* are *kW/m*, references [12,10].

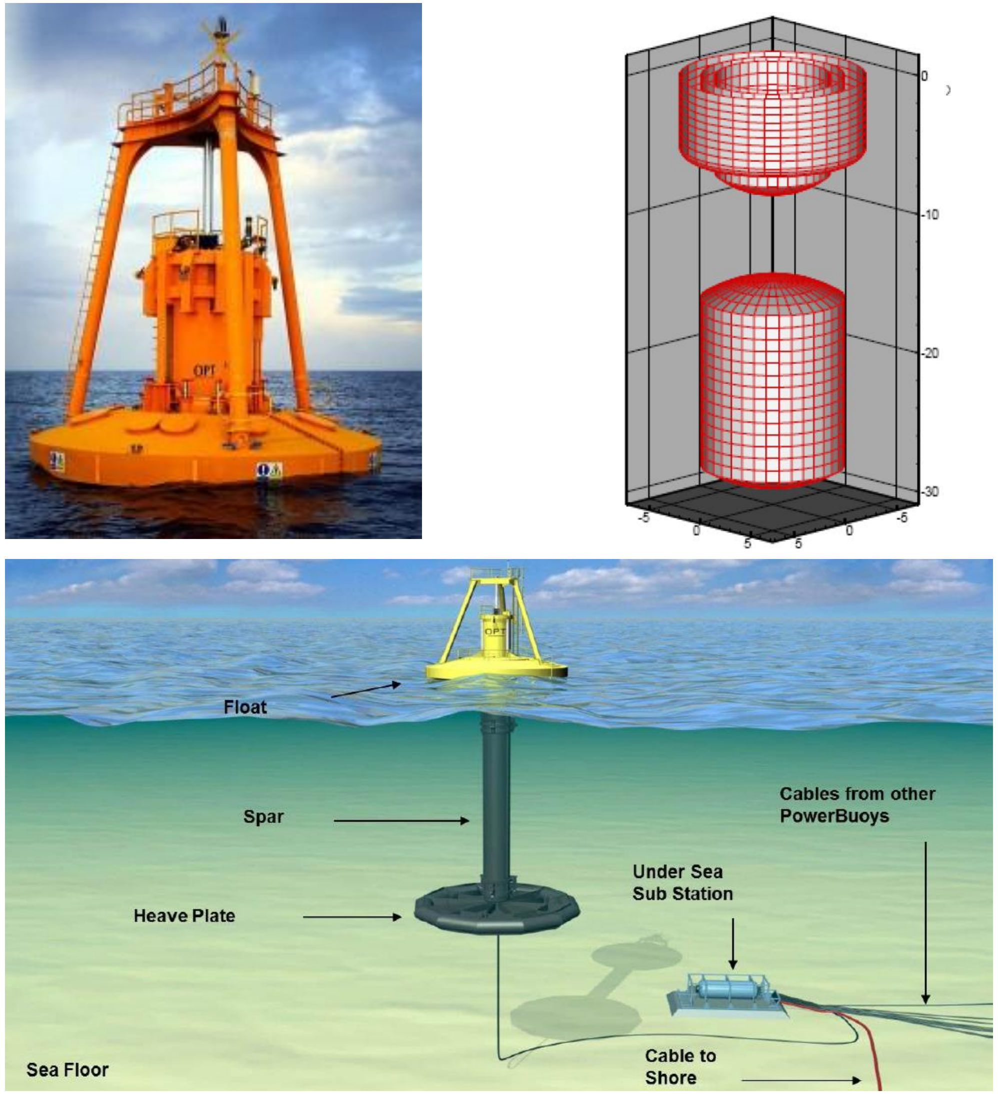


As stated on the map, the maximum wave energy flux is found in high seas, where the wave *energy flux* is greater than 90 *kW/m*. Nevertheless, the wave *energy flow* near the coast is lower than *40 kW/m*. As a paradox, the *"Technology Global Wave Potential"* is quantified by calculating the *energy flux* across a line *30 nautical miles* offshore, references [14,1].

4. STATE OF THE ART AND WEC CLASSIFICATION

The *"Technology Global Wave Potential"* considers the scientific paper *"Gunnar Mørk et al. – Assessing the Global Wave Energy Potential Year – 2010"*, reference [7,6]. This scientific paper calculate that the present *"Technology Global Wave Potential"* is *2.7 TW* (*1 TW = 1,000 GW*), for the *"Two Body WEC"*. For this *"Two Body WEC"*, the radius of the cylinder is *6.5m* and the radius of the inner cylinder is *4 m*, see figure *#4.7*.

Figure 4.7 Two Body WEC, reference [7,6]



4. STATE OF THE ART AND WEC CLASSIFICATION

Table 4.8 "Present Technology Global Wave Potential" is **2.7 TW.**

References: Scientific paper "Gunnar Mørk et al. – Assessing the Global Wave Energy Potential Year – 2010"

	GEOGRAPHICAL WEC AREA	TWO BODY FARM GW
1	Europe (N & W)	286
2	North Atlantic Archipelagos	111
3	North America (W)	207
4	Central America	171
5	South America (E)	202
6	South America (W)	324
7	Africa (S)	178
8	Africa (E)	127
9	Asia (E)	157
10	Asia (SE) and Melanesia	283
11	Asia (W and S)	84
12	Australia and New Zealand	574
	Global Wave Potencial (GW)	**2,704**

The *2.7 TW* calculation is quantified using the followings assumptions:

- Considering the *"SECOND-GENERATION WEC"*
- Considering energy across a line *30 nautical miles* offshore, discarding reserved areas for other uses, for example: Ports, Sea transport routes, Fishery area, Archaeological sites, biosphere reserves.

ETYMOL® OCEAN POWER

4. STATE OF THE ART AND WEC CLASSIFICATION

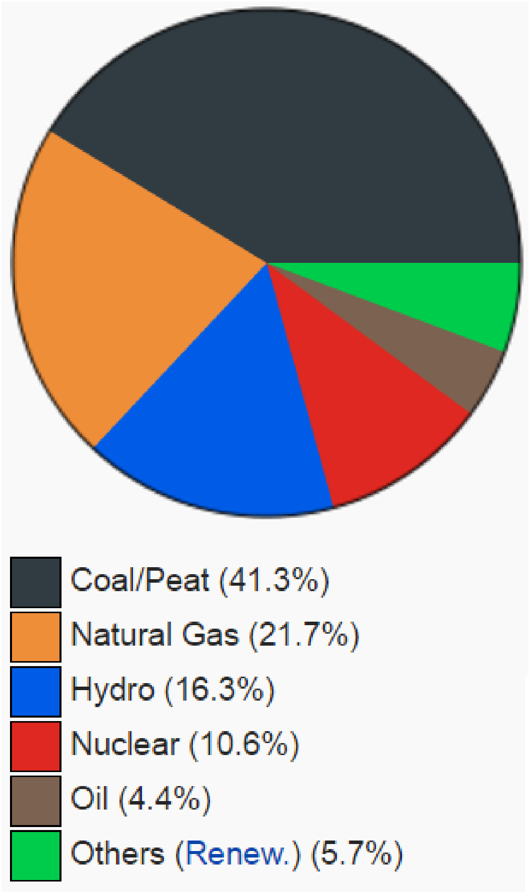
Table 4.9 "Present Technology Global Wave Potential" is **28.4 TW.**
References: [3] The "Basic Engineering of the Etymol 4 MW Model Wave Power Plant – 2016".

	GEOGRAPHICAL WEC AREA	ETYMOL FARM GW
1	Europe (N & W)	3,006
2	North Atlantic Archipelagos	1,167
3	North America (W)	2,176
4	Central America	1,797
5	South America (E)	2,123
6	South America (W)	3,405
7	Africa (S)	1,871
8	Africa (E)	1,335
9	Asia (E)	1,650
10	Asia (SE) and Melanesia	2,974
11	Asia (W and S)	883
12	Australia and New Zealand	6,033
	Global Wave Potencial (GW)	**28,419**

The present *"Technology Global Wave Potential"* for a *"SECOND-GENERATION WEC"* is 2.7 TW. Nevertheless, the *Technology Global Potential* for a *"THIRD-GENERATION WEC"* is *28.4 TW*. And considering the possibility of *WEC* stationed in the high seas, the *"Technology Global Wave Potential"* largely exceeds the value *28.4 TW*.

4. STATE OF THE ART AND WEC CLASSIFICATION

Graph 4.10 World average power consumption of 18 TW, reference [8]

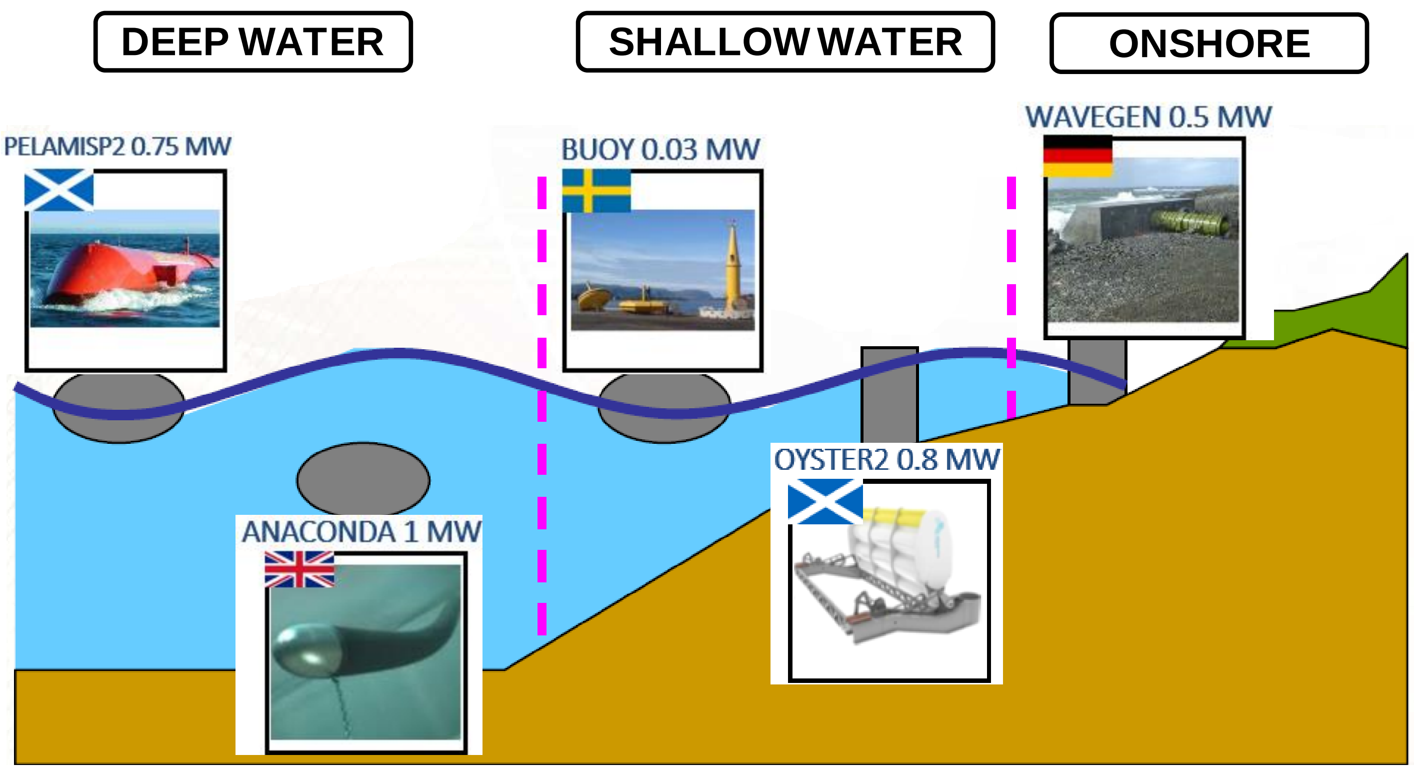


The "*IEA*" estimates that year's 2013 *world average power consumption* was *18 TW*, reference [8], see figure 4.10. This world energy consumption includes all the industries and sources: hydro power, fossil fuels, nuclear power, thermoelectric generation, transport fuel, mining industry, chemical industry, food, heating, amongst other uses.

Therefore, the 28.4 TW Technology Global Wave Potential largely exceeds the global needs.

4. STATE OF THE ART AND WEC CLASSIFICATION

Figure 4.11 Classification by *WEC* Location

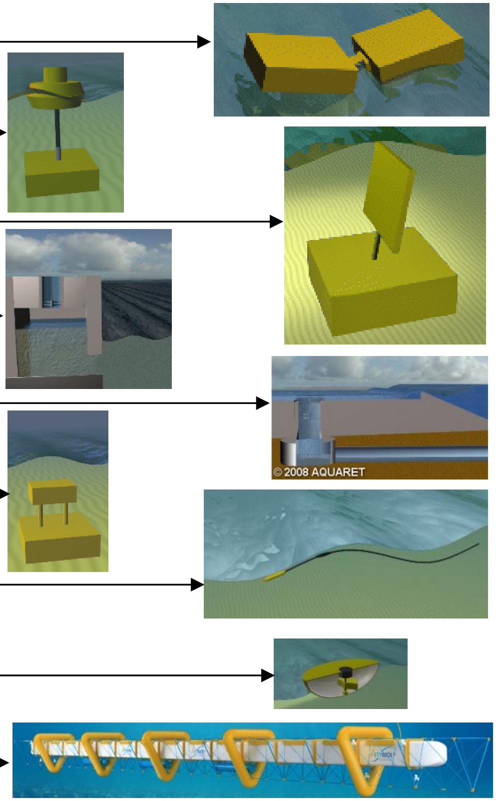


This report explores the existing wave energy technologies across a variety of design types classified by location. Each wave energy converter analyzed is benchmarked against the "*Etymol Wave Power Plant*". Then, this is a theoretical *energy-efficiency* study of "*Thirteen WEC´s Selection*".

4. STATE OF THE ART AND WEC CLASSIFICATION

Table **4.12** WEC class by it´s working principle

WEC CLASS	Working Principle	WEC example
A	Attenuator	
B	Point Absorber	
C	Oscillating Wave Surge Converter	
D	Oscillating Water Column	
E	Overtopping/Terminator	
F	Submerged Pressure Differential	
G	Other - Bulge Wave	
H	Rotating Mass	
I	Other	



This report explores the existing wave energy technologies across a variety of design types classified by *WEC* working principle. Each wave energy converter analyzed is benchmarked against the “*Etymol Wave Power Plant*”. Then, this is a theoretical *energy-efficiency* study of “*Thirteen WEC´s Selection*”. The classification of *WEC* working principle must be defined. For this purpose, we will use the classification used by “*EMEC*” (www.emec.org.uk).

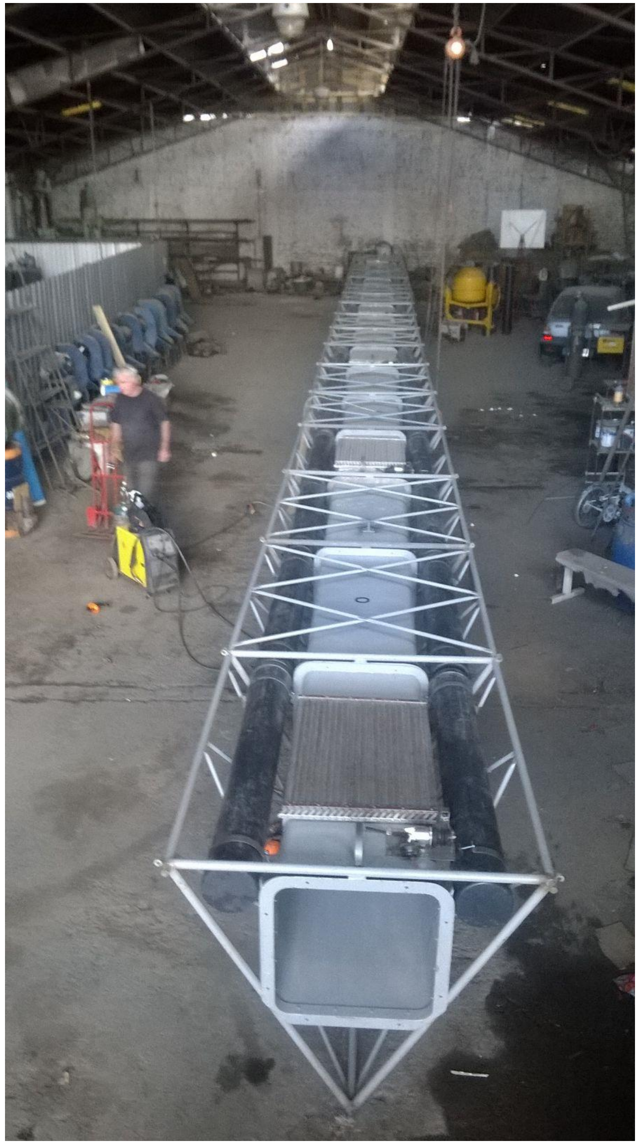
5. ETYMOL WAVE POWER PLANT BENCHMARKING

Because of the different *WEC* features such as location and working principle, the following questions arises:

- What is the ideal location that allows for a greater *energy-efficiency*?
- What is the working principle with the lowest *WEC-KPI*?

To answer both questions, the energy-efficiency of the *"Thirteen WEC´s Selection"* will be analyzed.

Figure 5.1 *"Etymol 1:5 Scale Model Wave Power Plant"*.



5. ETYMOL WAVE POWER PLANT BENCHMARKING

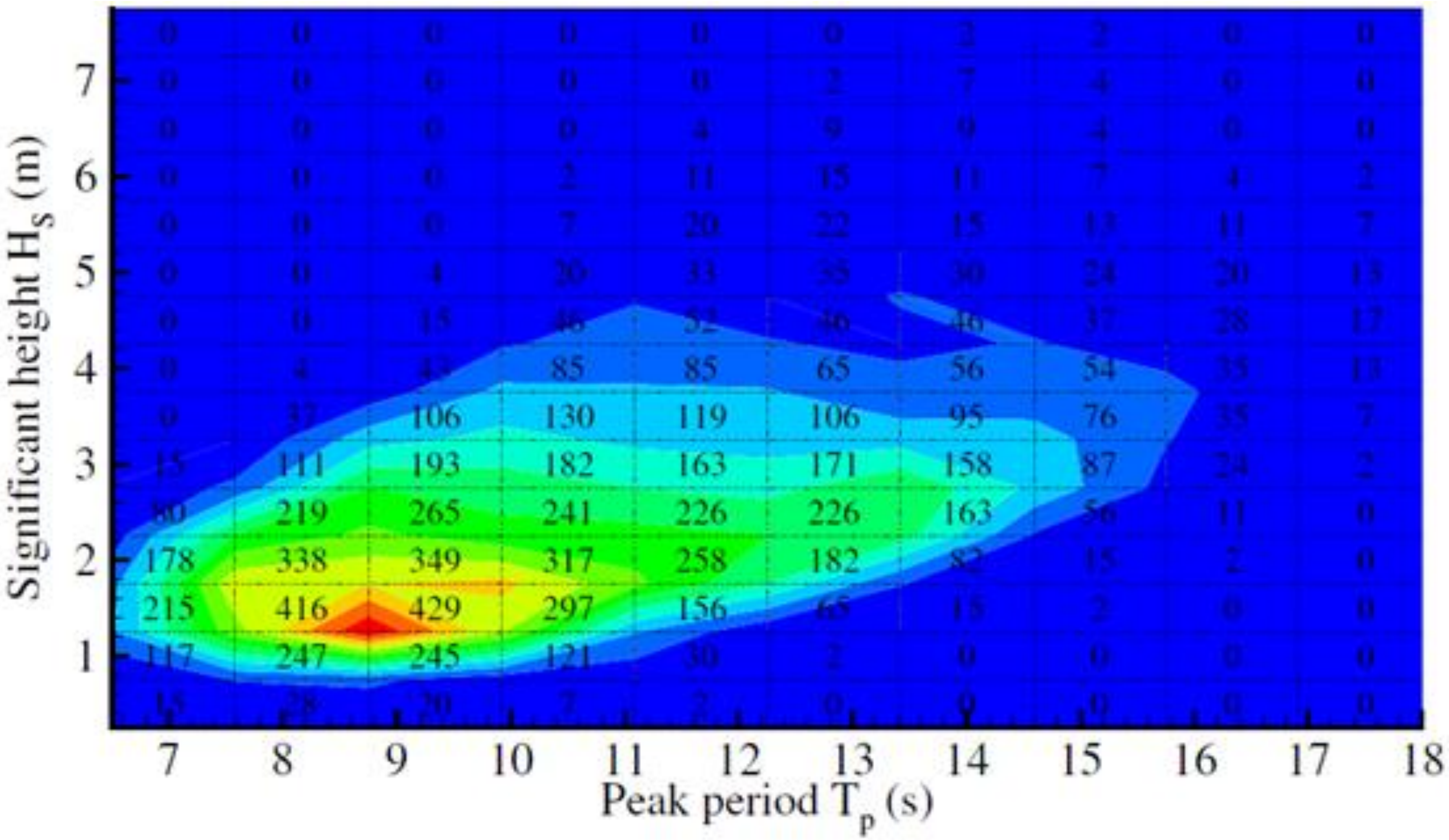
According to the *“ceteris paribus principle”* the *“Thirteen WEC´s Selection”* are located on the same latitude and sea conditions, see figure *#5.3* and graph *#5.4*. The power and weight data correspond to the theoretical performance of a *WECs* located in *latitude 41°25'N, longitude 8°50'W, Portugal*. In this site, the *annual average wave energy flux* is *33.7 kW/m*.

Figura 5.2 This is a locality of reference for a theoretical energy-efficiency study of thirteen selected WECs with different working principles. The WAVE HUB location is latitude 41°25'N, longitude 8°50'W, Portugal

ETYMOL® OCEAN POWER

5. ETYMOL WAVE POWER PLANT BENCHMARKING

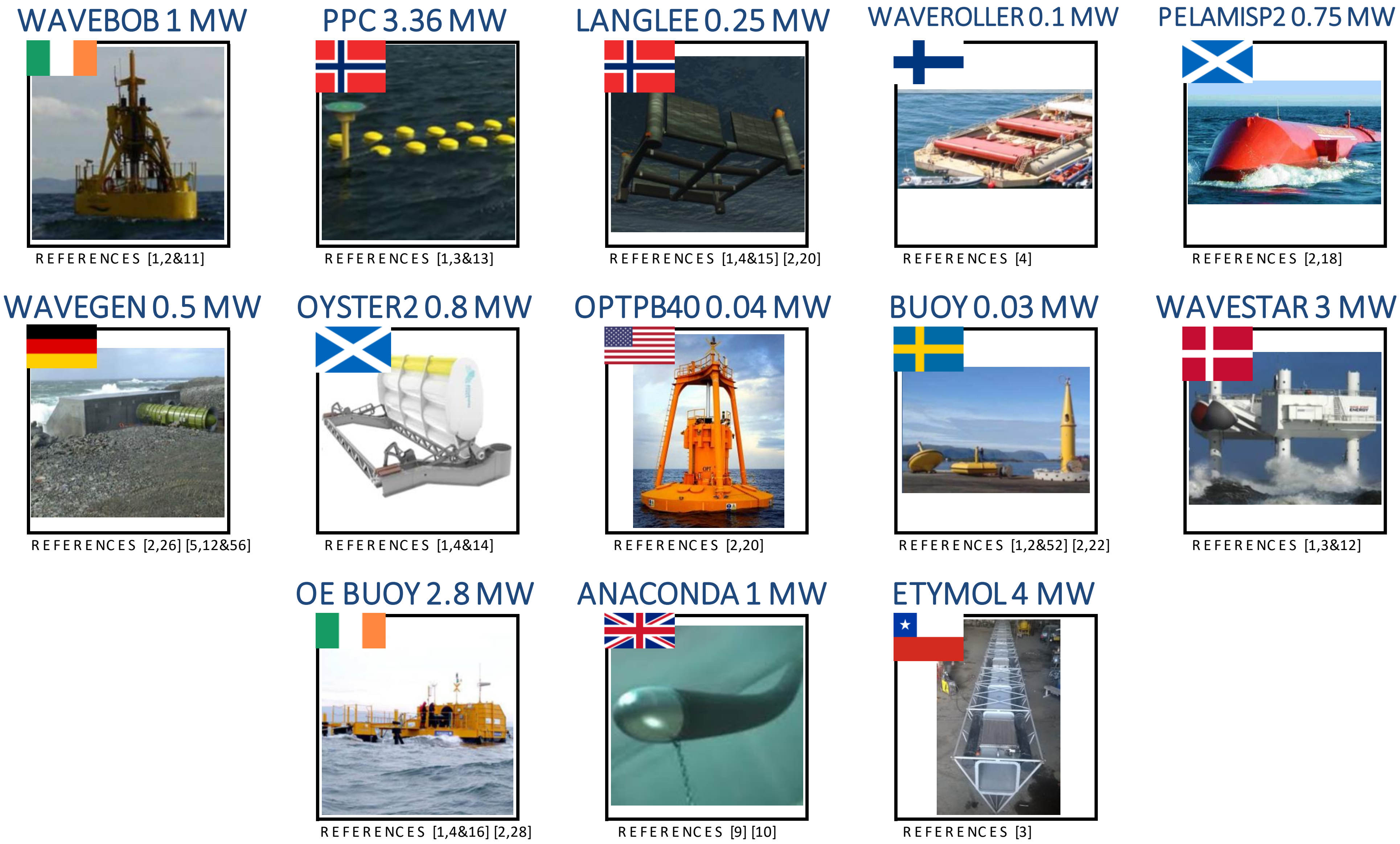
Graph 5.3 Scatter spread sheet for latitude 41°25'N, longitude 8°50'W, Portugal. The annual average wave energy flux per unit of wave-crest length for this point is 33.7 kW/m, references [1,5].



The power and weight data correspond to the theoretical performance of the Selection of *“Thirteen WEC´s Selection”* located in *latitude 41°25'N, longitude 8°50'W, Portugal*. In this area, the *annual average wave energy flux* is *33.7 kW/m*, see the *Graph #5.4*.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

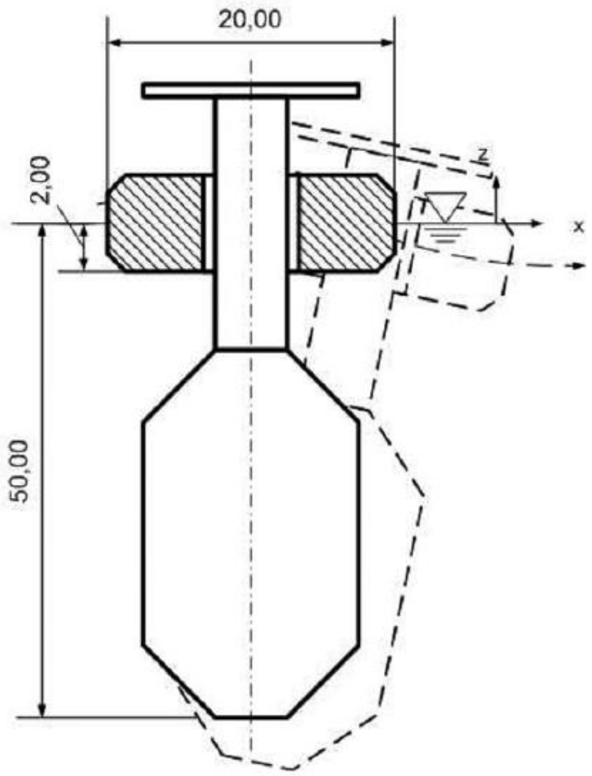
FIGURE 5.4 Selection of Thirteen WEC´s. The source document is indicated below of the image of the each WEC.



ETYMOL® OCEAN POWER

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.5 The WAVEBOB 1 MW model



MODEL
WAVEBOB 1 MW
BRANCH
WAVEBOB LTD.
COUNTRY
EMEC CLASS
(B) Point Absorber

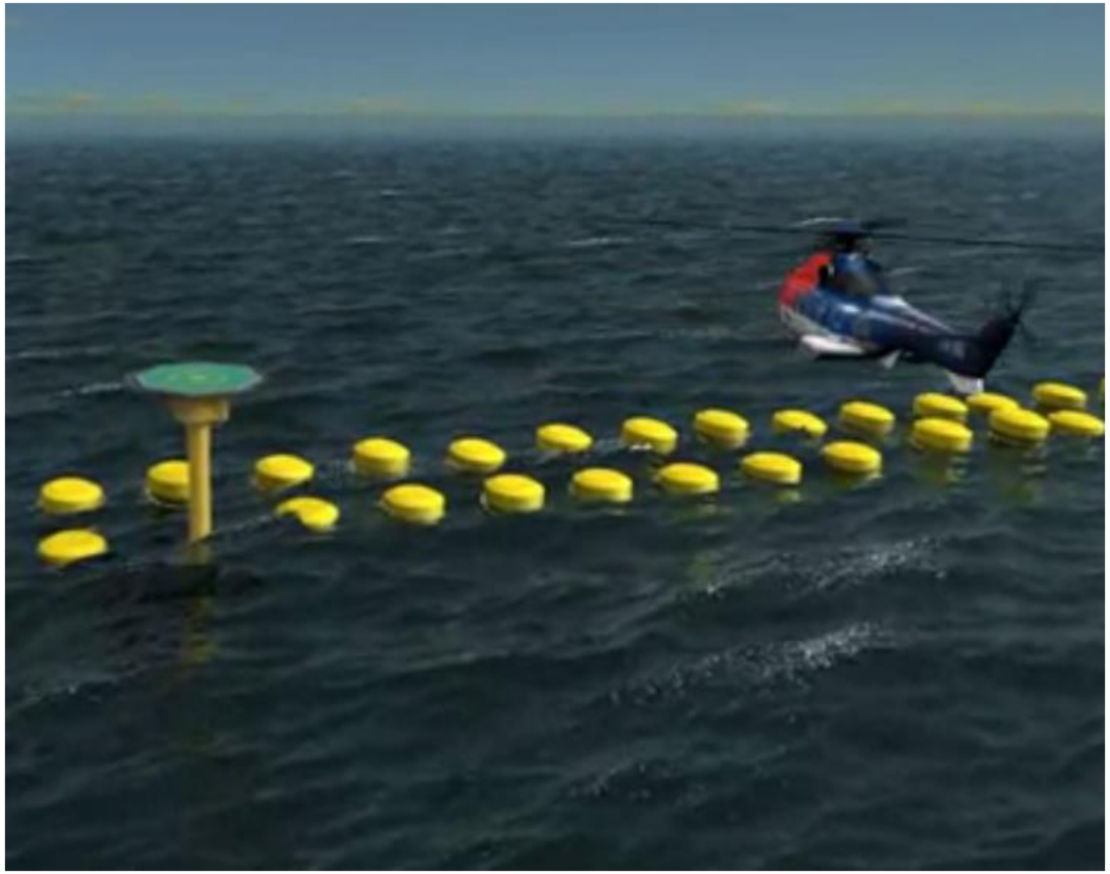
FIRST-GENERATION WEC

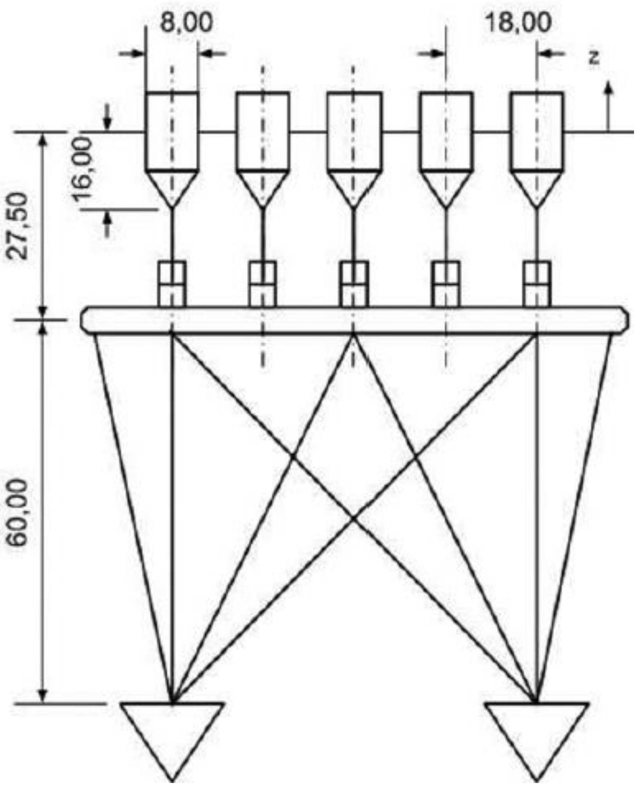
WEC-KPI [ton/MW]
28,663
WEIGHT (ton)
5,704
AVERAGE ANNUAL POWER (kW)
199
CAPACITY FACTOR
20%
REFERENCES
[1,2&11]

Note: The reference for power and weight *WEC* data is the scientific paper "*A. Babarit et al. – Numerical Benchmarking study of a selection of wave energy converters – 2011*", references *[1,2&11]*. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portugal*. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.6 The PPC 3.36 MW model





MODEL **PPC 3.36 MW**
BRANCH **PONTOON POWER AS**
COUNTRY
EMEC CLASS **(B) Point Absorber**

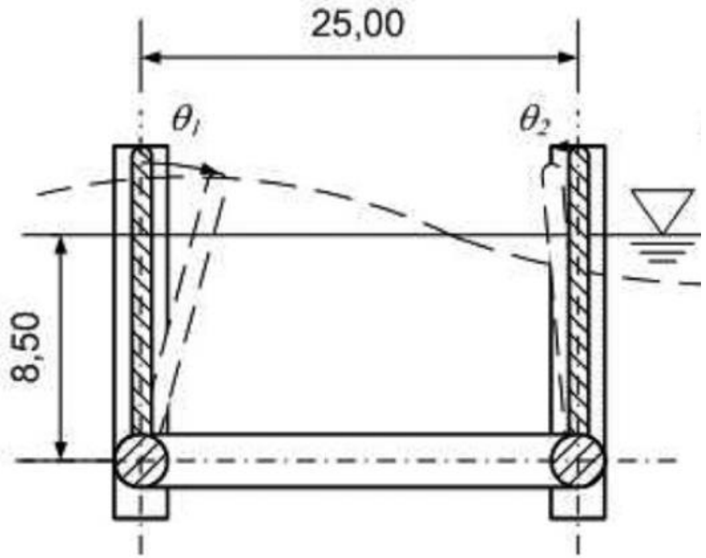
FIRST-GENERATION WEC

WEC-KPI [ton/MW] **16,508**
WEIGHT (ton) **5,233**
AVERAGE ANNUAL POWER (kW) **317**
CAPACITY FACTOR **9%**
REFERENCES **[1,3&13]**

Note: The reference for power and weight WEC data is the scientific paper "A. Babarit et al. – Numerical Benchmarking study of a selection of wave energy converters – 2011", references [1,3&13]. Moreover, the power and weight WEC data corresponding to the theoretical performance for a WEC located in latitude 41°25'N, longitude 8°50'W, Portugal. In this area, the annual average wave energy flux is 33.7 kW/m. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.7 The LANGLEE 0.25 MW model



MODEL
LANGLEE 0.25 MW
BRANCH
LANGLEE WAVE POWER
COUNTRY
EMEC CLASS
(C) Oscillating Wave Surge Converter

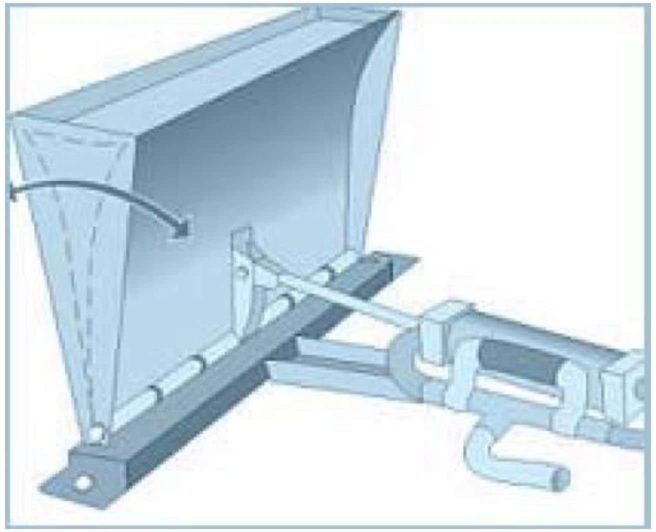
FIRST-GENERATION WEC

WEC-KPI [ton/MW]
15,596
WEIGHT (ton)
1,622
AVERAGE ANNUAL POWER (kW)
104
CAPACITY FACTOR
42%
REFERENCES
[1,4&15] [2,20]

Note: The reference for power and weight WEC data is the scientific paper "A. Babarit et al. – Numerical Benchmarking study of a selection of wave energy converters – 2011", references [1,4&15] [2,20]. Moreover, the power and weight WEC data corresponding to the theoretical performance for a WEC located in latitude 41°25'N, longitude 8°50'W, Portugal. In this area, the annual average wave energy flux is 33.7 kW/m. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.8 The WAVEROLLER 0.1 MW model



MODEL	**WAVEROLLER 0.1 MW**
BRANCH	**AW ENERGY**
COUNTRY	
EMEC CLASS	**(C) Oscillating Wave Surge Converter**

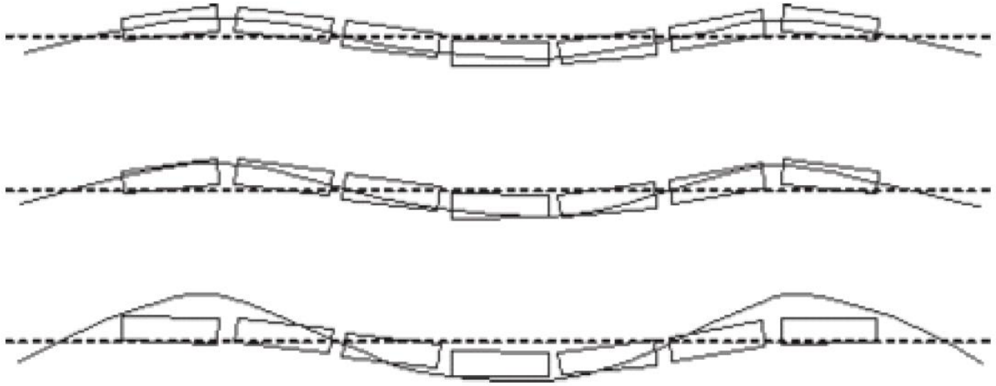
FIRST-GENERATION WEC

WEC-KPI [ton/MW]	**13,333**
WEIGHT (ton)	**280**
AVERAGE ANNUAL POWER (kW)	**21**
CAPACITY FACTOR	**21%**
REFERENCES	**[4]**

Note: The reference for power and weight WEC data is the http://aw-energy.com "*A first in independent verification the electricity output from a single waveroller 100kW-unit during a 24-hour period with significant wave height of 2.5m, typical at the Peniche project site in Portugal was 500 kWh*", WaveRoller 100kW-unit weight 280 tonnes, references [4]. Moreover, the power and weight WEC data corresponding to the theoretical performance for a WEC located in latitude 41°25'N, longitude 8°50'W, Portugal. In this area, the annual average wave energy flux is 33.7 kW/m. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.9 The PELAMIS P2 0.75 MW model



MODEL
PELAMIS P2 0.75 MW

BRANCH
PELAMIS WAVE POWER

COUNTRY

EMEC CLASS
(A) Attenuator

FIRST-GENERATION WEC

WEC-KPI [ton/MW]
12,857

WEIGHT (ton)
1,350

AVERAGE ANNUAL POWER (kW)
105

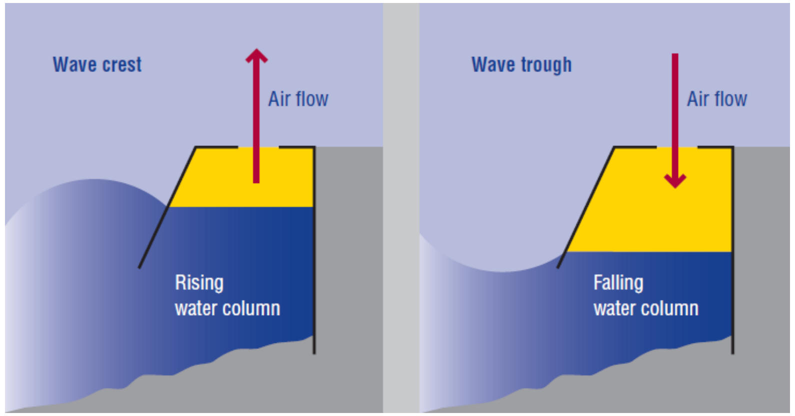
CAPACITY FACTOR
14%

REFERENCES
[2,18]

Note: The reference for power and weight *WEC* data is the report "*SI Ocean Strategic Iniciative for Ocean Energy – 2012", elaborated and signed by "The European Ocean Energy*" agency and "*The University of Edinburgh*", *references [2,18]*. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a WEC located in latitude 41°25'N, longitude 8°50'W, Portugal. In this area, the annual average wave energy flux is 33.7 kW/m. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.10 The WAVEGEN 0.5 MW model



MODEL **WAVEGEN 0.5 MW**
BRANCH **VOITH**
COUNTRY (German flag)
EMEC CLASS **(D) Oscillating Water Column**

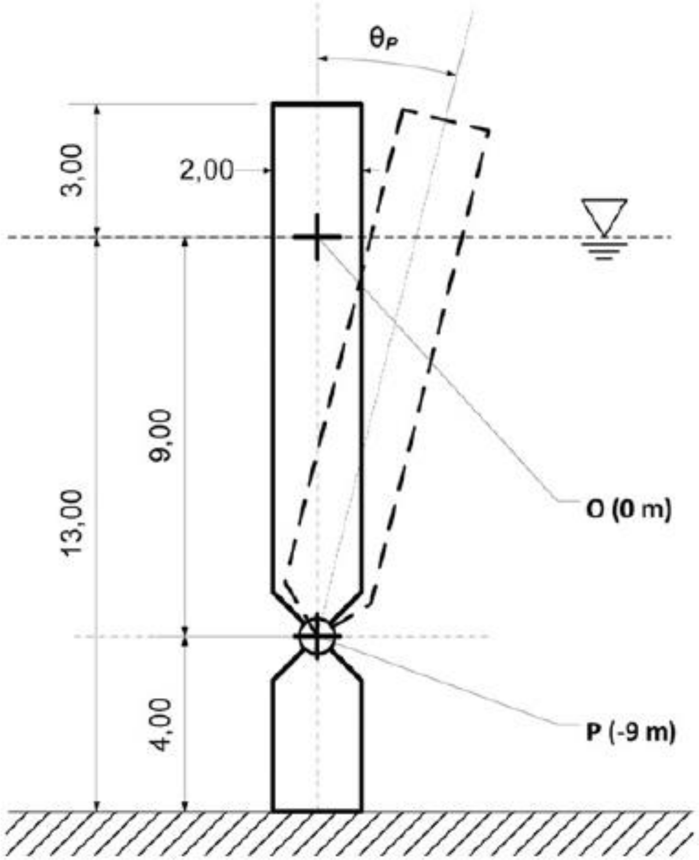
FIRST-GENERATION WEC

WEC-KPI [ton/MW] **11,111**
WEIGHT (ton) **1,000**
AVERAGE ANNUAL POWER (kW) **90**
CAPACITY FACTOR **18%**
REFERENCES **[2,26] [5,12&56]**

Note: The reference for power and weight WEC data is the report *"SI Ocean Strategic Iniciative for Ocean Energy – 2012"*, elaborated and signed by *"The European Ocean Energy"* agency and *"The University of Edinburgh", references [2,26] [5,12&56]*. Moreover, the power and weight WEC data corresponding to the theoretical performance for a WEC located in latitude 41°25'N, longitude 8°50'W, Portugal. In this area, the annual average wave energy flux is 33.7 kW/m. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.11 The OYSTER2 0.8 MW model



MODEL **OYSTER2 0.8 MW**	
BRANCH **AQUAMARINE POWER**	
COUNTRY 	
EMEC CLASS **(C) Oscillating Wave Surge Converter**	

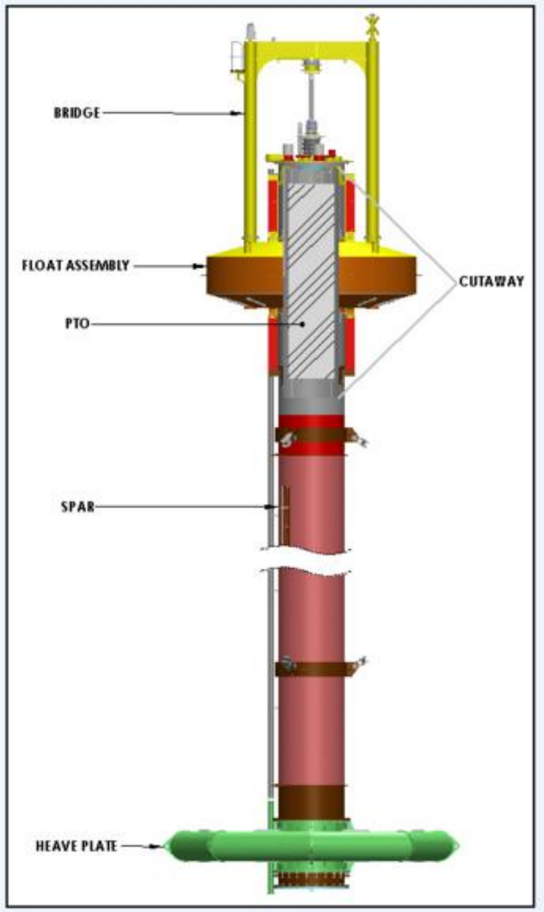
FIRST-GENERATION WEC

WEC-KPI [ton/MW] **10,201**	
WEIGHT (ton) **5,233**	
AVERAGE ANNUAL POWER (kW) **513**	
CAPACITY FACTOR **64%**	
REFERENCES **[1,4&14]**	

Note: The reference for power and weight *WEC* data is the scientific paper "*A. Babarit et al. – Numerical Benchmarking study of a selection of wave energy converters – 2011*", *references [1,4&14]*. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portuga*l. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.12 The OPTPB40 0.04 MW model



MODEL	**OPTPB40 0.04 MW**
BRANCH	**OCEAN POWER**
COUNTRY	(flag of the United States)
EMEC CLASS	**(B) Point Absorber**

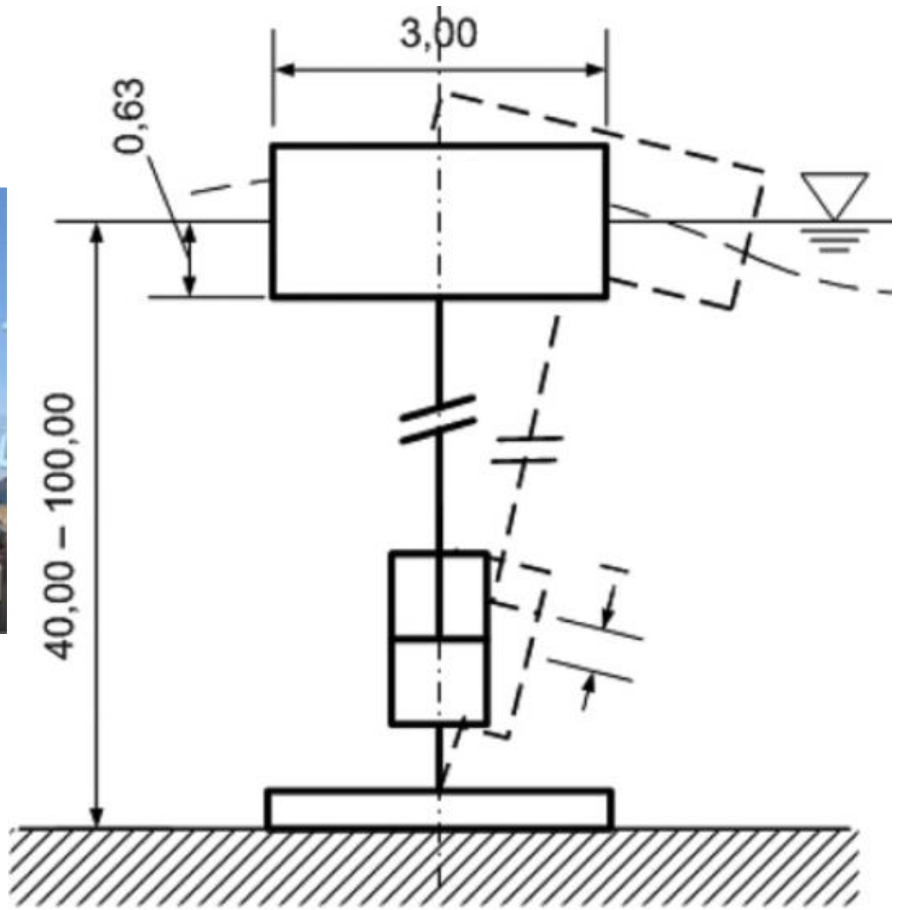
SECOND-GENERATION WEC

WEC-KPI [ton/MW]	**9,500**
WEIGHT (ton)	**114**
AVERAGE ANNUAL POWER (kW)	**12**
CAPACITY FACTOR	**30%**
REFERENCES	**[2,20]**

Note: The reference for power and weight WEC data is the report *"SI Ocean Strategic Iniciative for Ocean Energy – 2012"*, elaborated and signed by *"The European Ocean Energy"* agency and *"The University of Edinburgh" , references [2,20]*. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portuga*l. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.13 The BUOY 0.03 MW model



MODEL **BUOY 0.03 MW**
BRANCH **SEABASED**
COUNTRY
EMEC CLASS **(B) Point Absorber**

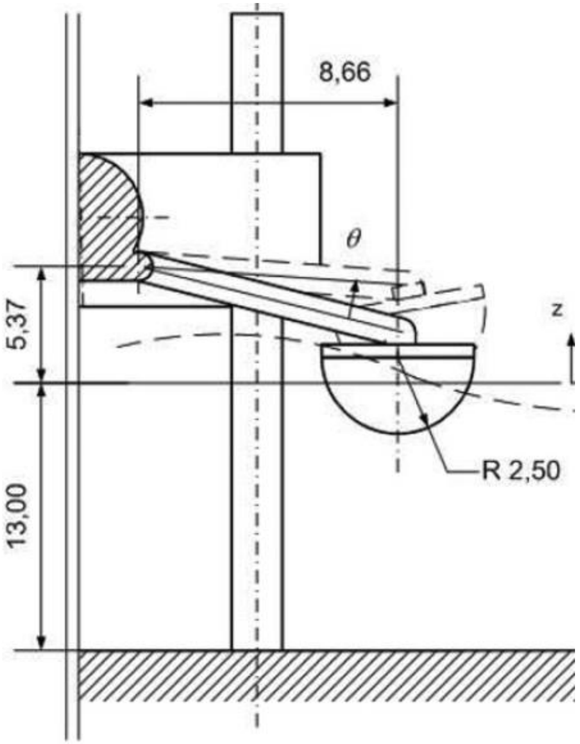
SECOND-GENERATION WEC

WEC-KPI [ton/MW] **8,857**
WEIGHT (ton) **31**
AVERAGE ANNUAL POWER (kW) **4**
CAPACITY FACTOR **14%**
REFERENCES **[1,2&52] [2,22]**

Note: The reference for power and weight *WEC* data is the scientific paper "*A. Babarit et al. – Numerical Benchmarking study of a selection of wave energy converters – 2011", references [1,2&52] [2,22]*. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portuga*l. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.14 The WAVESTAR 3MW model



MODEL **WAVESTAR 3 MW**
BRANCH **WAVE STAR ENERGY**
COUNTRY
EMEC CLASS **(B) Point Absorber**

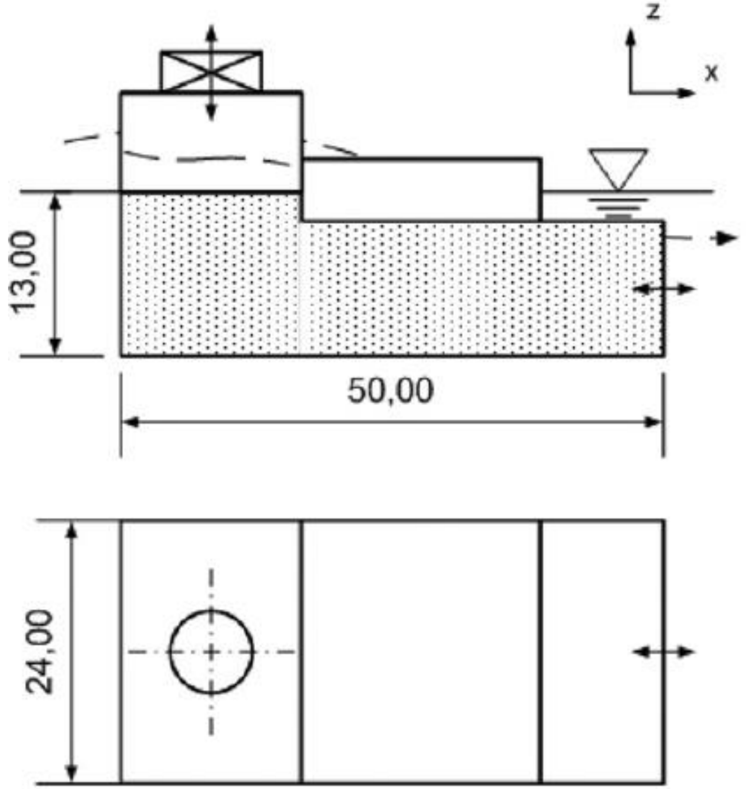
SECOND-GENERATION WEC

WEC-KPI [ton/MW] **5,281**
WEIGHT (ton) **1,600**
AVERAGE ANNUAL POWER (kW) **303**
CAPACITY FACTOR **10%**
REFERENCES **[1,3&12]**

Note: The reference for power and weight *WEC* data is the scientific paper "*A. Babarit et al. – Numerical Benchmarking study of a selection of wave energy converters – 2011*", *references [1,3&12].* Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W*, *Portugal*. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.15 The OE BUOY 2.8 MW model



MODEL **OE BUOY 2.8 MW**
BRANCH **MARINE RENEWABLE ENERGY**
COUNTRY
EMEC CLASS **(D) Oscillating Water Column**

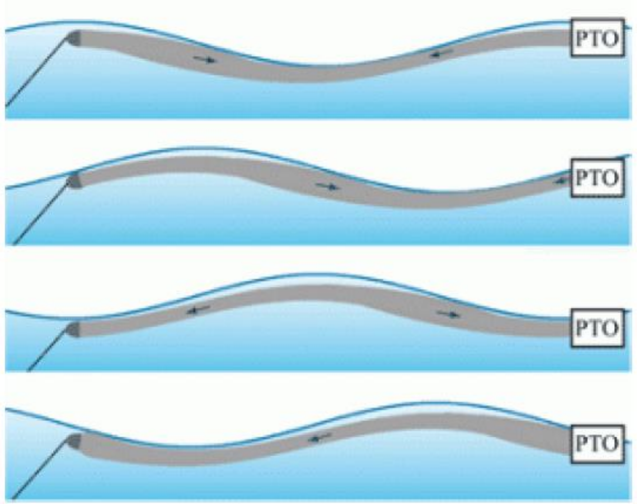
SECOND-GENERATION WEC

WEC-KPI [ton/MW] **4,905**
WEIGHT (ton) **1,800**
AVERAGE ANNUAL POWER (kW) **367**
CAPACITY FACTOR **13%**
REFERENCES **[1,4&16] [2,28]**

Note: The reference for power and weight *WEC* data is the scientific paper "*A. Babarit et al. – Numerical Benchmarking study of a selection of wave energy converters – 2011*", *references [1,4&16] [2,28]*. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portuga*l. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.16 The ANACONDA 1 MW model



MODEL **ANACONDA 1 MW**
BRANCH **CHECKMATE SEAENERGY LTD.**
COUNTRY 
EMEC CLASS **(G) Other - Bulge Wave**

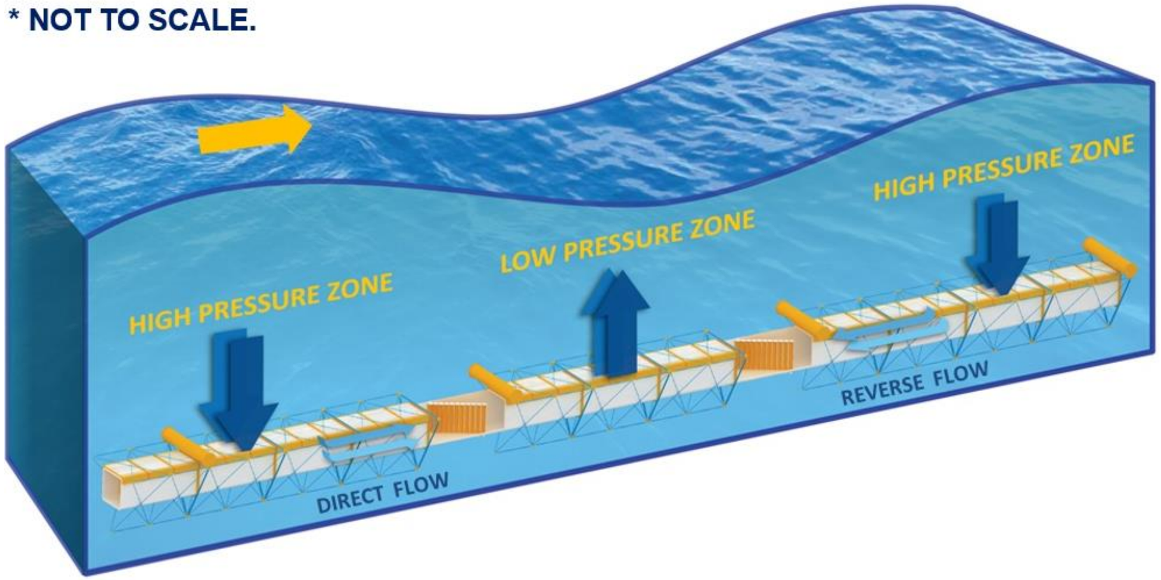
THIRD-GENERATION WEC

WEC-KPI [ton/MW] **746**
WEIGHT (ton) **500**
AVERAGE ANNUAL POWER (kW) **670**
CAPACITY FACTOR **67%**
REFERENCES **[9] [10]**

Note: The report "*Impact assessment of a new wave energy converter, Anaconda – 2009*", thesis work done at *"The University of Southampton"*, *references [9] [10].* Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W*, *Portuga*l. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Figure 5.17 The ETYMOL 4 MW model



MODEL **ETYMOL 4 MW**
BRANCH **ETYMOL OCEAN POWER SPA**
COUNTRY (flag of Chile)
EMEC CLASS **(I) Other**

THIRD-GENERATION WEC

WEC-KPI [ton/MW] **468**
WEIGHT (ton) **920**
AVERAGE ANNUAL POWER (kW) **1,964**
CAPACITY FACTOR **49%**
REFERENCES **[3]**

Note: The "*Basic Engineering of the Etymol 4 MW Model Wave Power Plant – 2016*", elaborated and signed by the "*Etymol Ocean Power SpA*", references *[3]*. Moreover, the power and weight *WEC* data corresponding to the theoretical performance for a *WEC* located in *latitude 41°25'N, longitude 8°50'W, Portuga*l. In this area, the annual average wave energy flux is *33.7 kW/m*. By providing estimates of annual energy absorption in realistic conditions for the structure proposed for wave energy conversion, the first aim of this technical note is to contribute to clarifying what can reasonably be expected as the mean output of a similar wave energy converter.

5. ETYMOL WAVE POWER PLANT BENCHMARKING

Table 5.18 The Benchmarking of Thirteen WEC´s Selection

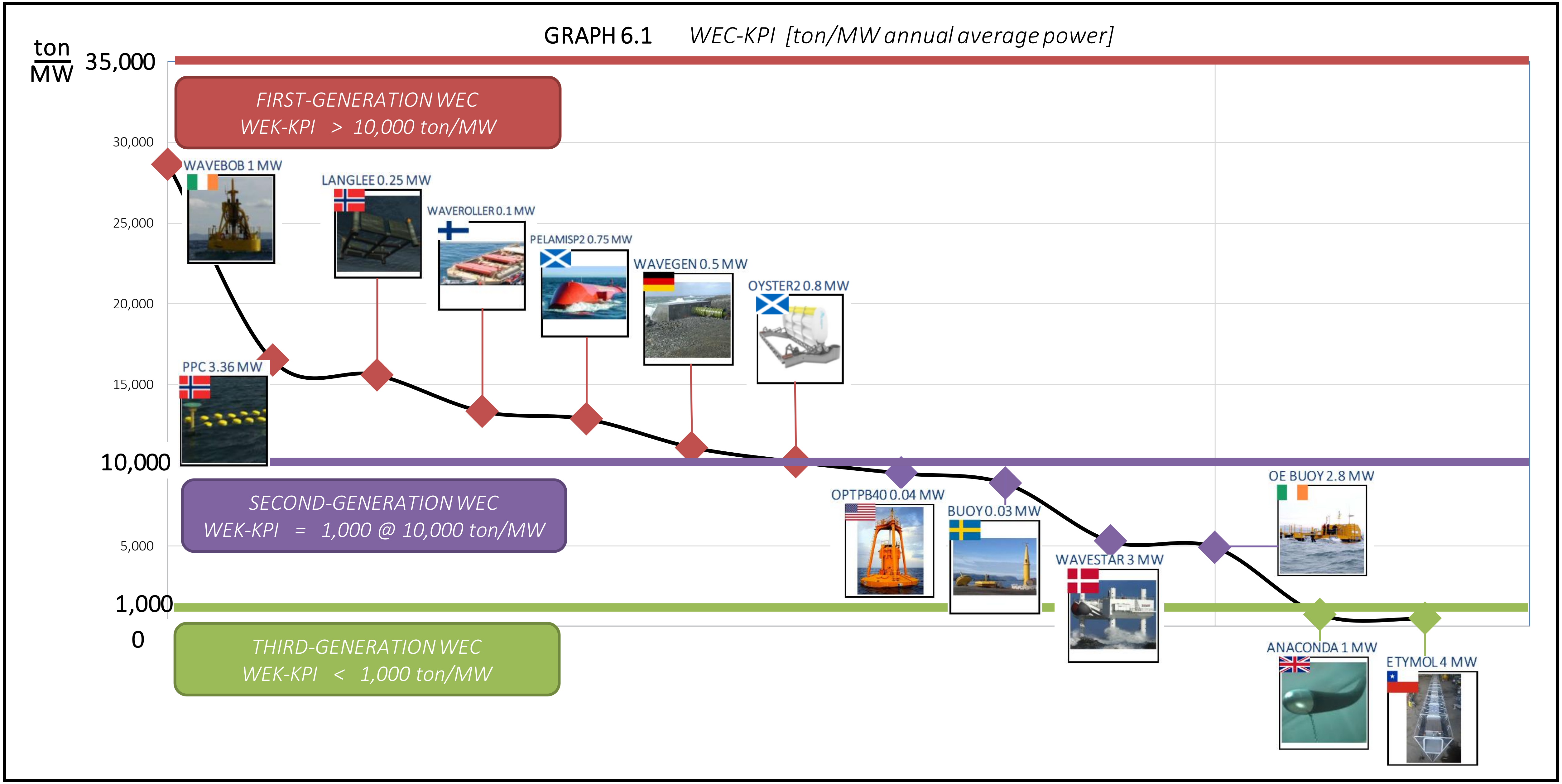
WEC MODEL	WEC BRANCH	COUNTRY	EMEC WEC CLASS	WEC-KPI ton/MW	WEIGHT ton	RATED POWER OUTPUT kW	CAPACITY FACTOR %	AVERAGE ANNUAL POWER kW	REFERENCE
WAVEBOB 1 MW	WAVEBOB LTD.	IRELAND	B	28,663	5,704	1,000	20%	199	[1,2&11]
PPC 3.36 MW	PONTOON POWER AS	NORWAY	B	16,508	5,233	3,620	9%	317	[1,3&13]
LANGLEE 0.25 MW	LANGLEE WAVE POWER	NORWAY	C	15,596	1,622	250	42%	104	[1,4&15] [2,20]
WAVEROLLER 0.1 MW	AW ENERGY	FINLAND	C	13,333	280	100	21%	21	[4] [3,4]
PELAMIS P2 0.75 MW	PELAMIS WAVE POWER	SCOTLAND	A	12,857	1,350	750	14%	105	[2,18]
WAVEGEN 0.5 MW	VOITH	GERMANY	D	11,111	1,000	500	18%	90	[2,26] [5,12&56]
OYSTER2 0.8 MW	AQUAMARINE POWER	SCOTLAND	C	10,201	5,233	800	64%	513	[1,4&14]
OPTPB40 0.04 MW	OCEAN POWER INC	USA	B	9,500	114	40	30%	12	[2,20]
BUOY 0.03 MW	SEABASED	SWEDEN	B	8,857	31	25	14%	4	[1,2&52] [2,22]
WAVESTAR 3 MW	WAVE STAR ENERGY	DENMARK	B	5,281	1,600	3,000	10%	303	[1,3&12]
OE BUOY 2.8 MW	MARINE RENEWABLE ENERGY	IRELAND	D	4,905	1,800	2,800	13%	367	[1,4&16] [2,28]
ANACONDA 1 MW	CHECKMATE SEAENERGY LTD	UK	G	746	500	1,000	67%	670	[9] [10]
ETYMOL 4 MW	ETYMOL OCEAN POWER SPA	CHILE	I	468	920	4,000	49%	1,964	[3]

FIRST-GENERATION WEC > 10,000 ton/MW

SECOND-GENERATION WEC 1,000 @ 10,000 ton/MW

THIRD-GENERATION WEC < 1,000 ton/MW

6. WHERE'S THE FUTURE OF THE WEC´S INDUSTRY GOING



6. WHERE'S THE FUTURE OF THE WEC´S INDUSTRY GOING

Figure 6.2 "*THIRD-GENERATION WEC*" <1,000 ton/MW

ETYMOL
1:5 PROTOTYPE

ANACONDA
1:50 PROTOTYPE

The two most efficient technologies: *Anaconda* and *Etymol*, have five similar features:

- Efficiency of the working principle(< *1,000 ton/MW*)
- Geometry, long (>*150 m*) and narrow structures, oriented to the wave direction.
- Operation: Underwater devices (> *5 m*).
- Devices that work in deep waters (depths > *40 m*)
- Working principle based in the absorption of the wave of pressure in order to drive a seawater flow (or flow of oil) in a natural and direct way. This working principle is highly *energy-efficient*, because this type of *WEC* works driving the pressure wave across the *WEC* vessel hull turning it naturally and directly into kinetic energy without any moving parts.

ETYMOL®
OCEAN POWER

6. WHERE’S THE FUTURE OF THE WEC´S INDUSTRY GOING

The question then is “*Where’s the Future of the WEC´s Industry Going*”. To answer this question, we think that the evidence points to “*Third-Generation WEC*”, that by definition are those whose *WEC-KPI* coefficient is less than *1,000 [ton/MW]*. The only known wave energy plants described in the state of the art analysis that qualify as a “*Third-Generation WEC´s*” are:

- *“Anaconda Wave Energy Plant”*
- *“Etymol Wave Energy Plant”*

Figure 6.3 *Etymol 4 MW Model Wave Power Plant*

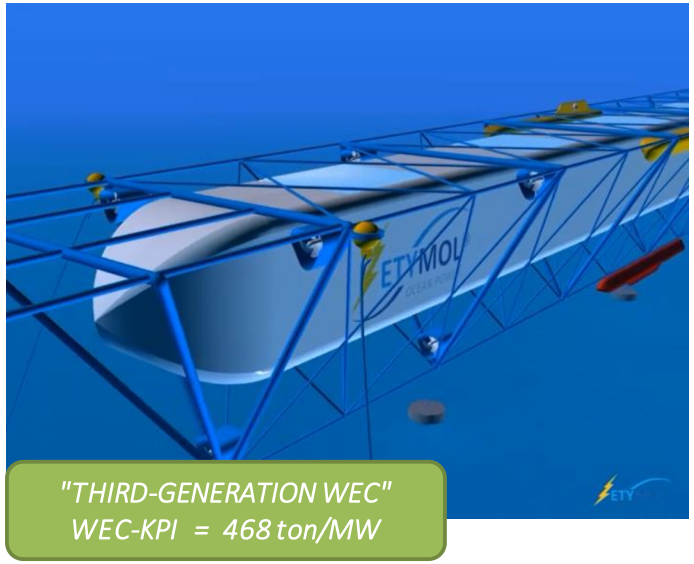


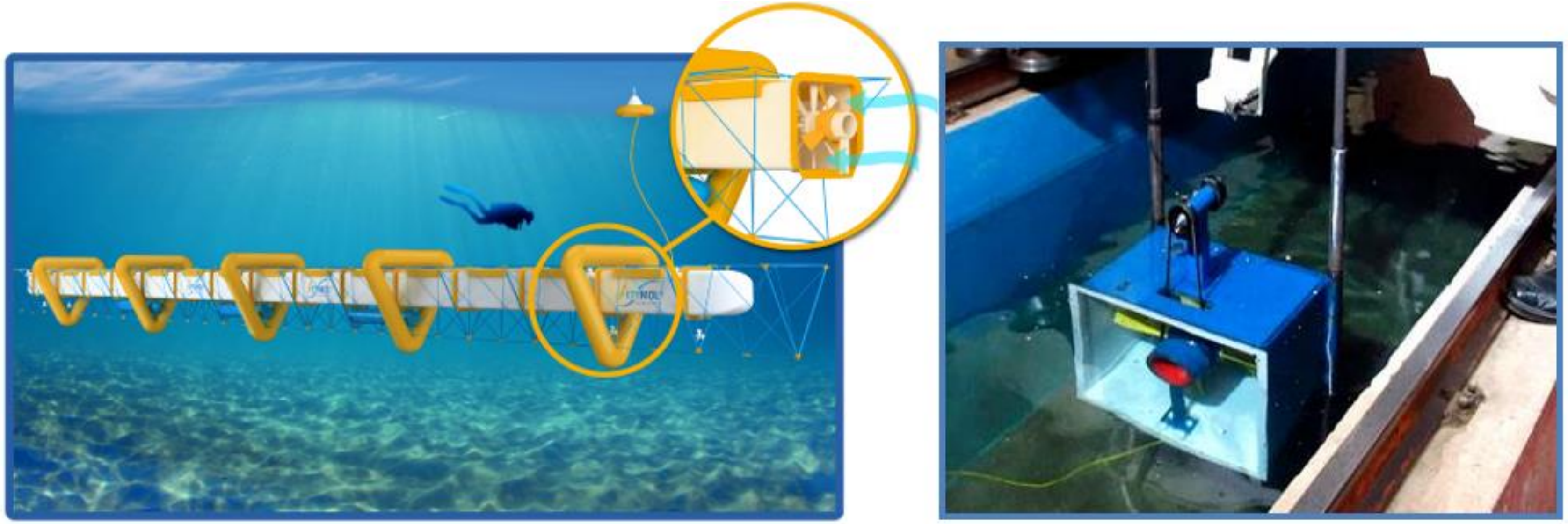
Figure 6.4 *Anaconda 1 MW Model Wave Power Plant*

ETYMOL® OCEAN POWER

6. WHERE’S THE FUTURE OF THE WEC´S INDUSTRY GOING

Updated information is scarce, so for each *WEC* described in this report, both the source and its release date is particularly listed, see the following section. Moreover, the power and weight *WEC* data corresponding to the theoretical performance. Some of the *WEC* model are from the *year 2011*. Nowadays, in *2016*, many of the technologies listed on this document have evolved and developed new prototypes and even in some cases, they may have increased their wave power converting principle efficiency.

Figure 6.5 *Etymol 1:5 Model Wave Power Plant, Power Take Off Testing*



ETYMOL®
OCEAN POWER

7. CONCLUSIONS

"*Etymol Power Plant*" has a low initial investment and operational cost in comparison to a fossil fuel power generation, or any other electric power generation system. The unique features are: operation below sea surface (submerged) in deep-water, generating electricity from the waves differential pressure. Finally, we firmly believe that "*Etymol Technology*" is the most profitable and sustainable form of wave energy in the known state of the art.

Figure 7.1 *Etymol 1:5 Model Wave Power Plant*

8. REFERENCES

[1] The scientific paper *“A. Babarit et al. – Numerical Benchmarking Study of A Selection of Wave Energy Converters – 2011”*.

[2] The report "*SI Ocean Strategic Initiative for Ocean Energy – 2012*", elaborated and signed by "*The European Ocean Energy”* agency and *“The University of Edinburgh”*.

[3] The *“Basic Engineering of the Etymol 4 MW Model Wave Power Plant – 2016”*, elaborated and signed by the "*Etymol Ocean Power SpA”*.

[4] Website – *2016*: aw-energy.com *“A first in independent verification. The electricity output from a single WaveRoller 100kW-unit during a 24-hour period with significant wave height of 2.5m, typical at the Peniche project site in Portugal was 500 kWh”, WaveRoller 100 kW-unit* weight *280 tons*.

8. REFERENCES

[5] The report "*Islay Limpet Wave Power Plant – 2001*", elaborated and signed by *“The Queen’s University of Belfast”, research funded in part by“* The European Commission in the Framework of the non Nuclear Energy Programme Joule III”.

[6] The scientific paper *“Kester Gunn et al. – Quantifying the Global Wave Power Resource – 2012”*

[7] The scientific paper *“Gunnar Mørk et al. – Assessing the Global Wave Energy Potential Year – 2010”*

[8] The report "*Key World Energy Statistics – 2015*", elaborated and signed by *“IEA”* (www.iea.org)."

[9] The report *“Impact assessment of a new wave energy converter, Anaconda – 2009”*, thesis work done at the *“University of Southampton”*.

8. REFERENCES

[10] The Innovations Case Study CTS153 "*Rubber snakes seek to slash cost of wave power – 2009*", report work done at the "*Carbon Trust*" (www.carbontrust.com).

[11] "*The European Marine Energy Centre*" website – 2016 (www.emec.org.uk).

[12] The report "Marine Energy Development Taking Steps for Developing the Chilean Resource – 2013", prepared for the "*British Embassy in Chile*" *by* "*Errázuriz & Asociados Ingenieros*" in cooperation with the "*University of Edinburgh*" and the Chilean law firm "*Guerrero, Olivos, Novoa y Errázuriz*".

ETYMOL®
OCEAN POWER

8. REFERENCES

[13] *“The Ocean Power Technologies Inc.”* website – 2016: www.oceanpowertechnologies.com/powerbuoy, *“The average annual output power from a single OPTPB40 40 KW Model, site dependent, 9 kW to 15 kW. The OPTPB40 weight is 114,220 kg*”. Other references [2,20].

[14] The scientific paper “Kester Gunn *et al. –Quantifying the global wave power resource – 2012*”.

ETYMOL® OCEAN POWER

ETYMOL®
OCEAN POWER

Ing. Lorenzo Sáenz M.

e-mail: saenz@etymol.com

www.etymol.com