FACULTEIT INGENIEURSWETENSCHAPPEN EN ARCHITECTUUR

The Sea:

An **Ocean** of Energy

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Contents

1 What is wave energy?

2 Types of wave energy convertors

3 Types of energy storage

1 What is wave energy?

1.1 Ocean Energy

1.2 Wave energy: characteristics

1.3 Wave energy: available resources

1.1 Ocean Energy

OCEAN ENERGY SYSTEMS
An IEA Technology Initiative

- Created by the International Energy Agency (IEA)
- Intergovernmental collaboration to advance **research**, **development** and **demonstration**
- All forms of energy **generation**, driven by **seawater**

Waves

Tidal Range

Tidal Currents

Ocean currents

Ocean Thermal Energy

Salinity Gradients

1.1 Ocean Energy

OES OCEAN ENERGY SYSTEMS
An IEA Technology Initiative

- Workshops
- Seminars/Webinars
- GIS Database for ocean energy
- Cost assessments
- Annual report with current status per country

23 countries, 9 invited

"As the authoritative international voice on ocean energy we collaborate internationally to accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally acceptable manner."

1.1 Ocean Energy

Ocean energy has many faces!

Tidal power stations

Tidal energy turbines

Wave energy

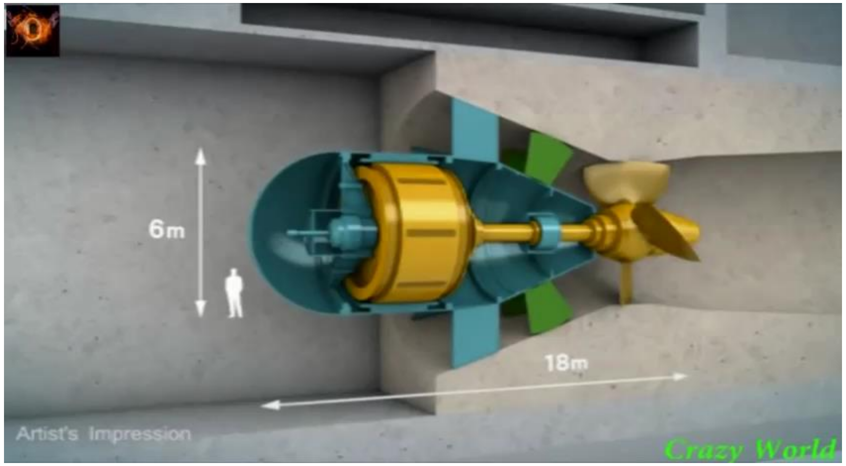
Osmotic ocean Energy

Thermal ocean energy

1.1 Ocean Energy

Tidal power stations

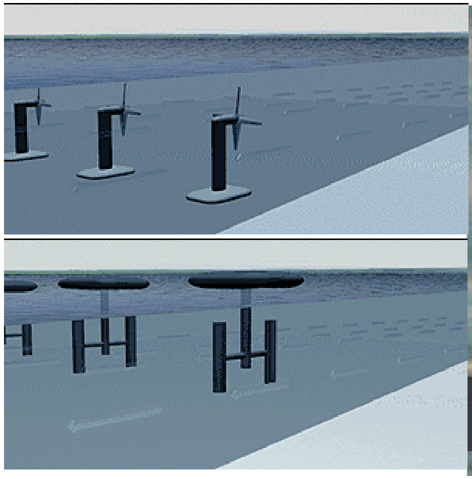
- La Rance, France
- Uses potential energy of tides
- Operational since 1966
- Barrage of 750m
- 240 MW installed power
- 20 years payback time
- 8m tidal range

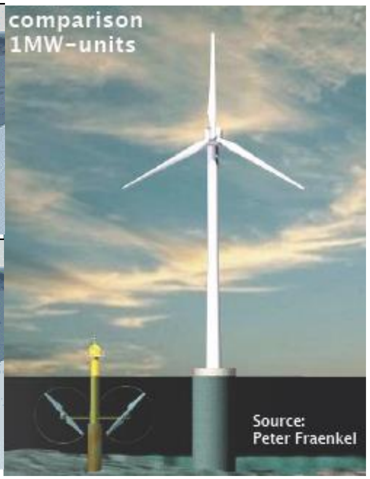


1.1 Ocean Energy

Tidal Energy turbines

- Uses kinetic energy of tides
- High energy density
- More uniform loads than wind power
- Highly predictable
- # projects in pipeline (UK)

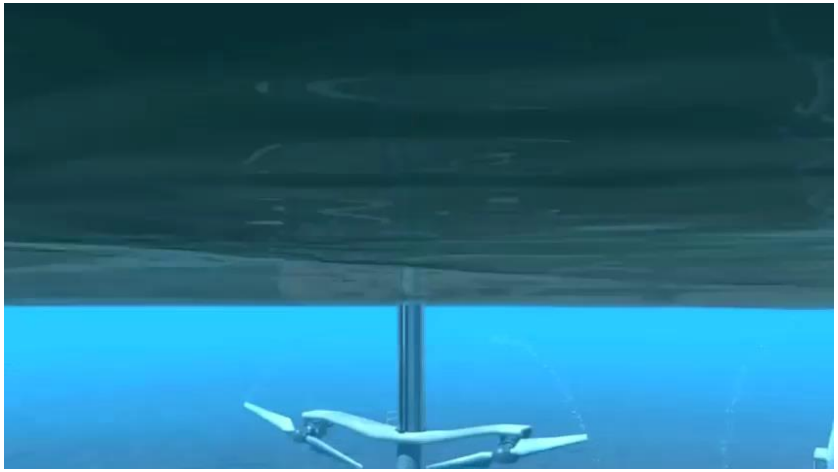




1.1 Ocean Energy

Tidal Energy turbines

Horizontal Axis Tidal Turbine



Vertical Axis Tidal Turbine

1.1 Ocean Energy

Tidal Energy turbines

Energy content:

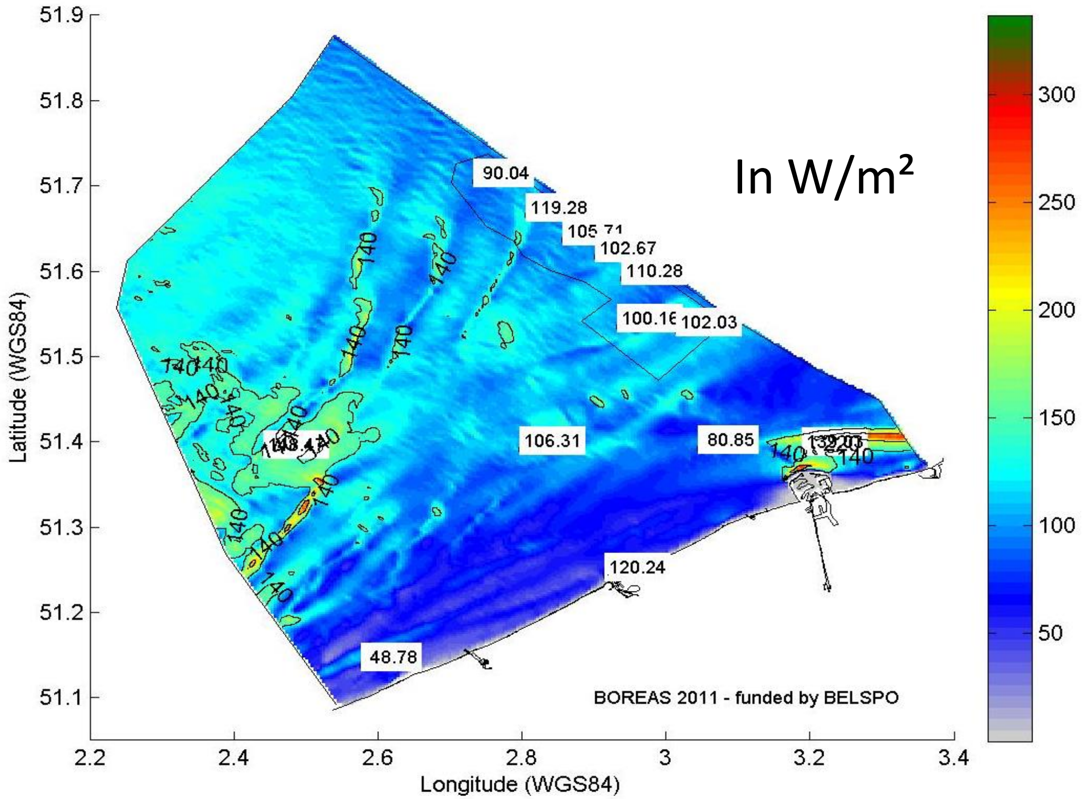
- Same formula as wind!
  - Rho: density [1,026kg/m³]
  - A: 'swept' area [m²]
  - V: velocity [m/s]

$$P = \frac{1}{2}\rho * A * v^3$$

- Differences:
  - $\rho_{seawater} \sim 800\rho_{air}$ (energy more concentrated)
  - V: current velocties
    - Sea currents: up to 2-3 m/s on springtide
    - Wind: ca. 8-10 m/s average offshore (approx. 5 beaufort)
  - A: swept area TEC << windmill

1.1 Ocean Energy

Tidal Energy turbines

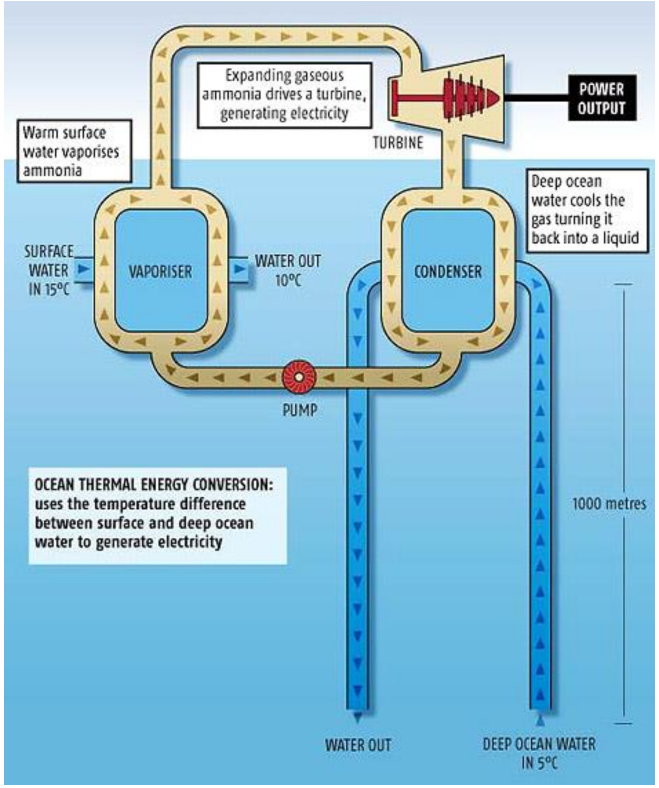


Where is the tidal energy?

1.1 Ocean Energy

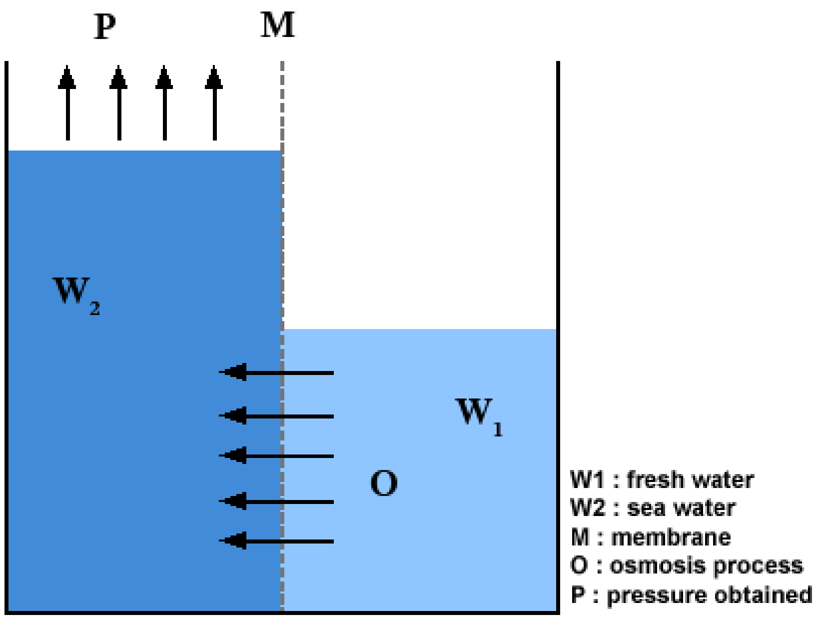
Thermal energy

Uses temperature differences of water



1.1 Ocean Energy

Osmotic energy



- Osmotic pressure → from solution with high water concentration to low water concentration
- Uses salt concentration differences of water

1.1 Ocean Energy

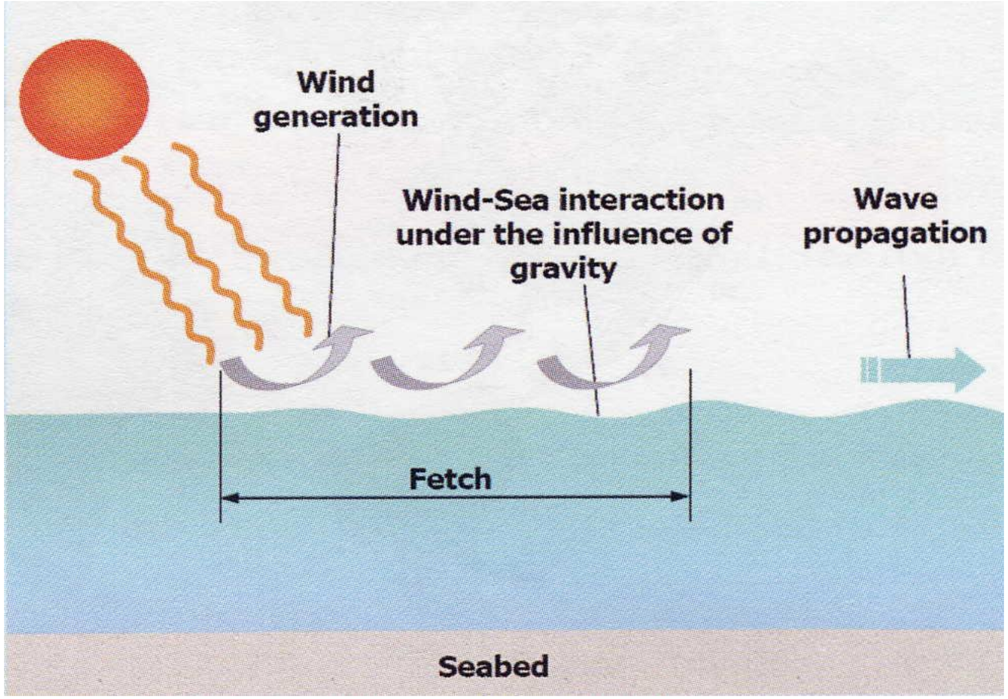
Wave Energy

How to harvest Lightning?

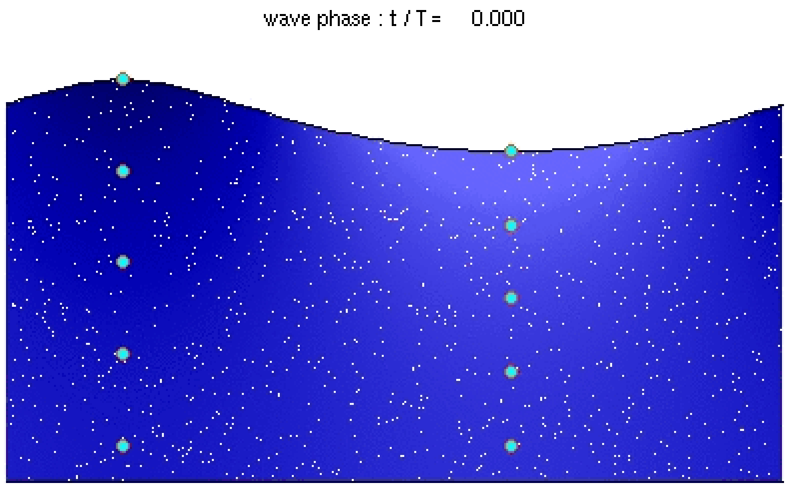
1.2 Wave energy characteristics

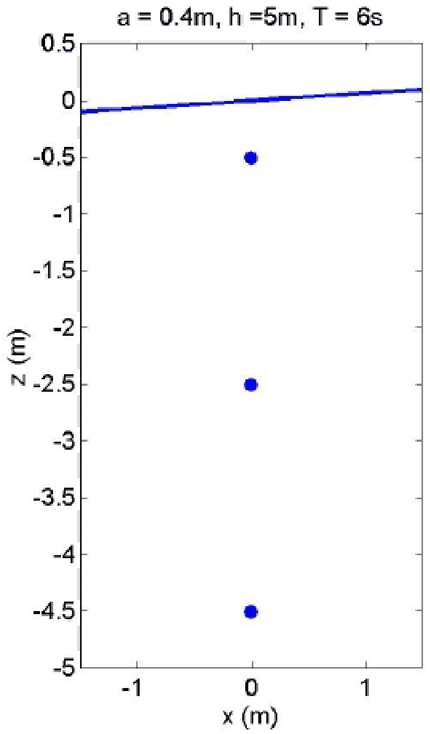
Sun → Temperature (pressure)difference→ Wind → Waves

Waves travel far distances without significant energy loss



1.2 Wave energy characteristics

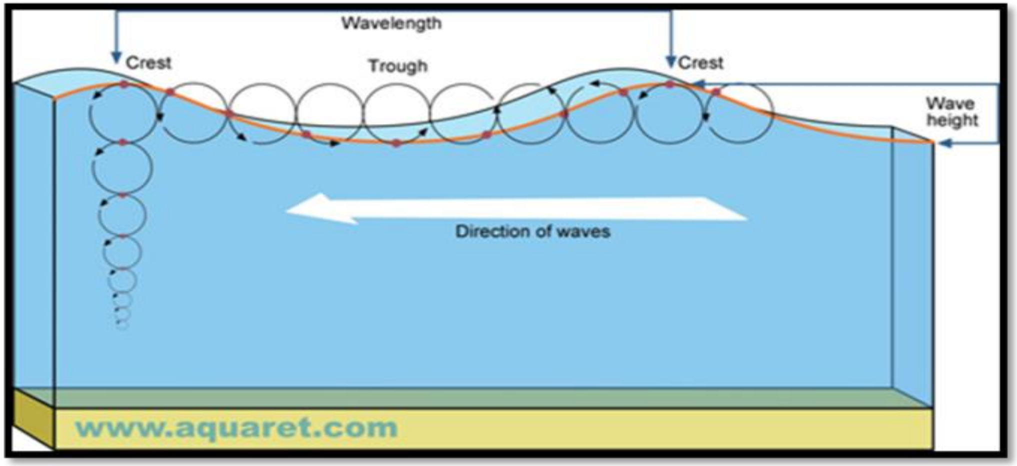




1.2 Wave energy characteristics

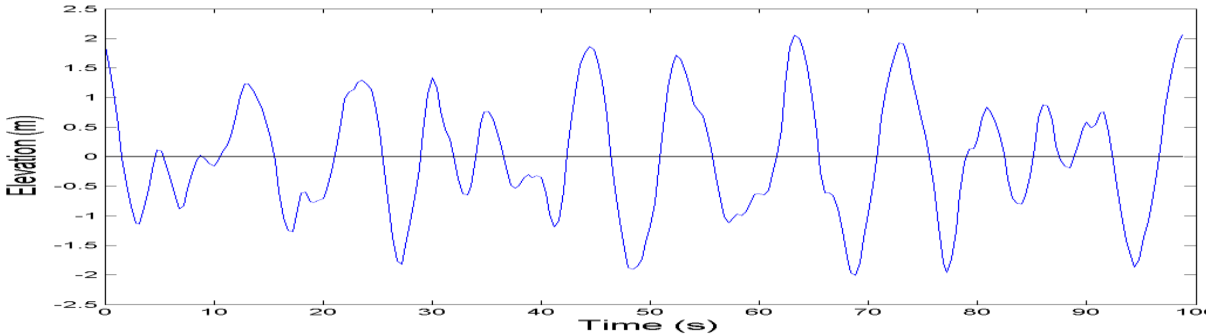
Simple form: linear and regular

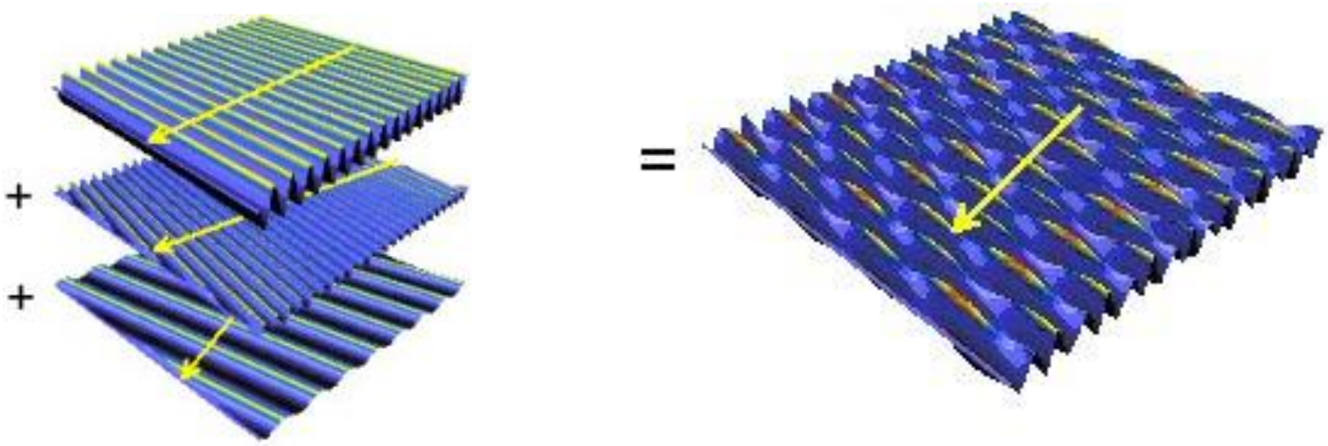
- Wave Height
- Wave Period/Frequency
- Wave Length



1.2 Wave Energy characteristics

Seastate: statistical superposition of multiple regular waves in all directions





1.2 Wave energy characteristics

- Wave power is expressed in kW/m wave crest of the wave

- Theory (deep water assumption):
  - Power ~ wave height² and period

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T_{m-1,0}$$

1.2 Wave energy characteristics

- Wave power is expressed in kW/m wave crest of the wave
- General theory:
  - Spectral analysis of irregular waves + frequency of occurence.
  - Power ~ wave height ² and period

$$P(f) = \int g\rho C_g S(f)\,df$$

$$S(f) = \alpha H_s^2 f_p^4 f^{-5} \gamma^{\beta} \exp\left(-\frac{5}{4}\left(\frac{f_p}{f}\right)^4\right)$$

Spectral density (JONSWAP)

1.2 Wave energy characteristics

Scatter diagram (wave climate: 5.1kW/m)

B - Scatter diagram (%)																		
H_{m0}	T_e (Seconds)																	
(m)	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	Total
0,5			1,0	3,6	4,9	7,5	5,6	2,2	1,0	0,5	0,3	0,2	0,2	0,2	0,2	0,2	0,2	27,6
1,0			0,1	5,1	11,8	5,6	7,3	3,2	0,7	0,2	0,1	0,1	0,1	0,0	0,0	0,0	0,0	34,4
1,5				0,0	4,8	8,6	2,9	1,3	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	18,1
2,0					0,1	4,7	3,4	1,0	0,1	0,0	0,0	0,0						9,4
2,5						0,4	3,5	0,9	0,2	0,0	0,0							5,0
3,0						0,0	1,0	1,4	0,3	0,0	0,0	0,0	0,0					2,7
3,5							0,1	1,0	0,3	0,1	0,0							1,4
4,0							0,0	0,3	0,2	0,1	0,0							0,6
4,5								0,0	0,1	0,0	0,0	0,0						0,2
5,0									0,1	0,0	0,0	0,0	0,0					0,1
5,5									0,0	0,0	0,0	0,0	0,0					0,0
6,0									0,0	0,0	0,0	0,0						0,0
6,5																		
7,0																		
7,5																		
8,0																		
8,5																		
Total			1,1	8,7	21,6	26,9	23,8	11,3	3,3	1,1	0,6	0,3	0,2	0,2	0,3	0,2	0,2	99,7

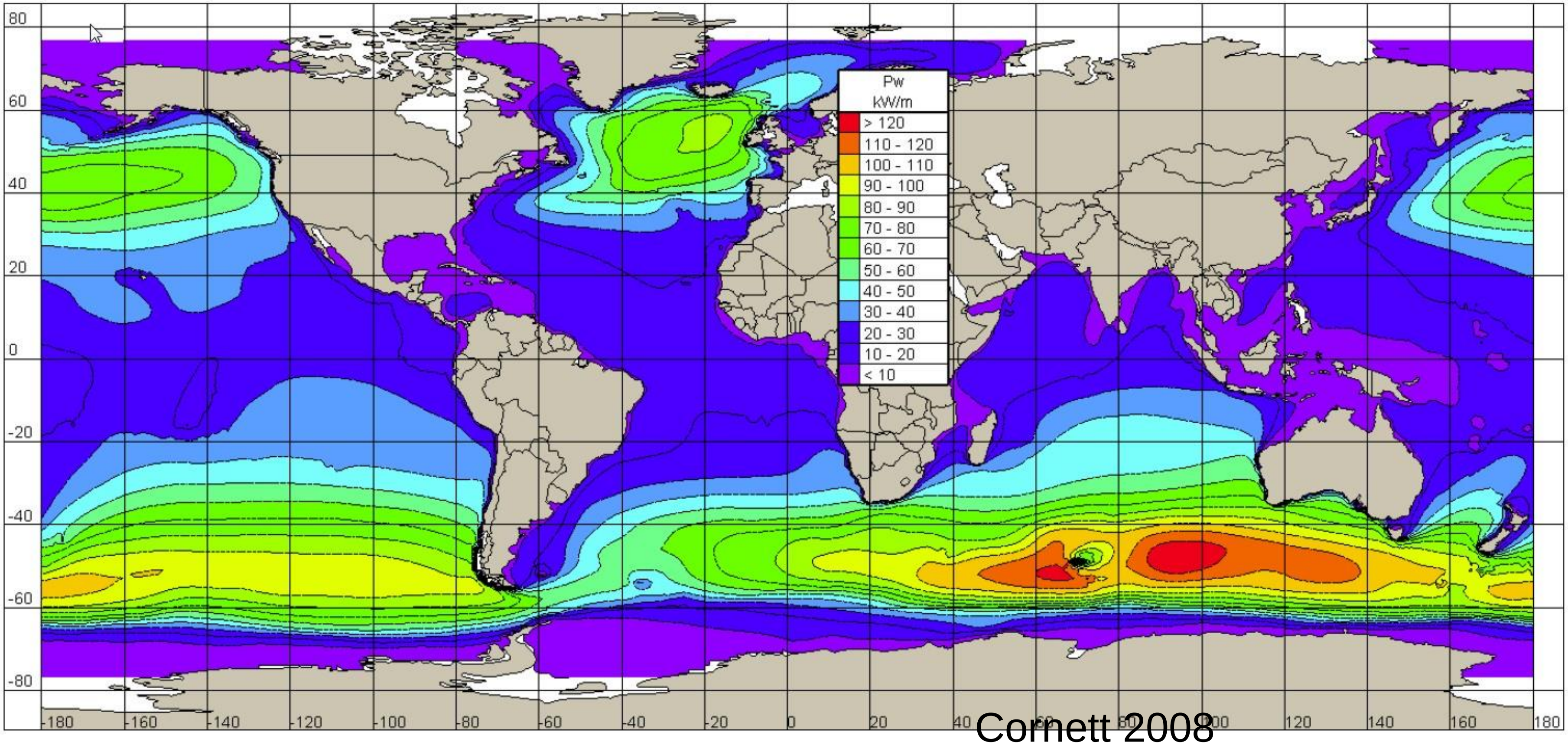
1.2 Wave energy characteristics

Wave power relative contribution (%): Wave power contribution / Total wave power * 100

H_{m0} (m)	T_e (Seconds)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
0,5			0,0	0,1	0,1	0,2	0,2	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0
1			0,0	1,0	2,9	1,7	2,6	1,3	0,3	0,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	10,1
1,5				0,0	3,3	7,2	2,9	1,5	0,3	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	15,3
2					0,1	7,7	6,6	2,2	0,4	0,0	0,0	0,0						17,0
2,5						1,1	11,0	3,3	0,7	0,1	0,0							16,3
3						0,0	4,7	7,7	1,8	0,3	0,0	0,0	0,0					14,6
3,5							0,4	7,3	2,7	0,8	0,1							11,4
4							0,0	2,8	2,8	1,2	0,4							7,2
4,5								0,3	2,0	0,7	0,4	0,1						3,5
5									1,0	0,4	0,4	0,3	0,0					2,1
5,5									0,2	0,4	0,1	0,2	0,1					1,0
6									0,0	0,3	0,1	0,1						0,5
6,5																		
7																		
7,5																		
8																		
8,5																		
Total			0,0	1,1	6,4	17,9	28,5	26,6	12,2	4,4	1,7	0,8	0,2	0,1	0,0	0,0	0,0	100,0

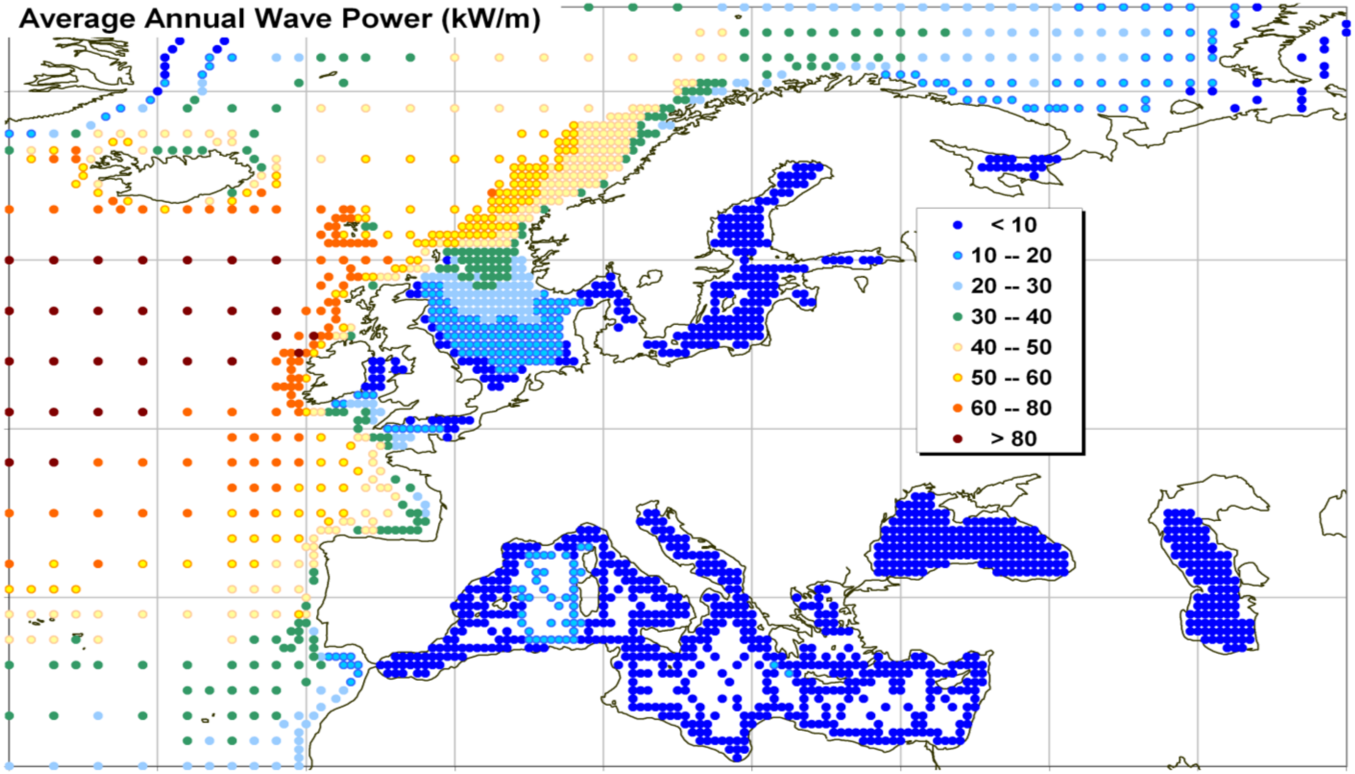
1.3 Wave energy: available resources

Wave Energy in P : kW/ meter wave crest



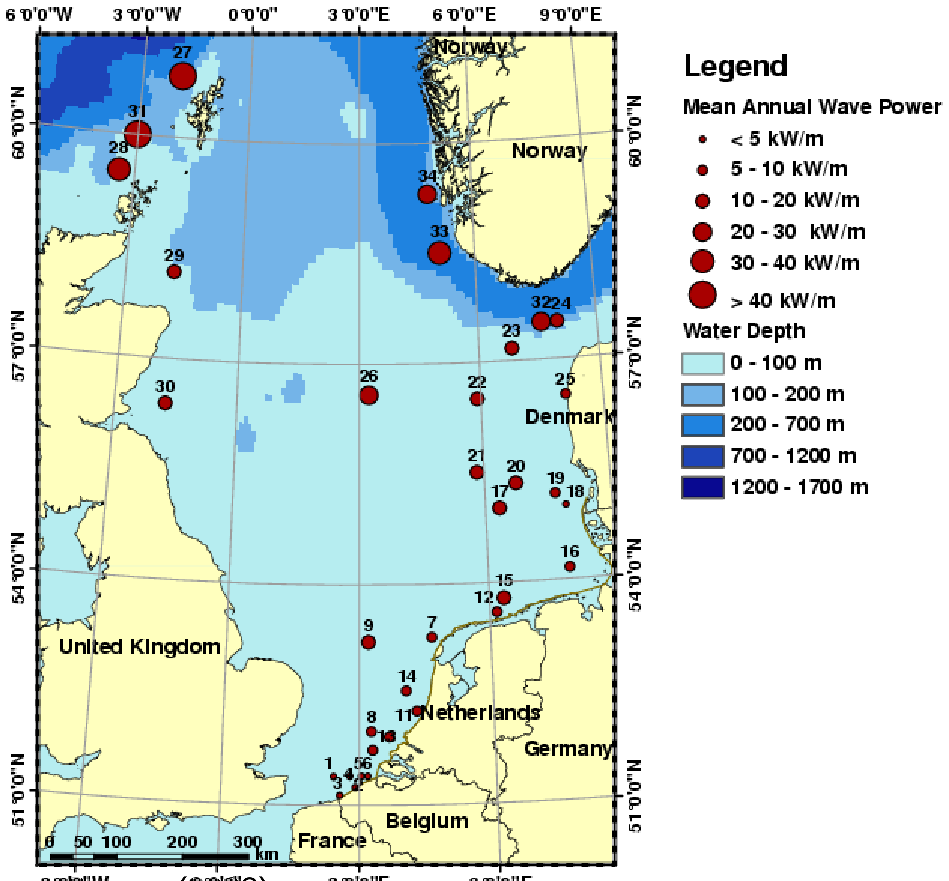
Cornett 2008

1.3 Wave energy: available resources



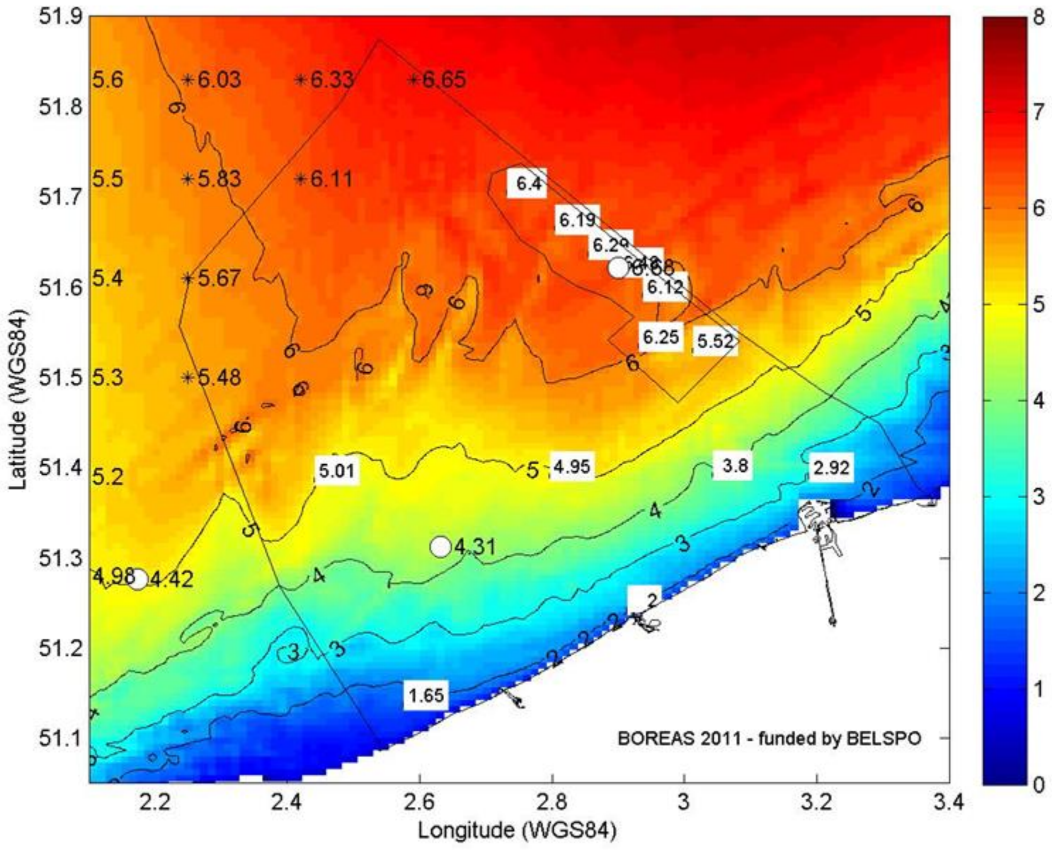
Available wave power, expressed in kW/m wavecrest. Source: WorldWaves data/OCEANOR/ECMWF.

1.3 Wave energy: available resources



Boreas (2008)

1.3 Wave energy: available resources



Boreas (2008)

1.3 Wave energy: available resources

- Necessary condition: high **resource**, good conversion **technology**
- But '**survivability**' is extremely important
  - Resistance to storm conditions:
    - General stabiltiy
    - Structural strength of the parts of the WEC
  - Fishermen to engineers: "You want to place devices where we don't dare to navigate in storms"
- Other criteria:
  - Others users, distance to shore and grid connection, etc. ,….

2 Types of Wave Energy convertors

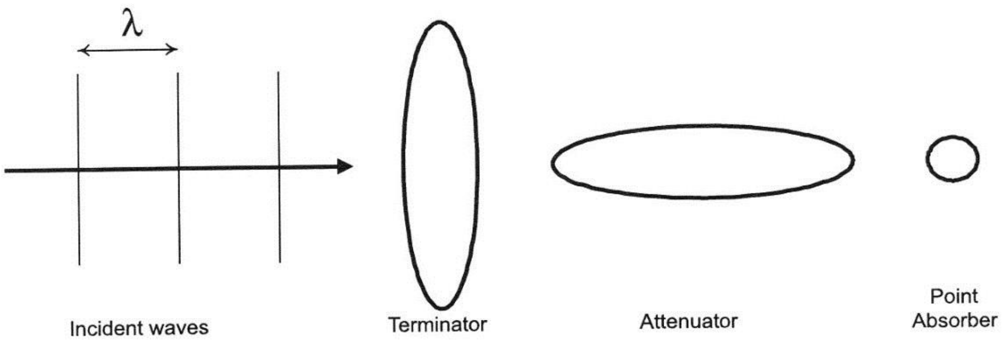
2.1 Oscillating water Column

2.2 Overtopping Device

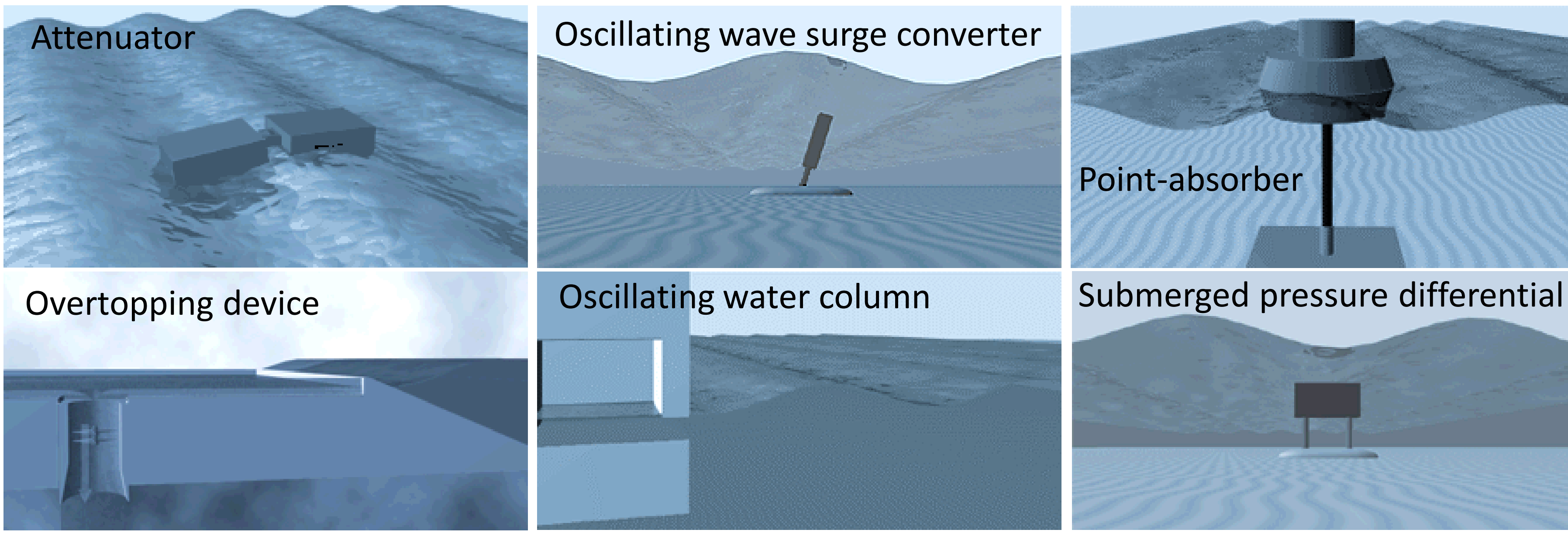
2.3 Attenuator

2.4 Point Absorber

- 2.4.1 Multiple point absorber
- 2.4.2 Single point absorber



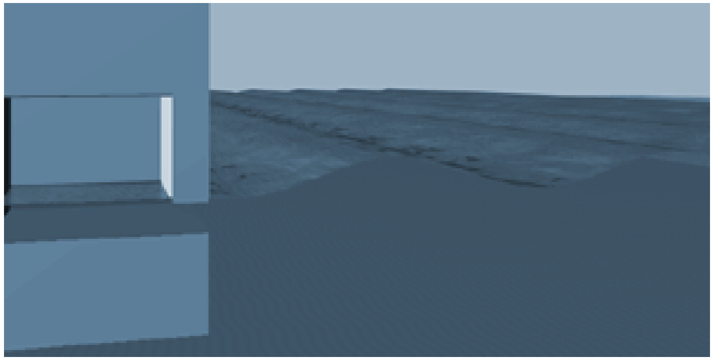
2 Types of Wave Energy convertors

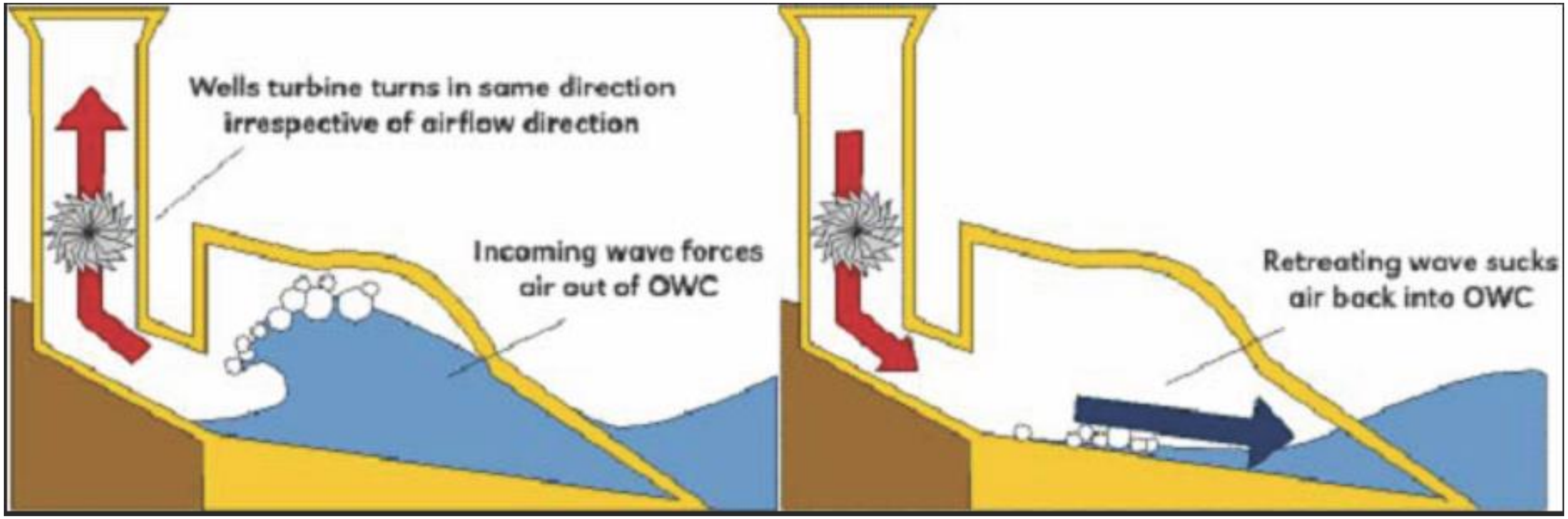


- 6 main types, all in full development
- No clear winner (depends on wave climate) <> wind energy: 3-bladed horizontal axis → Premature Technology

2.1 Oscillating water Column

- Low energy density of air
- Big concrete structure
- fixed or floating

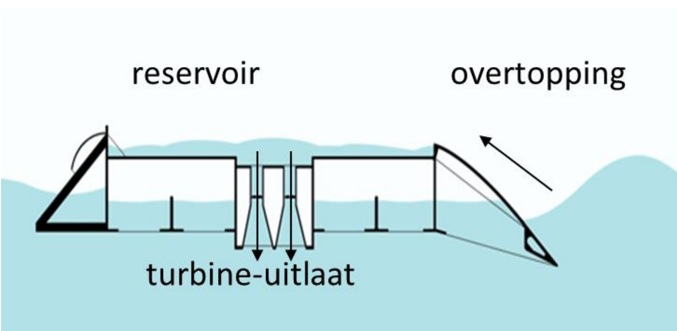


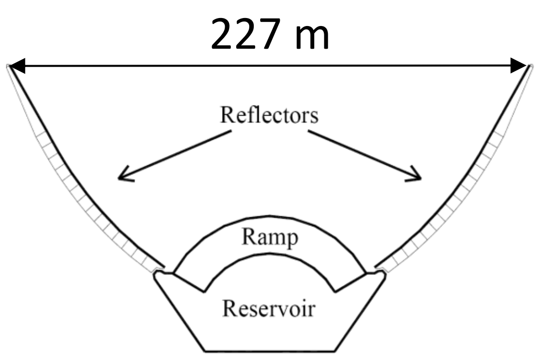


2.1 Oscillating water Column

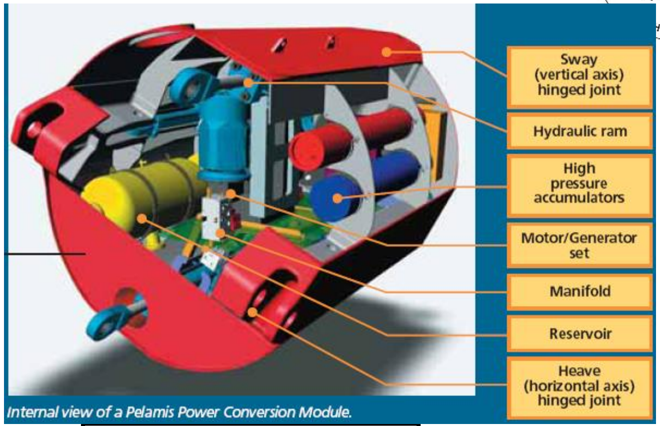
2.2 Overtopping device

- Conversion wave to potential energy
- High structural loads



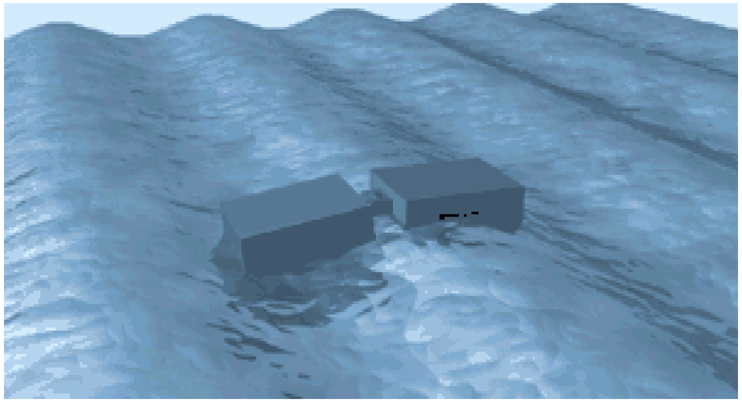


2.3 Attenuator



Example: Pelamis

- Long structure positioned in wave direction
- Hydraulic conversion of bending joints
- 180m L, 4 sections, D 4m, 750 kW



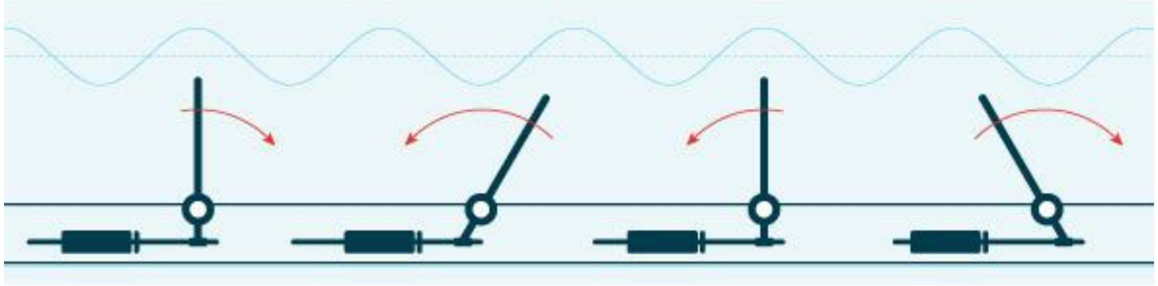
Attenuator (Pelamis)

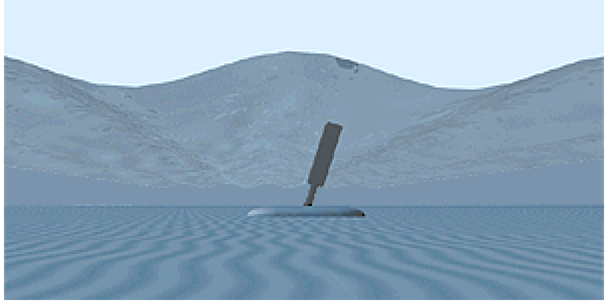
2.3 Attenuator

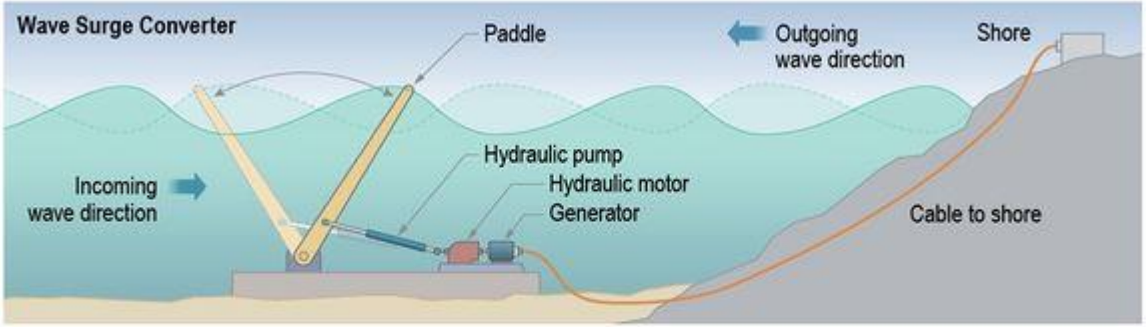
Pelamis Power Matrix

Significant wave height (H_{sig}, m) \ Power period (T_{pow}, s)	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

2.4 Oscillating Wave Surge Converter (OWSC)



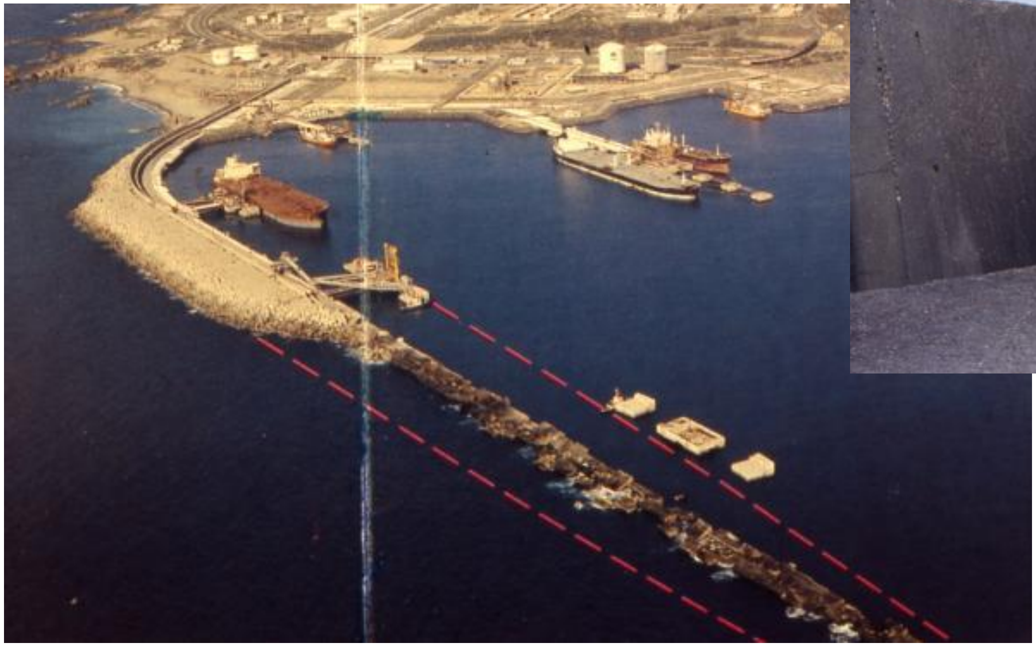




2.4 Oscillating Wave Surge Converter (OWSC)

Intermezzo: Structural/survival problems

Lessons from the past



Intermezzo: Structural/survival problems

Storm during construction of OWC breakwater Mutriku, 2008.

The water is pressed through the openings where the (air!) turbines should be placed in a later phase(normally only air can pass this opening, security valves were not yet installed).

Intermezzo: Structural/survival problems

GREEN ENERGY DREAM SUNK

LAST PHOTO

Generator vanishes under waves

PORT Kembla's revolutionary wave energy system today lies at the bottom of the sea, a victim of the wave power it is meant to harness.

The 170-tonne structure, which had been moored 150m offshore, broke free of its pylons on Friday afternoon. Developers Oceanlinx rushed to try to save it while it was lodged on rocks, but high seas prevented any recovery effort. Overnight the platform sank.

Port Kembla Port Corporation CEO Dom Figliomeni said that at this stage the structure was not posing a threat to shipping.

However, port and Oceanlinx representatives would meet today to discuss salvage options.

■ REPORTS PAGE 3

OceanLinx

Intermezzo: Structural/survival problems

Wave power prototype sinks after seven weeks

AquaBuOY 2.0 'highly successful', says developer

By **Lewis Page • Get more from this author**

Posted in Science, 9th November 2007 13:02 GMT

Free whitepaper – Cern and FuseSource Case Study

A prototype wave power installation has sunk off the Oregon coast. The company which designed the equipment described the project as "highly successful".

The patented $2m "AquaBuOY 2.0", a massive 72-foot-tall floating vertical cylinder built by Oregon Iron works, was moored two and a half miles off Newport early in September. It was not intended to generate useful electricity, but rather as a test bed for future versions. The AquaBuOY's onboard instrumentation and communications were actually powered by solar panels and windmills. It sank on 27 October, just over seven weeks after being deployed.

The prototype before it successfully sank.

According to Finavera, the renewable-energy company developing the AquaBuOY technology:

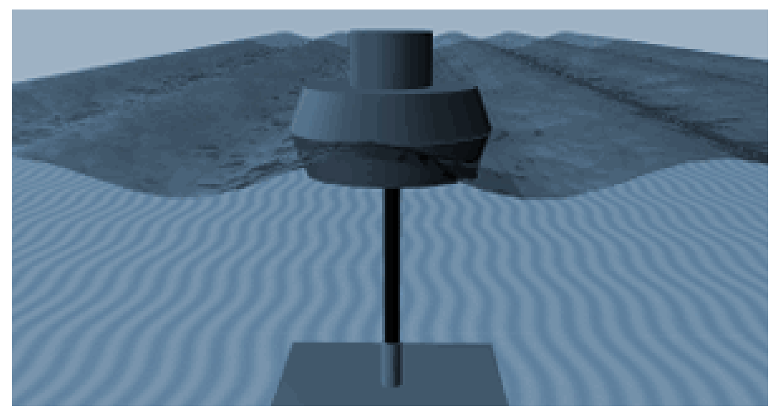
> **Any offshore system must survive the harsh ocean environment... AquaBuOYs are being designed for 100 year storms... Our maintenance and replacement cycles are being designed to extend the life of the system to beyond 20 years.**

However, Finavera's Mike Clark told local reporter Miriam Widman that the test platform had only been engineered to survive for three months; and that the company had planned to remove it the very day after it mysteriously went down. Clark seemed to feel that the situation might be misunderstood.

"So when people say - Oh there's this device and it sank. How do you expect it to last 20 years or even five years in a real commercial development? It wasn't designed for that," he fumed.

2.5 Point absorber(s)

- Water particle movement→ device movement → mechanical rotational or linear energy → electrical energy
- PTO (power take off) system converts mechanical movement into electrical energy
- Proven technology: good survival characteristics
- Cheap mooring
- Tuning is difficult but possible!



2.5.1 Multiple point absorbers

- One reference point for multiple absorbers
- Reduce cost of PTO by scale effects
- Expensive/complex structure

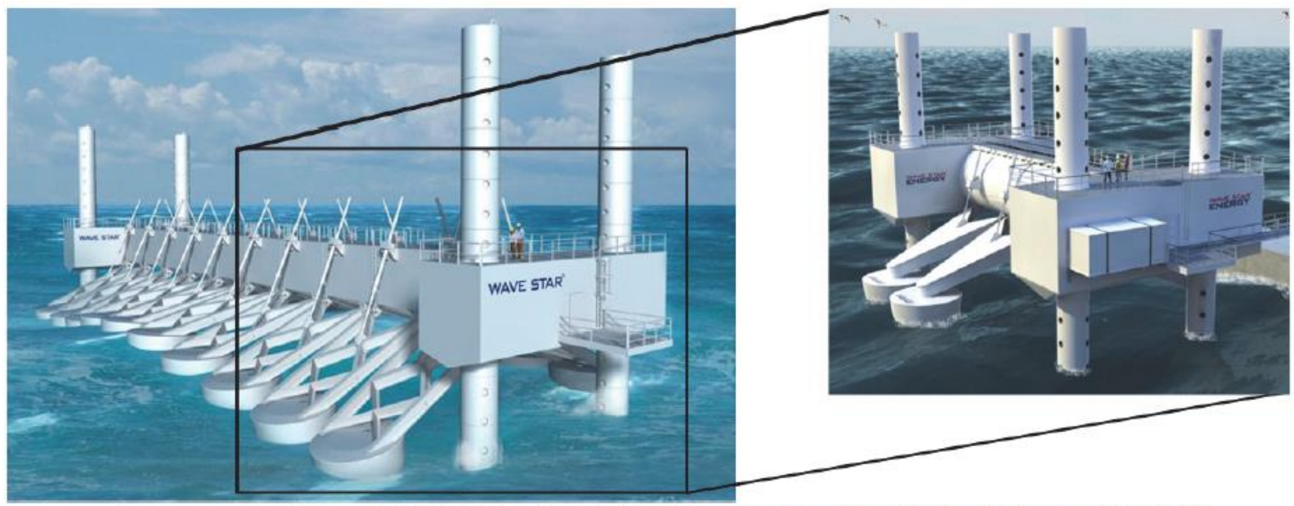
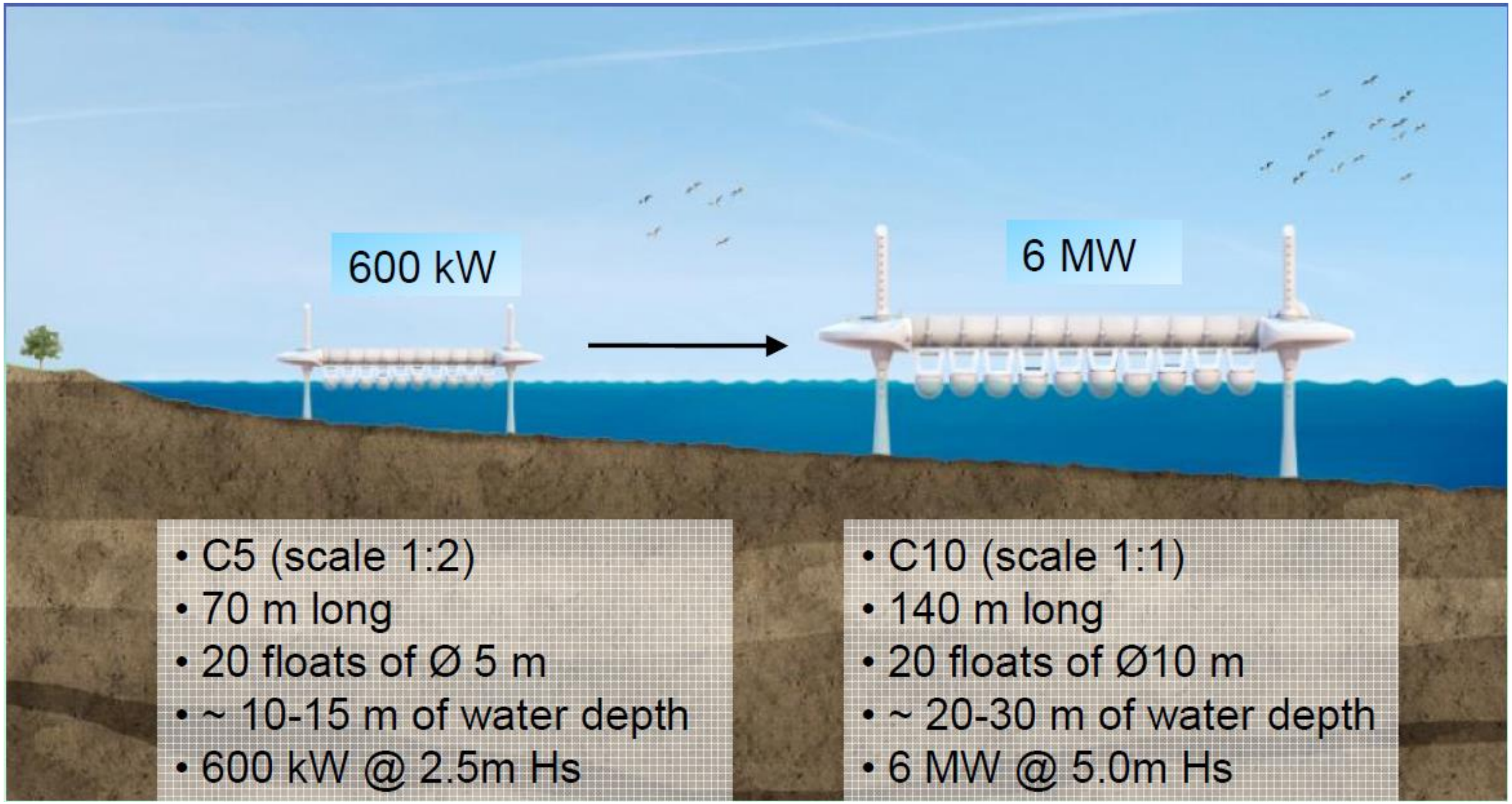


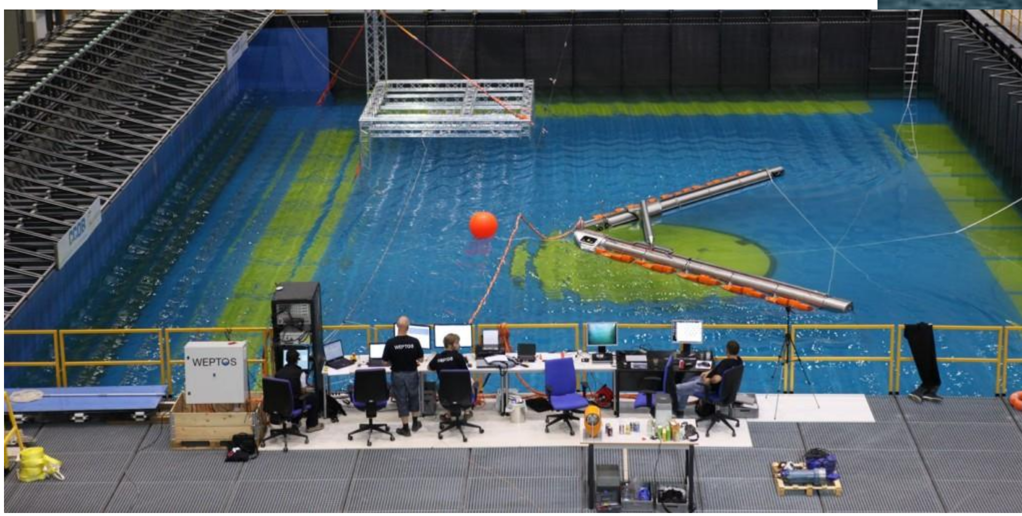
Fig. 3 Commercial converter with 20 floats (left) and test-section at Hanstholm with two floats (right)

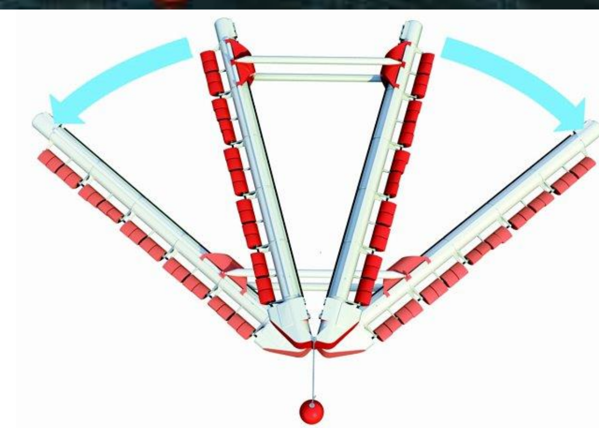
2.5.1 Multiple point absorbers



2.5.1 Multiple point absorbers

Example: Weptos

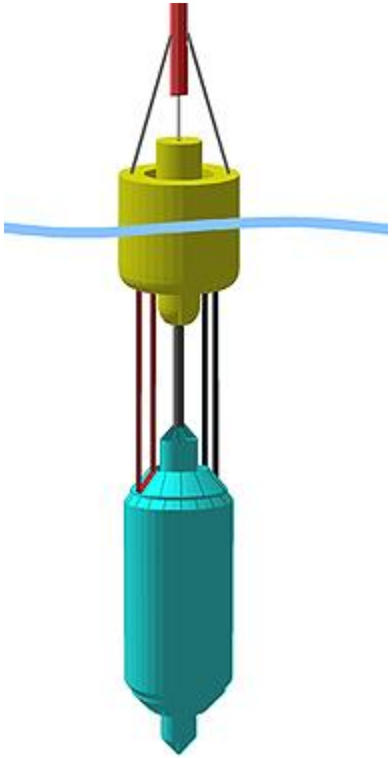




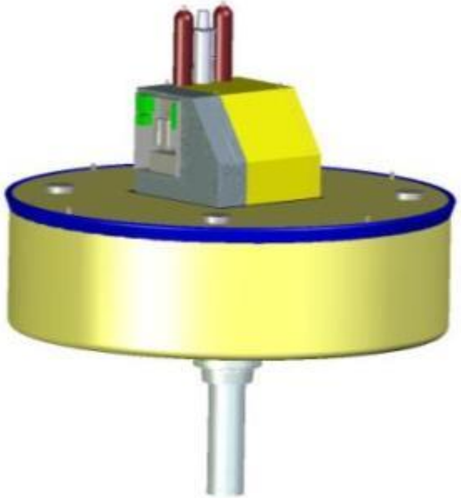
2.5.2 Single Point absorber

- Simple structure
- Simple mooring
- Cost reduction engineering!

Powerbuoy (US)

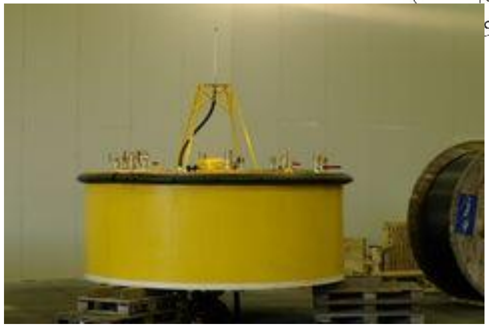


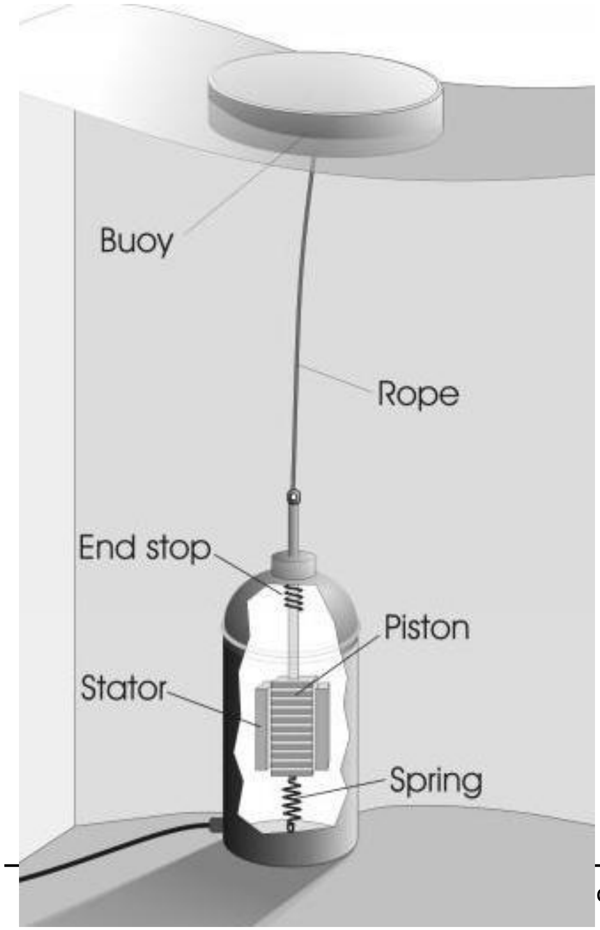
Wavebob (UK)



B1 --SEEWEC

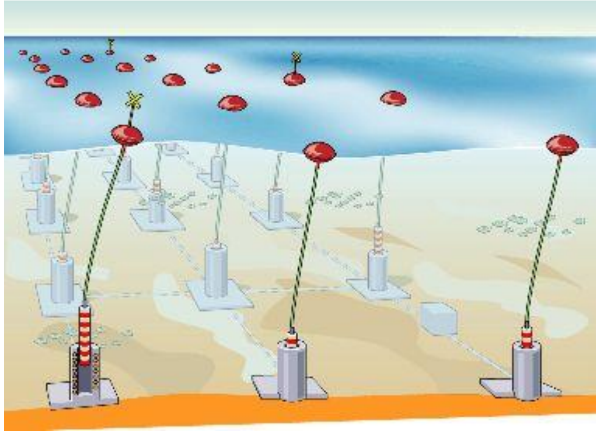
2.5.2 Single Point absorber





Lysekil test site

Future project:
+- 400 convertors, total 10 MW



2.5.2 Single Point absorber: SEEWEC

Sustainable **E**conomically **E**fficient **W**ave **E**nergy **C**onverter

Co-ordinator: J. De Rouck (october 2005 – march 2009)

SEEWEC

UNIVERSITEIT GENT

spiromatic

ABB

VARD

NTNU Norwegian University of Science and Technology

MARINTEK

TÉCNICO LISBOA

CHALMERS UNIVERSITY OF TECHNOLOGY

Fred.Olsen

natural power

2.5.2 Single Point absorber: SEEWEC

Started as a multiple point-absorber with floating platform, but evolved into a single point-absorber, moored to the sea bottom.

2.5.2 Single Point absorber: FlanSea

Flanders electricity from the **Sea**

FlanSea

DBE Wave & Tidal Solutions

UNIVERSITEIT GENT

Port Oostende

electrawinds POWERED BY NATURE

CLOOSTERMANS

CONTEC

spiromatic

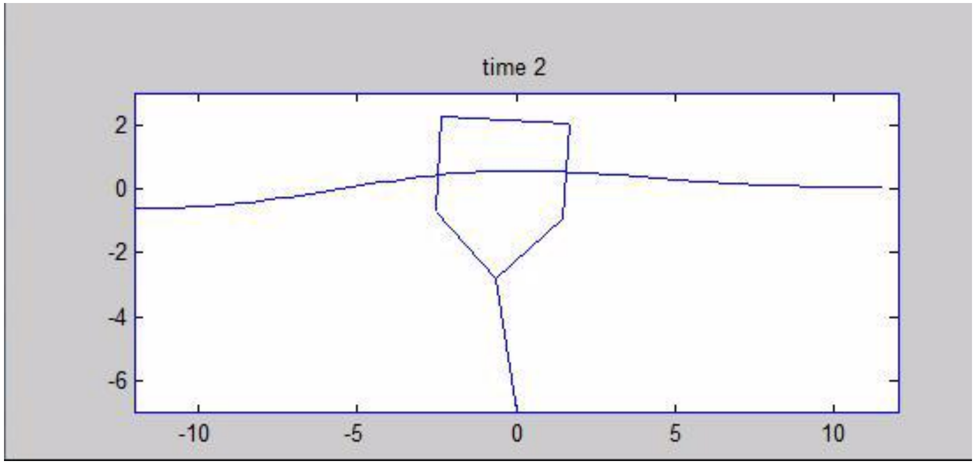
2.5.2 Single Point absorber: FlanSea

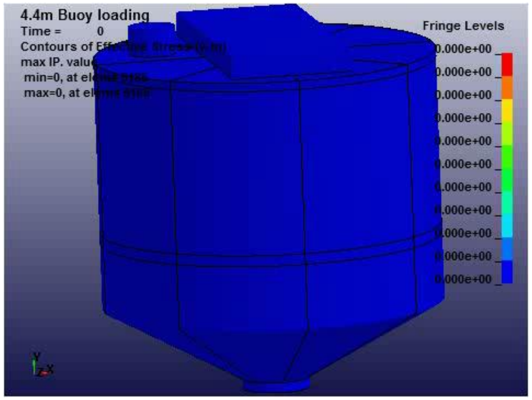
- September 2010: Start
- December 2011: Base case study PTO finished/scale model testing
- 2012: Beginning detailed design & construction
- Oktober 2012: First tests at sea with small mechanical model
- April-May 2013: 4.4 m D, 22 ton prototype device at sea in Ostend

" A journey of a thousand miles begins with a single step"

2.5.2 Single Point absorber: FlanSea

Wave energy research: Numerical model 1D/6D



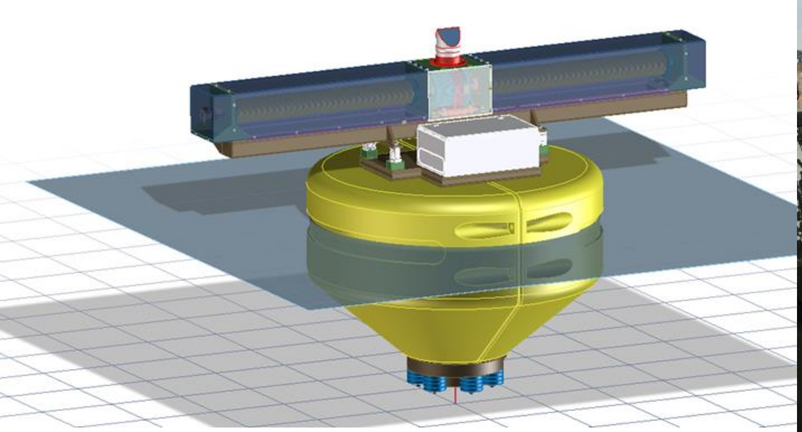


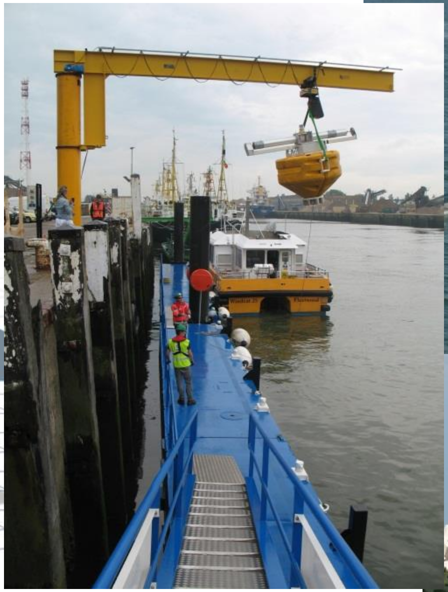
2.5.2 Single Point absorber: FlanSea

Scale testing in labo with model 1:9, D 50cm, weight 50 kg

2.5.2 Single Point absorber: FlanSea

Scale testing at Ostend Harbour, D1.8m, weight 1100 kg



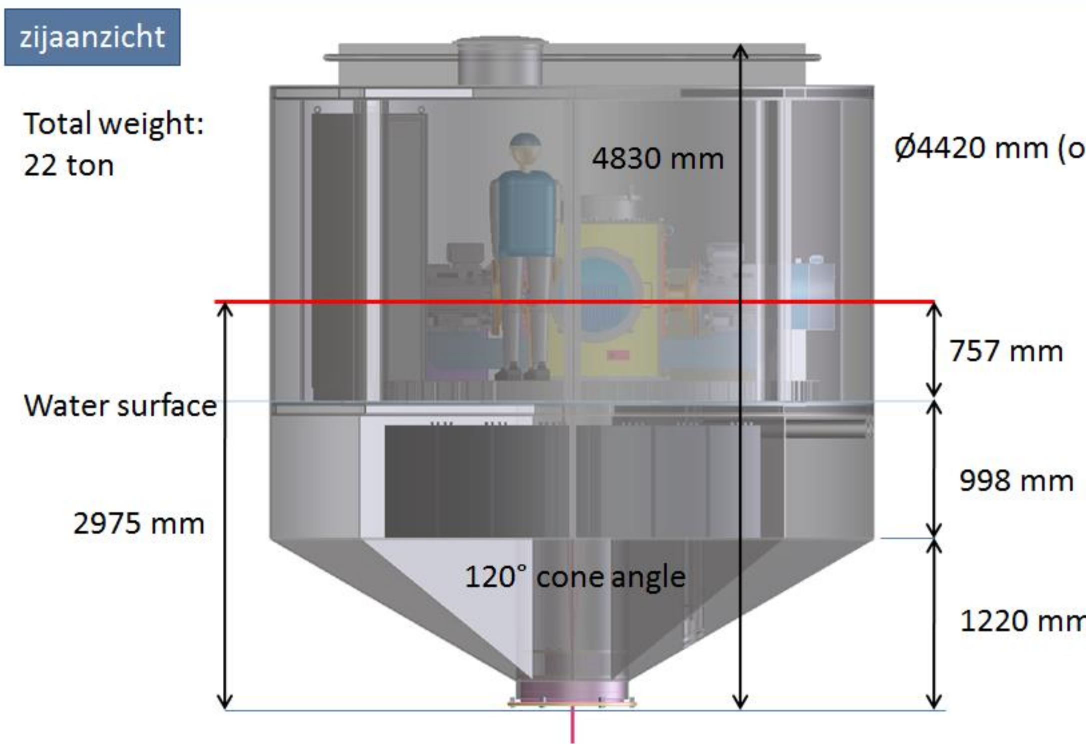


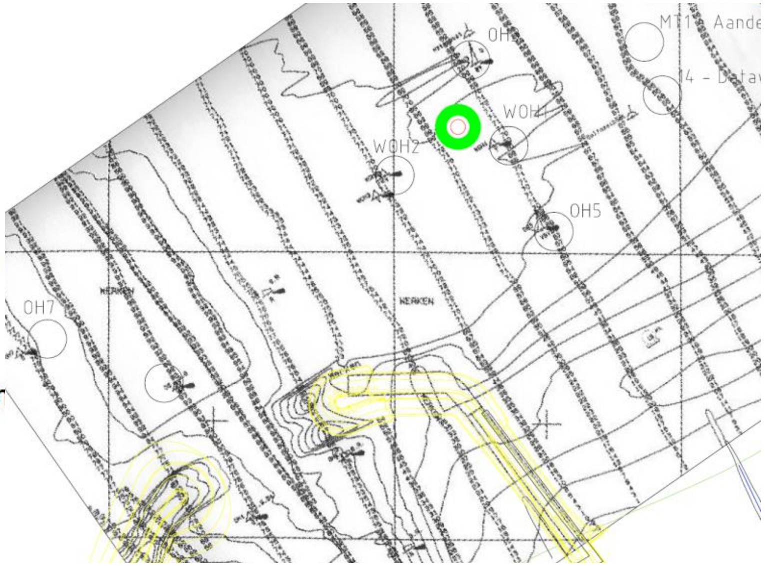
2.5.2 Single Point absorber: FlanSea

Scale testing at Ostend Harbour, D1.8m, weight 1100 kg

2.5.2 Single Point absorber: FlanSea

Building the real life Lab





2.5.2 Single Point absorber: FlanSea

2.5.2 Single Point absorber: FlanSea

2.5.2 Single Point absorber: FlanSea

2.5.2 Single Point absorber: FlanSea

- 35 ton steel slab
- 24 mm steel working cable

2.5.2 Single Point absorber: FlanSea

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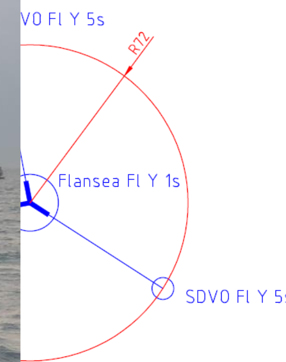
2.5.2 Single Point absorber: FlanSea



2.5.2 Single Point absorber: FlanSea

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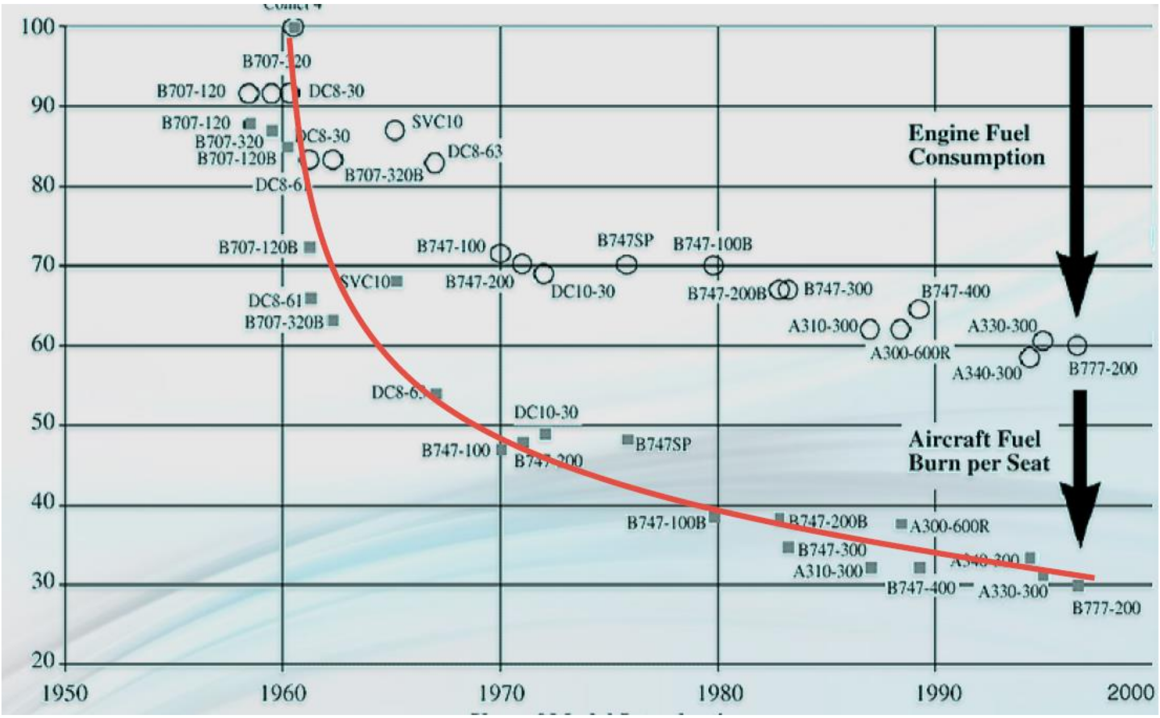
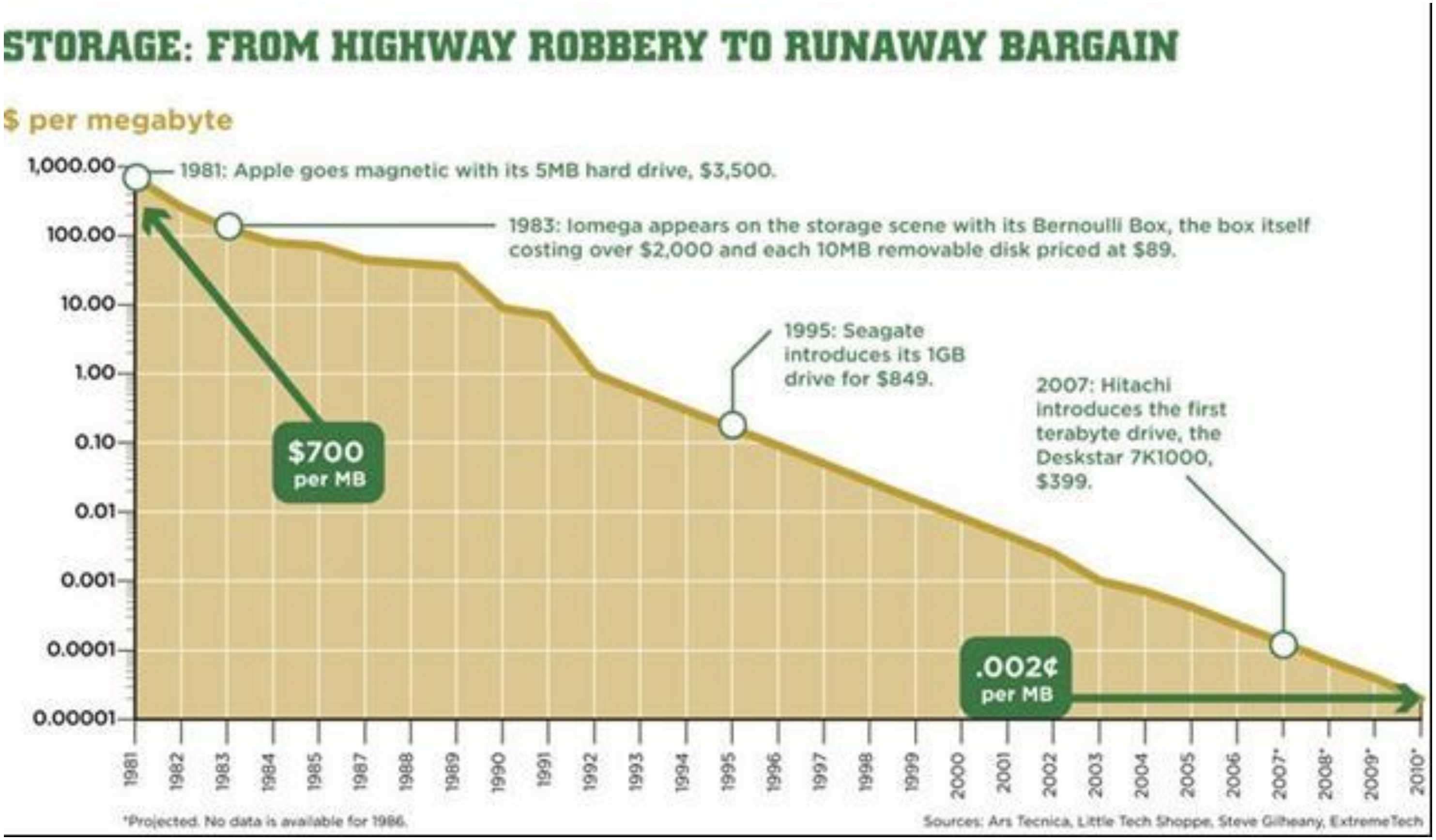
2.5.2 Single Point absorber: FlanSea

Cost reduction engineering will be the key to a lower Cost of Energy!



2.5.2 Single Point absorber: FlanSea

Cost reduction engineering will be the key to a lower Cost of Energy!



3 Types of Energy storage

Chemical battery storage

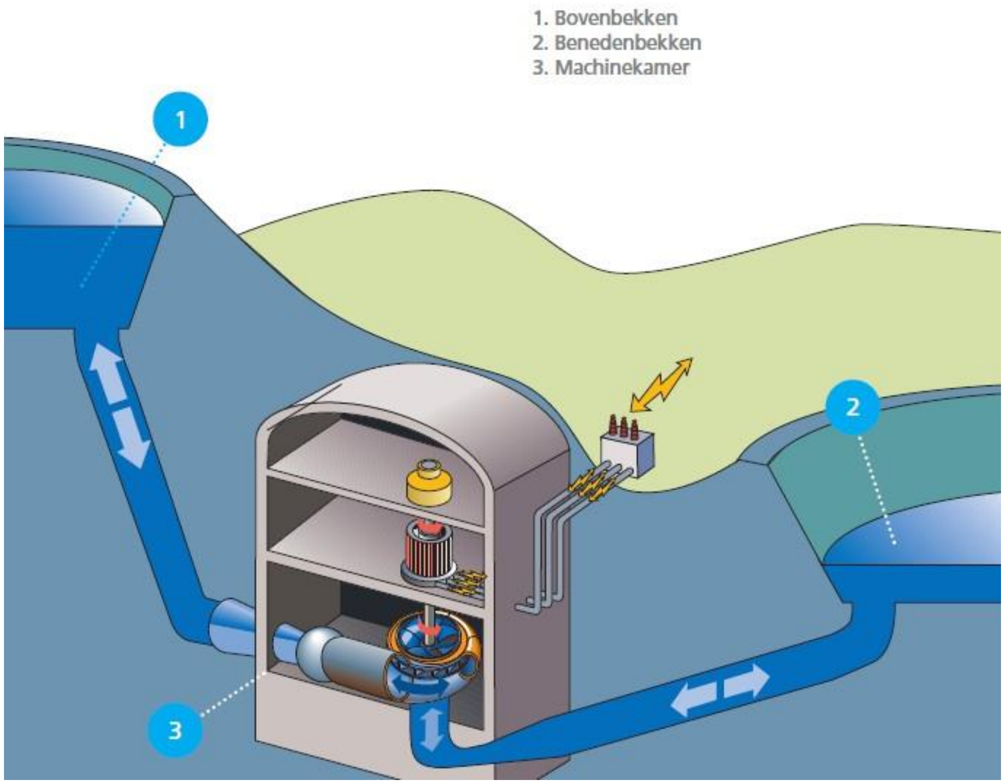
Compressed air storage

Potential energy storage (water)

Kinetic energy storage

3.1 Potential energy storage water

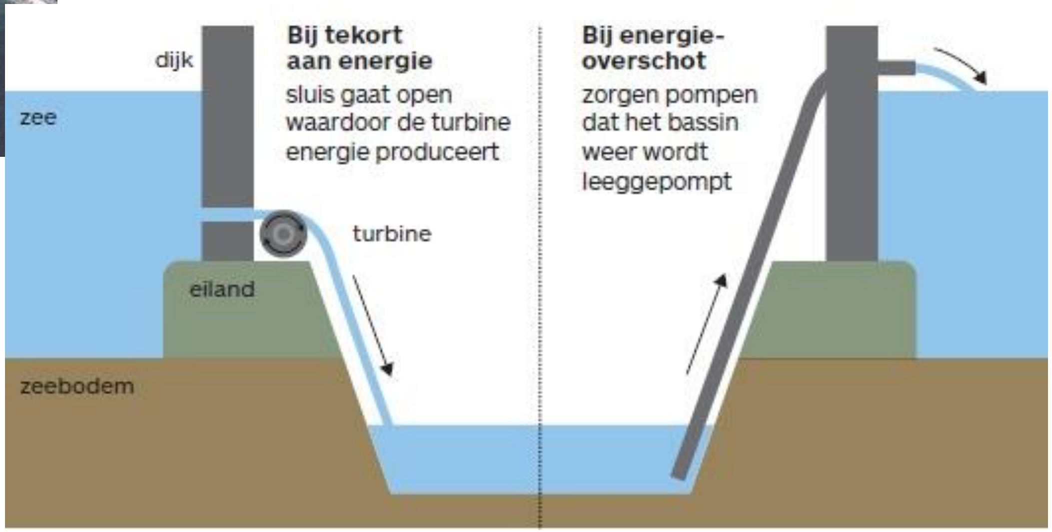
Coo Hydro Power plant: 1100 MW



- High construction and inst cost
- Low O&M costs
- Height needed
- Low Energy density(space needed)

3.1 Potential energy storage water

Energy Atol



CONCLUSION

The huge potential is there!

Funding needed for further research in energy production & storage

“ Those that say it can’t be done should get out of the way of those doing it.”

Chinese Proverb