“Energia e Sostenibilità nel XXI secolo”
ENERGIA DAL MARE: MAREE E MOTO ONDOSO

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Dip. ICEA- Università di Padova

Problems to solve (generic for all Renewables)

- Energy accumulation → The best strategy is the complementarity of the different sources: e.g. wave and sun are better than wind and sun. Waves are ... "durable"
- Generator cost grows with power: the ratio between design (="peak") and average power is the "Load Factor" LF. Lower LF means lower cost, and slightly lower yield
- Planning energy production: Renewables are ineffective if the carbon plants do not stop working. These require at least a 24 h advance programming → renewable energy is paid on the basis of a bid. The highest price is offered to energy that is "secure" and during the peak of the demand. Wave forecast is more efficient than other forecasts, but the grid must be suited to real time planning
- Gridded nets: the electric grid must be gridded to allow different source paths, not only delivery paths (dimension of cables, substations, ..)
- Impact: Always unacceptable when there is no real energy saving

Obiettivi

- Stimolare la curiosità verso alcune tecnologie che hanno possibilità concreta di estrarre energia dalle maree e dalle onde
- Delineare le potenzialità della risorsa ondosa (200 G€/anno in Europa, 1G€/anno in Italia)
- Presentare un sistema di conversione dell'energia mareale italiana molto interessante
- Evidenziare le prospettive per l'Italia, soprattutto l'opportunità di fare ricerca e sviluppo in questo ambito

  Gruppo Marittimo

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Layout

- Convertitori di energia delle onde da vento (WEC)
  - Disponibilità di energia
  - Principi di funzionamento
  - Dispositivi in Europa e in Italia
  - Prove su modello fisico nei laboratori ICEA
- Convertitori di energia delle onde di marea (TEC)
  - Disponibilità di energia
  - Principi di funzionamento
  - Dispositivi in Europa e in Italia
- Conclusioni

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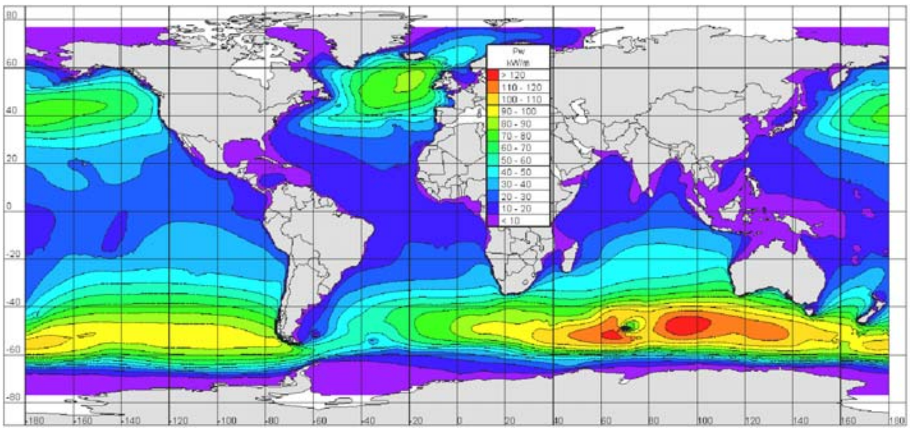
DISPONIBILITÀ DI ENERGIA
ondosa

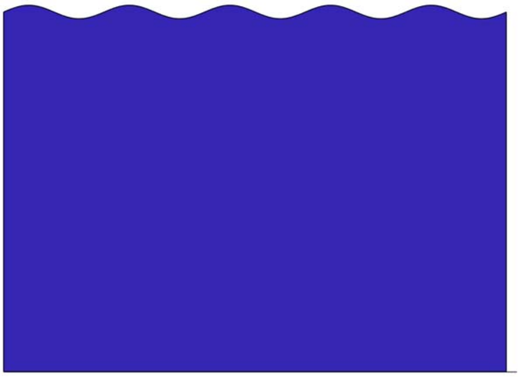
Disponibilità di energia

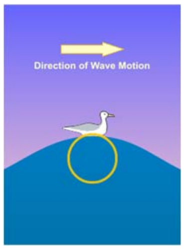


Cornett, 2008, A Global Wave Energy Resource Assessment, ISOPE2008

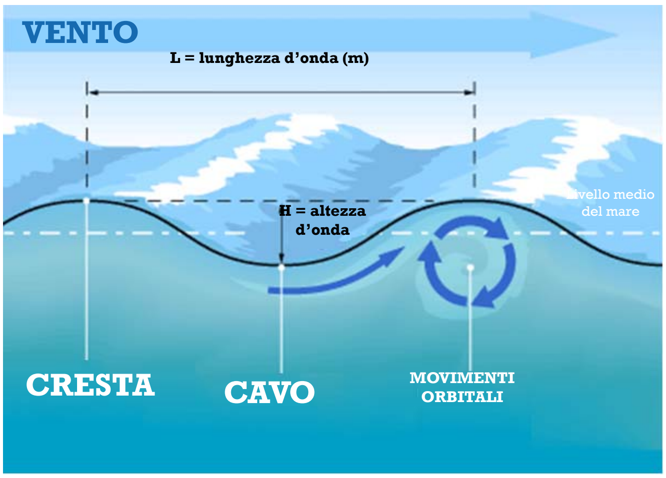
Cos'è un'onda?

T = periodo d'onda (s)

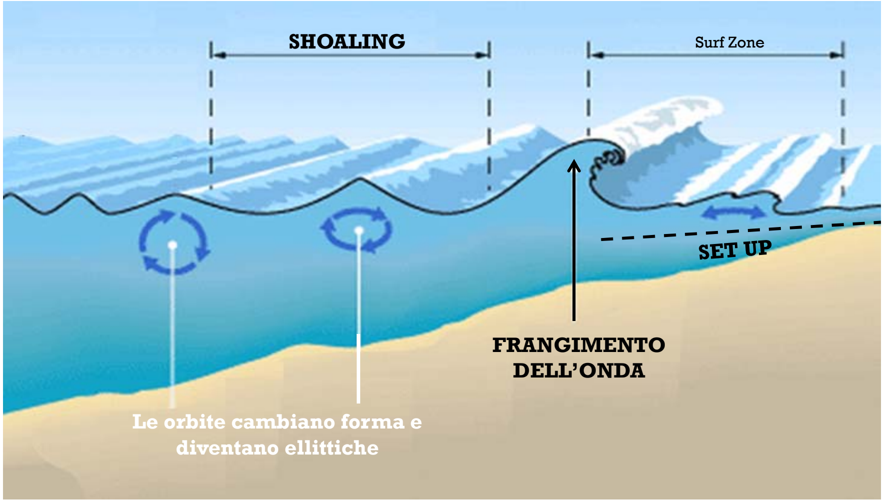




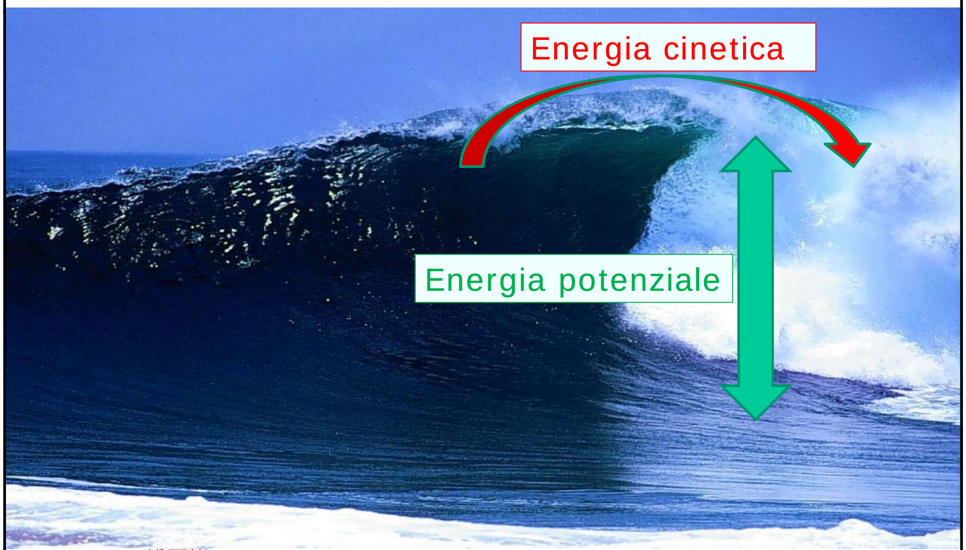
Come si possono caratterizzare le onde?



Quando le onde si avvicinano alla costa subiscono diverse trasformazioni



Energia ondosa



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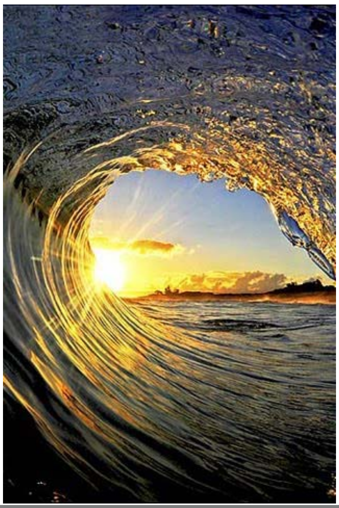
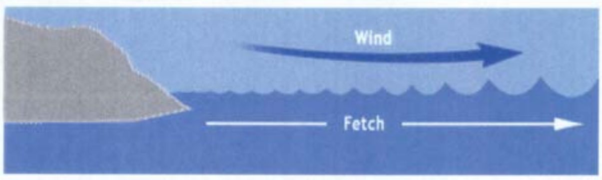
Onde frangenti



Come si generano le onde



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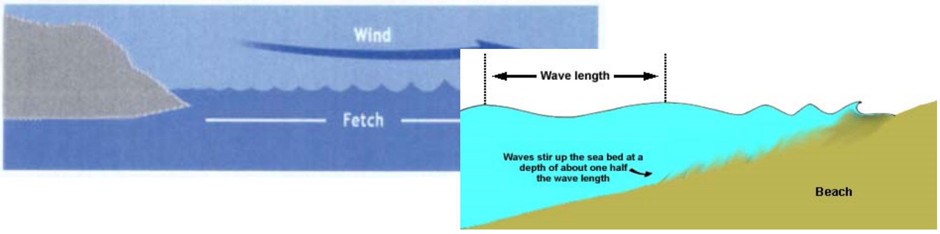
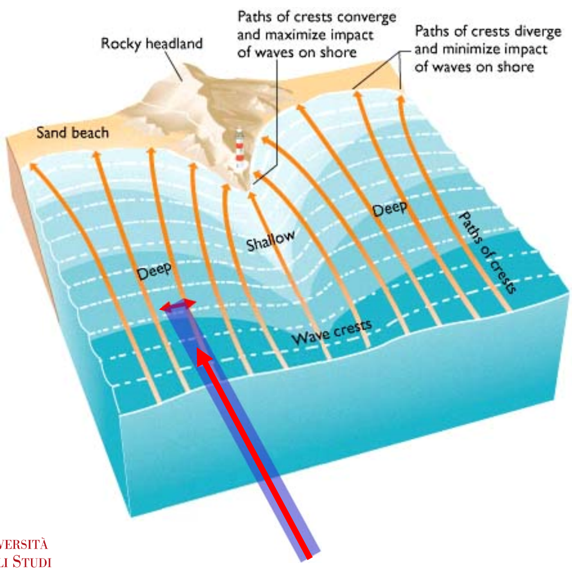
Trasferimento di energia alle onde

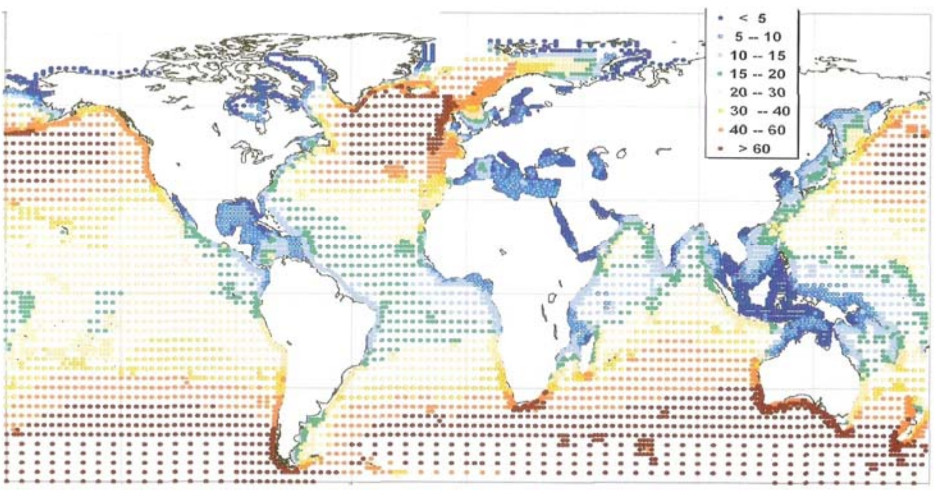


Energia del sole → generazione di venti → immissione di energia nel mare al ritmo di 0.1 W/m^2 (media) << irraggiamento solare (350 W/m^2) ma il vento fa crescere l'onda mentre questa avanza.
→ Si raccoglie l'onda dalla parte opposta del bacino.
1 fronte largo 1 m che avanza per 100 km, assorbe
0.1 W/m^2 * 100 000 m = 10 kW/m in media

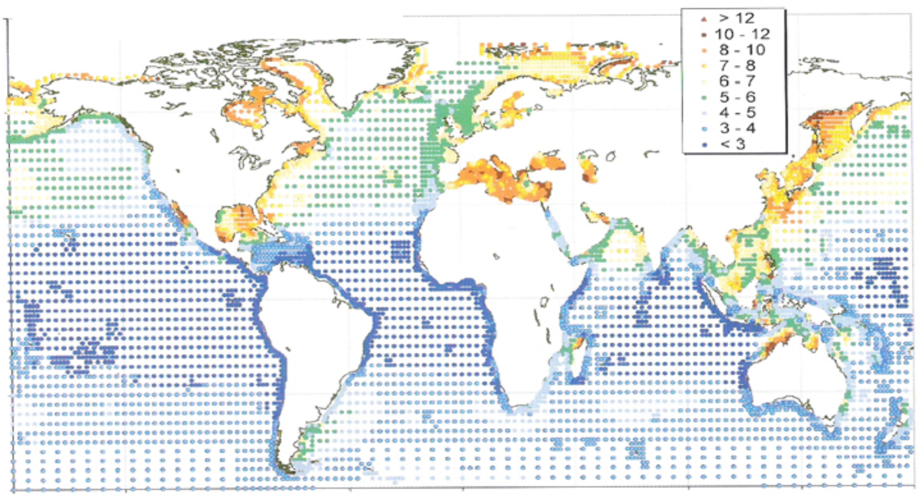
Unità di misura: <kW/m>



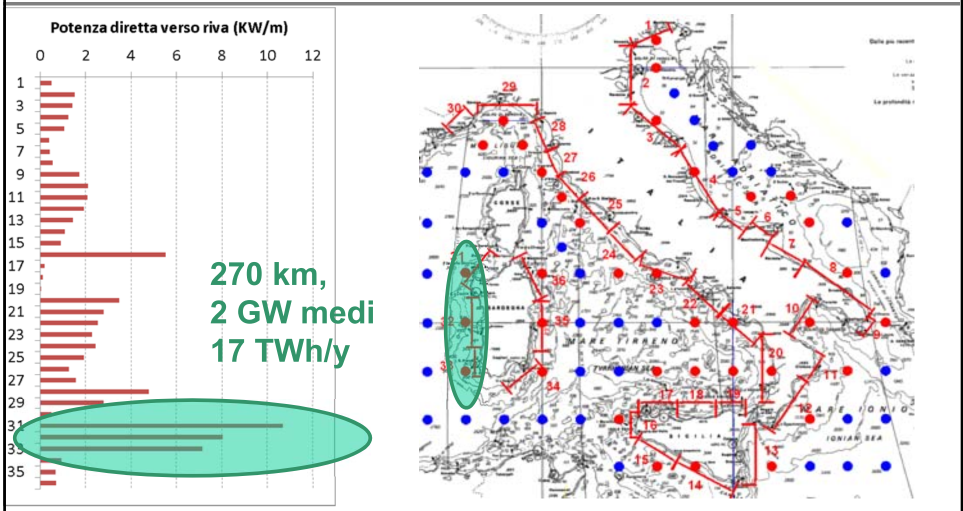
Disponibilità di Energia <kW/m>



Hs_{100}/Hs_{mean} → Rapporto costo/Beneficio



Italia



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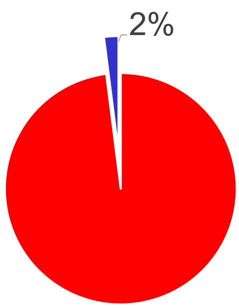
Italia



Consumo energia elettrica in italia: 330 TWh/y

$330\ 10^9$ kWh/y x 0.15 €/kWh

→ 50 Miliardi di €/anno

Convertendo l' energia nel 270 km di costa Sarda (17 TWh/anno), con un'efficienza del 33% → si fornirebbe circa il 2% del consumo annuo, ossia →1 Miliardo di €/anno

NB: non propongo di installare questi dispositivi!!

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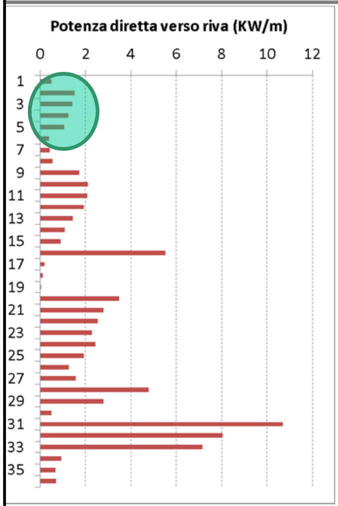
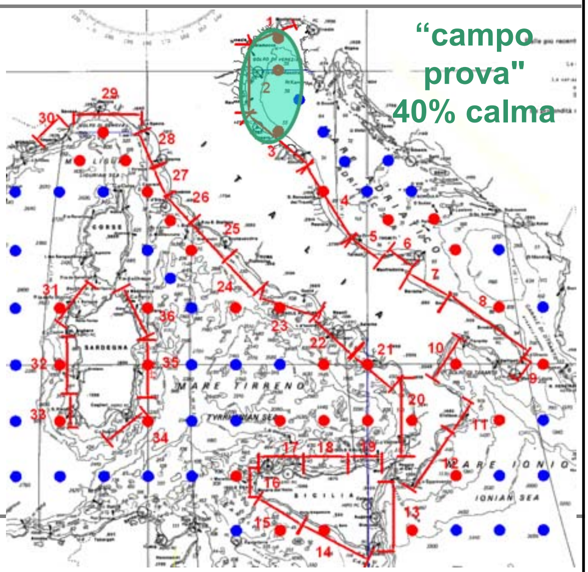
... e in Veneto?





Europa

Sviluppo fronte oceanico sfruttabile ca. 10’000 km

Potenza media > 50kW/m=50MW/km

→500 GW in media nell’anno

500GW*n°ore anno= 4000 TWh/y (η=0.3→ 180 T€/y)

Consumo **mondiale** annuo:

16695 TWh/anno

ca. 25% consumo mondiale

→ molto più di quanta ne serva

Ma come si può estrarre energia elettrica dalle onde del mare?

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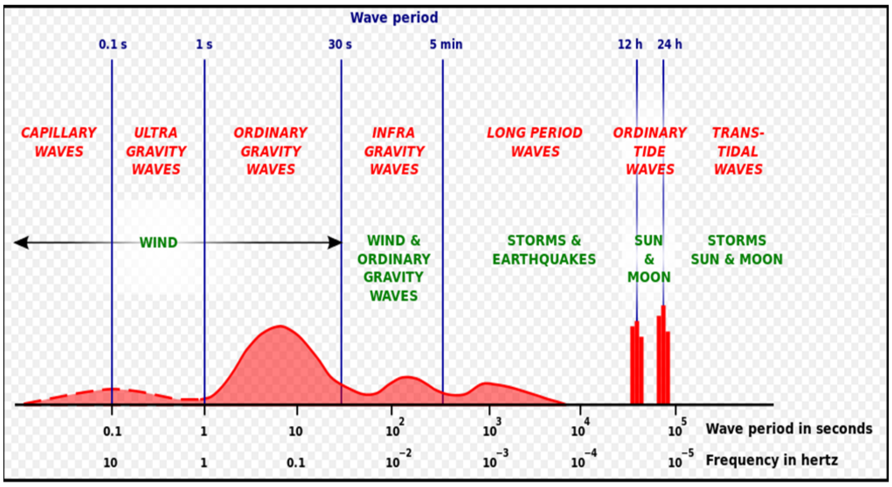
L'energia del mare è contenuta nelle onde da vento e nelle maree



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Energy from the sea: Problems to solve (WECs specific)

- Wave movements are slow, whereas generators are more efficient if they spin fast → System to "multiply the frequency"
- Energy varies within the wave period, whereas generators are more efficient when the output is constant → average within wave period
- Real waves are irregular i.e. group of high waves – with large energy - come after groups of small waves → System to convert both high and small waves
- No fixed period → Resonance conditions should be adjustable
- The high waves, although infrequent, are those that define the forces for structural design, whereas the energy production relies on the average storms and stays in safe mode during extreme conditions → System to reduce the extreme load when in safe mode
- Aggressive environment → Isolate from marine environment
- Environmental impact (e.g. acustic) → Far from shore, detailed EIA

Energy from the sea

Flussi di marea

Correnti Marine

Gradienti di salinità

Gradienti termici

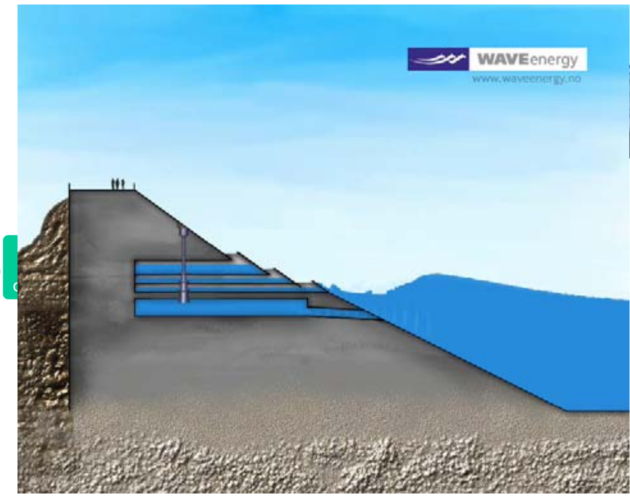
Moto ondoso (W.E.C.)

Wave OVerTopping devices (OVT)

"Slot Cone Generator®"

Energy from the sea

- Flussi di marea
- Correnti Marine
- Gradienti di salinità
- Gradienti termici
- Moto ondoso (W.E.C.)



Energy from the sea

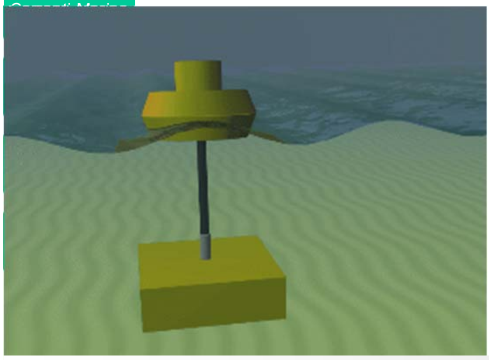
- Flussi di marea
- Correnti Marine
- Gradienti di salinità
- Gradienti termici
- Moto ondoso (W.E.C.)
  - Wave OVerTopping devices (OVT)
  - Wave Activated Bodies (WAB)

“Slot Cone Generator®”

“Wave Hub ®”

Energy from the sea

Flussi di marea



“Slot Cone Generator®”

“Wave Hub ®”

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Energy from the sea

- Flussi di marea
- Correnti Marine
- Gradienti di salinità
- Gradienti termici
- Moto ondoso (W.E.C.)
  - Wave OVerTopping devices (OVT)
  - Wave Activated Bodies (WAB)
  - Oscillating Water Column devices (OWC)

“Slot Cone Generator®”

“Wave Hub ®”

“Pico®”

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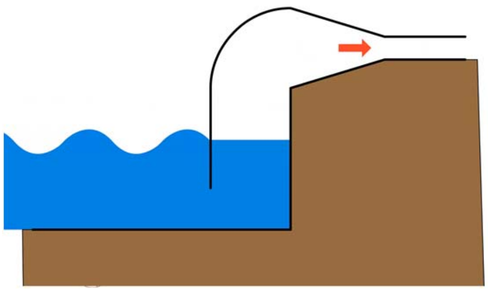
Energy from the sea



"Slot Cone Generator®"

"Wave Hub ®"

"Pico®"

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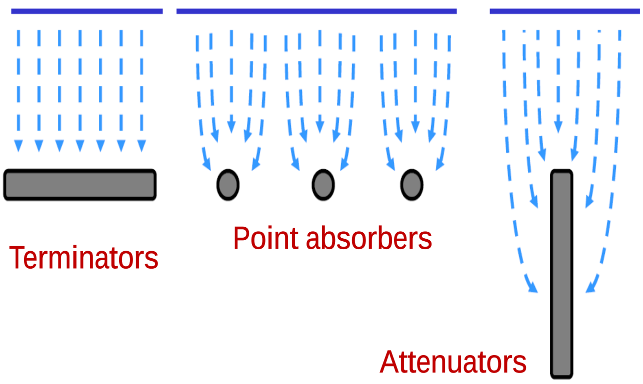
Classification

Location: At the shoreline, Nearshore, Offshore (=floating)

Orientation: Teminators; Point absorbers; Attenuators



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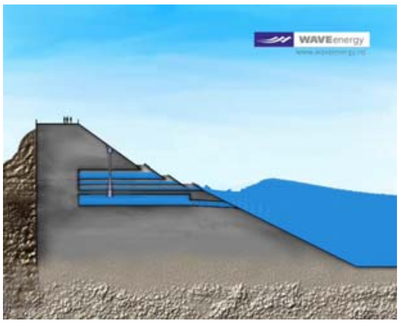
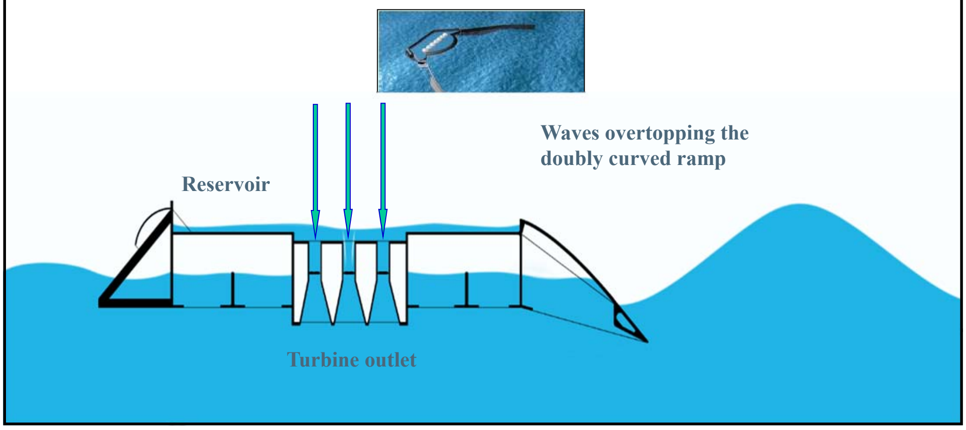
Early flight

WECs based on overtopping principle OTD



Wave Dragon (OTD)

Wave Dragon



Wave Dragon

Bio-fauling: special paintings are used to reduce the growth

Wave Dragon

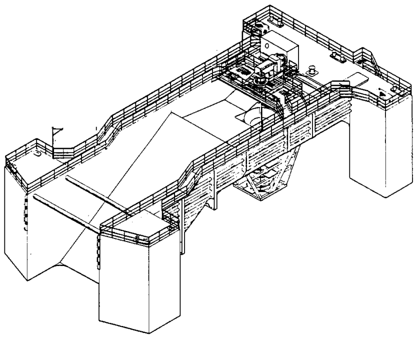
Unit	Climate	Production	Dimensions
4MW	24 kW/m	12 GWh/y/unità	260m x150m
7MW	36 kW/m	20 GWh/y/unità	300m x170m
11MW	48 kW/m	35 GWh/y/unità	390m x220m

1:50 Wave basin	1:4,5 Nissum Bredning	Prototipe scale 7 MW Milford Haven
		

WAVEPLANE

The turbine harvests the moment of inertia and not only the hydrostatic pressure

Sea Power



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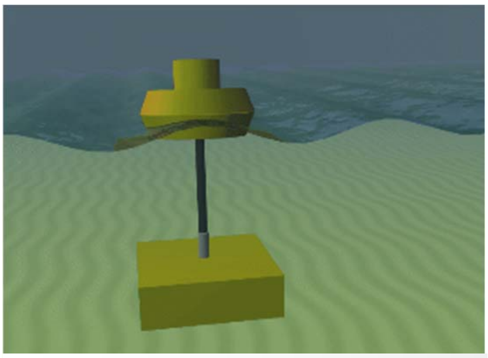
WECs directly activated by wave action
WAB



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Ocean Power Technology (Powerbuoy)

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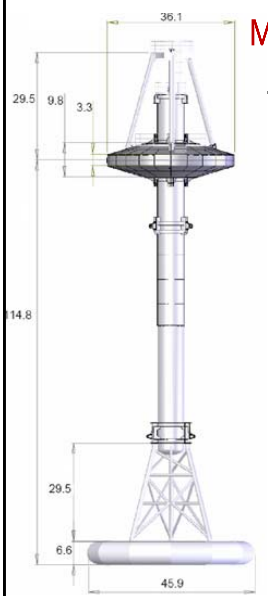
Modelli: PB150 (EMEC) + *PB500*



PB150=150 kW
(*PB500=500 kW*)

Wave Hub (UK),
5MW

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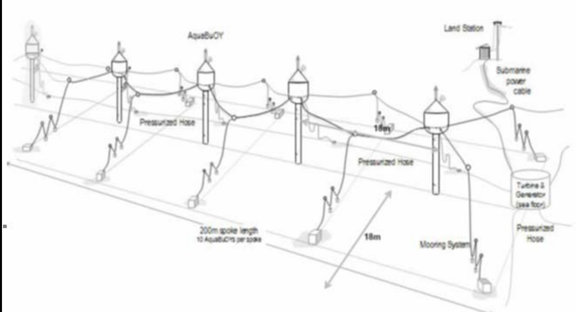
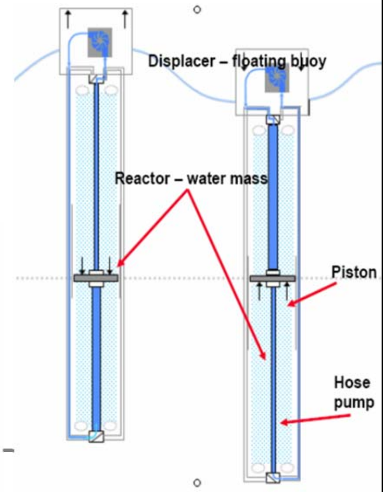
AcquaBuoy





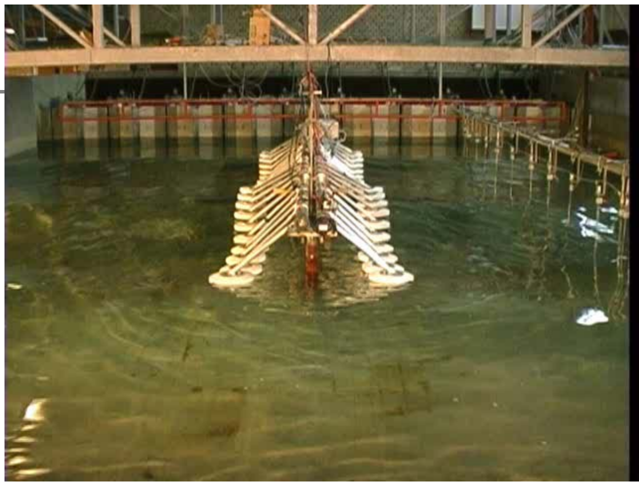
Wavebob

The Wave Energy Converter *Wave Star*

A multi point absorber system

Scale 1:10 testing in Nissum Bredning

Scale 1:40 testing at AAU



Niels and Keld Hansen came up with the Wavestar concept in 2000. Per Resen Steenstrup purchased the rights to the machine in 2003. In February 2010 Wave Star Energy was reorganized in the company Wave Star A/S.

Test in 1:10 scale, in Nissum Bredning

Test in 1:2 scale, port of Hanstholm

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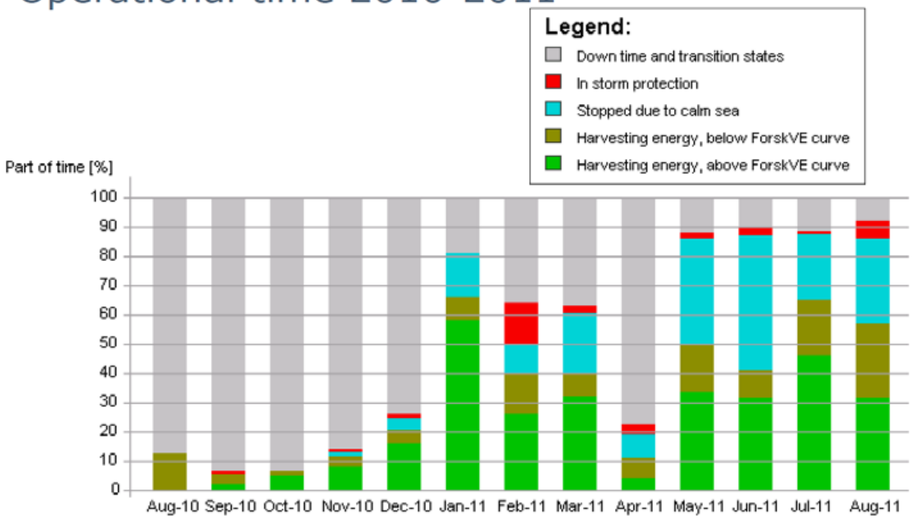
Operational time 2010-2011

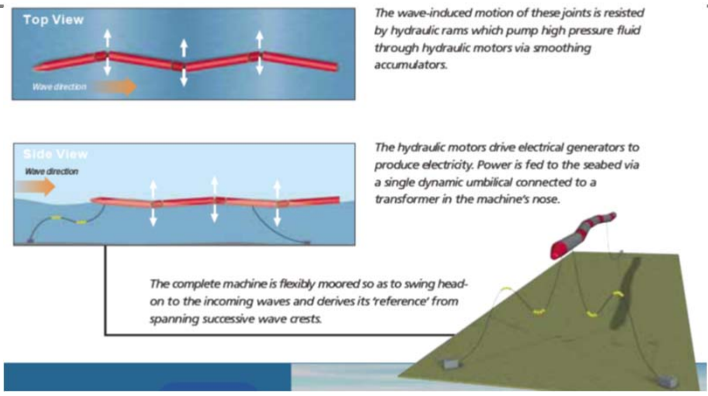


Peak Power = 110 kW for 2 units

Design peak 600 kW for 20 units

The Pelamis Wave Energy Converter is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints.

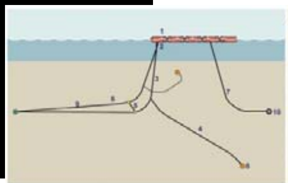
"Pelamis®"
VIDEO



3 Pelamis sold to a Portughese consortium. 750kW each, installed in 2006 in Agucadora (PT).

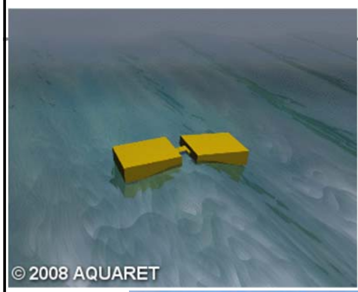
Cost 3.5 €/W (assessed 0.265 €/kWh), maintenance 8%. Failed

Ocean Power Delivery→ Pelamis Wave Power Pelamis P2

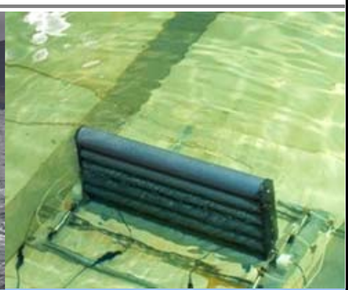


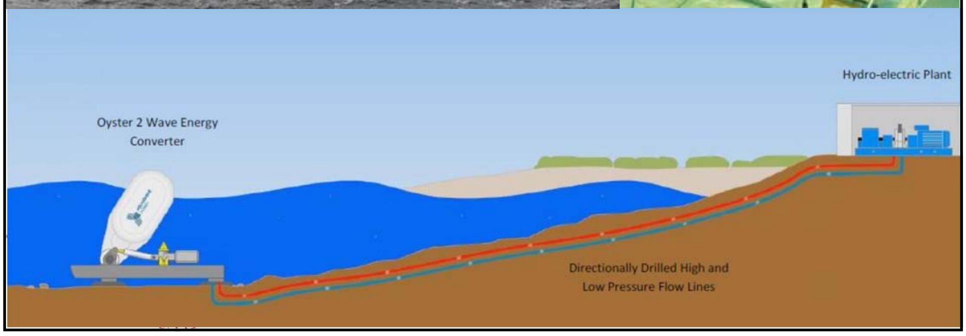
Component	Description
1	Pelamis P2 – 180m
2	Yoke
3	Tether lines
4	Rear lines – studlink chain, 130m long
5	Front connection line
6	Front lines – studlink chain, 140m long
7	Yaw restraint Line
8	Rear embedment anchors – 4T
9	Front embedment anchor – 7.5T
10	20T clump weight anchor

DEXA

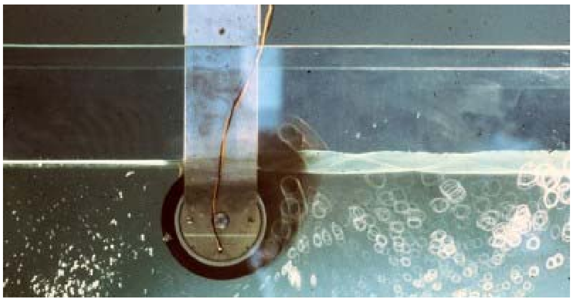


Acquamarine Power (Oyster)





Salter's duck



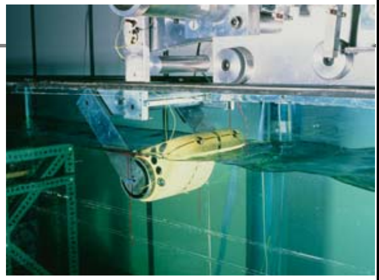
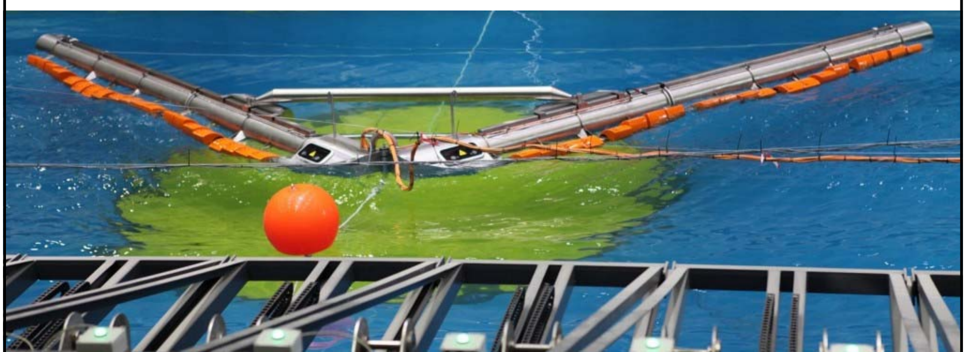


foto con tempo di esposizione di 1 s

WEPTOS



Working principle → video at 2'30"

WEPTOS WEPTOS Offshore #1, Lillebælt

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WEPTOS WEPTOS Offshore #1, Lillebælt

Lillebælt, Brandsø

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WEPTOS Offshore #1, Lillebælt

The installation of the Weptos WEC was completed on the 22th of July 2017 and testing of functions was started. Unfortunately, a few days later, water penetration was detected in the generator houses and the plant was disconnected, dragged back to the harbor and lifted out of sea.

Then, after a period of regular operation the project was unfortunately affected by a major incident on the October 10 as the Weptos WEC was found stranded at the coast of Brandsø. The tether tube was broken and mooring buoy, hawser connection and WEC were transported for safe storage in port. Fortunately, no major damage to the WEC it-self has been detected.

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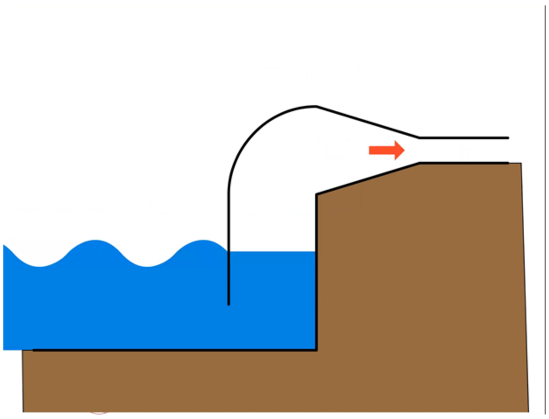
WEC based on the OWC principle



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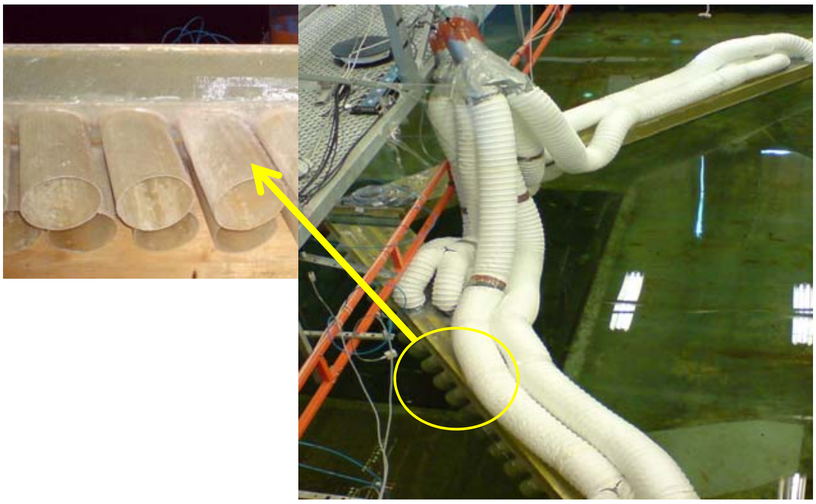
OE Buoy

Leancon

Wave basin tests



Italian devices

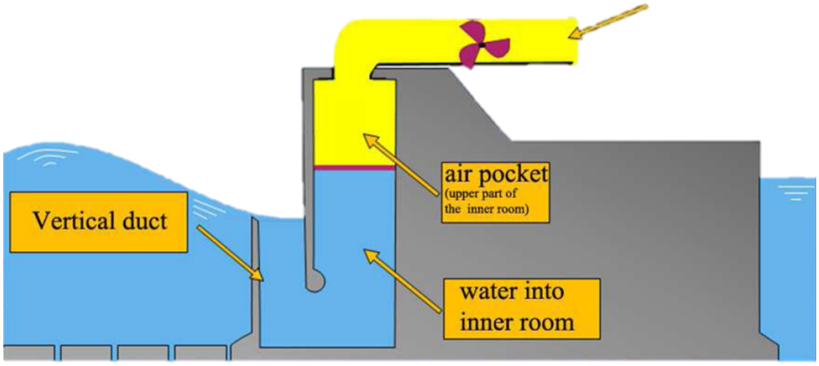
- **REWEC3** (demonstation 20 kW)
- **ISWEC** (demonstation 10 kW)
- **Dimemo/Obrec** (demonstation, 3 kW)

- **40 South Energy** (demonstation?, unpublished)
- **Generma** (sea proof of concept)
- **ShoWED** (demonstation, 1 kW, abandoned?)
- (SeaBreath, Technofue, ...

In Italy the wave climate is mild and the availability of energy is limited. A smart strategy is to design a device that serves a double purpose, e.g. integrated in a port structure

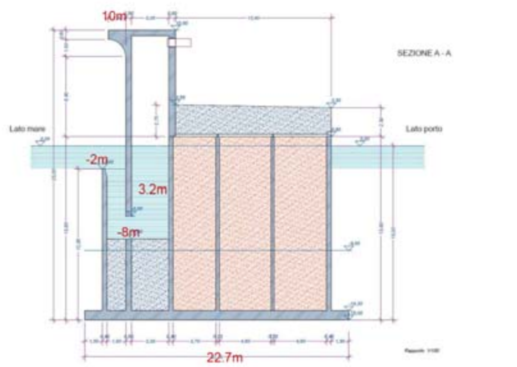
REWEC3

Cost: +7% of dike cost
CAPTURE WIDTH:
60-110% of dike length



Boccotti et al. Ocean Engineering 34 822 (2007) 820–841

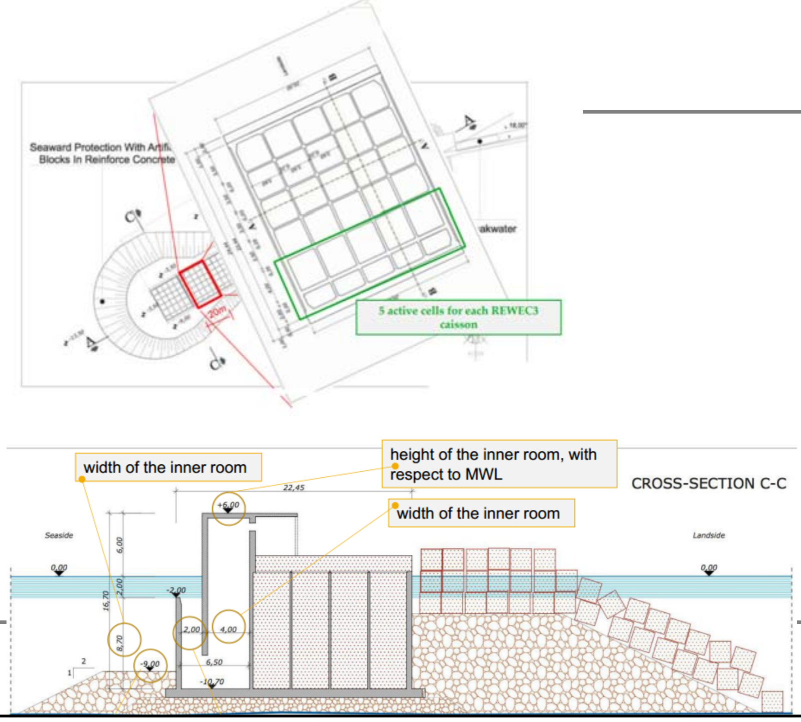
Extension of Civitavecchia Port



Extension of Civitavecchia Port

Other REWEC3 projects

- Porto di Salerno
- Porto delle Grazie di Roccella Ionica (RC)
- Porto di Crotone
- Porto di Vibo Valenzia
- Porto di Genova



Average electrical power per year from a REWEC

• Tyrrhenian Sea, Mediterranean Sea:	5.700 MWh/km
• Channel of Sicily, Mediterranean Sea:	7.000 MWh/km
• West Sardinia, Mediterranean Sea:	10.000 MWh/km
• USA, California:	66.000 MWh/km
• Atlantic EU coast:	40.000 MWh/km
• Mauritania:	32,000 MWh/km

From Prof. Arena

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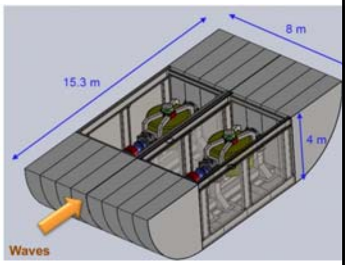
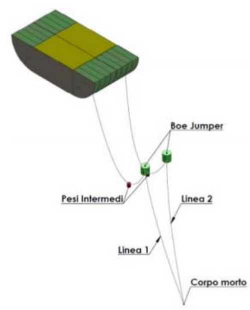
ISWEC, Pantelleria, 100 kW, 240 MWh/y, Rina Certified





ISWEC in the Adriatic sea (Ravenna platform)

ISWEC (Inertial Sea WEC) deployed in March 2019, 50 kW
Support of ENI, developed by W4E (Wave for Energy) with Terna and Fincantieri
Soon deployed in the Sicilian Channel, at the Eni Prezioso Platform

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ISWEC

W4E focuses on 2 types of products:

• ISWEC: 100 kW for the Mediterranean (wave power <30kW / m)

• IOWEC: developed for Ocean applications (wave powers> 30kW / m)

Keypoints:

1. Absence of moving parts exposed to the marine environment, reducing the need for scheduled maintenance
2. Modular system, easily transportable
3. Active control system, able to tune the system to the various incoming waves and convert the maximum available energy content.

Dimemo (Diga Marittima per l'Energia del Moto Ondoso) / OBREC (Overtopping BReakwater for Energy Conversion) Molo S. Vincenzo, Port of Napoli, since 2015

Dimemo/Obrec

CONVERTITORI DI ENERGIA MAREALE

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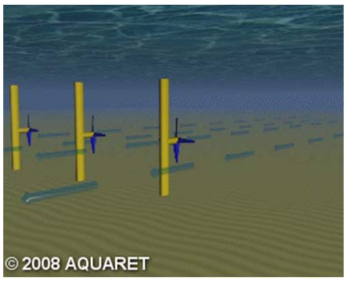
Classificazione dei “Tidal Energy Converters”

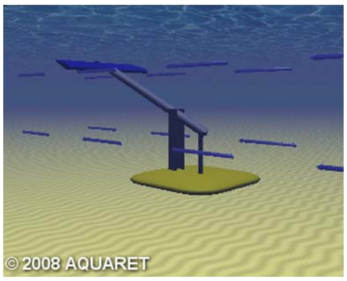
Principi di funzionamento:

- Energia potenziale = sfruttano il dislivello idraulico
- Energia cinetica (tipicamente molti dispositivi affiancati)
  - Turbine ad asse orizzontale/verticale
  - Hydrofoil (profili alari) oscillanti

Posizione

- acque basse
- acque profonde
  - Superficiali (galleggianti) – e.g. **Orbitel O2**
  - Al fondo (posate al fondo) – e.g. **Sabella**
  - A mezza altezza (ancorate con cavi), e.g. **SeaPower**





https://youtu.be/rtD7GnuGFNw

Available tidal Energy: barrages and lagoons, river mouths

The first tidal energy converters were formed by gates that enclosed water in high tides and used the return flow to operate grain mills.

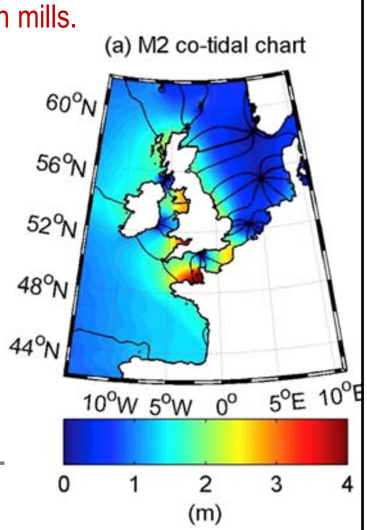
There is a need for:

- suitable location
- significant jump

Unacceptable impact produced by:

- the necessary civil engeineering works
- the effect of limited circulation on water quality

→ technically <100 GW> but realistically less than <1 GW> [= 87’600 GWh/y]



Neil et al., Energy, (73) 2014

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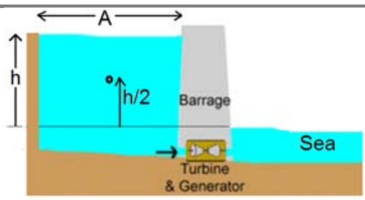
Energia potenziale

Tidal Barrage TEC: focus on tidal range

$$E_P = \frac{1}{2}\rho A g h^2$$ *h=head*



Generation (water is turbined) during:

- **ebb tide (fase di discesa).** Flood is free, trap inside
- **flood tide (salita).** Ebb is free, easier to empty pollutants/sediments
- **both.** More continuous production (e.g. 14 h/day for EVERY DAY)

Possible use of second basin

Coastlines are classified as

- microtidal (range < 0.5 m), mesotidal (between 0.5 and 4 m), macrotidal (> 4.0 m).

Actually, only macrotidal coastlines are attractive.

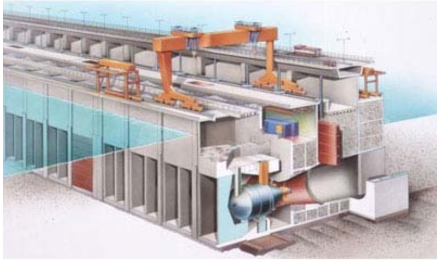
Note: **limited n° of suitable sites, large impact** → negligible potential from a global perspective

Rance River, Bretagne

Le Rance began operation in 1966, with generating capacity od 240 kW, fostered for years the use of marine energies

240 MW (24 x 10 MW)

Generates during both ebb and flood



Sihwa Lake, South Korea

43.8 km² artificial lake built in 1994, using a 12.7 km long seawall to provide flood mitigation, and secure irrigation water by converting the costal reservoir to fresh water.

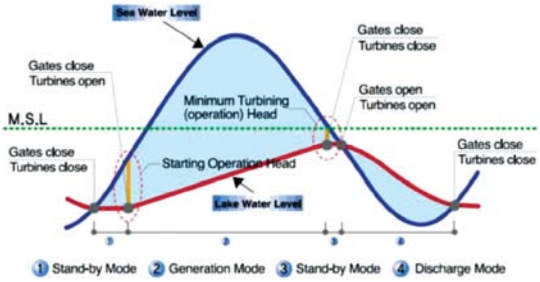
Tidal Range Converter:

10 turbines x 25.4 MW

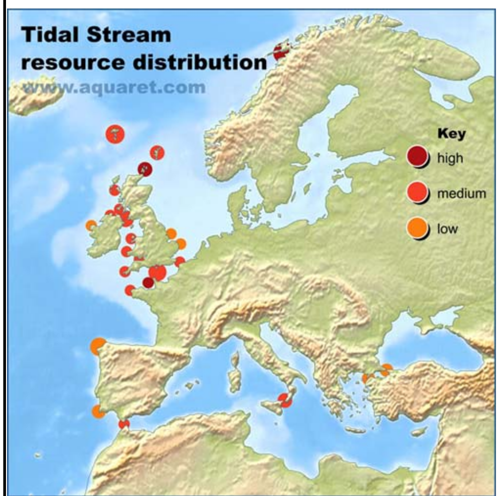
Tidal range: 3.3 m to 7.8 m

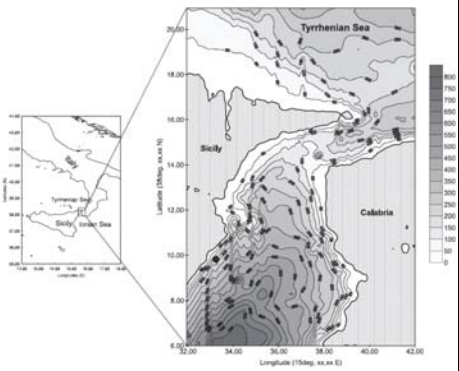
you may watch:

https://www.youtube.com/watch?v=26l0x6nyiyo



Tidal stream





EU Project: Lifelong Learning Programme

SeaGEN – horizontal axis

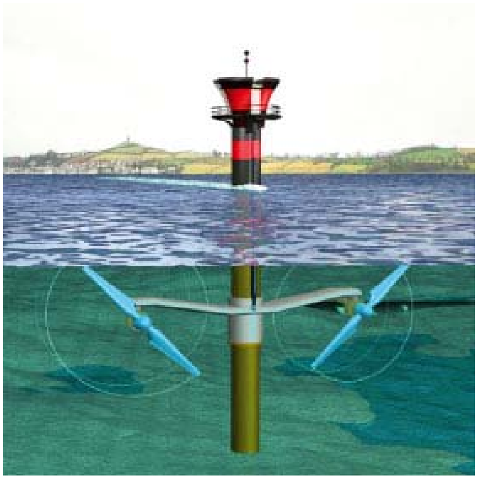
Underwater turbine generating electricity from tidal streams,

Situated at Strangford Lough, in Northern Ireland 150kW

Connected to the UK grid on since 2008 (first in UK).

d=16 m, tip velocity 2.4 m/s

SeaGen previously also known by the name of the developers, Marine Currents Turbines (UK), is now wholly owned by Siemens.



Open Centre – horizontal axis

Designed by the Open Hydro Group, built by Cantick Head Tidal.

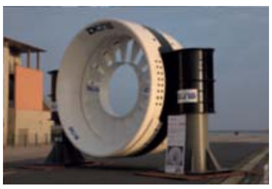
Tested at EMEC in Orkney, 2006.

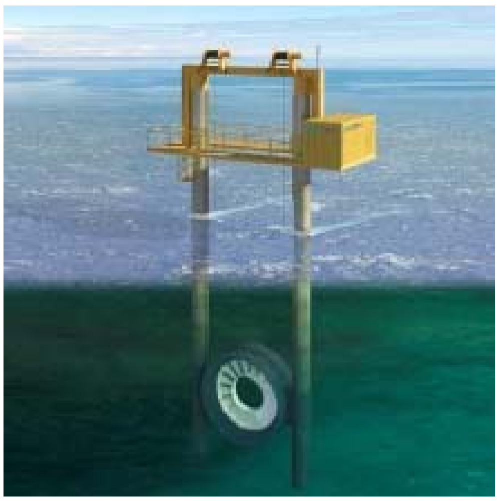
Connected to UK grid in 2008.

A devices has been installed at the Bay of Fundy

Asymmetric load absorbed by 2 piles

Large underwater turbine, resembling a jet engine, fixed to the sea floor.





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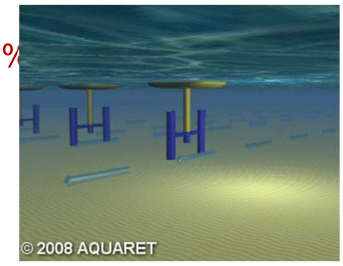
Kobold– vertical axis

Deployed in 2001 in Messina straight
Ponte di Archimede S.p.A
Water depth 20 m, 150 m offshore
Current velocity 2 m/s
Vertical blades partially free to pitch
rotational speed multiplied 90 times
P=128 kW,
Efficiency 25 to 30%



Stingray

Developed by Engineering Business Ltd

150 kW device tested in the Yell Sound, Shetland, in 2002. <u>No more in operation</u>

The controllable hydroplane angle applies the vertical upward or downward lift

Stingray

Developed by Engineering Business Ltd

150 kW device tested in the Yell Sound, Shetland, in 2002. No more in operation

Vertical motion attached to a pivoting arm, with a hydraulic cylinders that pressurize fluid used to power a hydraulic motor that drives an electric generator.

Not successful

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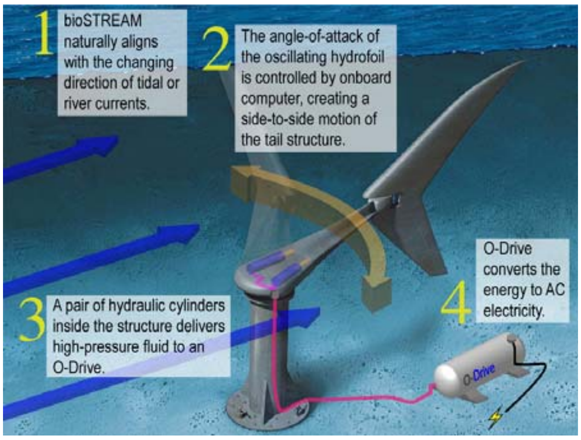
BioStream

Biostream Ltd.

Oscillating hydrofoil with vertical axis

Rotates 360°

Controlled hydraulic PTO



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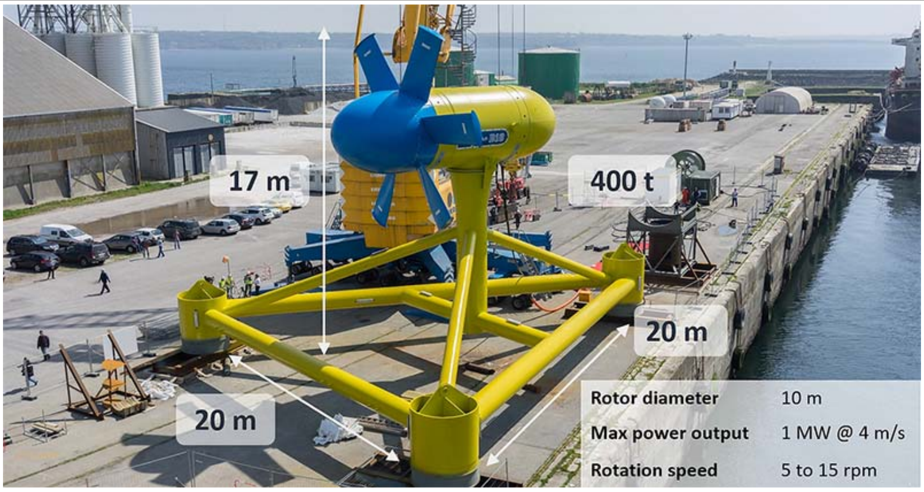
Sabella



Orbital O2 - floating

Two contra-rotating turbines mounted on a single crossbeam

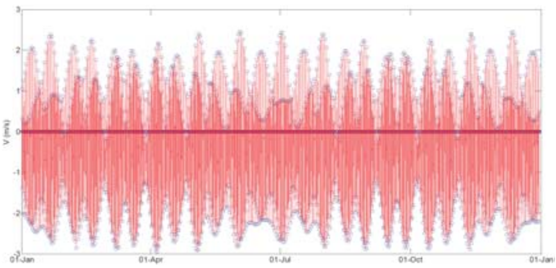
Each unit has a peak power of 2MW is buoyant and moored with steel lines to the seabed

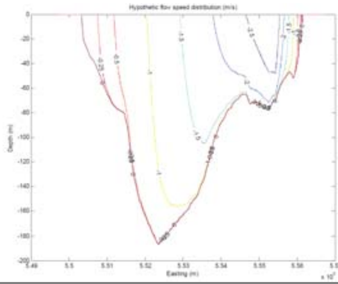
Rotating blades to adapt to flow inversion, without reorientation of the barge

Barge subject to wave action, rotates to align perpendicularly to wave front

Messina Strait

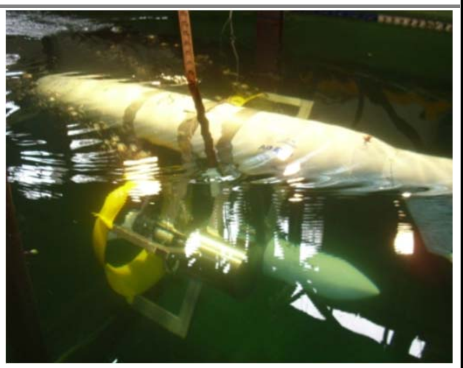
Available resource 1471 GWh
using a Significant Impact Factor of 0.2
and realistic η → Possible output = 126 GWh
Possible locations: white area in figure





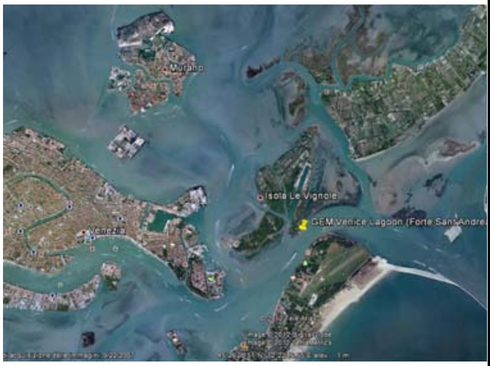
Coiro et al, 2013 Tidal current energy resource assessment: The Strait of Messina test case. ICCEP2013

Gemstar



Developed in the Water Tank of the Naval Laboratory of University of Napoli Federico II. Patent by Prof. Coiro.

Gemstar



Deployed in 2012 in front of the island of Forte Sant Andrea, in Venetian Lagoon. Such location with currents up to 1.6 m/s, depth 10 m below sea level. turbine diameter=3.08 m; diffuser diameter = 4.08 m. 38 rpm. Tip speed 1.5 m/s; Overall dimensions 9.2 m x 5.2 m x 10.4 m

Italian device: Gemstar

Sometime called "kite" system, but more properly bottom tethered floating Stream TEC type

Device of 300 KW suited to in the Messina Strait, where current > 2.0 m/s. The output is constant up to currents of 3.0 m/s, and in safe mode hereafter.

Yearly contribution of almost 1 GWh/y (300'000 €/y)

Total cost of order 2'000'000 €. Within the P.O.N. funding program, a low interest 3'000'000 € loan with 20 years payback period is offered to the (hypothetical) builder

FASI DI SVILUPPO DI UN WEC

- Fase 1 : Verifica dell’idea
- Fase 2 : Stima dell’efficienza del dispositivo
- Fase 3 : Studio di fattibilità
- Fase 4 : Studi specifici
- Fase 5 : Studio in sito su modello in scala 1:4-1:10
- Fase 6 : Dimostrazione
- Fase 7 : Commercializzazione

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Laboratories Available to the University of Padova

Wave flume

Length	36 m
Width	1.0 m
Depth of flume	1.3 m
Water depth	1.0 m
Maximum height	0.3 m
Wave period	0.5-5 s

Instrumentation
Resistive wave gauges
Air and current flow meter
Pressure transducers and strain gauges
High resolution cameras
Electronic water discharge measuring instruments
Automatic bottom profilers

Laboratories Available to the University of Padova

Wave Basin

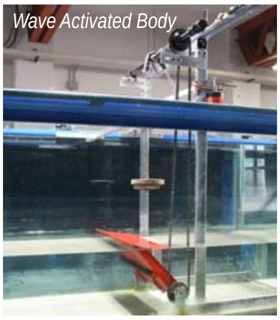
Dimensions	20.6 m x17.8 m
Water depth	0.80 m
Wave paddle	0.85 m high 8.0-12.0 m long
Water depth	0.80 m
Maximum height	0.3 m
Wave period	0.5-5 s

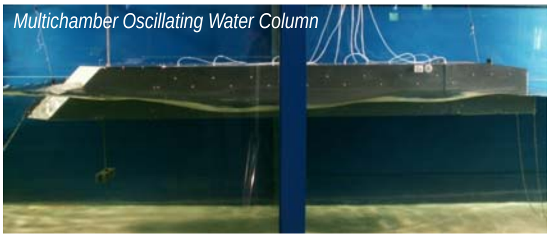
Instrumentation
Automatic bottom profilers (laser and touch-sensitive probes)
Resistive wave gauges
Laser level and laser measuring device
Pressure transducers and strain gauges
High resolution cameras

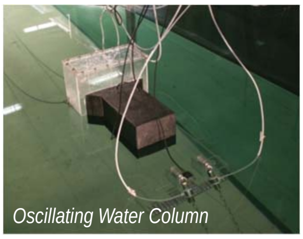
Laboratories Available to the University of Padova

Voltabarozzo facility (Ministery Public Works)

STUDI IN LABORATORIO MARITTIMO







Conclusioni

- Ad oggi la tecnologia dei Convertitori di Energia Ondosa non è matura.
- Alcuni dispositivi italiani sono molto promettenti.
- Per convertire molta energia, dell'ordine del 2% di quella consumata in Italia, è necessario posizionare centinaia di chilometri di dispositivi (al largo, dove l'impatto è inferiore).
- Per la fase della sperimentazione in situ in scala ridotta, l'Italia ha condizioni ideali: vi sono diverse zone idonee, con molti lunghi di calma, in periodi ben prevedibili.
- La fase di dimostrazione potrebbe essere svolta al largo della costa occidentale della Sardegna (10 kW/m).

Grazie per l'attenzione!
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