Technology State of the Art:
Wave and Offshore Wind Energy

Estado de arte tecnológico: Energia das ondas e eólica offshore

1999 2000 2001 2002 2003 2004 2005 2006 2007 2008

Frank Neumann, WavEC

WaveEnergy Centre
Centro de Energia das Ondas

Seminar Maritime Renewable Energy in Portugal, 24.11.2008

Maritime Renewables Overview

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Wave Energy - in areas with medium-high average swell

Offshore Wind Energy - medium-high average wind speeds; shallow water

Tidal Stream Energy - in high tidal range area; clustered coastlines

Tidal Impoundment/Barrages - in high tidal range estuaries or open seas

Salinity Gradient Energy - in estuarine area with large discharge

OTEC – Ocean Thermal Energy Conversion - Deep ocean with high surface temp.

Others (Marine Biomass, Ocean Currents, etc.) - First trials / technical uncertainties

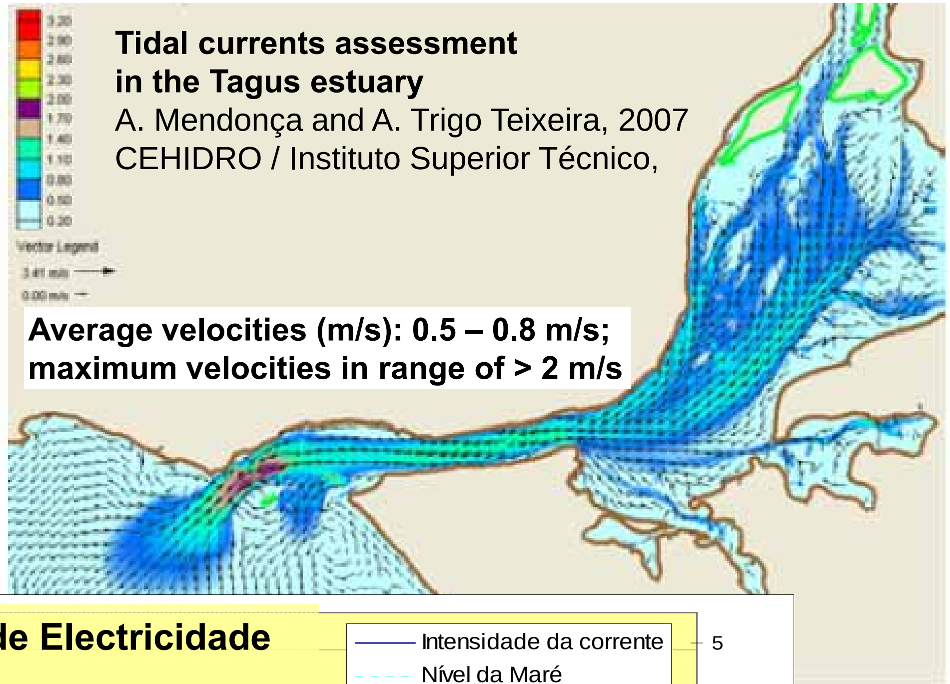
Tidal Stream resource

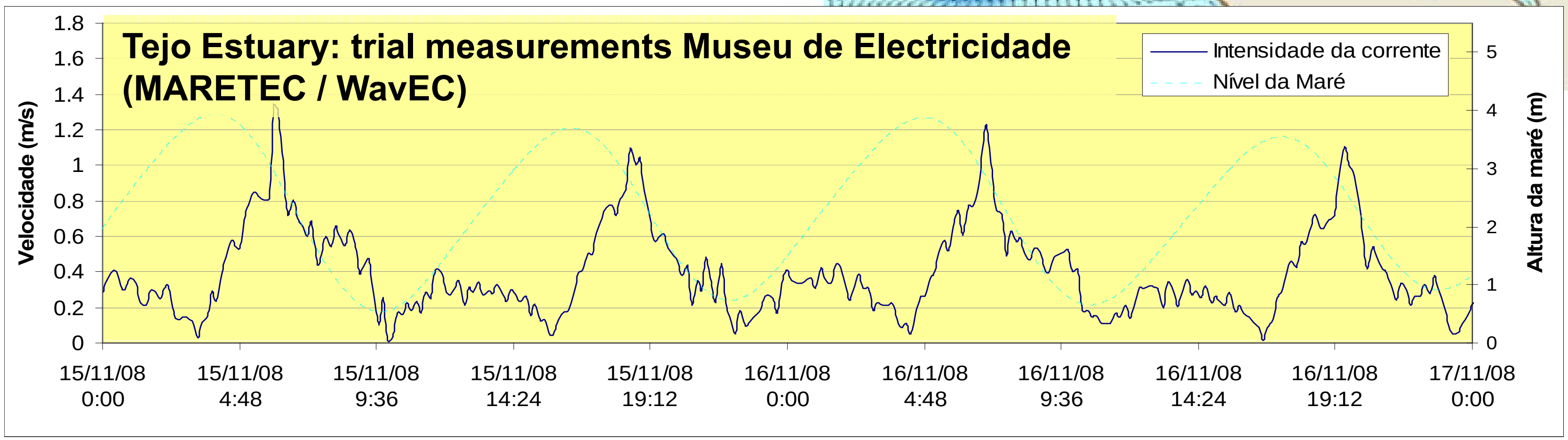
Tejo Estuary: high current velocities in centre

Minimum velocity for practical purposes ~ 1 m/s;

Mean spring peak tidal currents faster than 2-2.5 m/s;

Lower energy density inadequate for economic viability



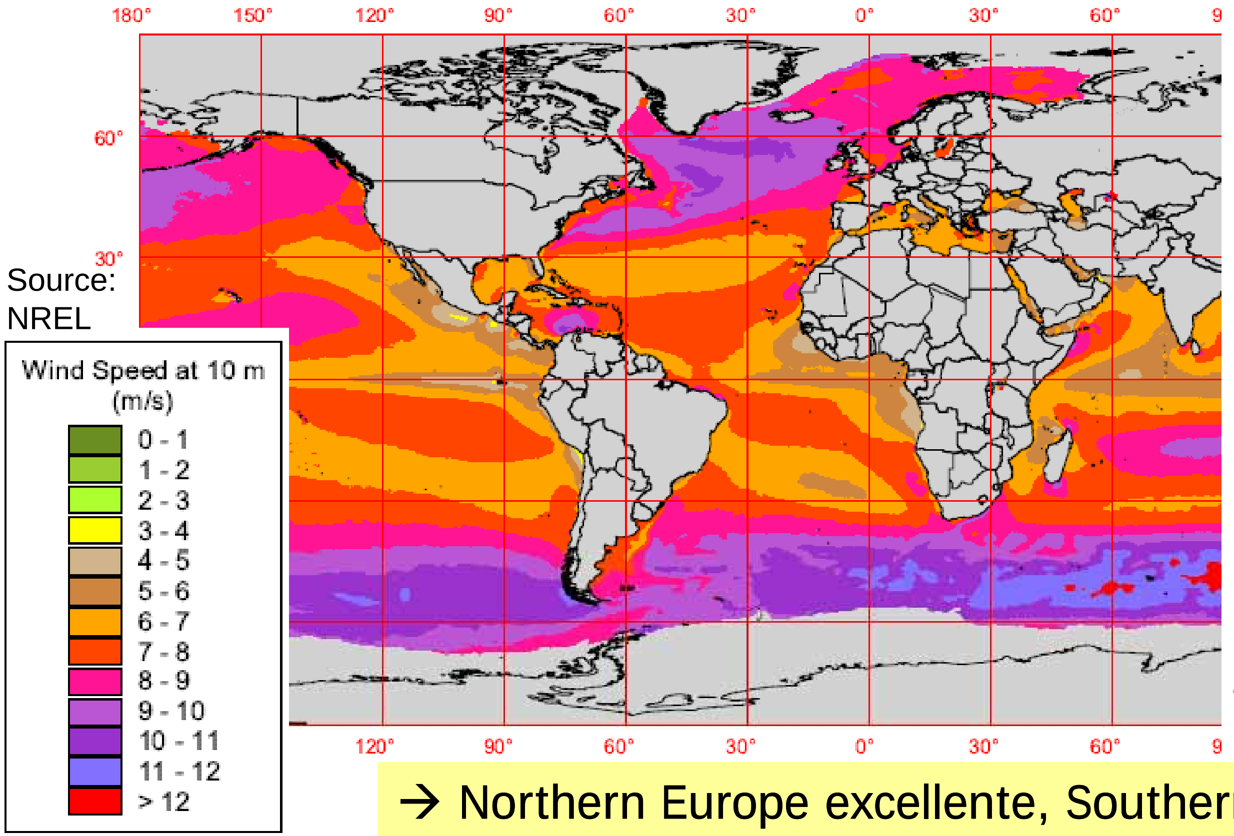


Offshore Wind Resource

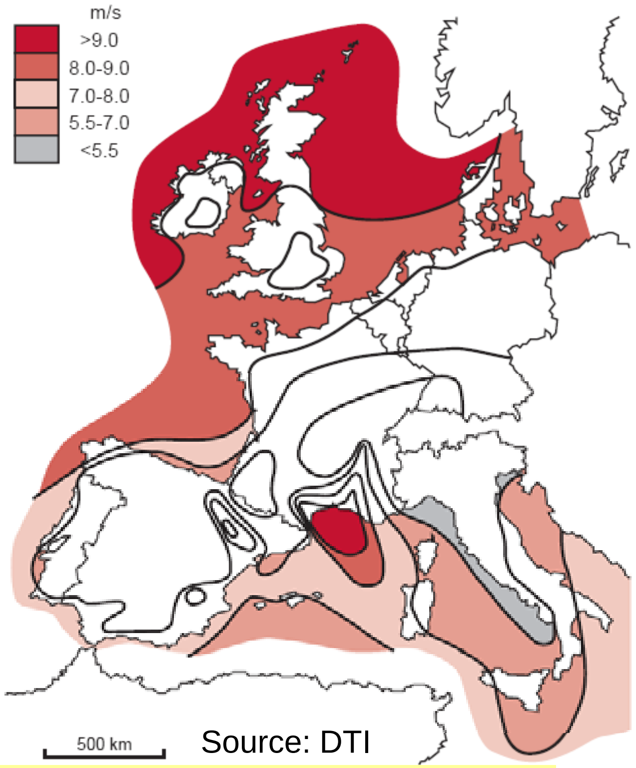
Offshore wind resource larger, more consistent and less turbulent than on land

European and large part of world-wide *Near-shore* areas favourable

- From 6-7 m/s average speed resource is considered ‘suitable’



Source: NREL



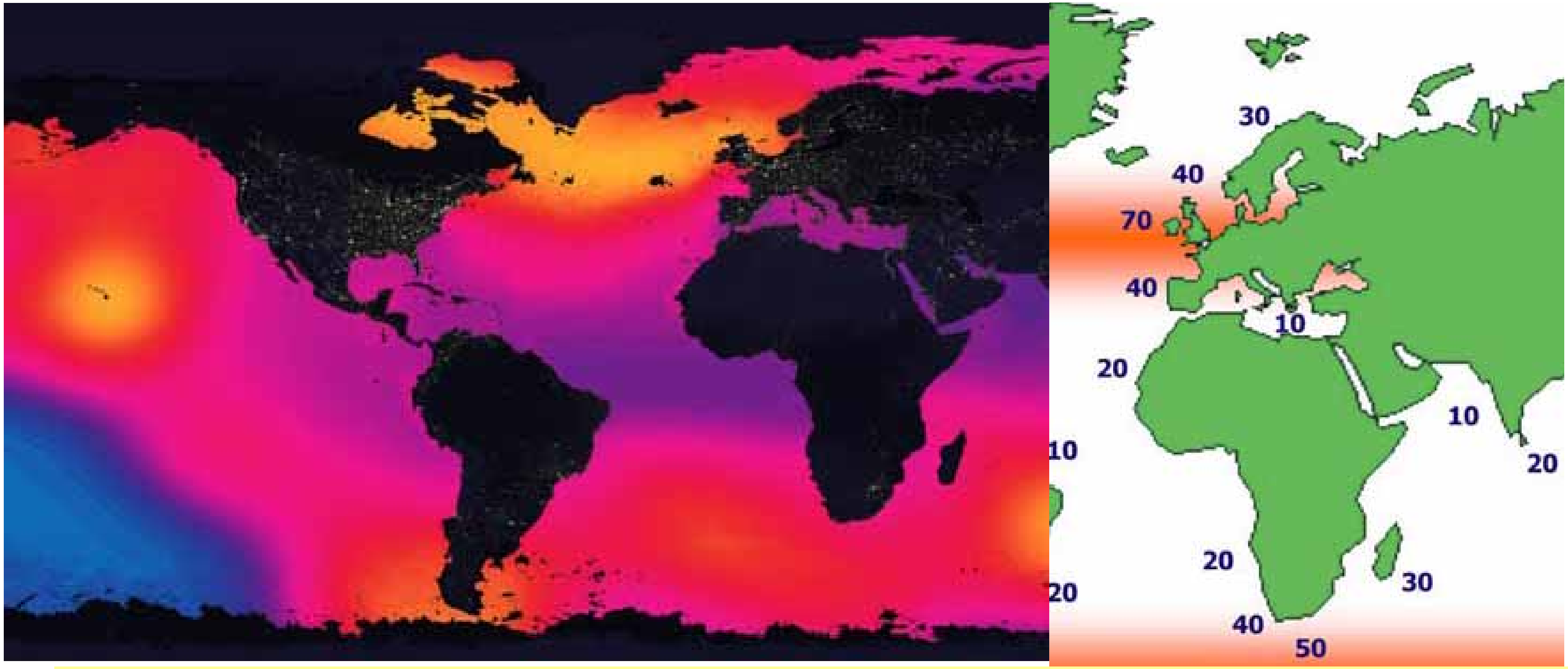
Source: DTI

→ Northern Europe excellente, Southern Europe good resource

Wave energy resource

Resource expressed in annual average power [kW/m] parallel to coastline

European Atlantic coastlines and extreme south/north open coasts favourable
- ‘Economic potential’ considered from ~20 kW/m average annual power



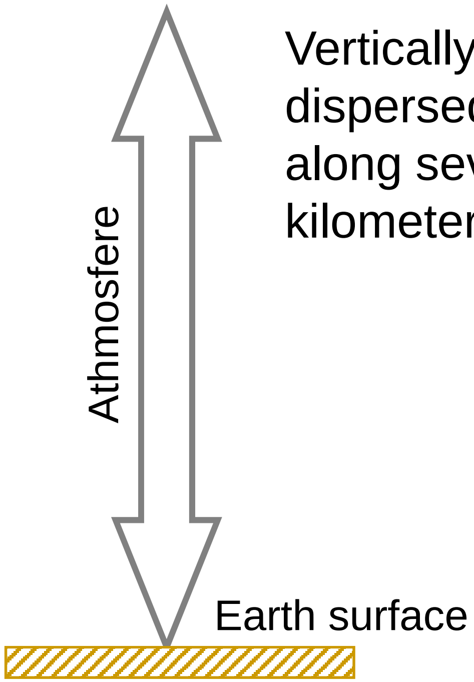
→ Medium-high wave energy resource along Portuguese western coastline

Reasonable predictability of wave energy resource on open Atlantic coastline
(Portugal, Ireland, France, Espanha do NoNorthern Spain, Western Scotland etc.)

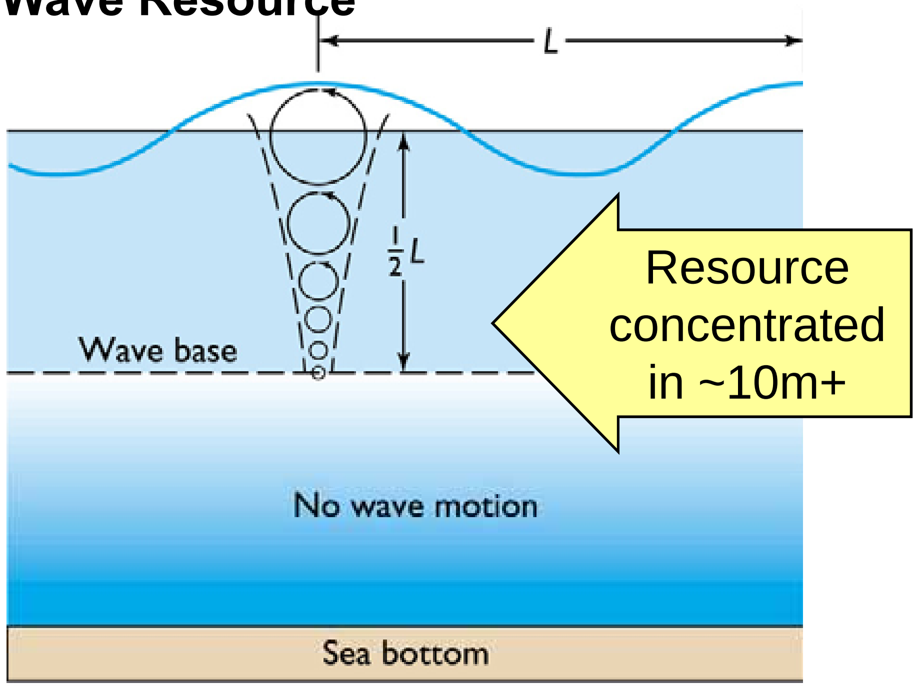
Wave Energy: comparatively high resource concentration

Wind resource:

Vertically dispersed along several kilometers



Wave Resource



(b) ORBITS OF WATER PARTICLES

The ascension of offshore wind (OW)

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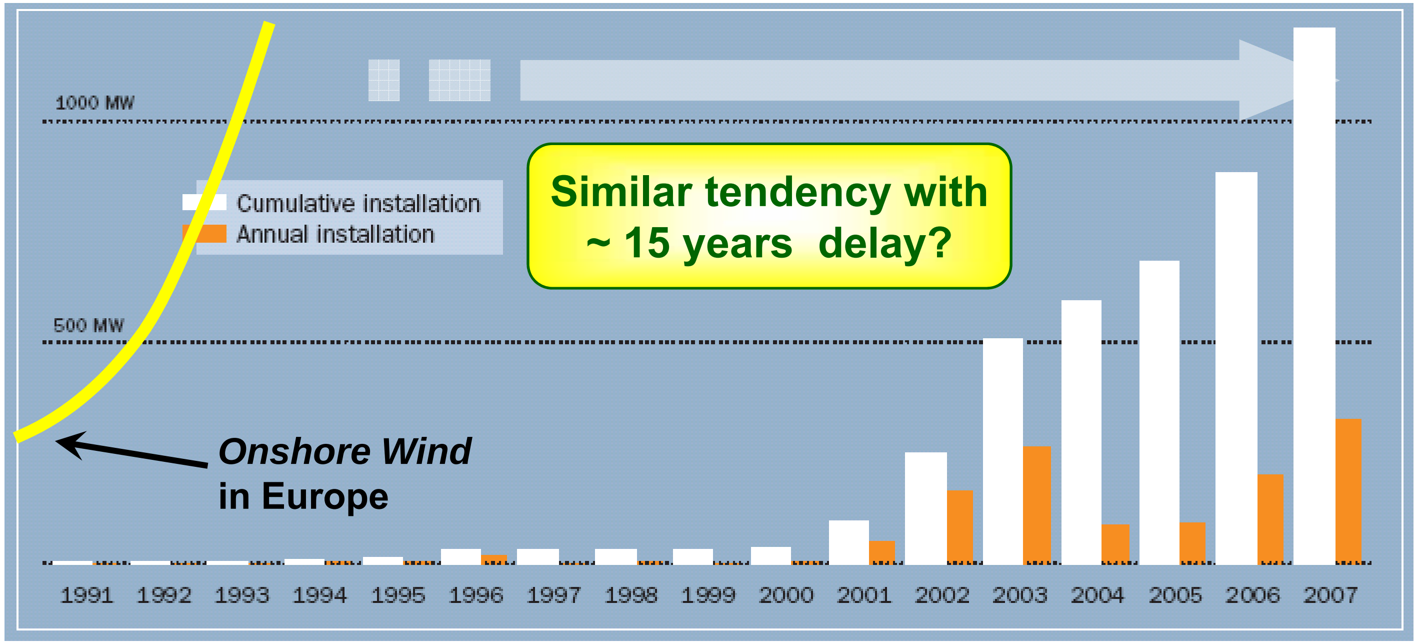
First offshore wind farms since the 90s, until 2003 only niche market
(Protected waters, close to coast, limited installed power, 'demo')

Since 2003 – farms > 100 MW and water depths of up to 45m

Market impulses mainly in the UK, Germany, (The N'lands, Scandinavia)

Hundreds of MW/year expected during the forthcoming years



Source: WAB

➢ Predictions for dramatic growth until 2020 (mainly in UK, D, ES)

OW State of the Art - Turbines

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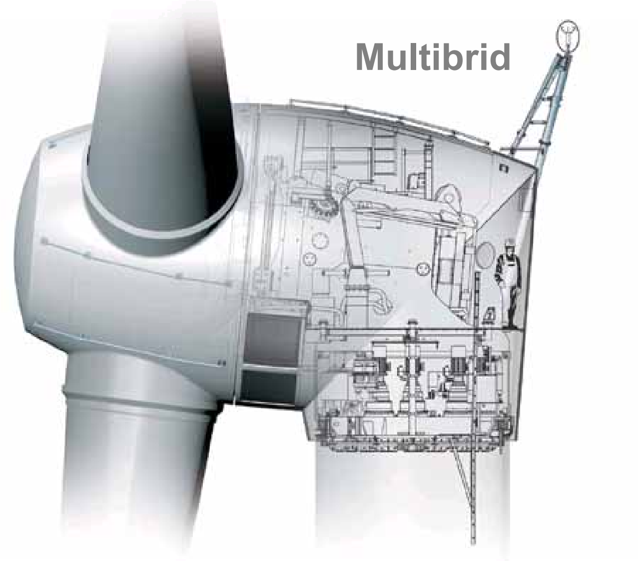
Until recent past, typically modifications of existing turbine models (~2MW; Vestas, Siemens, Nordex)

Technical reliability was not convincing to date! → new generation under test

New farms to be equipped with special 'offshore' multi-MW turbines

→ Vestas, Siemens, GE (3-3.6 MW)

→ RePower, Multibrid, Bard,...(?)
(5 MW class affirming)



Development has seriously started up in Asia and North America

USA: manufacturers (Clipper →7.5MW, GE) / projects (Capewind, Delaware,...)

China, South Corea, India, Japan → turbine development 2-5 MW

'Designs' formerly abandoned for onshore wind might gain significance

2-bladed turbines (less weight, higher full load factor → price)

Downwind turbines might be alternative (passive yaw mechanism)

OW status of implementation

Operational farms ~1.2 GW in UK, DK, S, NL

Farms to be installed during next years (~2015?):

UK 2.5GW;

D 3.5GW;

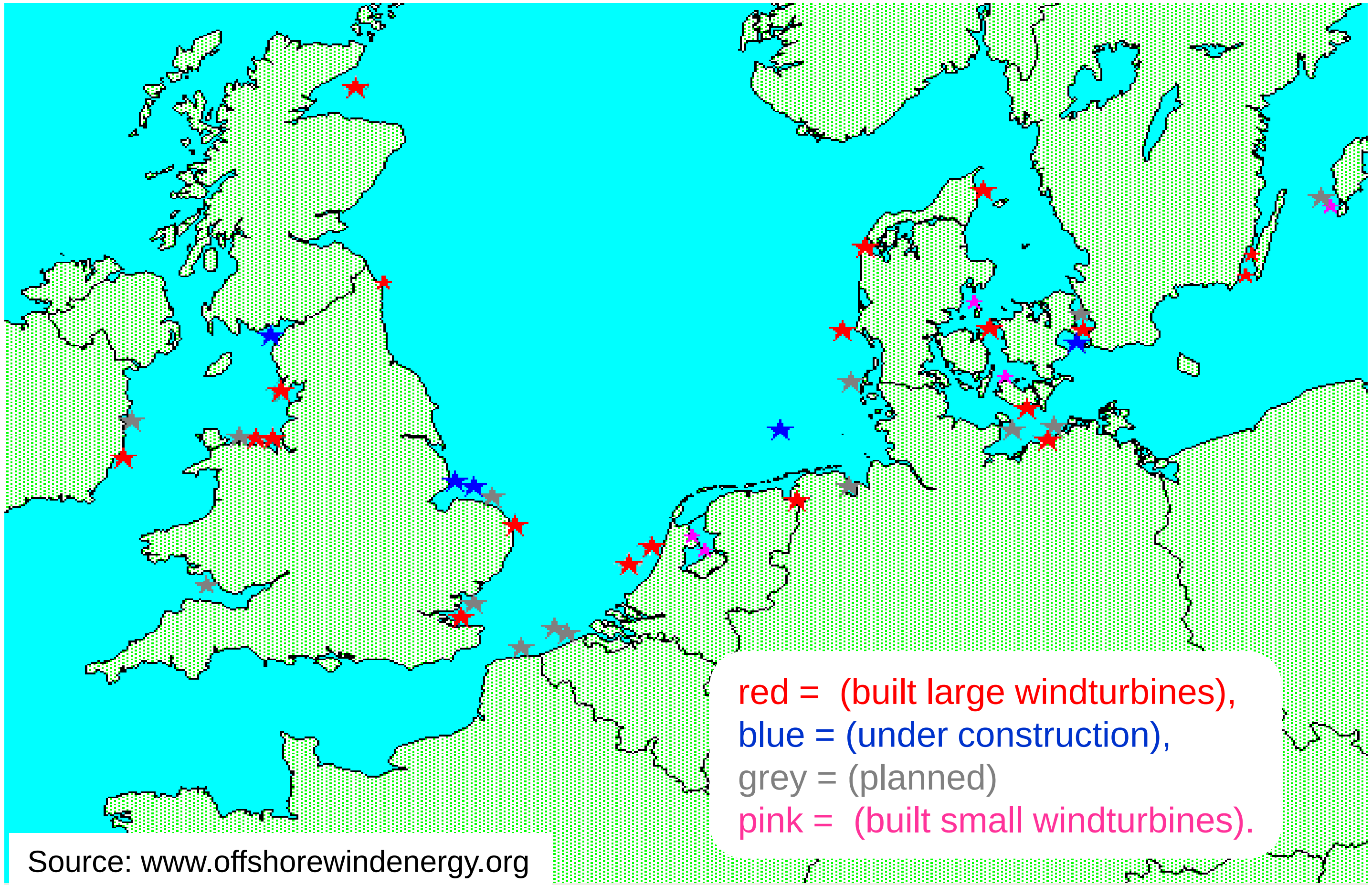
NL 500MW;

DK 400+500MW;

F 105+705 MW;

...;

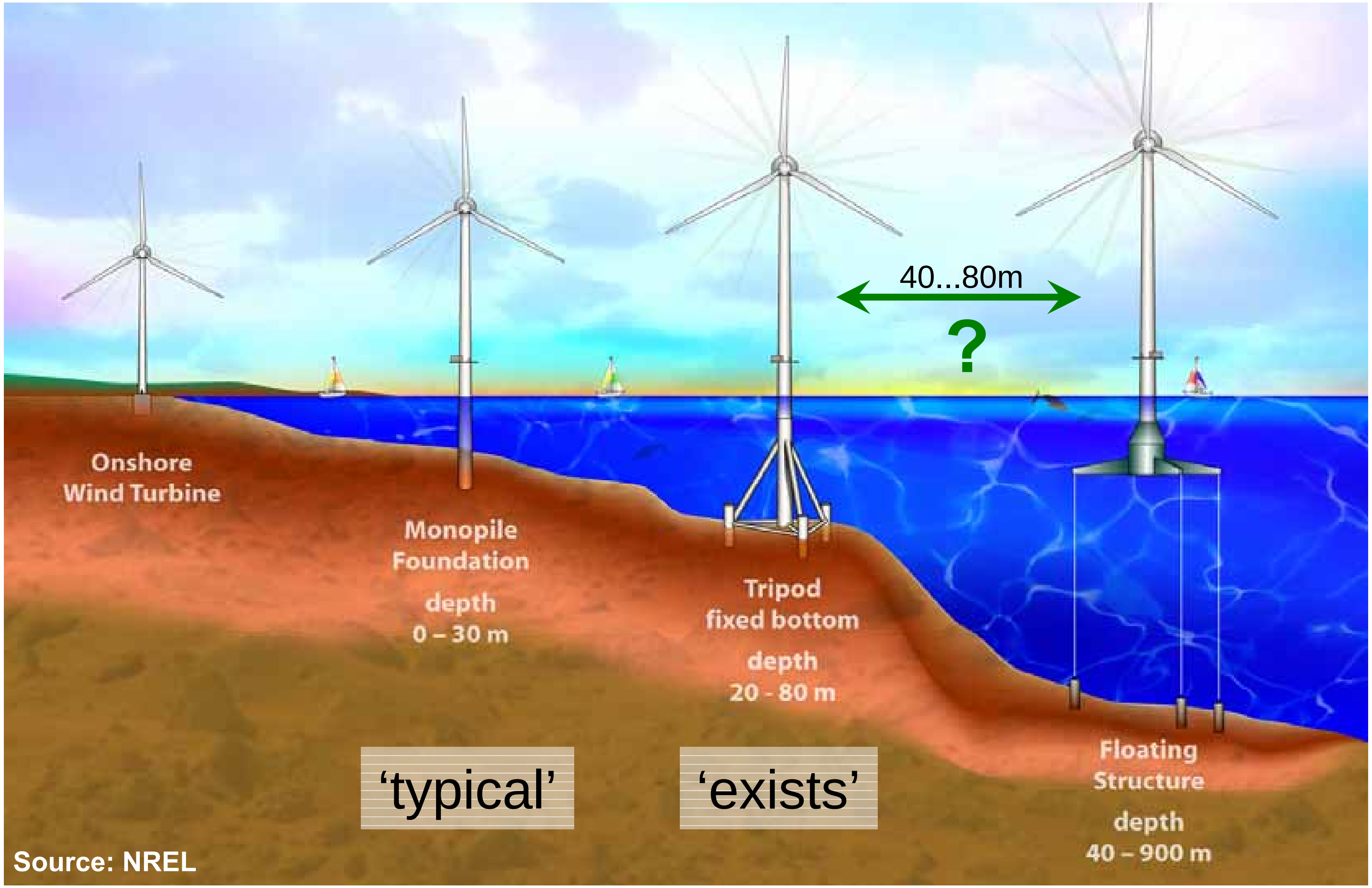
Norway 1+1.5GW floating;...



Mainstream development: shallow water (≤ 25m) → monopile/gravity

Alternatives (tripod, lattice): up to ~50m;

Future: floating substructures



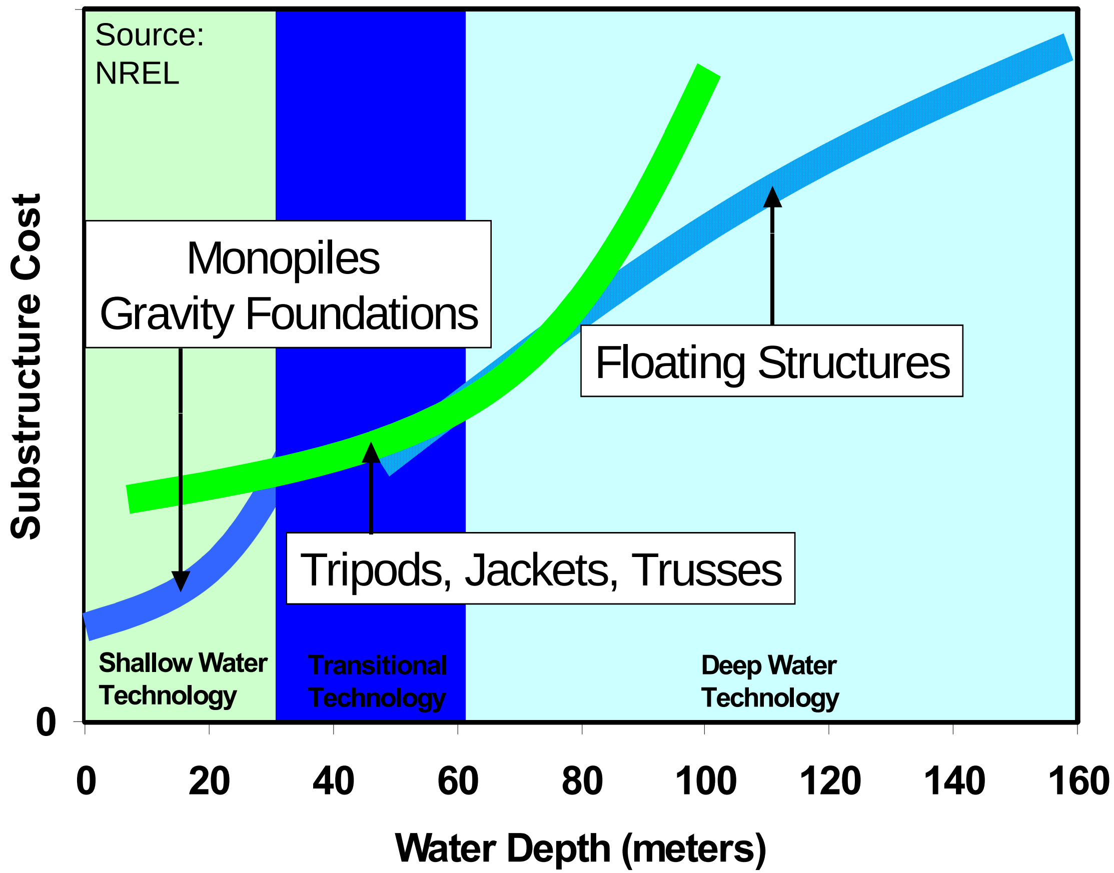
OW state of the Art - Foundations 2/3

Shallow water sites are quite limited regarding overall exploitable resource

Monopile & *gravity* foundations have clear physical limts

d > 50m: substantial economical constraints for substructures in general

Foundations of ‘present’ farms typically 25% of total investment

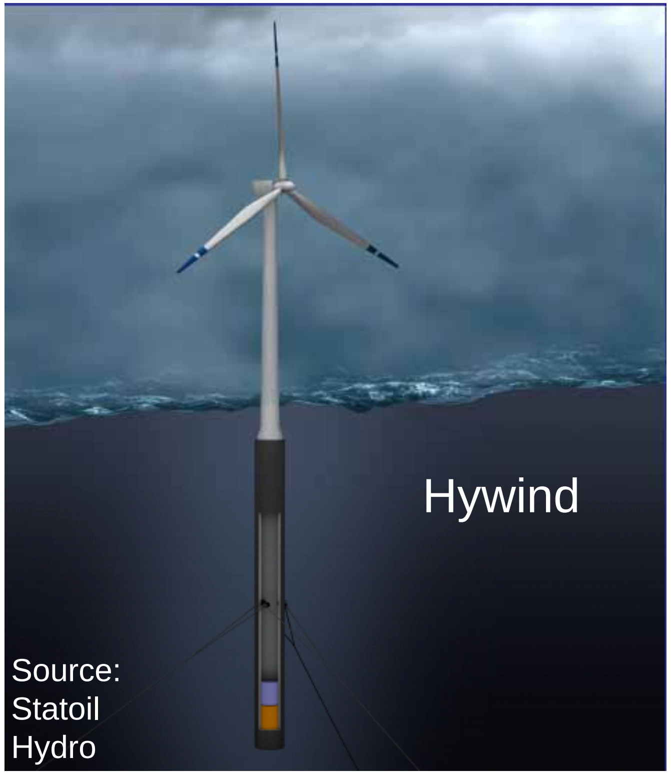


Floating substructures may play a crucial role for the development of economic viability of the technology branch in the medium term

Floating versions available on the market within next years (<2015?)

- Hywind (Statoil Hydro): d>100m, Siemens turbines, prototype 2009
- SWAY: d>80m, inclined downwind turbines, prototype 2010 (?)
- BlueH Group: d>40m, especial 2-bladed turbine 2MW, pilot 2007

Others: Ventotec, Dutch Tri-Floater, WindSea (early stage), PrinciplePower; MIT developments; Double Taut Leg



Source: Statoil Hydro

Blue H (80kW in Puglia/Italy); *full-scale* 2MW under development

Source: BlueH group

OW: Installation and Maintenance

Existing barges reserved until 2011 (A2Sea); general deficit of installation capacities expected between 2010 and 2012

- More than 5 new barges ordered by A2Sea (70% market share)

A2Sea: "...has not been a market, but a collection of projects."

Jack-up barge **(foundations)**

Crane vessel **(turbines)**

Maintenance still relevant factor (reliability issues)

- Options: Helicopter access or barges with special access (e.g. Ampelmann)

OW: Economic Viability Aspects

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Full load factors between 35% e 50% expected (turbine/location/variab.); results in the past usually not published → frequent failures

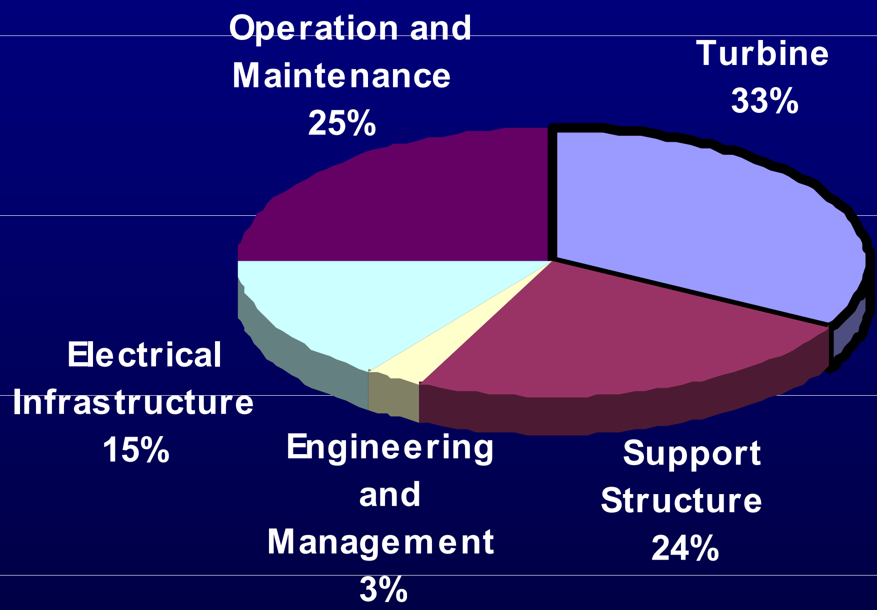
Typical cost ~1,5 M€/MW (initial projects) → ~2,5 M€/MW (present) → depends on local characteristics, infra-structure politics, offer/demand

Capital return in < 10 years difficult

Turbines ~33% of life cycle costs
vs. ~60% *onshore* ***(?)***

Support structure and O&M costs indicated ~25% each (CA-OWEE, 2001)

Major margins for improvements: installation, reliability/maintenance, foundations



(derived from NREL cost model and ***CA-OWEE report 2001***)

Offshore Wind: potentialities / constraints summary

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- Basic conversion technology well established; strong market pull
- Turbine size limits possibly not yet yielded (2MW, … 5MW,… → 7,5MW, …?)
- Conventional technology limited by water depth (foundation costs & practicality)
- Best places (North / Baltic Sea) taken; visibility issues for ner-shore sites
- Floating substructures on the way towards market; after long R&D efforts
- Floating substructures ("deepwater offshore wind") vast world-wide potential
- Portuguese coastline apparently suitable for deepwater offshore wind
- Cost estimations for deepwater offshore wind hard to find

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Representative choice of existing floating offshore wind concepts

Representative choice of existing wave energy conversion technologies

Conversion technologies: generic observations

2/2

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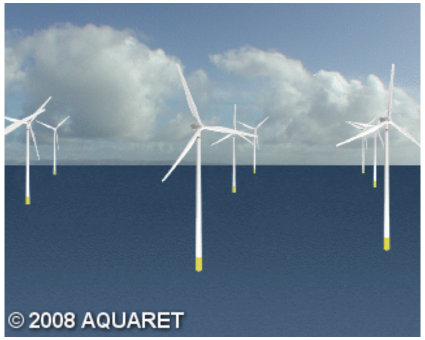
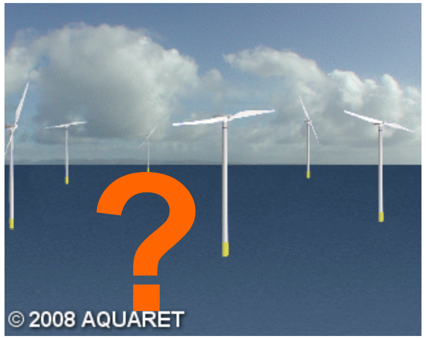
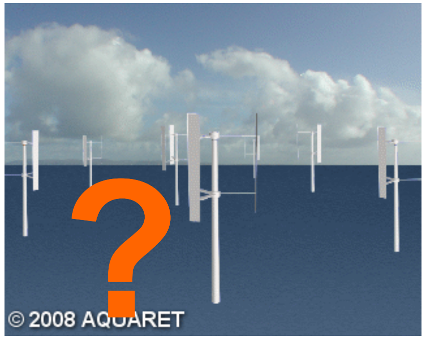
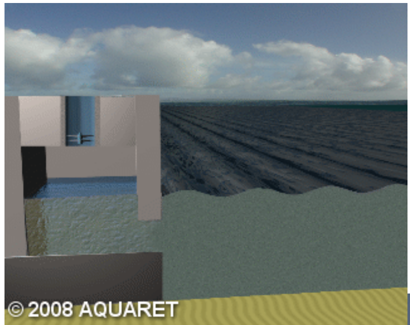
Offshore wind: power-conversion-relevant components

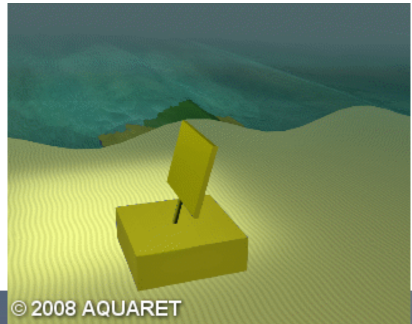


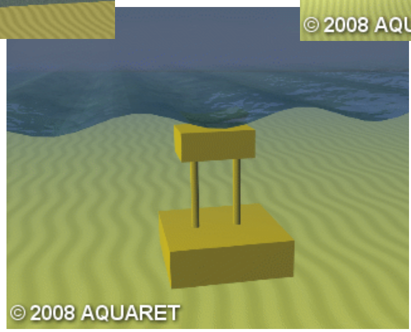


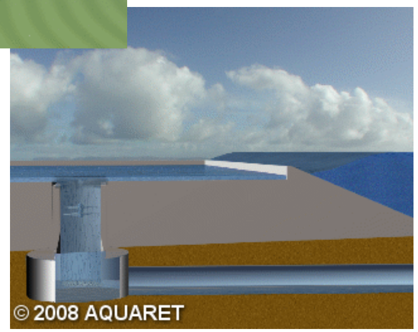


Wave: power-conversion-relevant components









Wave Energy: ‘close to where the challenge is’

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Matters: Spray / Direct wave impacts / Number of dynamic load cycles / Relationship design load / survival load...

3 different examples with common concerns !

OWC: vapour/droplets, high speed, turbine & auxiliaries

Source: Wave Dragon

Source: Pelamiswave

(Offshore oil&gas equipment often for different exposure AND different budgets)

Wave Energy: Status of implementation

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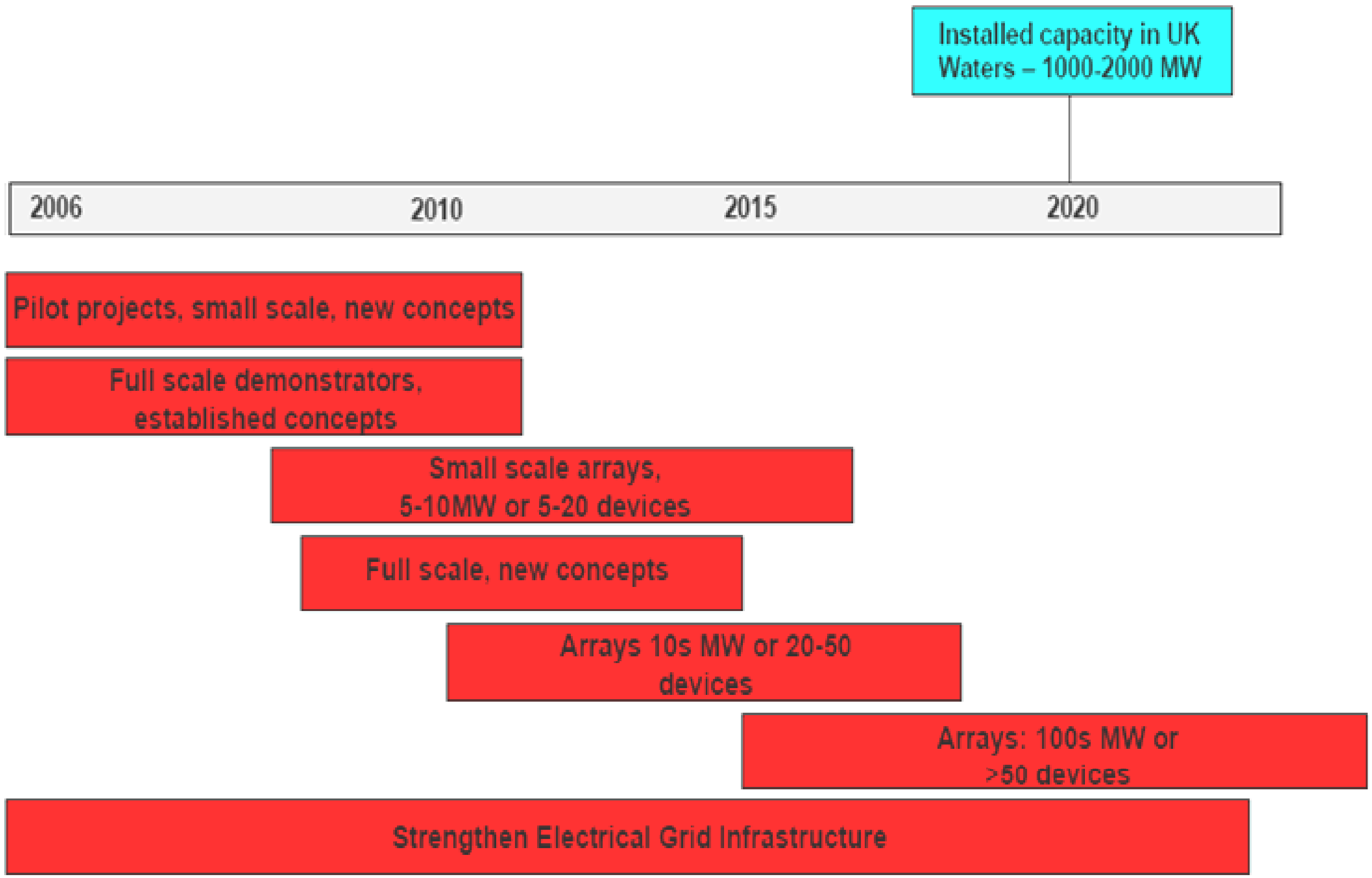
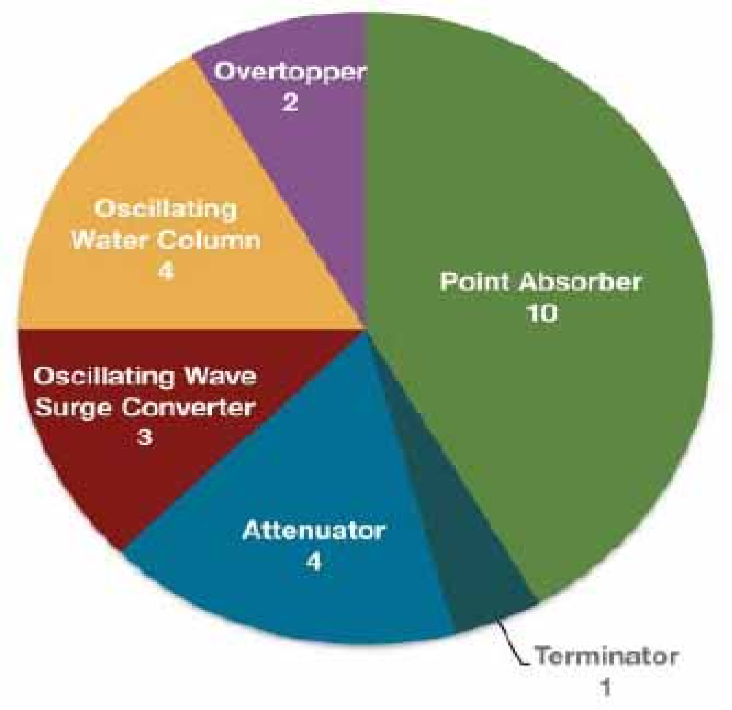
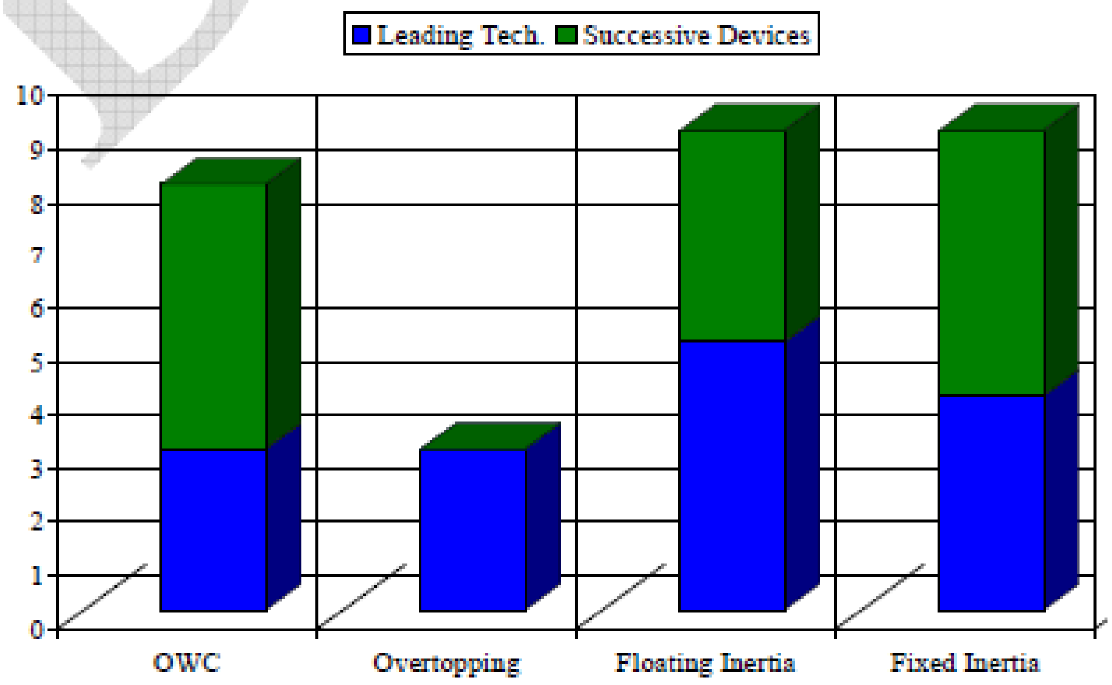


Source: UK Energy Research Centre; Jan 2007

UKERC

Diversity of devices





Greentech InDetail, 10/2008

B. Holmes **UCC;** Waveplam, 11/2008

Distinctions:

Offshore (typically h ≥40m), Near-shore (typically h=10m-40m), Onshore (linked to land)

OWC; Overtopping; Terminator; Attenuator, Point Absorber (floating inertia); OWSC (fixed inertia)

WavePLaM: Knowledge raise and removal of barriers

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www.waveplam.eu

executive agency eaci for competitiveness & innovation

Oscillating Wave Surge Converter: WaveRoller, Oyster

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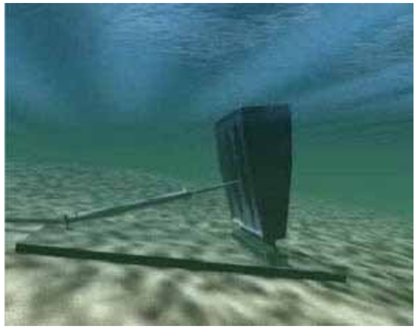
WaveRoller



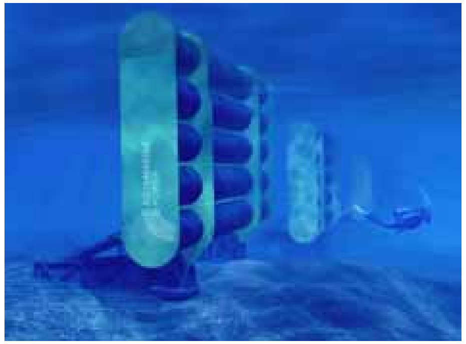
Developed since 1993; completely submerged; field-testing (incl. EMEC) of progressive stages

h =10-15 m
Wing size varies

Fibreglass wing, base structure in reinforced concrete, hydraulic modular PTO on base.

Test installation in Peniche (2007-2008); 13 kW wing (3*5m); full-scale prototype in development for deployment at same site (100kW ?)

Oyster



Recent development surface-piercing; substantial hydrodynamic modelling performed (QUB)

h > 12m

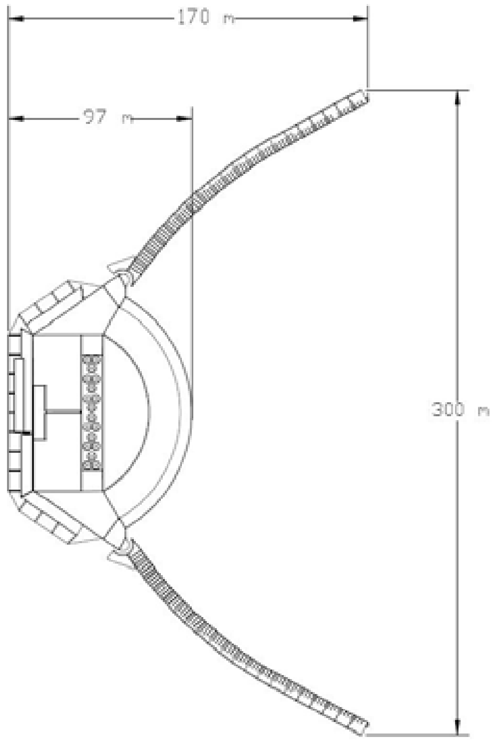
Steel pipes on steel frame mounted on bottom-structure;
Pelton turbine PTO on land (transport of pressurized water to land)

Prototype constructed and to be tested at EMEC: 350 kW, 18x10x2m

Overtopping Device: Wave Dragon

Real sea tests at 1:4.5 scale (nissum Bredinng Denmark) over 3000 operating hours

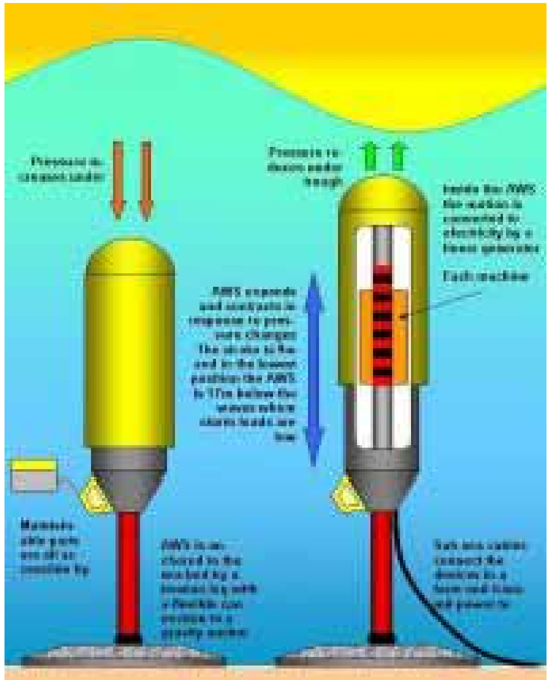
h > 20 m; 300 x 170m; 11-14m draft; 6-3m height



Large reinforced concrete structure providing a floating basin, actively draft-controlled. Collector arms attached to basin for wave concentration; special low-head turbine PTO (similar to Mini-Kaplan turbines). Simple slack mooring.

7 MW demonstration project (18 turbinas turbines of 385kW planned 2-3 miles off Welsh coast Demo project financing partially secured; plans for grids connection 2009-2010. PLans to expand to 77 MW farm

Submerged Pressure Differential / Point Absorber: AWS



Real-sea testing of a 2MW test platform performed in Aguçadora (North Portugal) in 2004; primary extraction mechanism and linear generator proven.

h= (80-100 m); floater diameter ~9m; floater height ~20m;

Strongly modified reduced prototype being engineered for testing at EMEC (2010); hydraulic PTO (other options investigated); Steelframe structure and composite or steel hull; gravity anchor with fast installation mechanism

Several non-standard components

Indicated Iberian market (Portugal/ Spain) as most interesting location for full-scale next generation prototype (500kW?); follow system engeneering/ development approach, not to stick to one specific technology only. Financed by Shell Technology Ventures and Tudor Investment.

(Multiple) Point Absorber: FO3

First generation platform at 1:3 scale in real-sea tests in Norwegian Fjord; substantial operational experience and PTO testing performed (after small-scale tests at CeSOS, Norway)

h= 30-100m; 36x36x14.5m; 7m draft

Various point-absorbing buoys mounted on floating platform (oil&gas technology standard); main materials plastic composites (lightweight); hydraulic PTO (others considered); multiple low-cost slack-mooring

Test platform survived considerable storm conditions.

1.5-2.5MW rated power platform under economic viablity studies; Company Fred. Olsen Ltd. (Norway) directly conducting development (since 2001); 1 of 4 winners for Wavehub concession

Fixed → Floating OWC: Oceanlinx

Costeira - Escala real

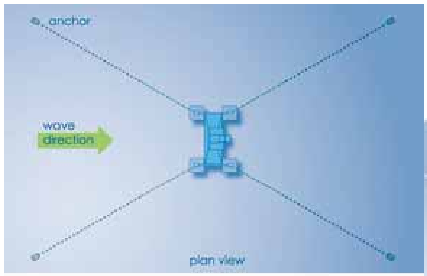
Flutuante - Escala 1:3

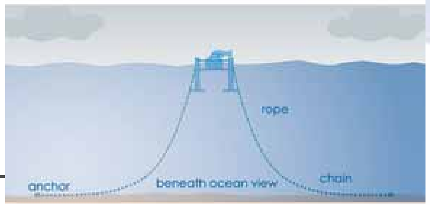
500 KW prototype tested at East Australian coast (2006-2007); proof of concept and turbine operation

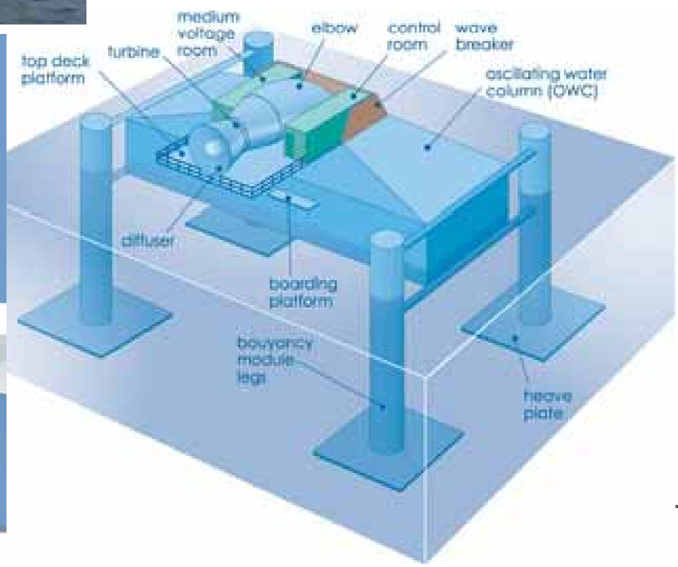
h>30m (?); 35m x 25m; 10m freeboard (onshore prototype)

Chamber and parabolic walls steel-made (onshore prototype); turbine generation group (Deniss-Auld turbine) inhouse development

Catenary moorings for next level floating offshore plant; seakeeping with inertia plates





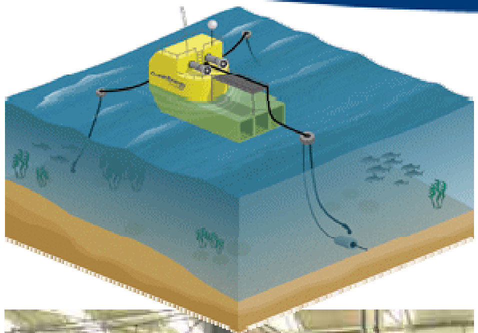


1 of 4 winners for Wavehub concession

Project in Hawaii (2.7 MW - 3 units);
Florence Wave Park project (USA, 10 units of 1.5 MW)

Supported by New Energy Fund

Floating OWC: OEbuoy



Scale 1:4, 15 kW

Field trials under way in Galway Bay (Ireland) of a 1:4 scale prototype; after extensive model testing at UCC-HMRC.

h>30m (?); 35m x 30m; 10m freeboard (onshore prototype)

Scale device in steel, next generation concrete structure; full-scaledimensions presumably ~50x20m; rated power presumably up to 1 MW; PTO Impulse turbine.

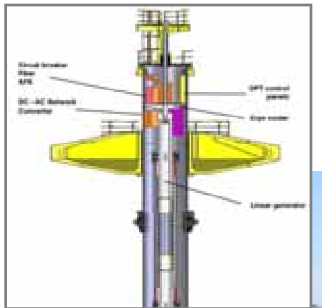
Scaled device survived extraordinary storm conditions.

Modified version of the Japanese 'Backward Bent Duct Buoy' tested in 70s/80s;

UCC-HMRC (University College Cork/ Ireland) focal point of wave energy R&D

Large EC-funded project started in 2008 for further component development (FP7-CORES)

Point Absorber: OPT Powerbuoy



First 40kW Powerbuoy deployed in Santoña/Spain in the context of Iberdrola wave farm, after two other 40kW prototypes have been tested offshore Hawaii and New Jersey since 2004.

h> 50 m; buoy diameter ~5m, length ~15m (40kW prototype)

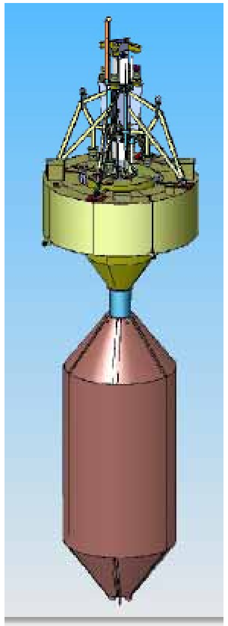
Slightly submerged buoy and cilindric structure for vertical movement conversion made of steel; moorings 3-point catenary

Ongoing project with Iberdrola/Spain (Santoña, 9 km offshore; 1.39 MW 1 x 40 kW (PB-40), + 9 x 150 kW (PB-150)

1 of 4 winners for Wavehub concession

Pre-arrangement with Total and Iberdrola reported for development of project in France (2-5MW); existing preliminary agreements for an Australian coastline deployment (10 MW)

Point Absorber: Wavebob



1:4 scale prototype under renovation after accident in field trials in Galway Bay. Wave tank testing at scales 1:20 and 1:50 had been conducted.

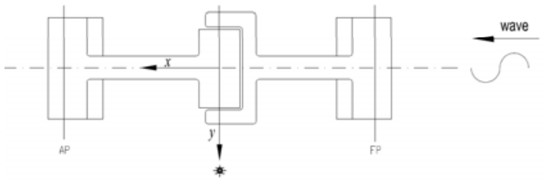
h > 75 m; floater diameter 15m; lenght 30-40m

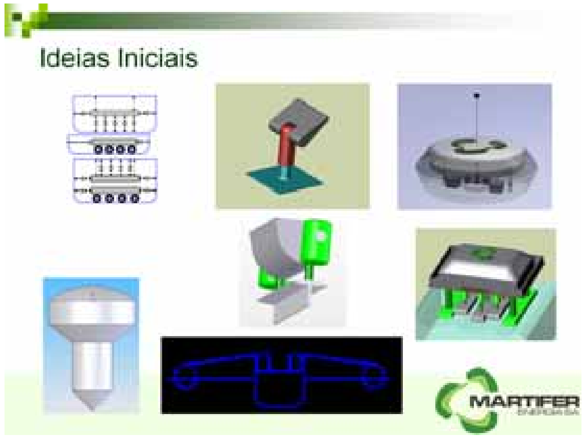
Structural components mase of steel but canbe out of concrete; rated power of next generation plants will be in rangeof 1 MW; hydraulic PTO wth alternatives being investigated; 3-point catenary mooring

2009 the 1:4-scale device tests are planned to continue; next development steps are a 1:2 and 1:1 demo plant successively. Demonstrator will have 1-1.5MW, depending on which of the preferred locations (Portugal, Ireland) is chosen.

Strategic development agreements with Vattenfall and Chevron;

(Attenuator): Martifer - FLOW





Internal tests procedures completed; engineering phase of full-scale prototype in final fase; construction activities have started.

h= > 30m (?); total length 75m; 22m width; 17m height

Articulated cylindric steel floaters connected in central axis of 3m diameter hosting the PTO (hydraulic); rated 1.5-2MW, specialist company 'Briggs Marine' initially contracted for mooring system design

Concept development (numerical modelling) under collaboration of IST and INETI; straight-forward development strategy followed wth little disclosure towards public, being possible as strong own financila resources exist.

Acquired local shipyard facilities to enhance independence for construction

Attenuator: Pelamis

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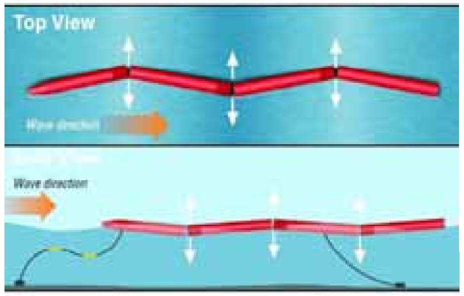


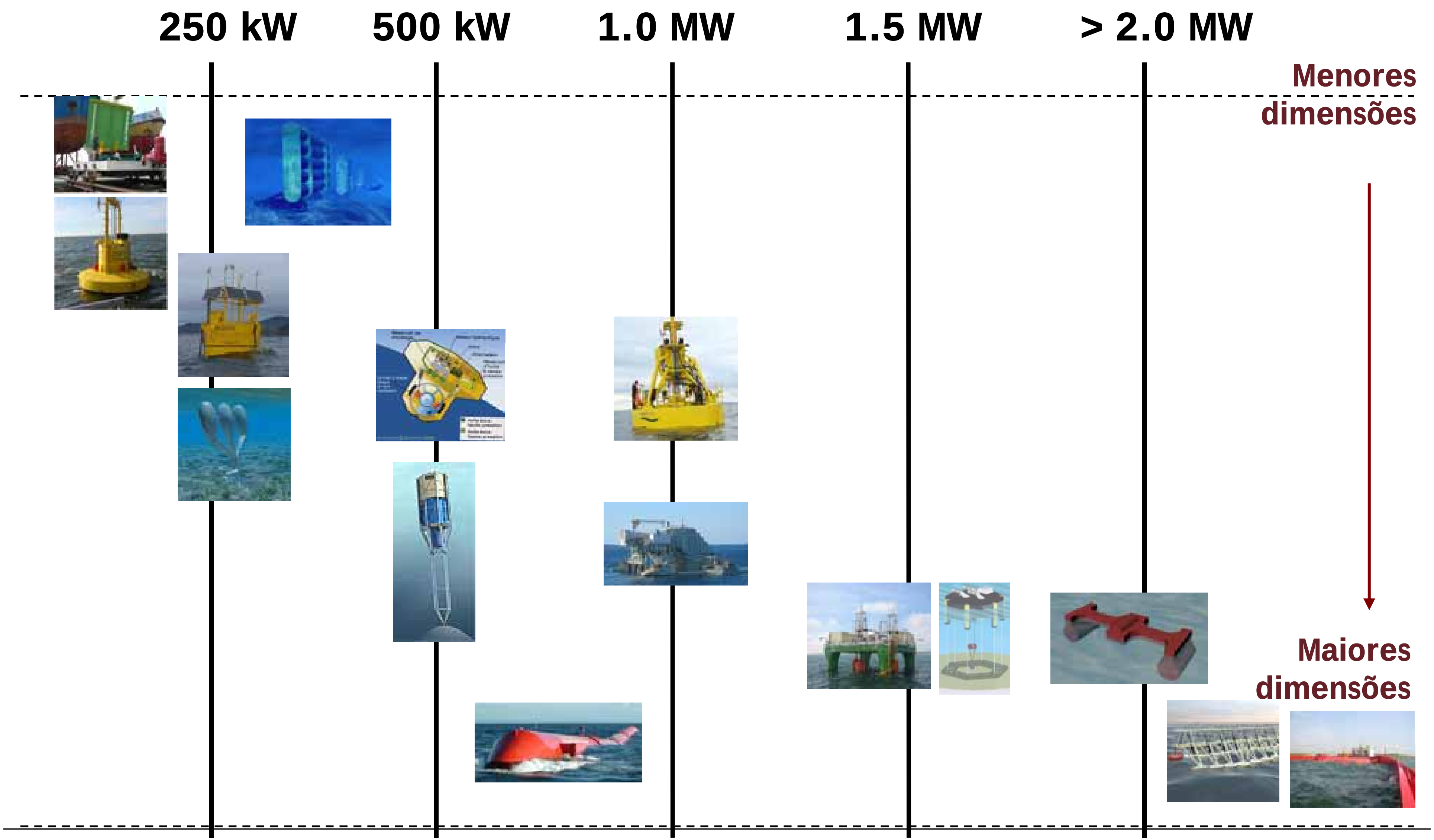
World-wide first wave farm of 3 Machines was deployed offshore Aguçadora (Northern Portugal) in 2008, after extensive and successive testing and commissioning trials. Overall development included upscaling several times from laboratory to real-scale. 1 full-scale prototype was tested in EMEC since 2004.

h= (50-100 m); 150m length, 3m diameter

Cylindric steel structures made in 4 segments and 3 segment-interconnecting PTO modules per device (rated power 750 kW). Hydraulic PTO and flexible two-point mooring of device.

By far most advanced device, qualified team of > 70 staff; several commercial pre-arrangements in pipeline; Venture-capital funded

Potência versus Dimensões



Wave: Economic Viability Aspects

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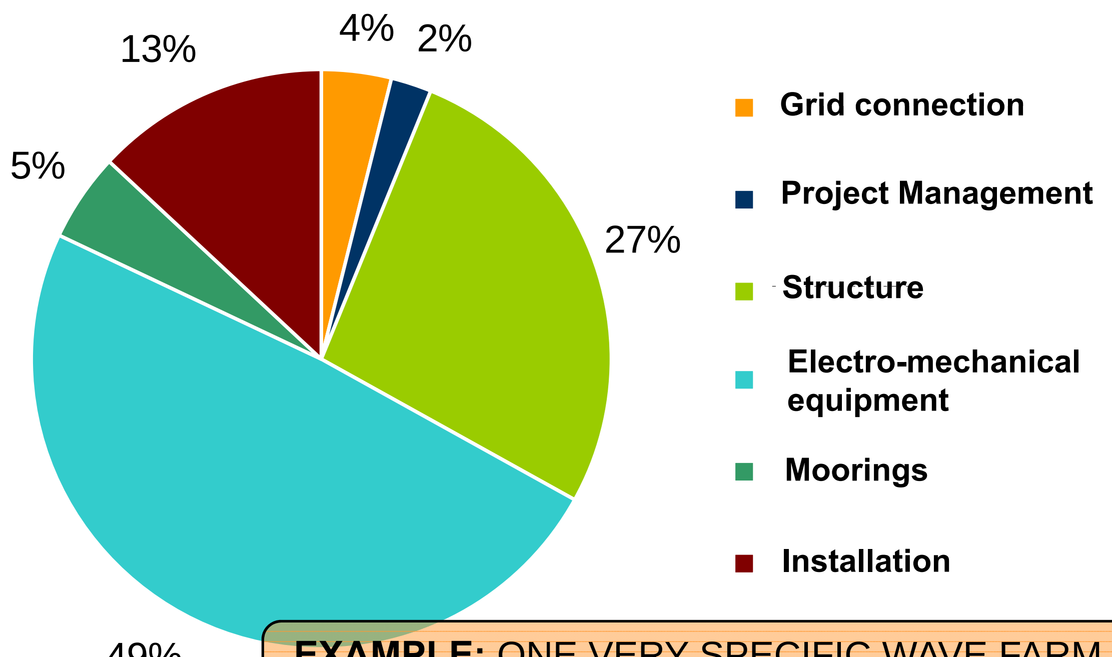
Full load factors claimed often up to 40%; however more realistic average value 25%
No sufficient results yet and usually not published

Typical cost at least 4-5 M€/MW (initial projects) → fast learning curve expected
(depends mainly on survivability experience and reduction of cost possibilities)

Capital return for early projects very difficult; first small-scale farms hardly below 10y

PTO ~50% of total costs; structure and installation following

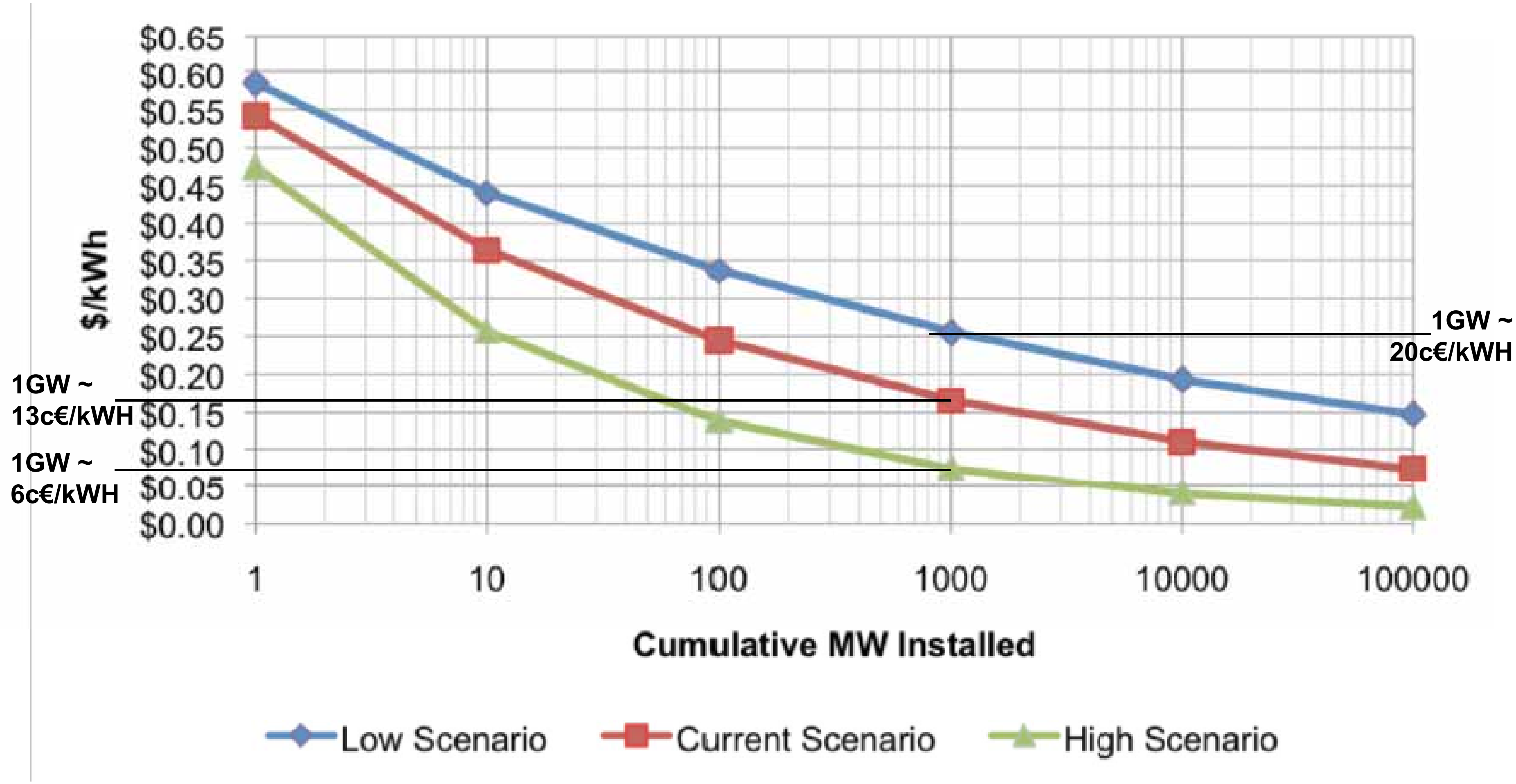
Major margins for improvements: Survivability, moorings; reliability, handling issues for maintenance



EXAMPLE: ONE VERY SPECIFIC WAVE FARM
(Carbon Trust, 2006)

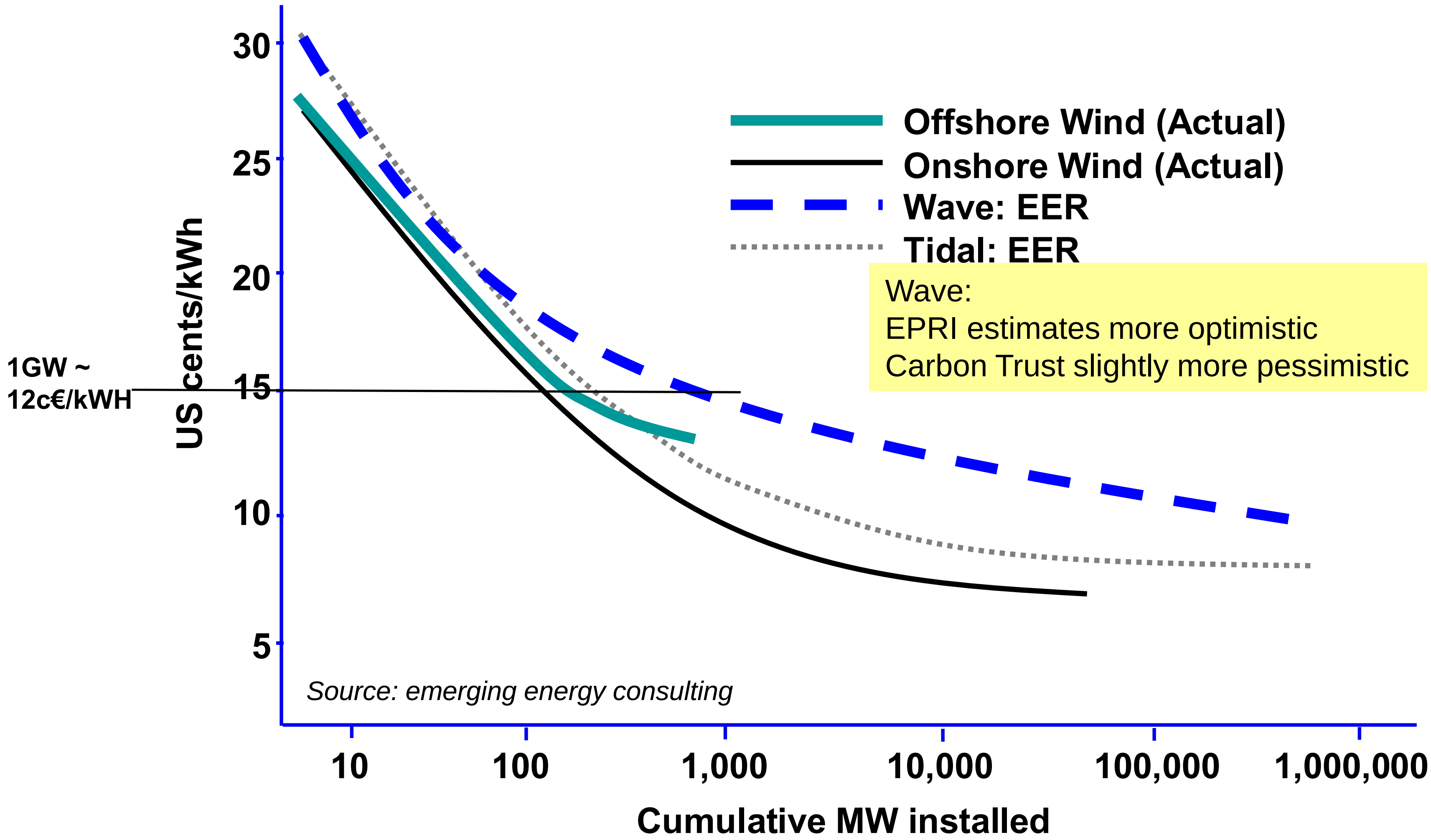
Wave Energy: cost development

WaveEnergy Centre
Centro de Energia das Ondas



Source: Greentech InDetail, 10/2008

Electricity cost prediction



Comparison: maturity level

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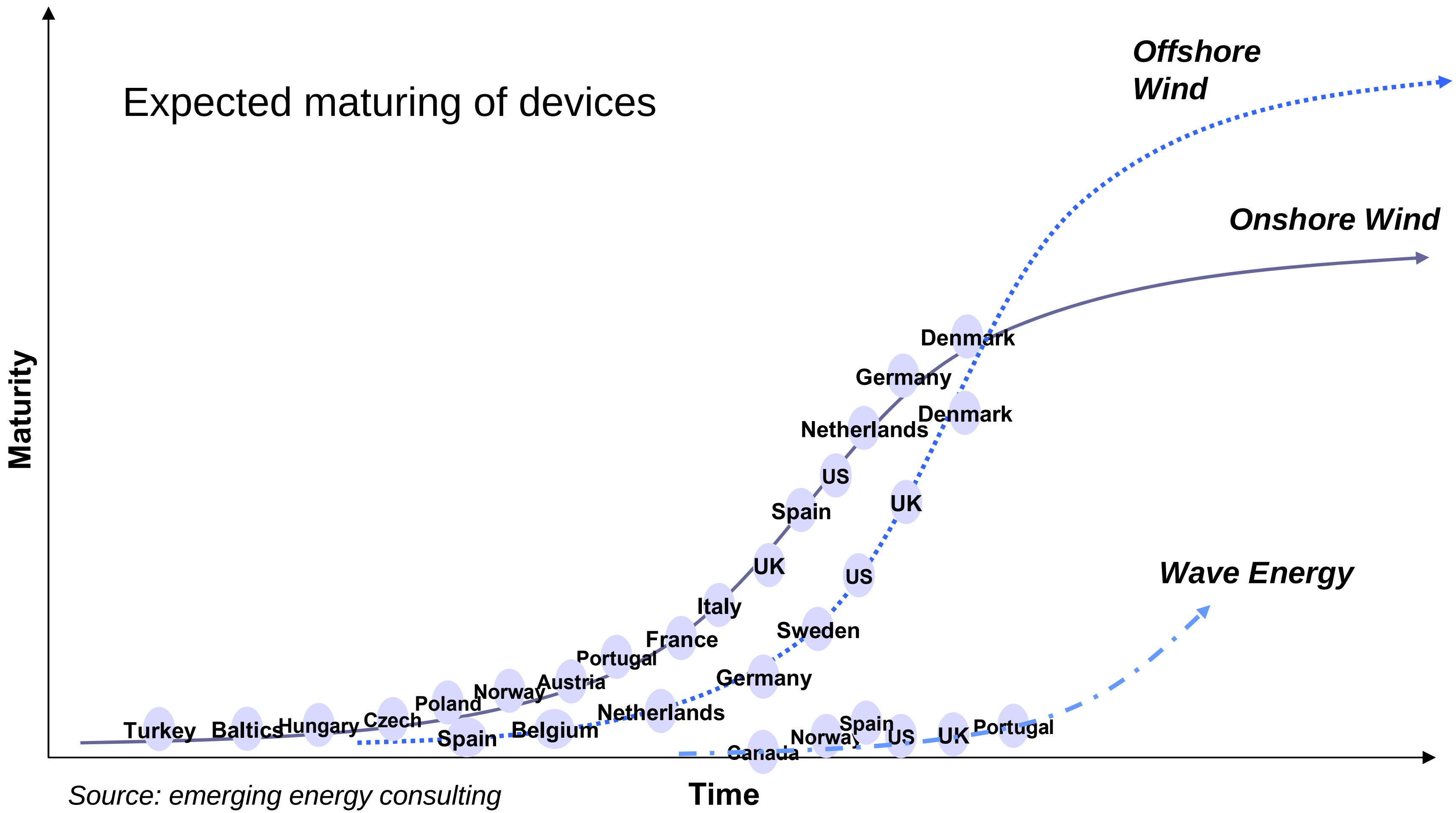

Source: emerging energy consulting

Conclusions

WaveEnergy Centre
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Offshore Wind

Offshore Wind market is in plain "Take-off" phase

Relevant cost reduction potential exists

Preferential locations "occupied"; opportunities mainly exist in joint-venture-like undertakings

Floating substructures promising near-future solution

Portuguese Home market interesting, but complex

Wave

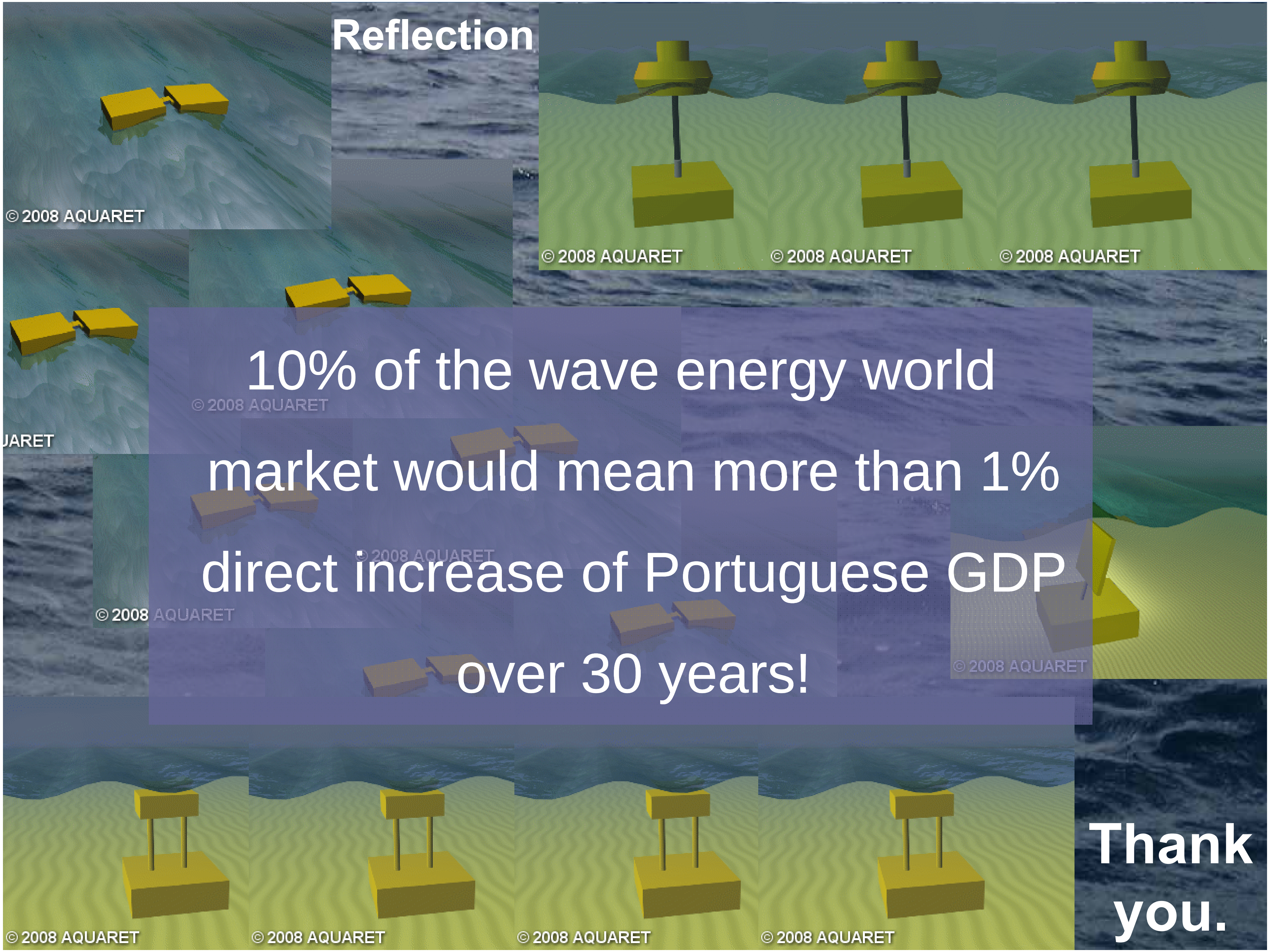
Wave Energy market prepares to consolidate (pre-comercial phase)

Extreme cost reduction potential exists but has to be proven

Vast areas favourable for installation exist along Atlantic coastline;

Several technologies might exist after first phase of market consolidation

Portugal has competitive advantage due to existence of grid and potential licensing facilitation (pilot zone)


Reflection
10% of the wave energy world market would mean more than 1% direct increase of Portuguese GDP over 30 years!
Thank you.
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