Türkiye Offshore Energy Conference, Istanbul, 19-21 June 2013

DEVELOPMENTS IN WAVE ENERGY CONVERSION

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SUMMARY

- The resource
- The technologies
- The power take-off equipment
- The situation of wave energy conversion
- Wave energy conversion in the Mediterranean

THE RESOURCE

WAVE ENERGY

SOLAR ENERGY

↓

WIND ENERGY

↓

WAVE ENERGY

Typical values of wave energy flux per unit wave crest length (annual average)

Deep water: 4-70 kW/m

Near shore: lower values,
Depending on:

- bottom slope
- local depth (wave breaking)
- bottom roughness (friction)
- bottom configuration (diffraction, refraction)

Close to the surface (h<20m): density flux of energy (kW/m^2) can be much higher than wind energy

THE WAVES AS ENERGY RESOURCE

The waves are generated by the wind.

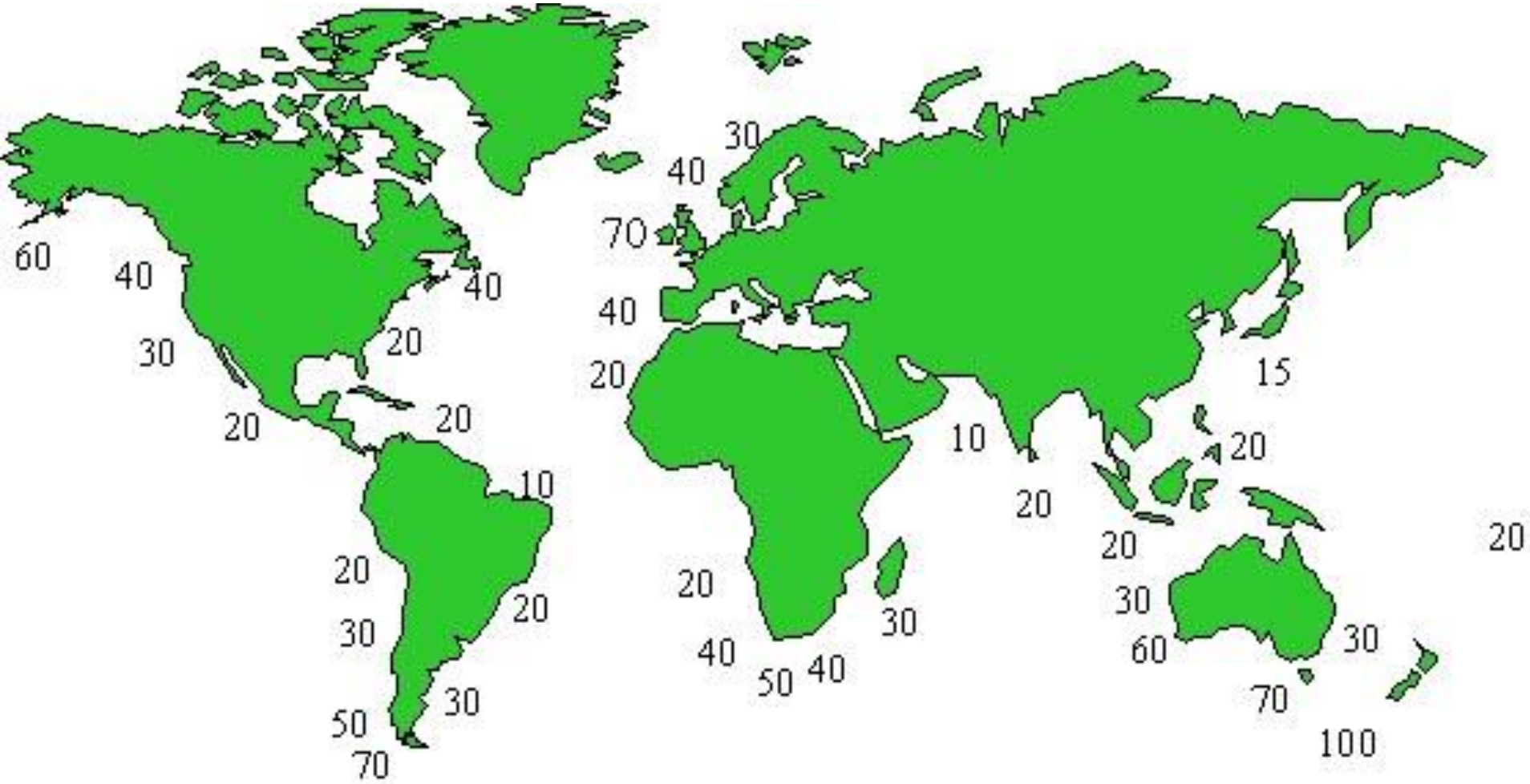
In deep water (> 100 - 200m) they travel large distances (thousands of km) practically without dissipation.

The characteristics of the waves (height, period, etc.) depend on:

- **Sea surface area acted upon by the wind (large oceans versus Mediterranean)**
- **Duration of wind action**

World distribution of wave energy level

Annual-averaged values in kW/m (deep water, open sea)

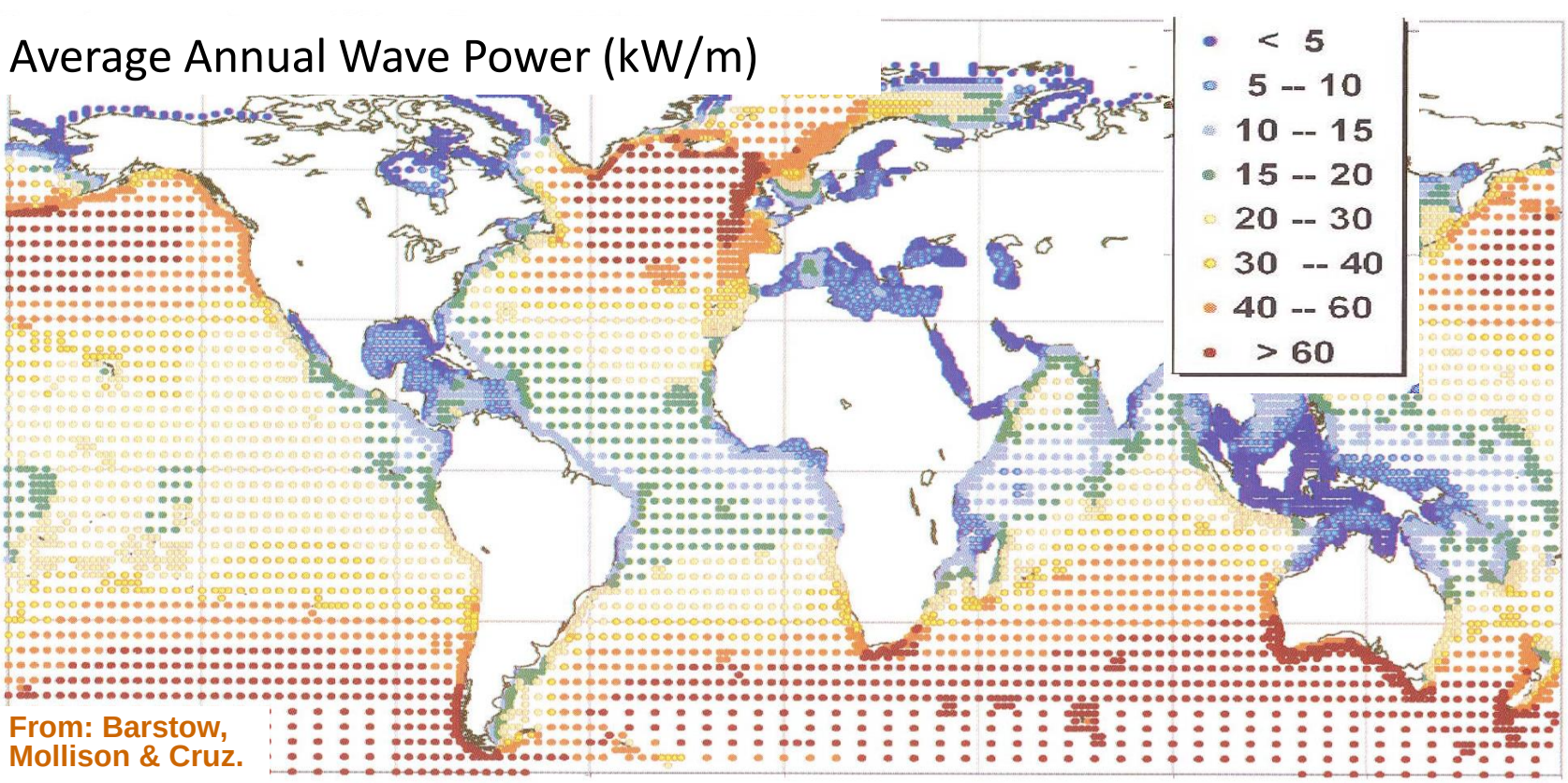


Wave Energy Resource

• **The total theoretical wave power resource in the oceans is very large: 1-10 TW** (average world electrical power consumption: 2 TW).

- **It is larger**
  - off western coasts of the continents (Coriolis force)
  - in moderate to high latitudes

Average Annual Wave Power (kW/m)



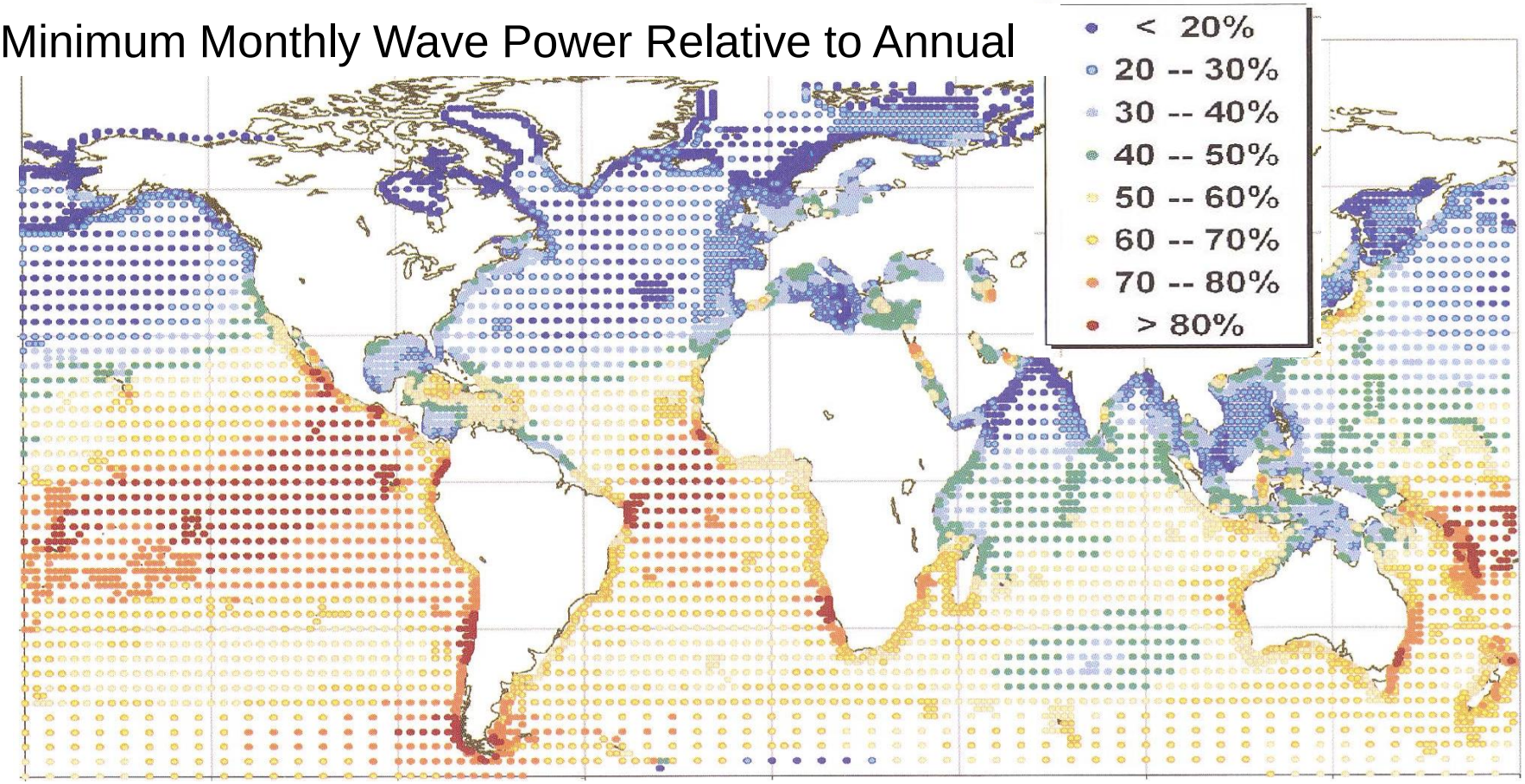
From: Barstow, Mollison & Cruz.

Wave Energy Resource

Seasonal Variation

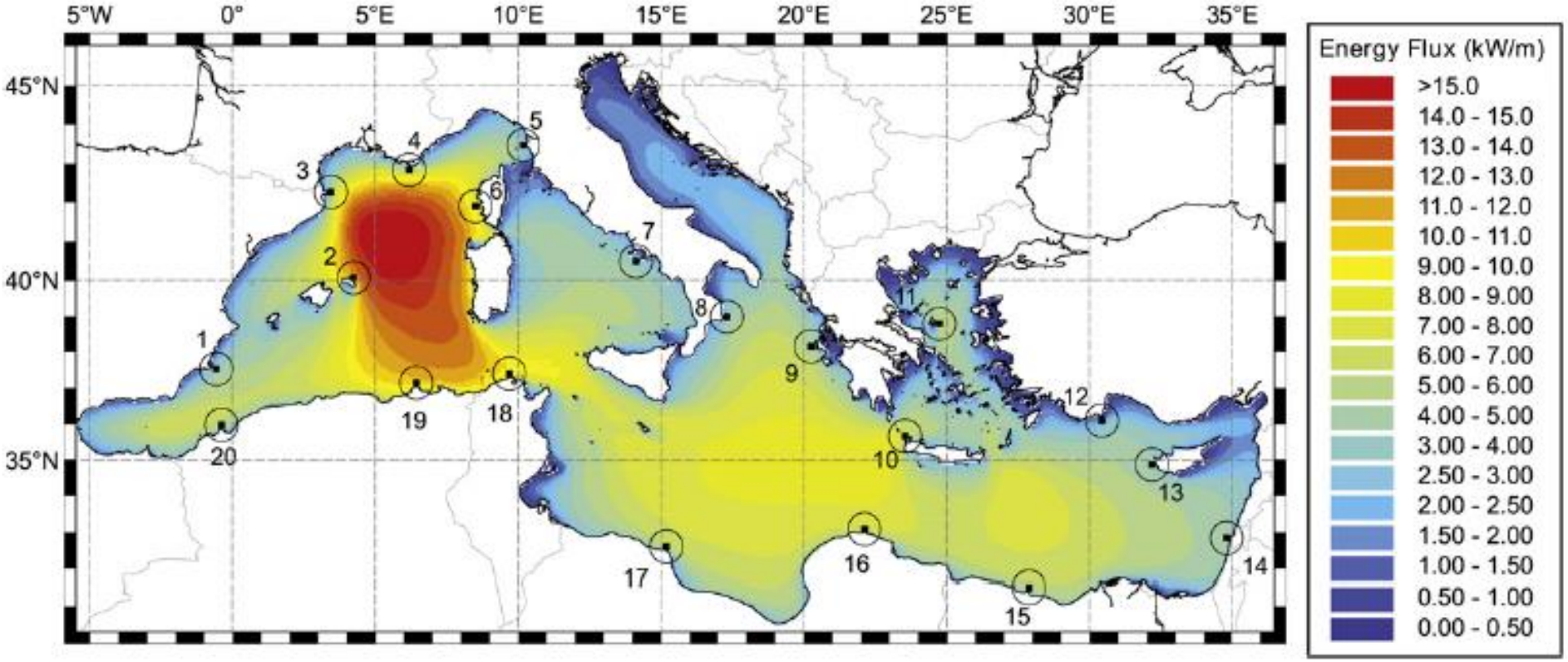
Seasonal variations are much larger in the Northern Hemisphere than in the Southern Hemisphere (an important advantage)

Minimum Monthly Wave Power Relative to Annual



From: Barstow, Mollison & Cruz, 2008

Distribution of average power per unit crest length in the **Mediterranean**, 2001-2010

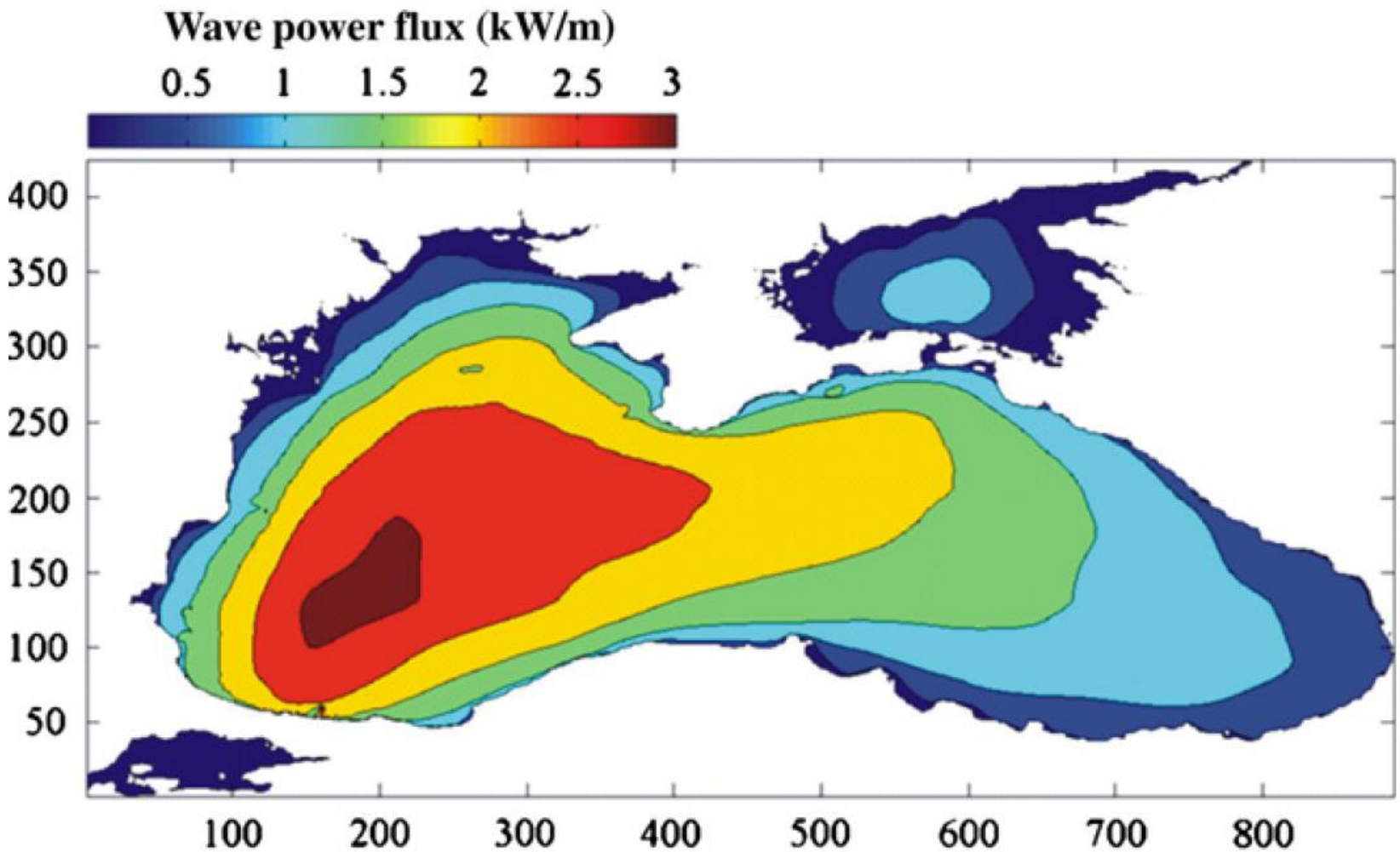


L. Liberti, A. Carillo, G. Sannino, Wave energy resource in the Mediterranean, the Italian perspective. *Renewable Energy*, vol. 50, p. 938-949, 2013

Site	Location	Lon.	Lat.	Depth (m)	J_{mean} (kW/m)	E_{annual} (MWh/m)
1	Cabo de Palos (Es)	−0°33′45″	37°34′30″	121	3.91	34.25
2	Menorca (Es)	4°15′0″	40°4′30″	65	10.90	95.48
3	Cabo Creus (Es)	3°26′15″	42°19′30″	439	5.34	46.78
4	Hyères (Fr)	6°11′15″	42°53′15″	1476	6.47	56.68
5	Livorno (It)	10°11′15″	43°30′45″	83	3.24	26.02
6	Ajaccio (Fr)	8°30′0″	41°57′0″	786	8.44	73.93
7	Napoli (It)	14°7′30″	40°30′45″	782	3.51	30.70
8	Crotone (It)	17°18′45″	39°0′45″	615	3.70	32.41
9	Kefallonia (Gr)	20°15′0″	38°12′0″	1512	4.91	43.01
10	Ag. Gramvousa (Gr)	23°33′45″	35°42′0″	374	7.10	62.20
11	Skyros (Gr)	24°45′0″	38°49′30″	269	5.16	45.20
12	Gelydonia Burnu (Tr)	30°26′15″	36°8′15″	444	2.26	19.80
13	Peyia (Cy)	32°11′15″	34°53′15″	1290	3.83	33.55
14	Haifa (Il)	34°48′45″	32°45′45″	252	4.02	35.22
15	Ras El-Kanayis (Eg)	27°52′30″	31°19′30″	420	5.30	46.43
16	Ras Al Hilal (Ly)	23°33′45″	35°42′0″	374	6.59	57.73
17	Misrata (Ly)	15°11′15″	32°30′45″	161	5.68	49.76
18	Ras Angela (Tn)	9°41′15″	37°27′0″	250	9.25	81.03
19	Cap Bougaouni (Dz)	6°26′15″	37°12′0″	2354	10.33	90.49
20	Orano (Dz)	−0°22′30″	36°0′45″	1428	5.15	45.11

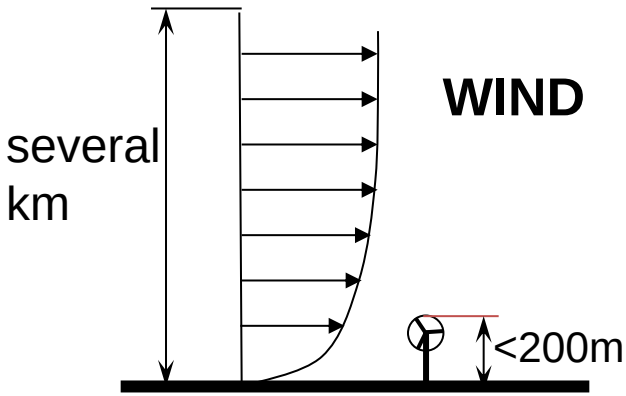
L. Liberti, A. Carillo, G. Sannino, Wave energy resource in the Mediterranean, the Italian perspective. *Renewable Energy*, vol. 50, p. 938-949, 2013

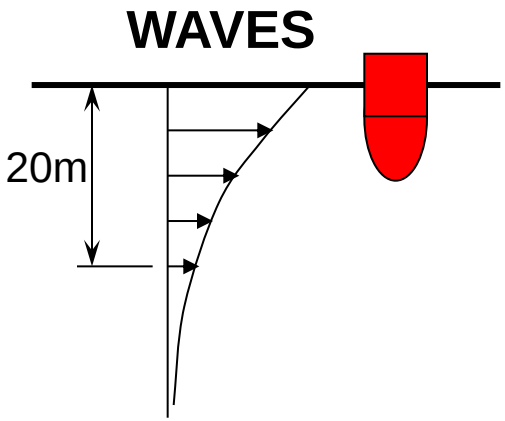
Distribution of average power per unit crest length in the **Black Sea**, from 15-year hindcast data



A. Akpinar, M.I. Kömürcü. Assesssment of wave energy resource of the Black Sea based on 15-year numerical hindcast data. *Applied Energy*, vol. 101, p. 501-512, 2013.

WIND VERSUS WAVES





The wind velocity profile extends over several km.

A wind farm explores a tiny sublayer

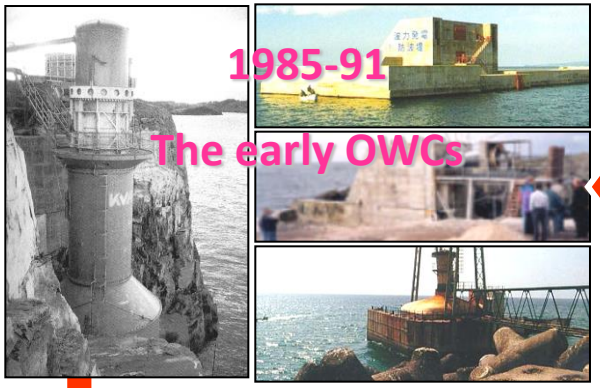
Most of the wave energy flux is concentrated near the surface

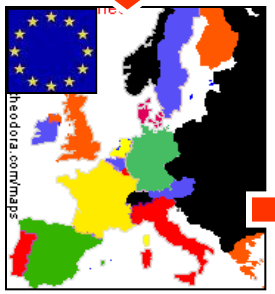
A wave farm can absorb a large part of the wave energy flux.

THE TECHNOLOGIES

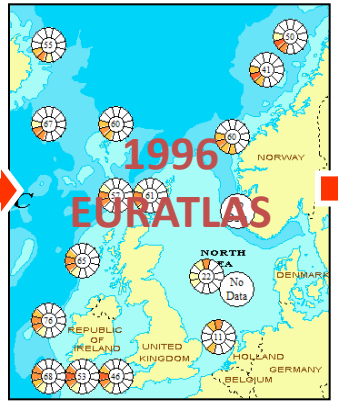
How far have we gone in 40 years ? Some milestones:

1975- …The early theoreticians





1991: EU backs up wave energy



Wave Energy Converter Types

Unlike the case of large wind turbines …

… there is a wide range of wave energy devices, at different development stages, competing against each other.

Wave Energy Converter Types

RESONANCE

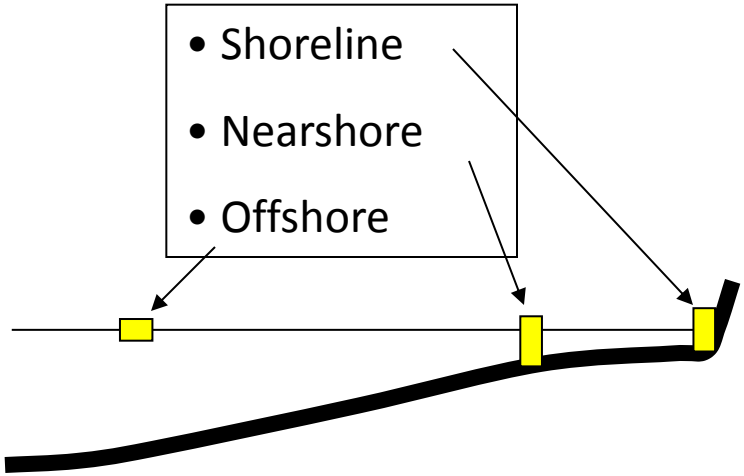
- Oscillating Water Column (with air turbine)
  - Fixed structure
    - Isolated: Pico, LIMPET, Oceanlinx
    - In breakwater: Sakata, Mutriku
  - Floating: Mighty Whale, BBDB, Spar buoy
- Oscillating body (hydraulic motor, hydraulic turbine, linear electric generator)
  - Floating
    - Heaving: Aquabuoy, IPS Buoy, Wavebob, PowerBuoy, FO3
    - Pitching: Pelamis, PS Frog, Searev, SeaRay
  - Submerged
    - Heaving: AWS
    - Bottom-hinged: Oyster, Waveroller

RUN UP

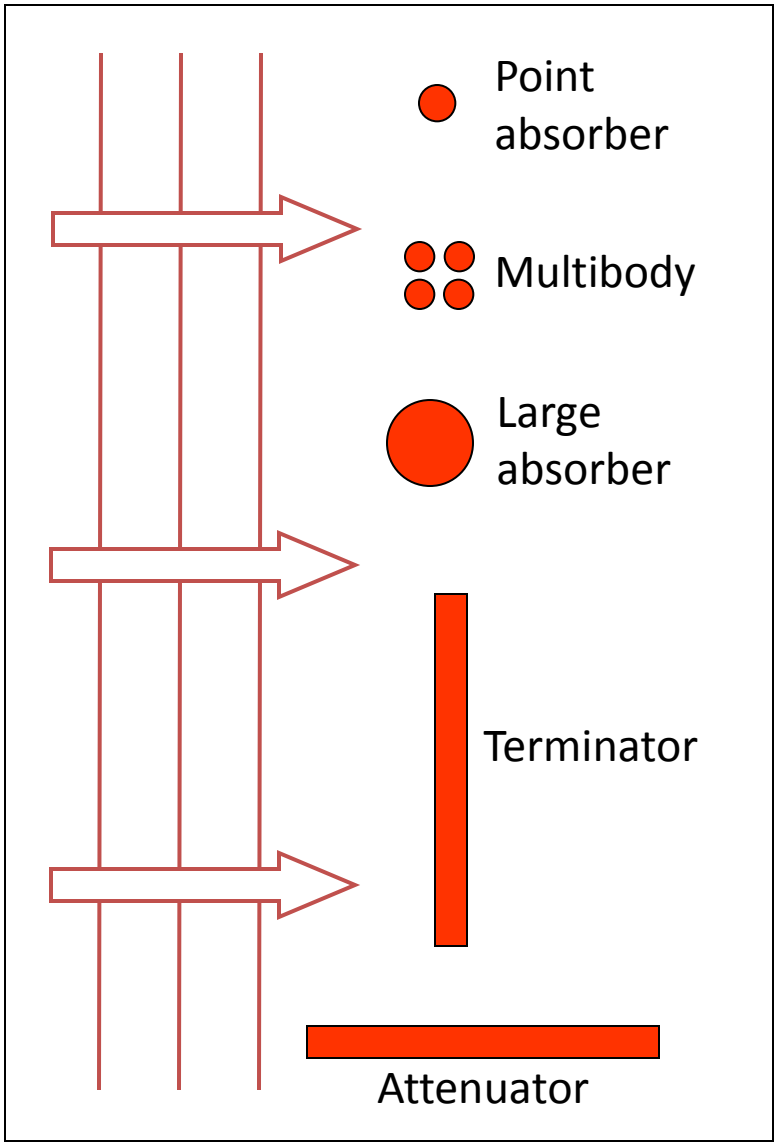
- Overtopping (low head water turbine)
  - Fixed structure
    - Shoreline (with concentration): TAPCHAN
    - In breakwater (without concentration): SSG
  - Floating structure (with concentration): Wave Dragon

Wave Energy Converter Types

Different ways of classifying WECs:

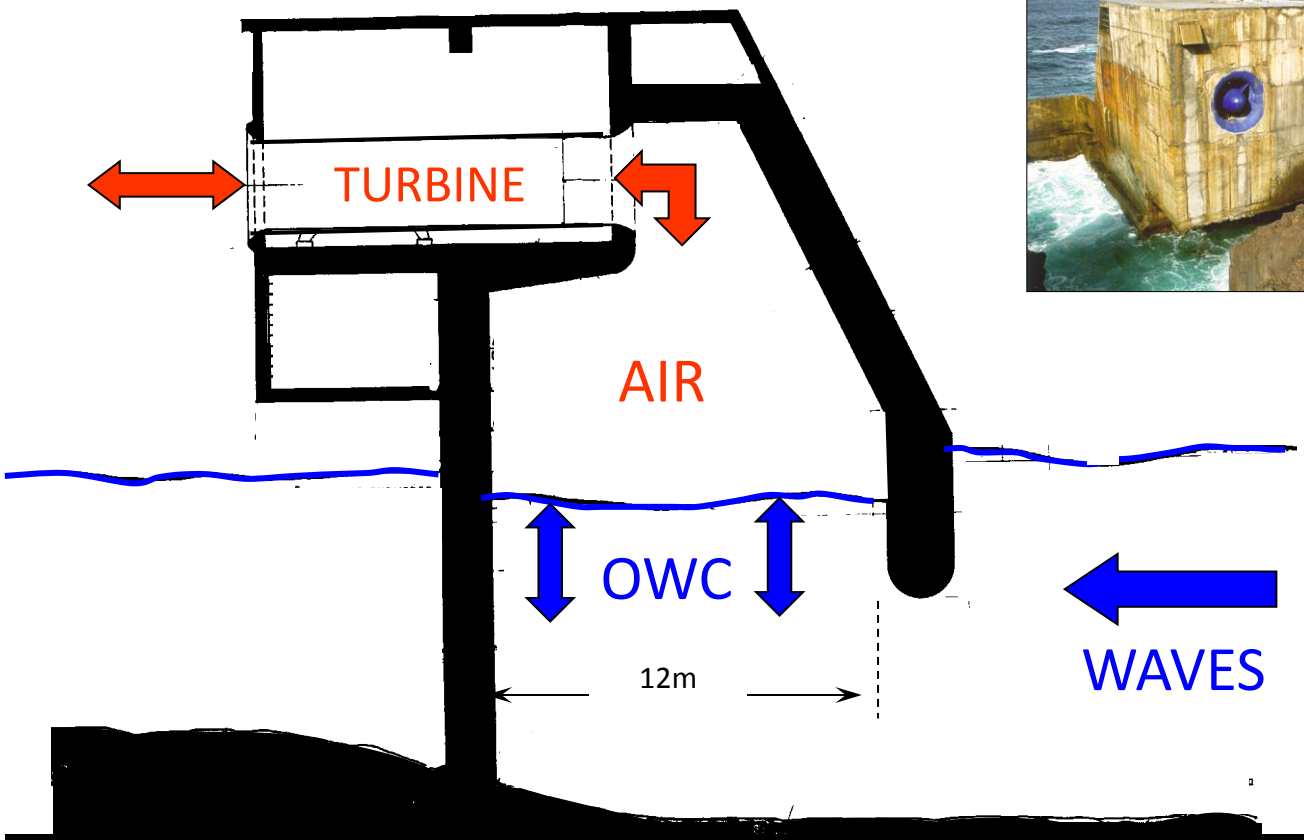


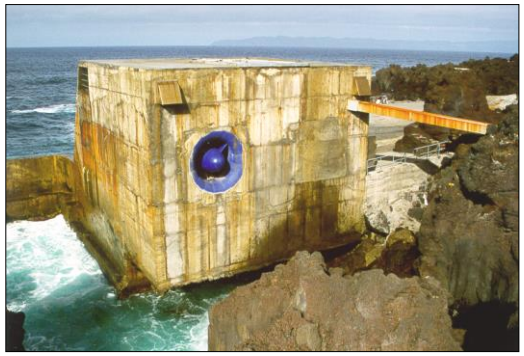
According to working principle



Wave Energy Converter Types

OWC (Oscillating Water Column)





Cross-section of bottom-standing OWC plant.

Earlier OWC prototypes: the structure is fixed to the bottom

Floating OWCs are more appropriate for large-scale exploitation of wave energy.

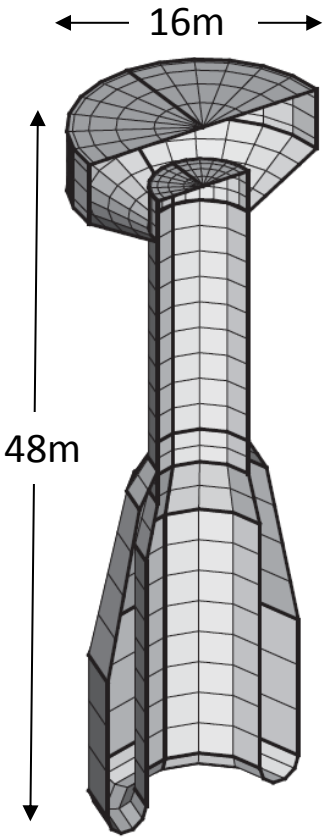
Mighty Whale, Japan, 1998

BBDB, Ireland, 2008

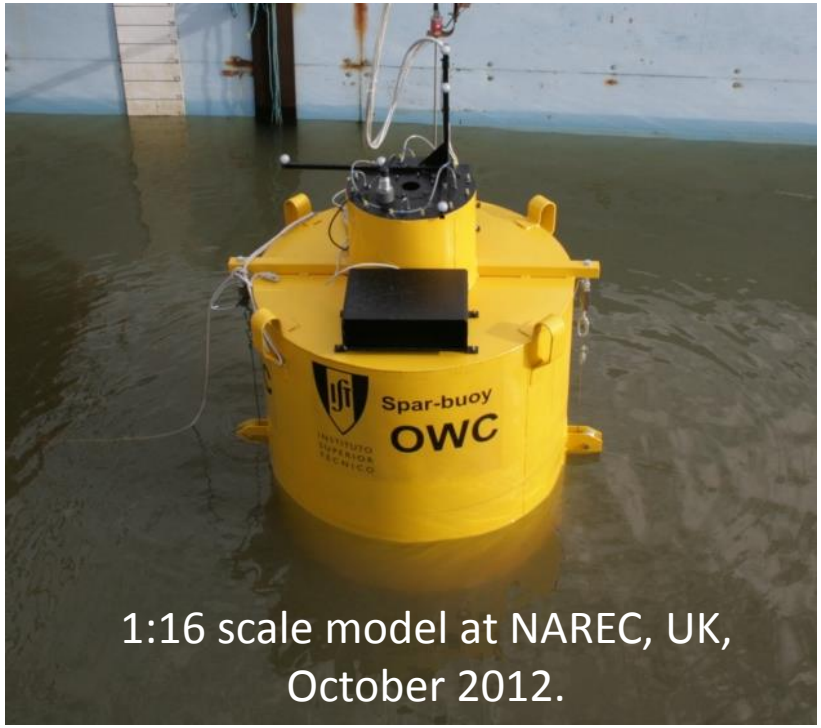
Oceanlinx Mk 3, Australia, 2010

OWC: floating

Spar-buoy OWC

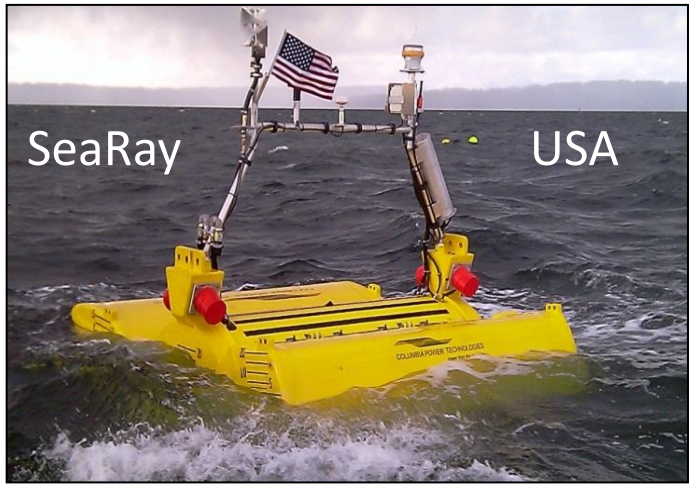


At Nazaré, Portugal, 2012.



1:16 scale model at NAREC, UK, October 2012.

Oscillating Bodies



Multibody

WaveStar, Danmark

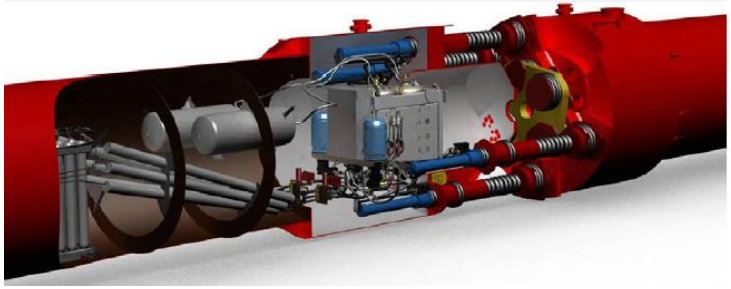
Hyperbaric converter, Brazil

Floating, Multibody,

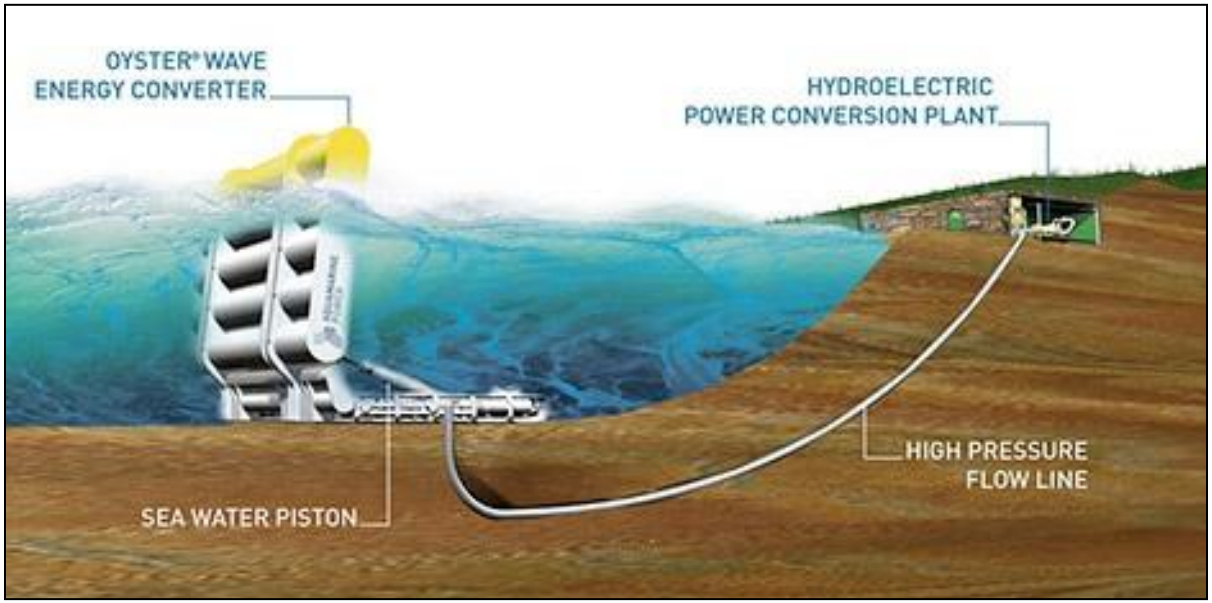
Pelamis, UK

3-unit farm, Portugal, 2008.

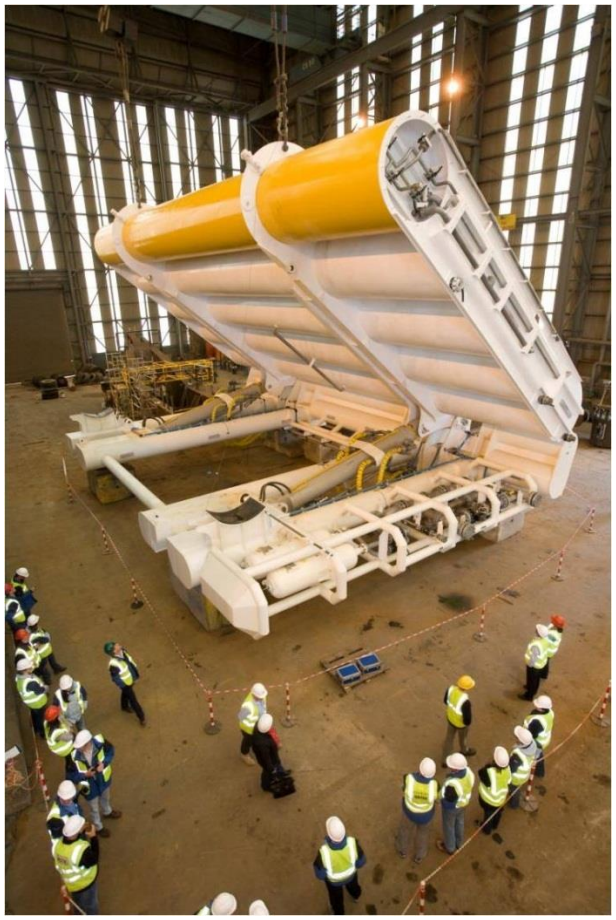
New Mark 2 version



Submerged, Bottom-hinged, Nearshore

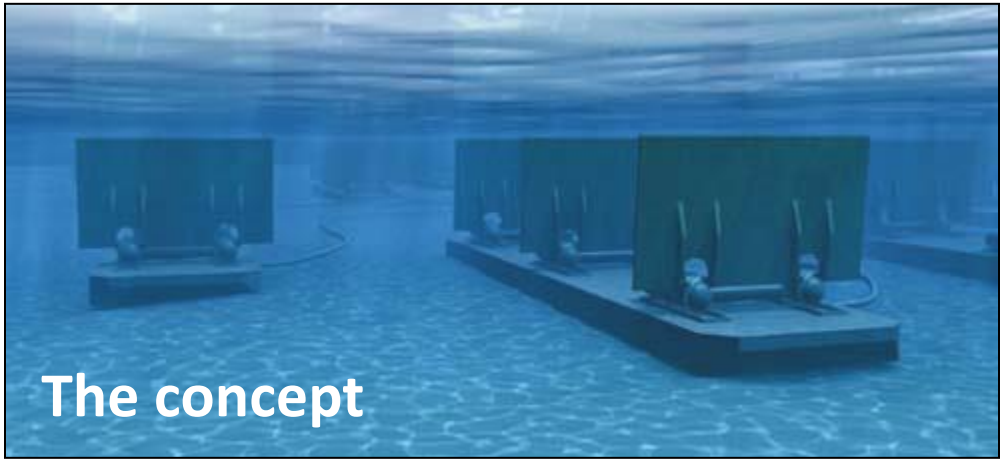


Oyster, UK



Submerged, Bottom-hinged, Nearshore

WaveRoller, Finland



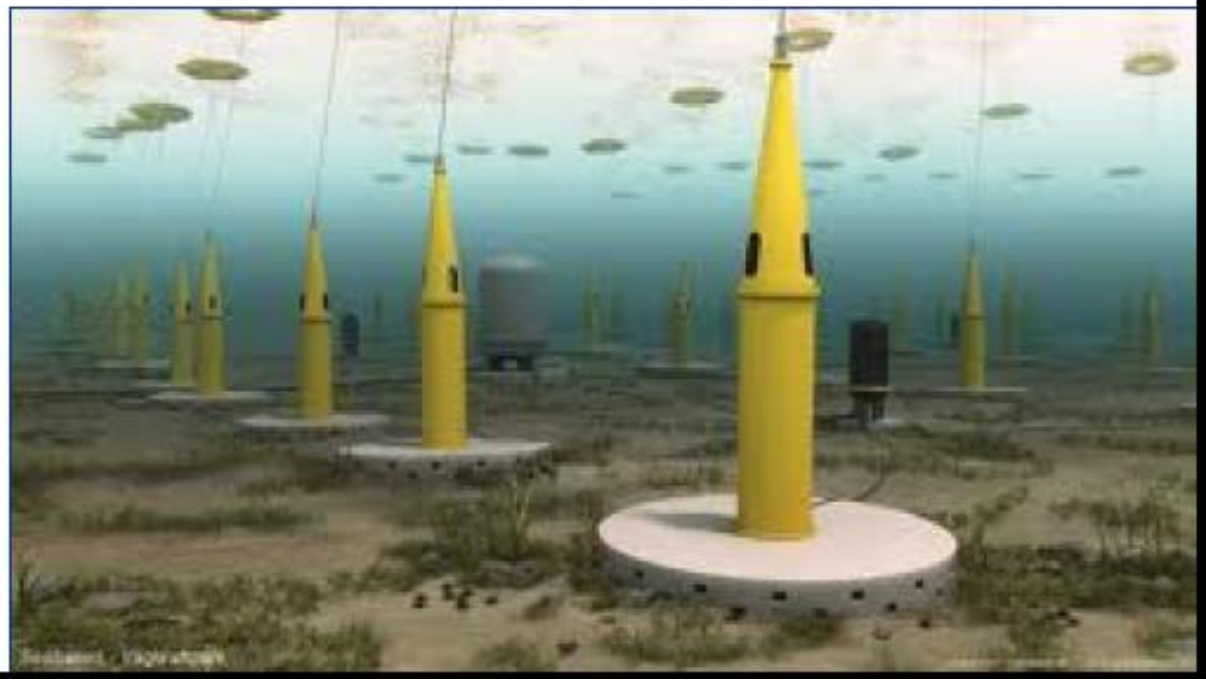
3 x 100 kW, being installed at Peniche, Portugal, 2012

Demonstration – Wave (SWEDEN)

Sotenäs Demonstration project

- **Seabased Industry,** spin-off from the wave energy research at Uppsala University.
- Demonstration wave park
  - **10 MW, ~400 WECs**
  - **€ 29M**
  - **Under construction**

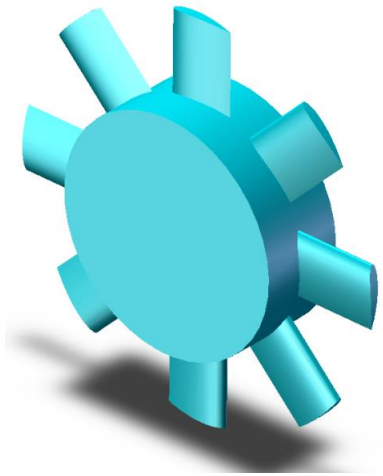
since early 2012.



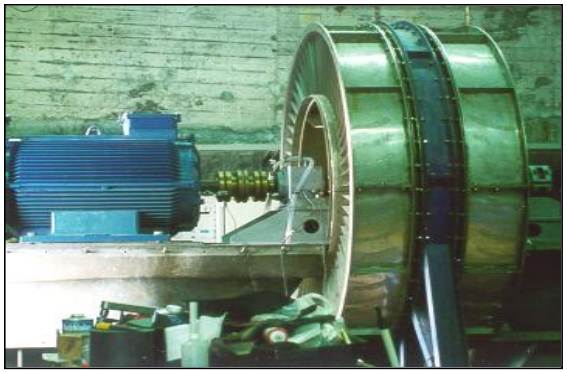
Swedish Energy Agency

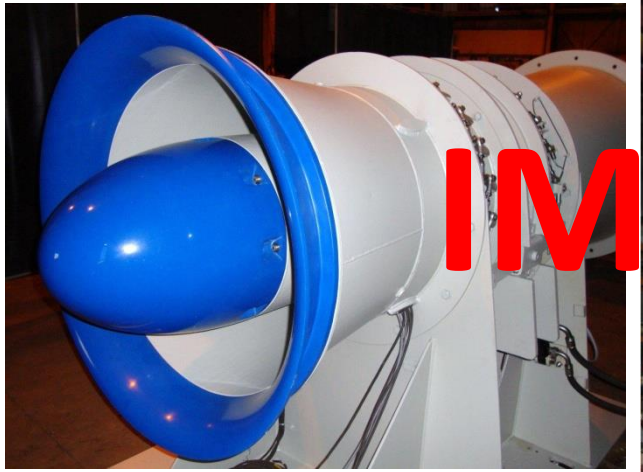
THE POWER TAKE-OFF EQUIPMENT

Special air turbines for oscillating-water-column plants

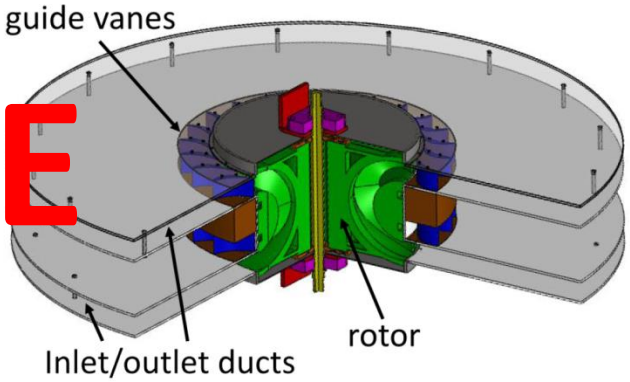


WELLS

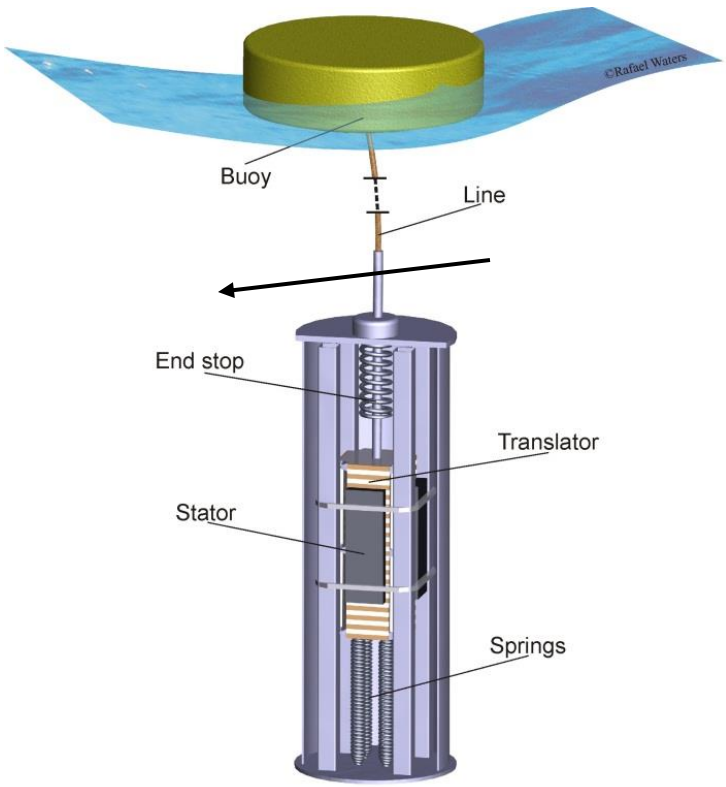




IMPULSE

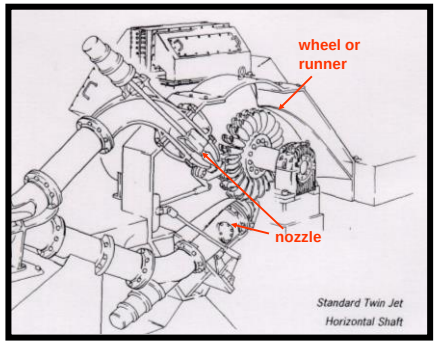


Linear electric generator

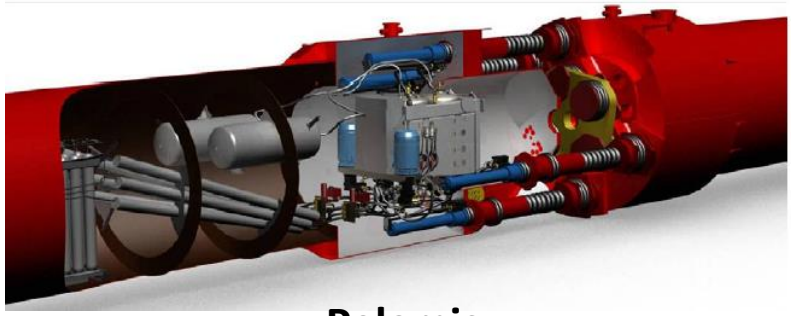


Uppsala University, Sweden

High-head hydraulic turbines



High-pressure-oil PTO



Pelamis

THE SITUATION OF WAVE ENERGY CONVERSION

A few basic concepts:

- Oscillating water column (OWC)
- “point absorber”
- large oscillating-body (multi-body)
- run-up device, ...

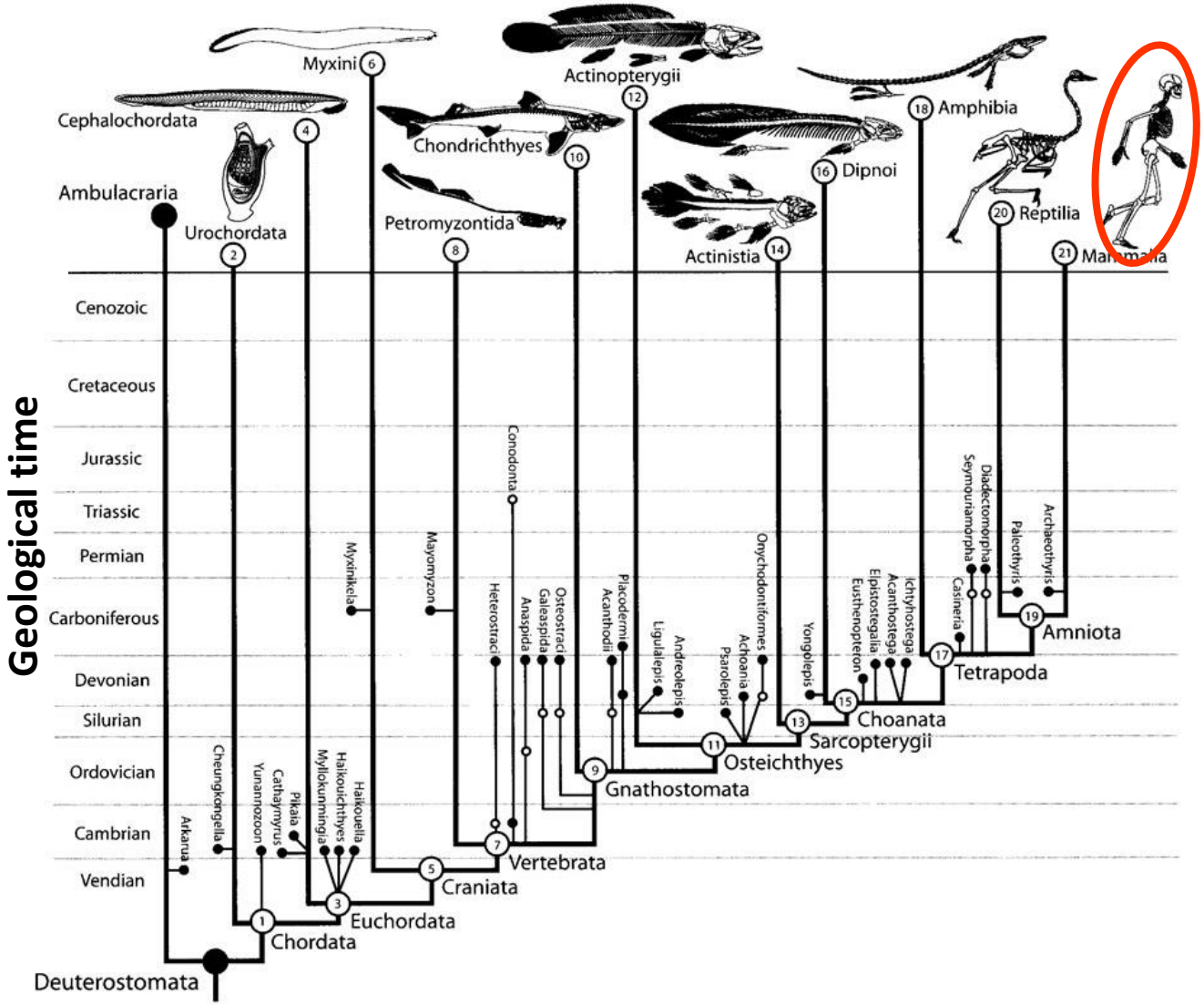
A large number of designs (>50) of which a few (≈15 ?) reached (or are close to) the prototype stage.

There are several effective ways of absorbing energy from the waves.

No technology appears to be dominant (unlike wind).

Like in life, will there be a Darwinian preservation of favoured wave energy converter designs in the struggle for the market?

How long will it take ? Which one(s) will be the **winner(s)** ?



Like in life, will there be a Darwinian preservation of favoured wave energy converter de for the market?

How long will it take which one(he **winner(s)** ?

Oscillating Water Column
(with air turbine)

Fixed structure

Isolated: Oceanlinx

In breakwa Mutriku

Floating: Mighty Whale, BB

Heavi y, IPS Buoy, Wavebob,

Floating

Oscillating body
(hydraulic motor, hydraulic turbine, linear electric generator)

ng: Pelamis, PS Frog, Searev

Heaving: AWS

Submerged

Bottom-hinged: Oyster, Waveroller

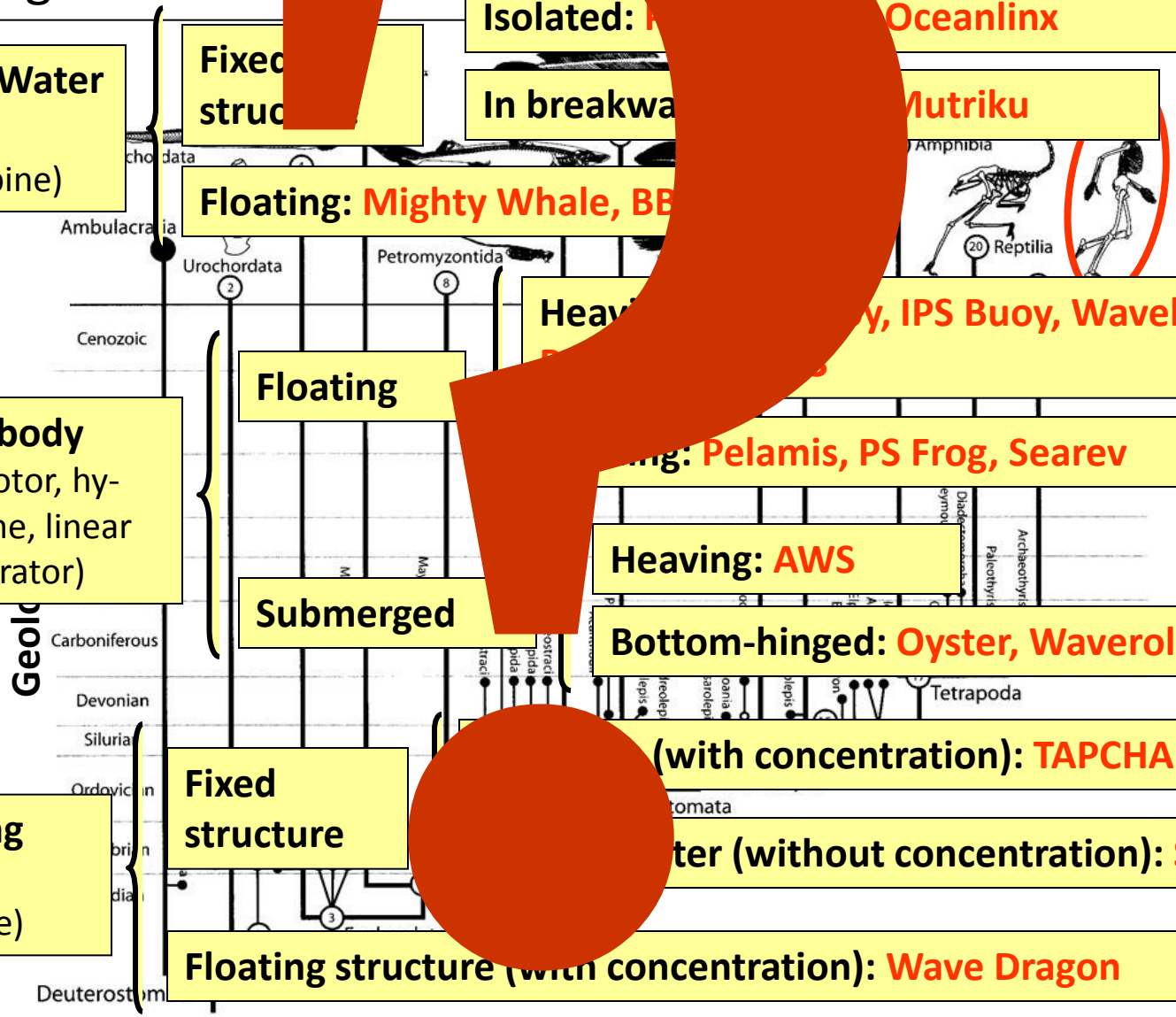
(with concentration): TAPCHAN

Fixed structure

Overtopping
(low head water turbine)

ter (without concentration): SSG

Floating structure (with concentration): Wave Dragon



Possibly the “most difficult” of the renewables.

From the develpment and economic point of view, the situation is similar to wind in the 1980s ?

Except for a small number of cases, there is little or no experience of maintenance, reliability and survival (under extreme conditions) in real open-sea, for more than a few months.

The most advanced technologies are at the pre-commercial stage.

For most technologies, the **capacity factor**: annual-averaged power divided by rated power, is similar to wind (~0.3 – 0.35) (possibly larger in the **southern hemisphere** due to smaller seasonal variations).

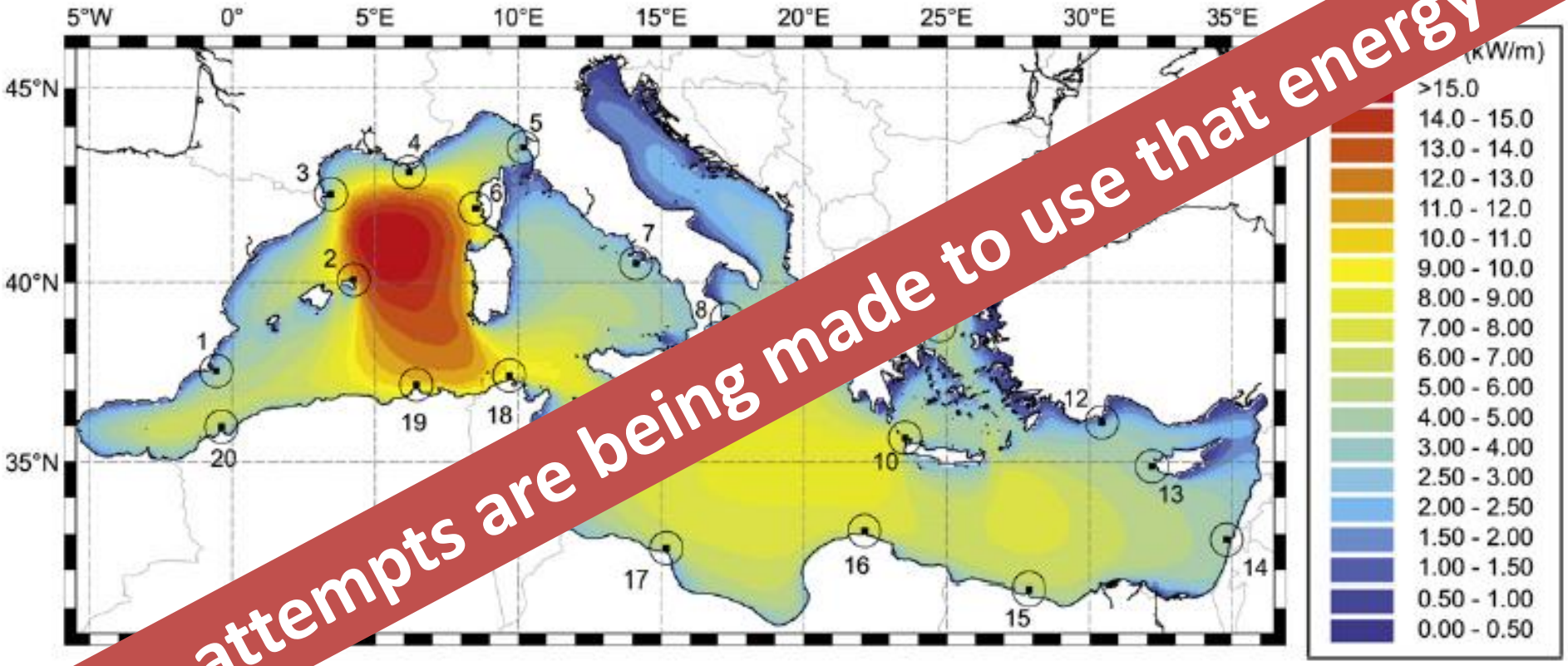
At the present stage of technology development, the unit cost of electricity from waves ranges **between wind and large photovoltaics.**

In order to be competitive with onshore wind, a cost reduction factor of about 3 will be required for the best designs (2 or less if compared with offshore wind).

As for wind, the extensive exploitation of wave energy will require large **arrays or farms**.

WAVE ENERGY CONVERSION IN THE MEDITERRANEAN

The level of wave energy resource in most of Mediterranean is substantially lower than in the large oceans.

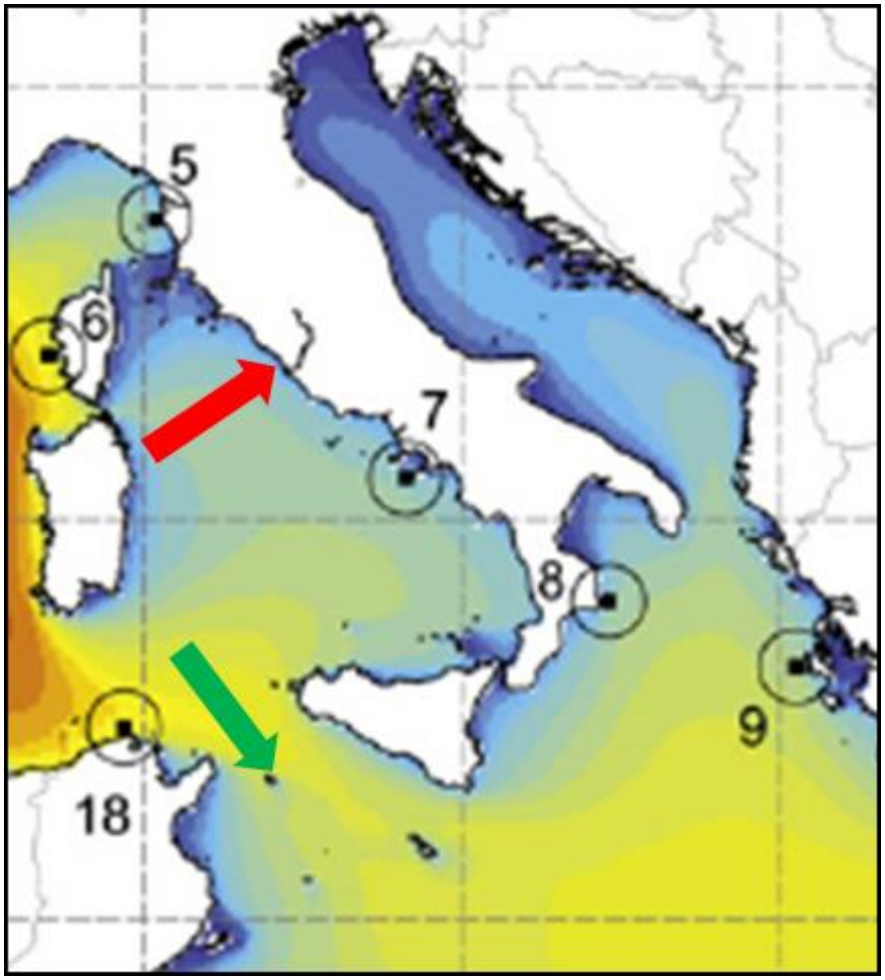


Yet, attempts are being made to use that energy !

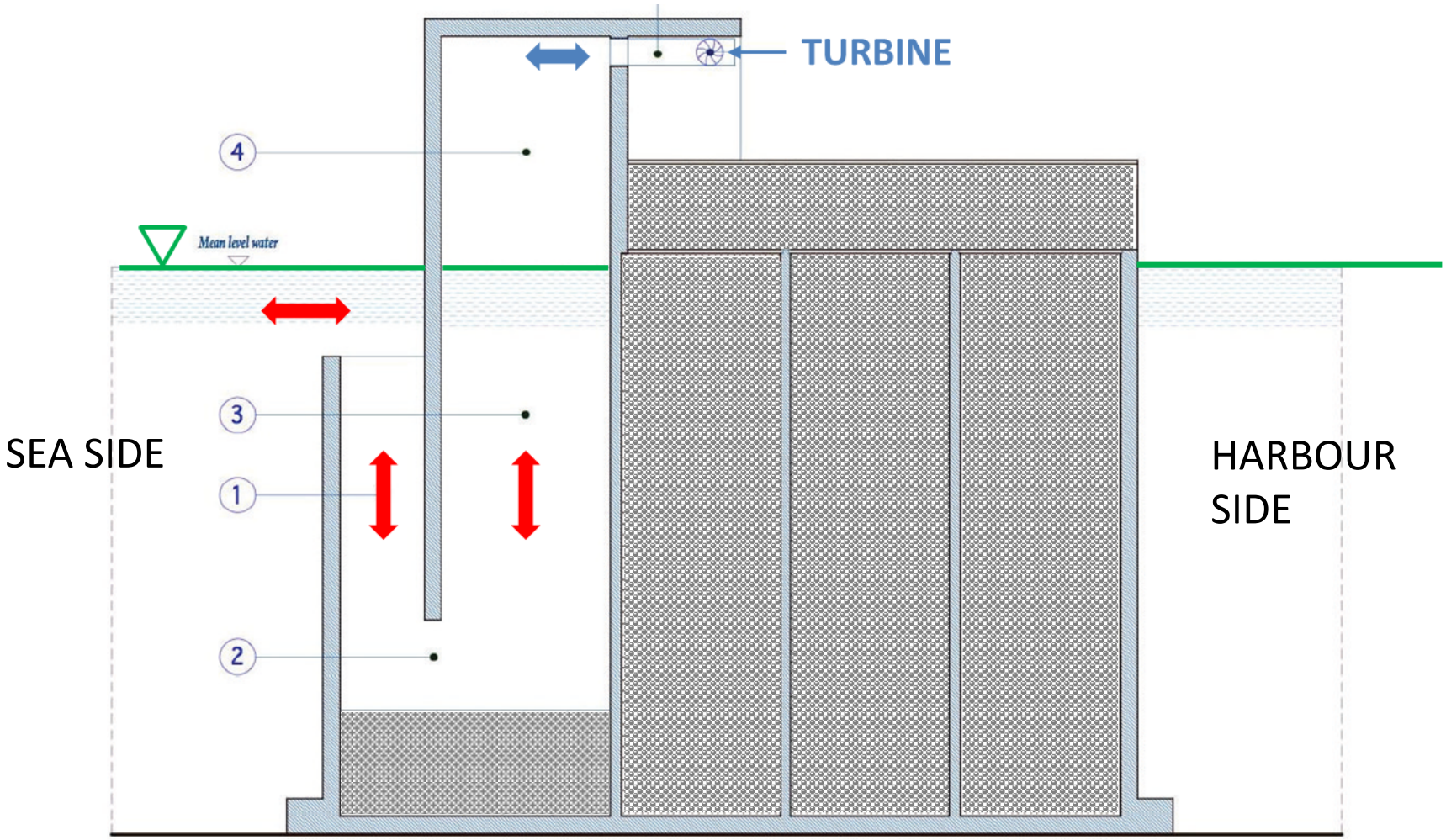
- Most of the Research & Development is taking place in **Italy**.
- Combine **caisson breakwaters for harbour protection** with energy production from waves.
- Technology: **oscillating water column** with air turbines.
- This is being done in **coastal areas of low wave energy content**.

New harbour breakwaters to include wave energy absorption:

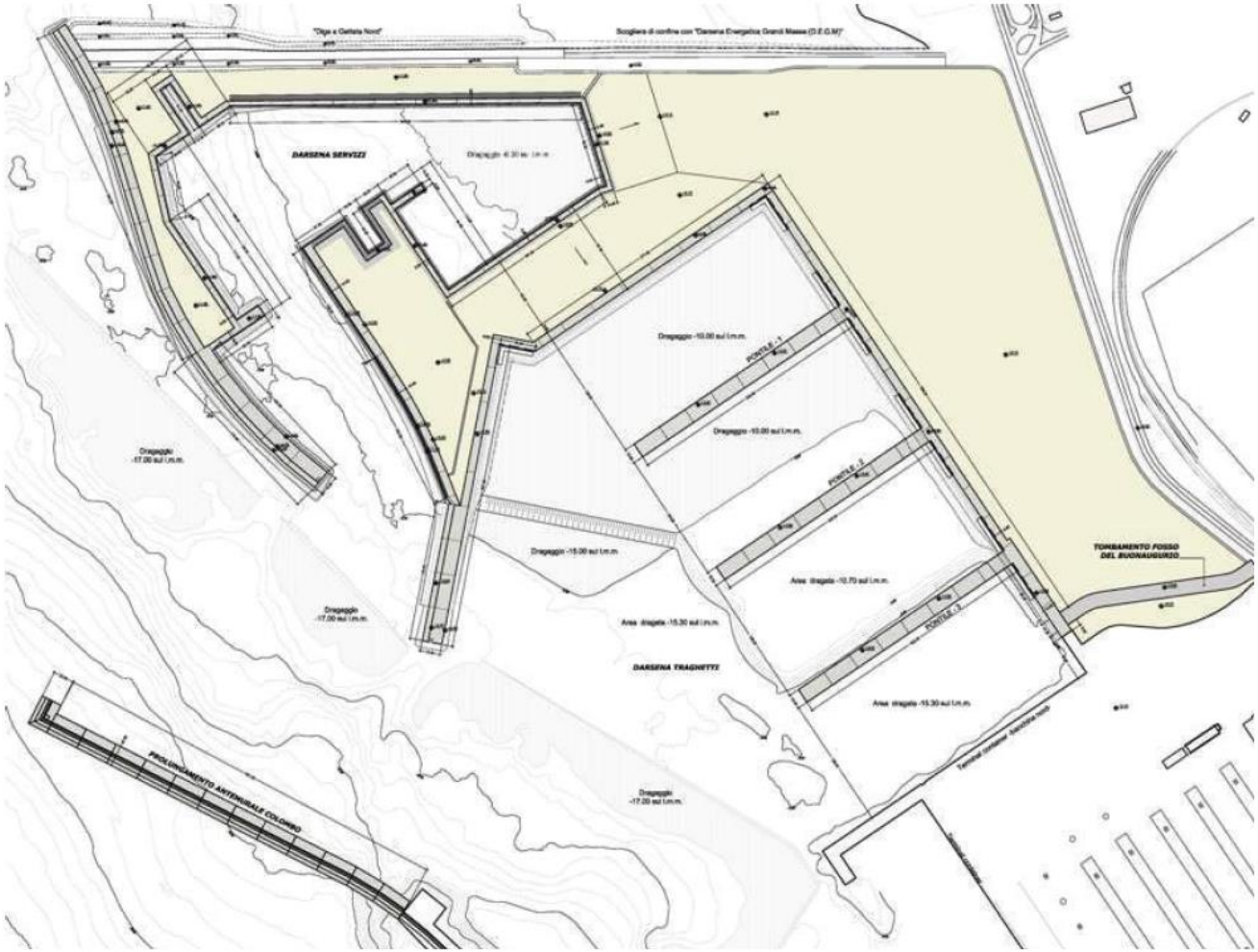
- **Civitavecchia** (near Rome)
- **Pantelleria island** (between Sicily and Tunisia)



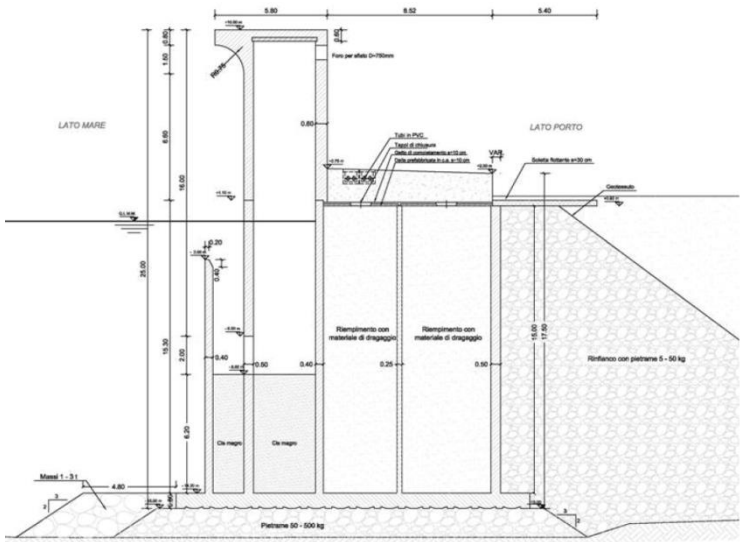
The technology: U-shaped oscillating-water-column in a caisson breakwater



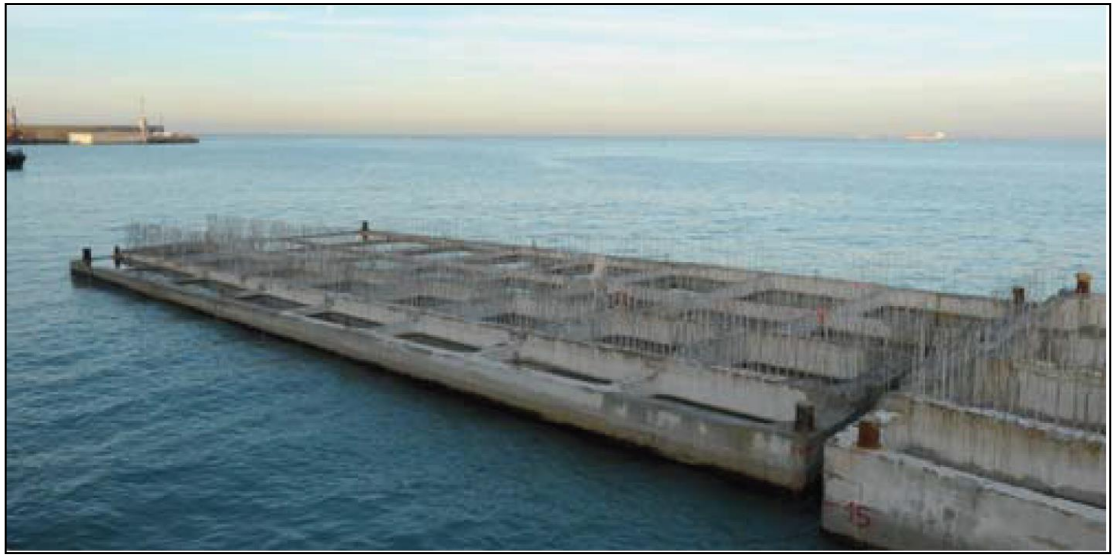
Enlargement of Civitavecchia harbour



Enlargement of Civitavecchia harbour



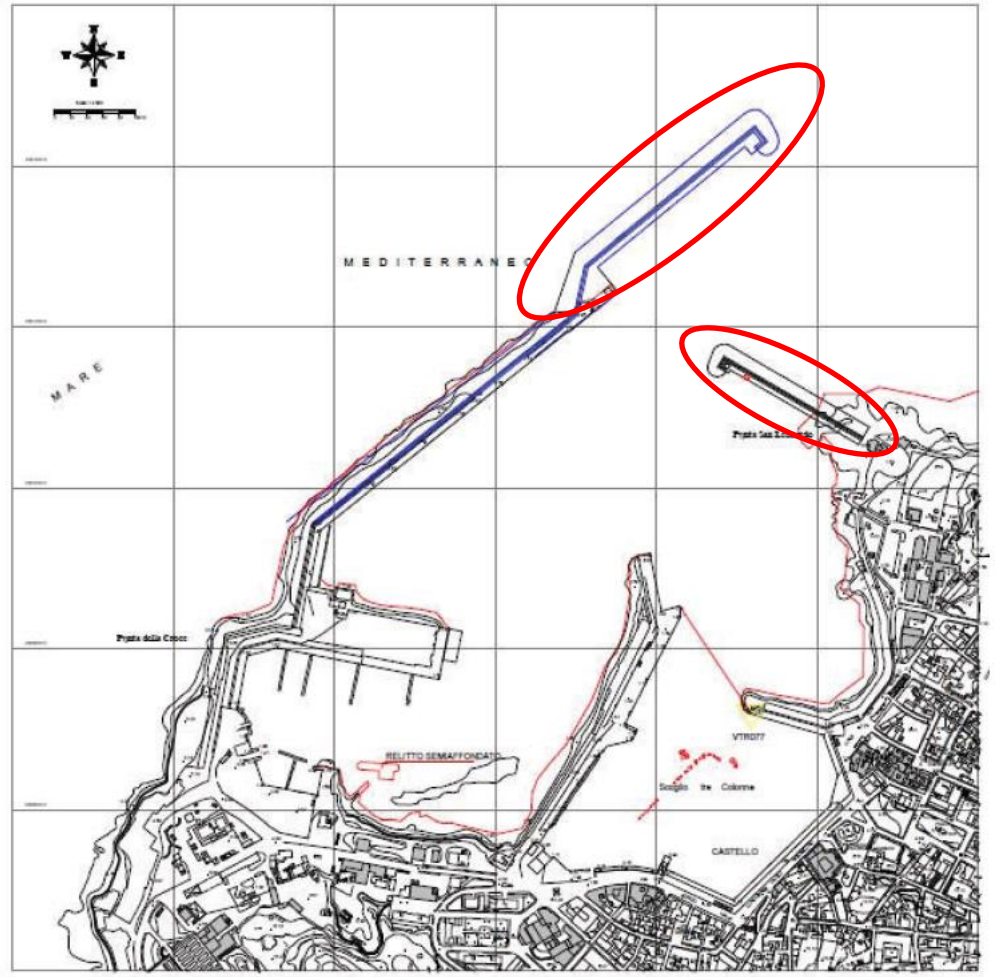
Cross-section of the REWEC3 wave energy converter in the Civitavecchia harbour



REWEC3 caisson at the preliminary stage, before placing in situ (2012-2013).

- F. Arena, A. Romolo, G. Malara, A. Ascanelli. **On design and building of a U-OWC wave energy converter in the Mediterranean sea**. 32nd Int. Conference Ocean Offshore Arctic Engineering, Nantes, France, June 10-13, 2013.
- F. Arena, V. Fiamma, V. Laface, G. Malara et al. **Installing U-OWC devices along the Italian coasts.** 32nd Int. Conference Ocean Offshore Arctic Engineering, Nantes, France, June 10-13, 2013.

Port of Pantelleria



Thank you for your attention