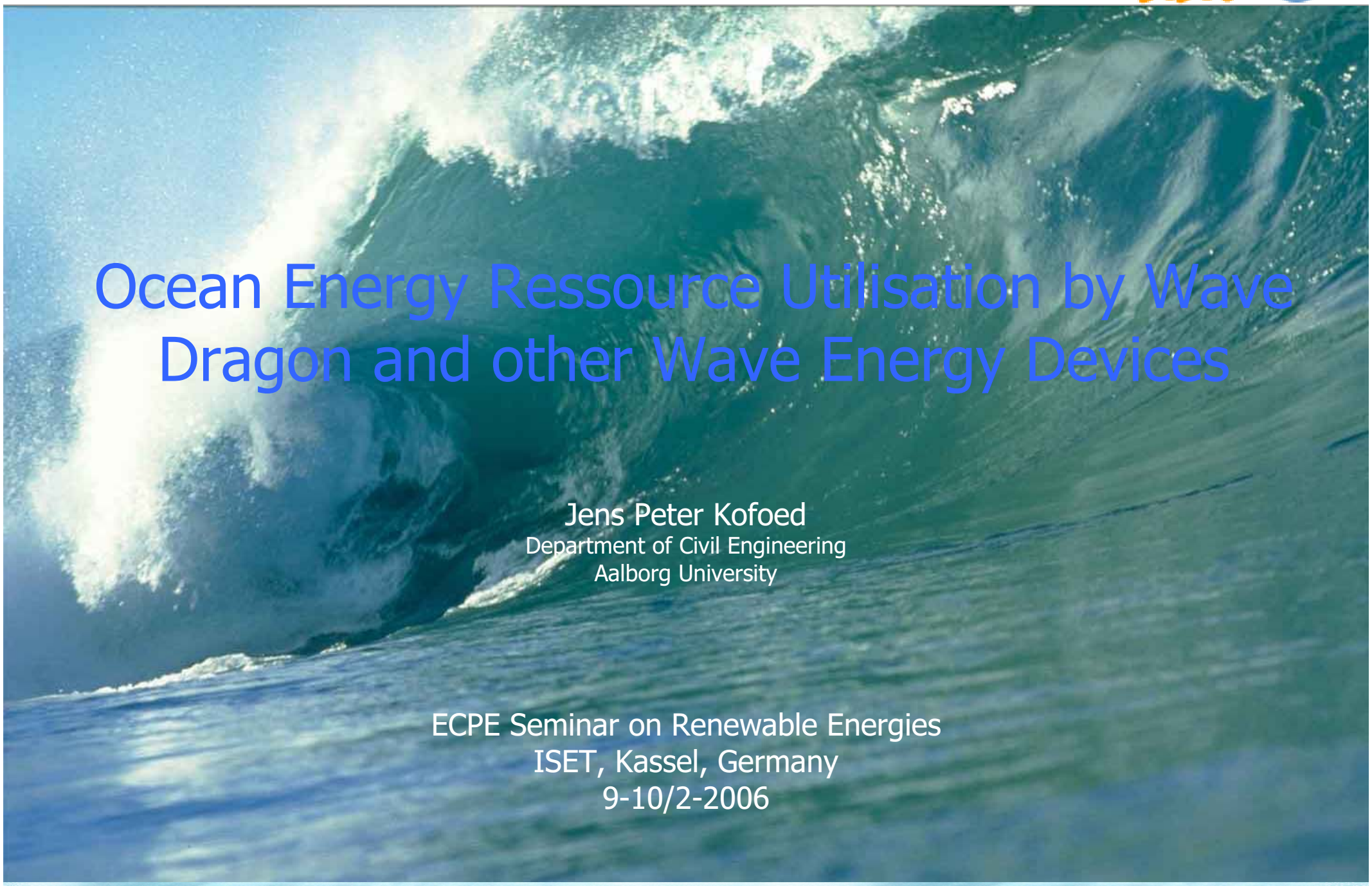

Ocean Energy Ressource Utilisation by Wave Dragon and other Wave Energy Devices

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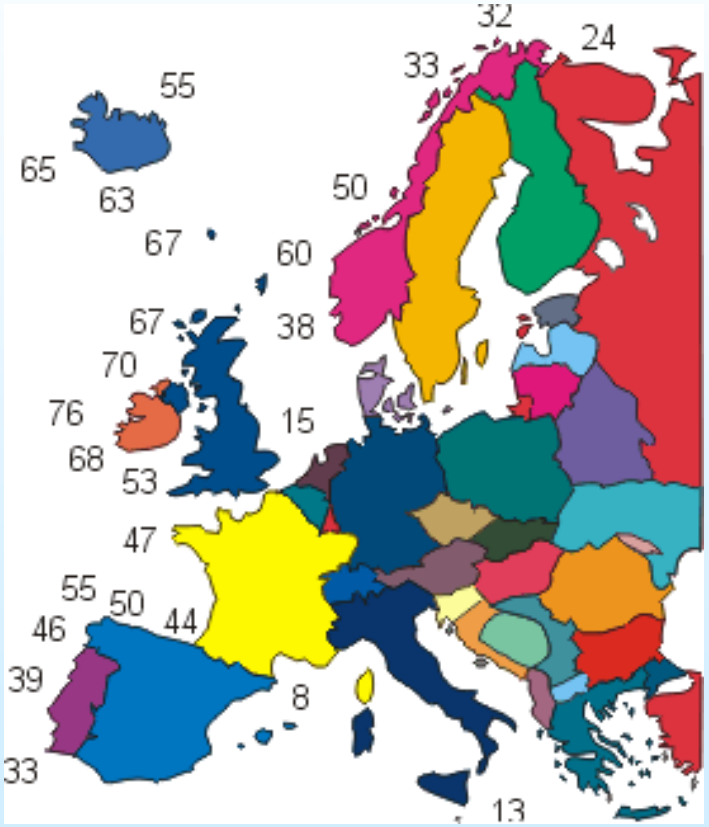
Aalborg University

ECPE Seminar on Renewable Energies
ISET, Kassel, Germany
9-10/2-2006

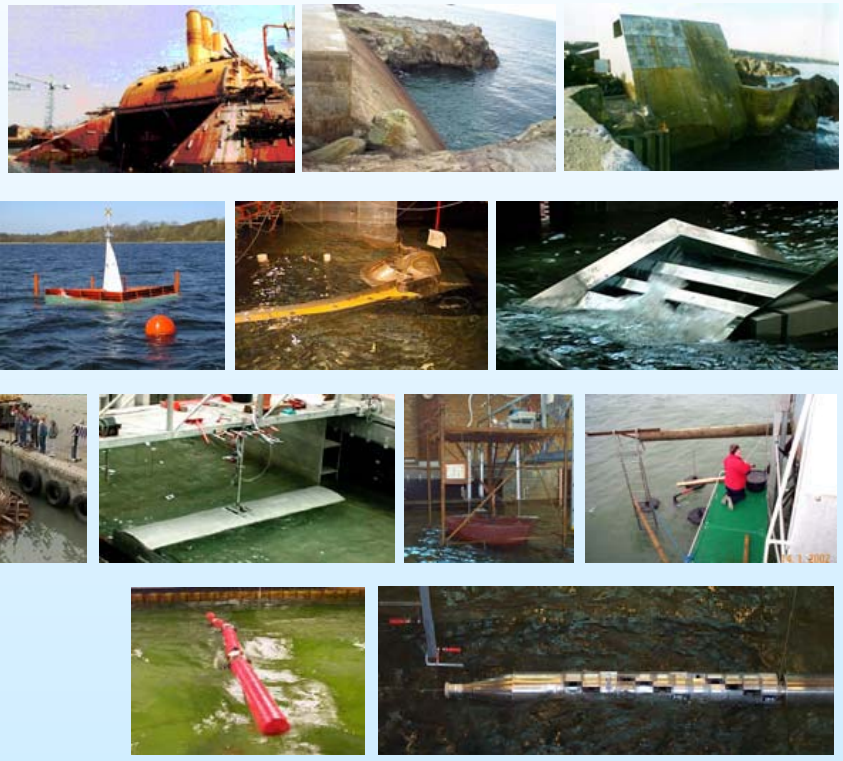
The Potential of Wave Energy

- Denmarks consumption of electricity: 3,7 GW
- Wave energy, Danish west coast (offshore):
  - Up to 25 MW/km
  - Average ~16 MW/km
  - ~150 km available, ~2,4 GW
- At North Atlantic European Coasts: 25 - 75 MW/km
- In the Mediterranean: 4 - 11 MW/km
- Total potential off European coasts: ~320 GW

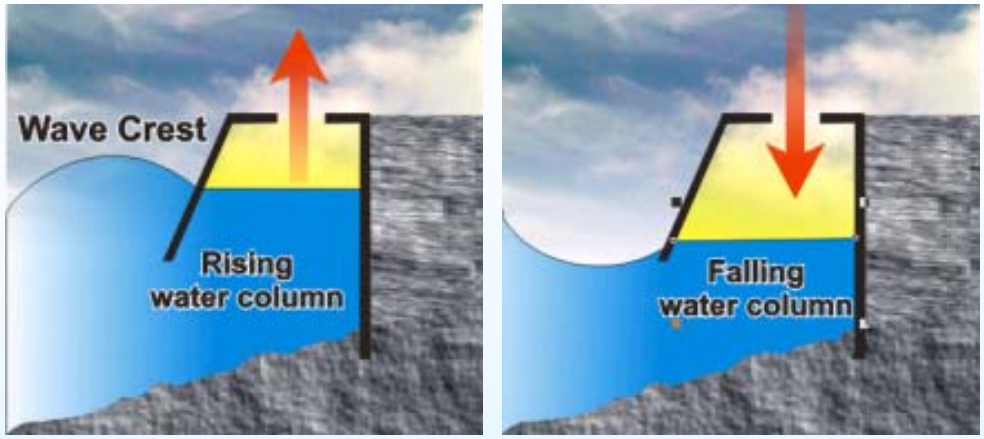


Principles for Utilisation of Ocean Energy (Waves)

- Oscillating Water Columns
- Overtopping devices
- Point absorbers
- And many others …



Oscillating Waver Columns

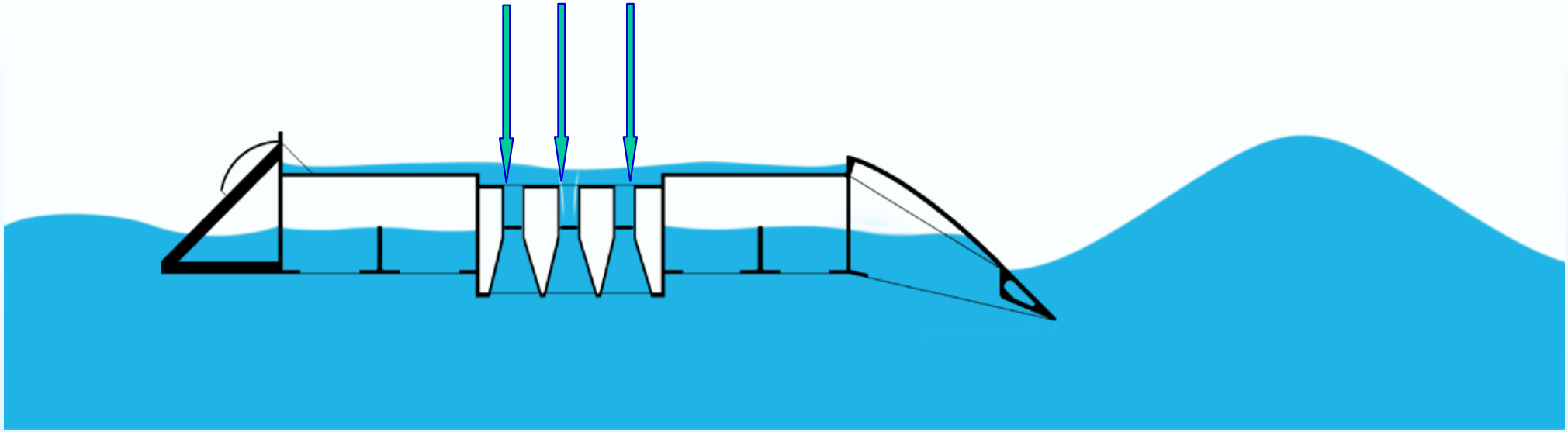


WaveGen, Islay

Pico, Azores

Energetech, AU

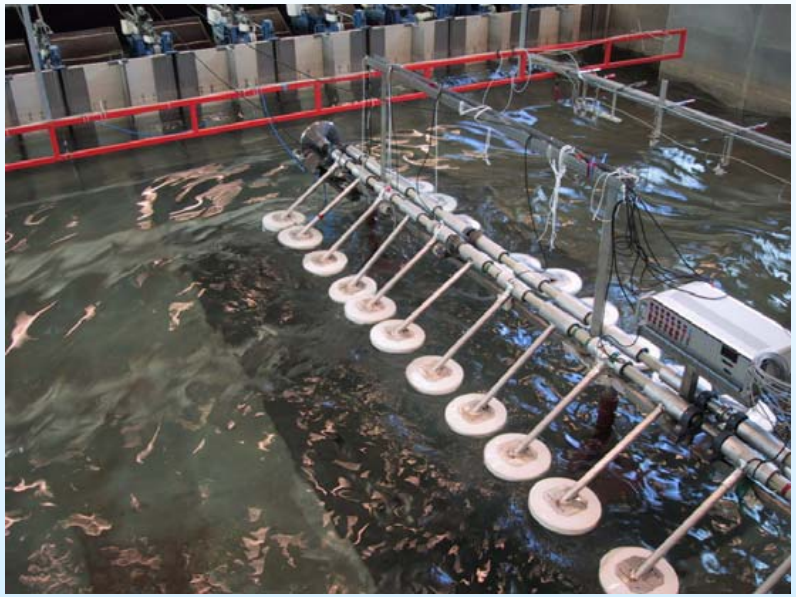
Overtopping devices



Wave Dragon, Nissum Bredning

SSG, Kvitsøy

Point absorbers

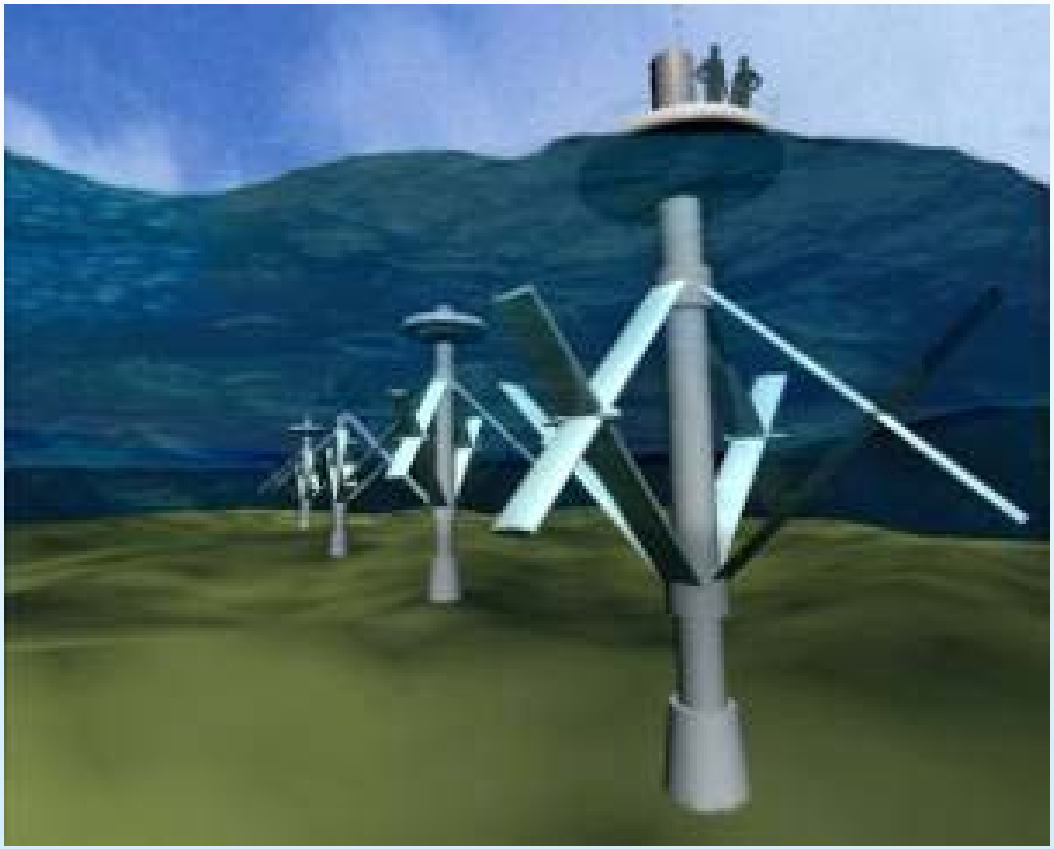


Wave Star

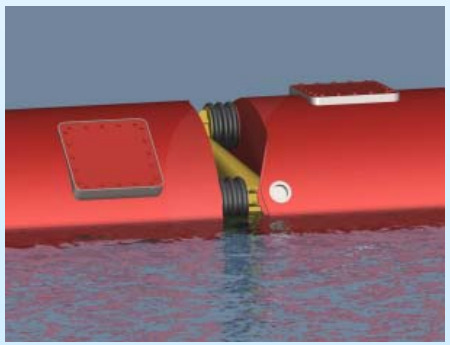
AquaBuOY

AWS, Portugal

And some of the others



Wave Rotor



Pelamis, Orkney

State of the art

- Rougly 10 prototype devices installed
- First 3 commerciel units sold
- European Wave Energy Organization formed
- Technology verified
- Technology currently relying on subsidies

Wave energy in 10 – 20 years

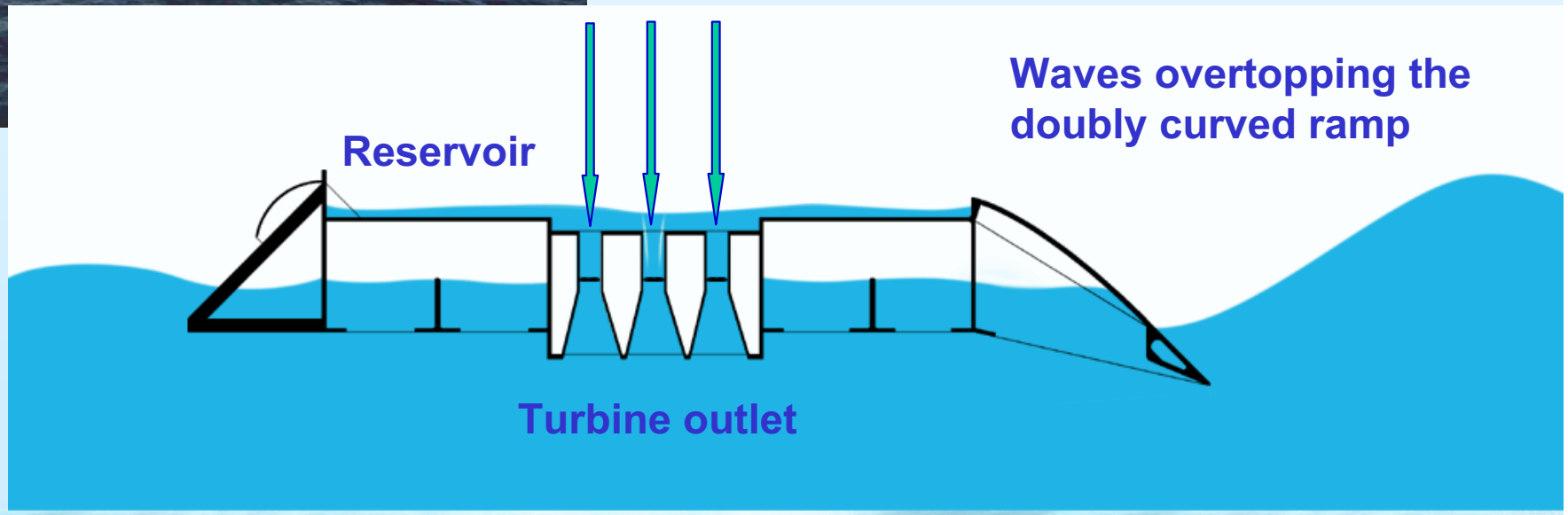
- EU will push the development until 10-20 well functioning devices have been installed
- The time scale (due to the large size of the devices delays the development
- Energy price: 0.12-0.25 €/kWh
- A lot depends on political will the coming years – (ie. political stability in the Middle East, Russia etc., price of oil)
- Security of supply is an important factor

The Wave Dragon Case

Wave Dragon principle

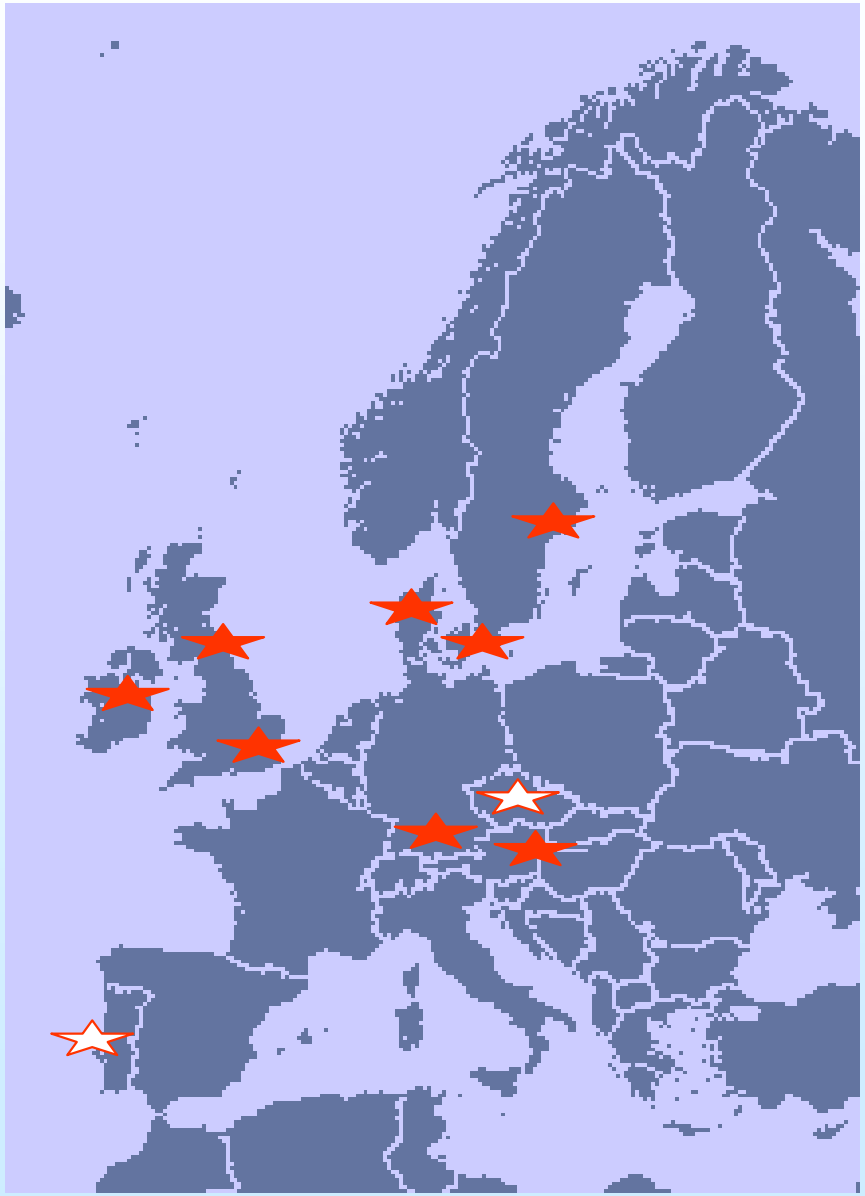
The *Wave Dragon* is a slack-moored wave energy converter that can be deployed alone or in parks wherever a sufficient wave climate and a water depth of more than 25 m is found.

Climate	Power production
24 kW/m	12 GWh/y/unit
36 kW/m	20 GWh/y/unit
48 kW/m	35 GWh/y/unit



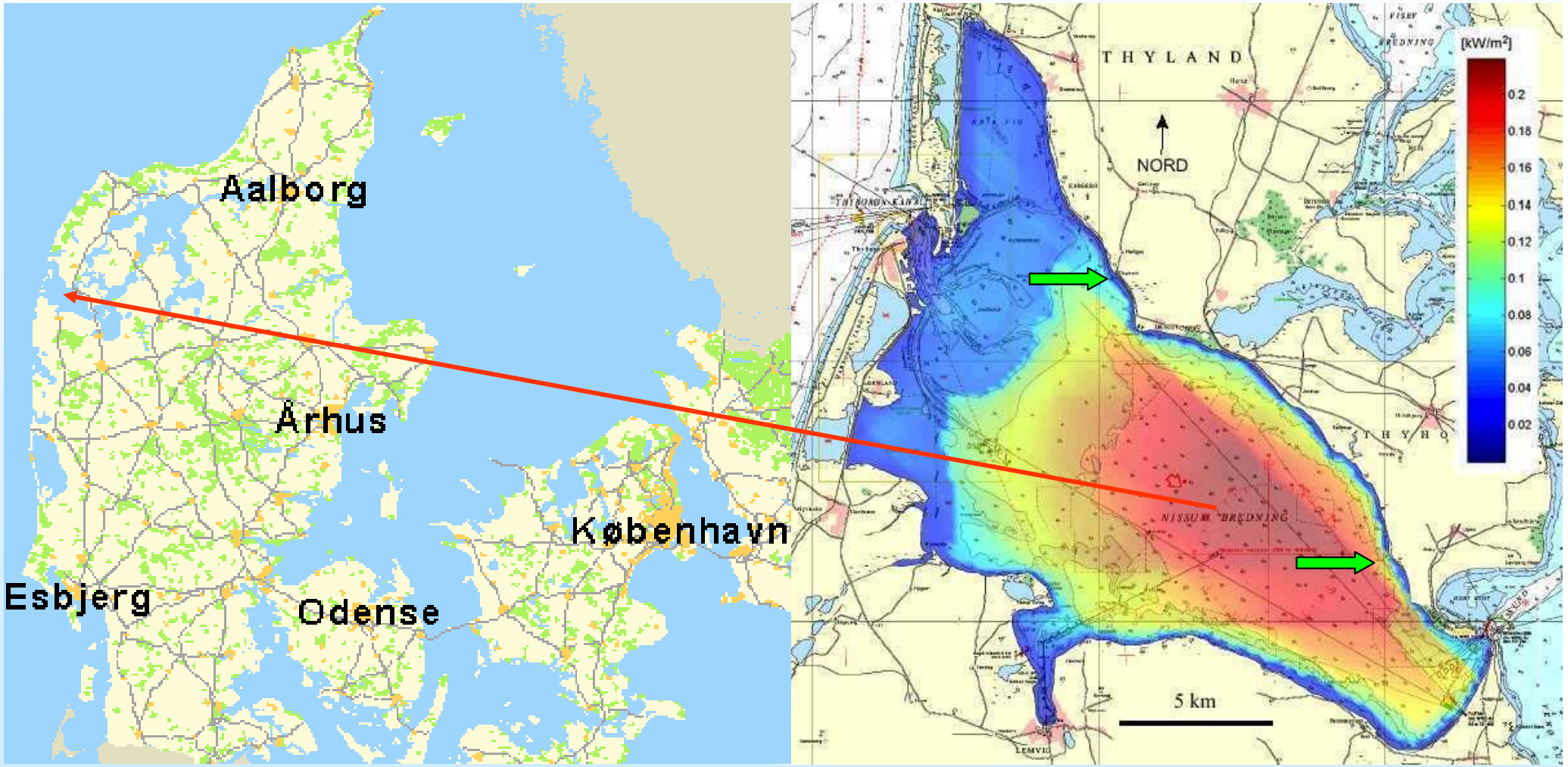
Wave Dragon partners/subcontractors

- Löwenmark F.R.I, Inventor, Consulting Eng. (DK)
- SPOK ApS, Project Management Cons. (DK)
- MT Højgaard A/S, Construction Enterprise (DK)
- Aalborg University – Hydraulics & Coastal Engineering Laboratory (DK)
- Balslev A/S, Consulting Engineers - electrical and automation systems (DK)
- Niras as, Consulting Engineer, Wave forecasting models (DK)
- Armstrong Technology Associates Ltd., Naval Architects (UK) (Babcock Design & Technology)
- VeteranKraft AB, Consulting Engineers - hydro turbine design (S)
- Nöhrlind Ltd, Research & Business strategy development (UK)
- Technical University Munich, Hydro turbine testing and CFD modelling (D)
- Kössler Ges.m.b.H., Manufacturer of hydro turbines (A)
- ESBI Engineering Ltd. (IE)
- Wave Energy Centre, Lisbon (PT)
- Rozmerovy Nacrte (CS)



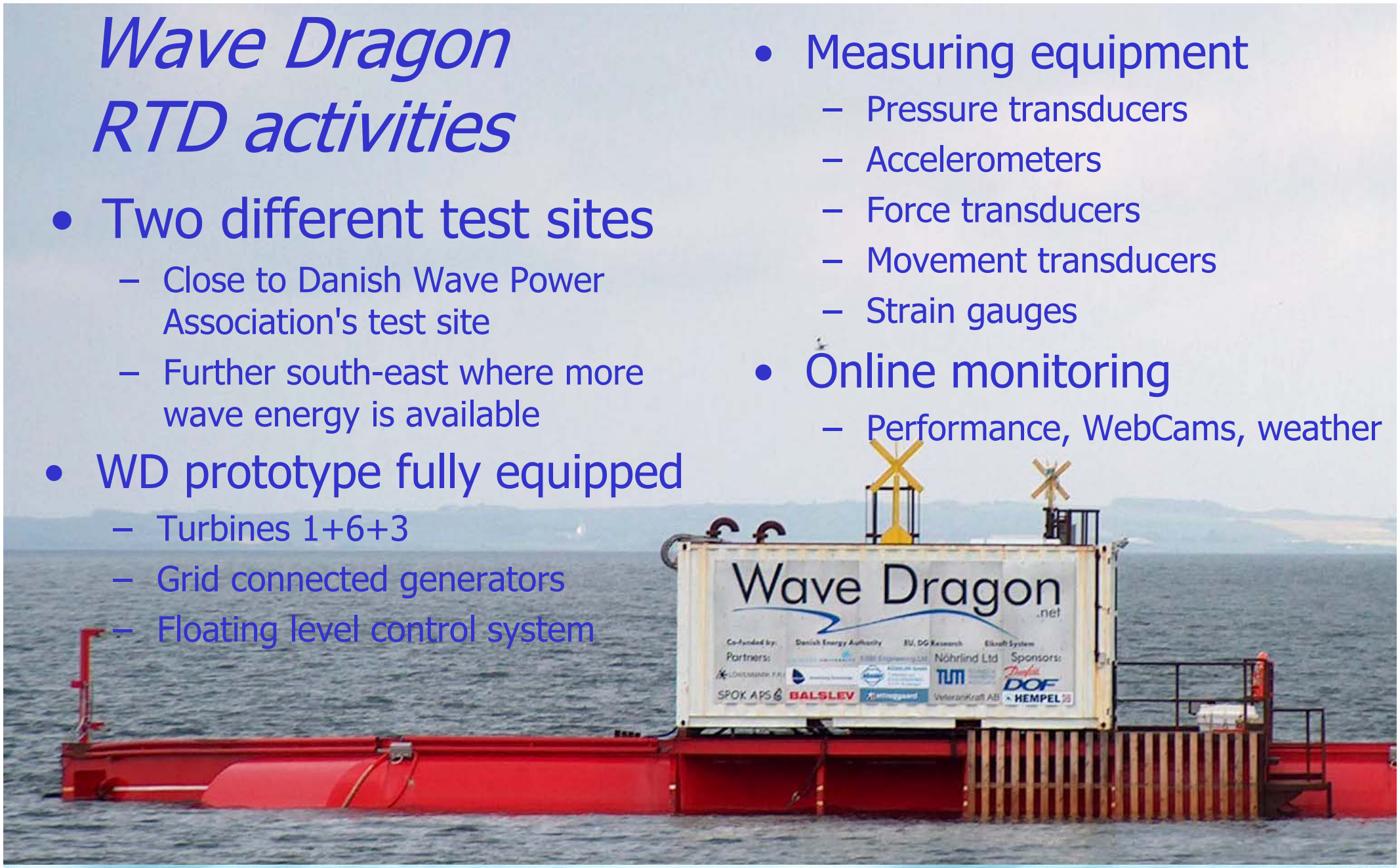
Nissum Bredning, Denmark

The wave climate in scale 1:4.5 of the North Sea



Wave Dragon RTD activities

- Two different test sites
  - Close to Danish Wave Power Association's test site
  - Further south-east where more wave energy is available
- WD prototype fully equipped
  - Turbines 1+6+3
  - Grid connected generators
  - Floating level control system
- Measuring equipment
  - Pressure transducers
  - Accelerometers
  - Force transducers
  - Movement transducers
  - Strain gauges
- Online monitoring
  - Performance, WebCams, weather



First offshore wave energy converter producing power to the grid, May '03

Prototype overtopping measurements

$$Q^* = \frac{q\sqrt{s_{op}/2\pi}}{\sqrt{gH_s^3 L}}$$

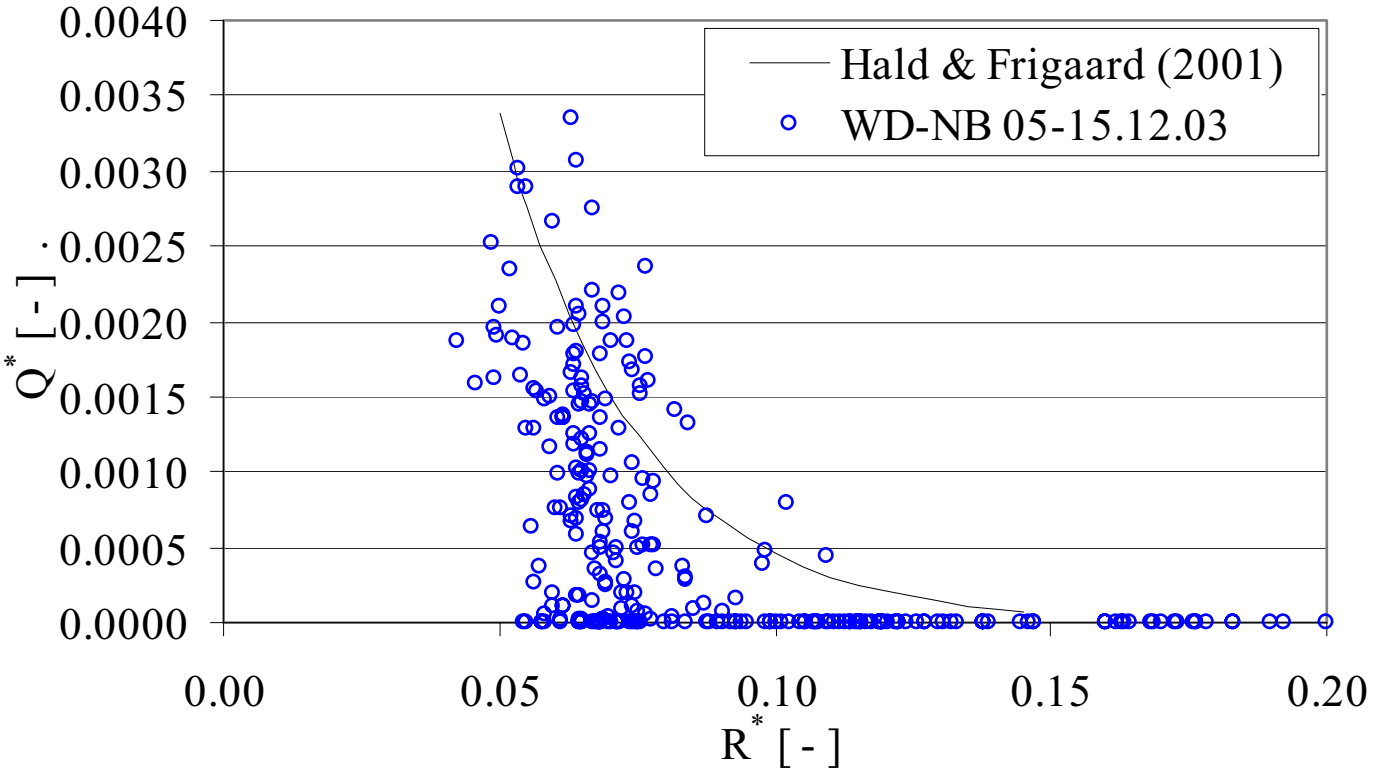
$$Q^* = 0.025\exp(-40R^*)$$

Bulk overtopping data:

- Wave directionality, limited weather vaning
- Dummy turbines not included
- Spilling and leakage

Conclusion:

In ordinary, well controlled, operational conditions, the **overtopping rates are as expected** – indications of even higher rates under certain circumstances.



$$R^* = \frac{R_c}{H_s}\sqrt{\frac{s_{op}}{2\pi}}$$

Power Take Off

- Optimal turbine/generator speed found from turbine characteristics based on measured head
- PLC controls frequency inverters to obtained optimal speed
- Frequency inverters reports generator and net data back to PLC

Turbines:

Propeller

Cylindergate

Efficiency ~90 %

Low-head

Variable speed

PMG's:

2.5 kW each

Directly axle-connected to turbines

Suitable for frequent start/stop

PMG and grid frequency inverters:

Downscaled 250 kW wind turbine inverters

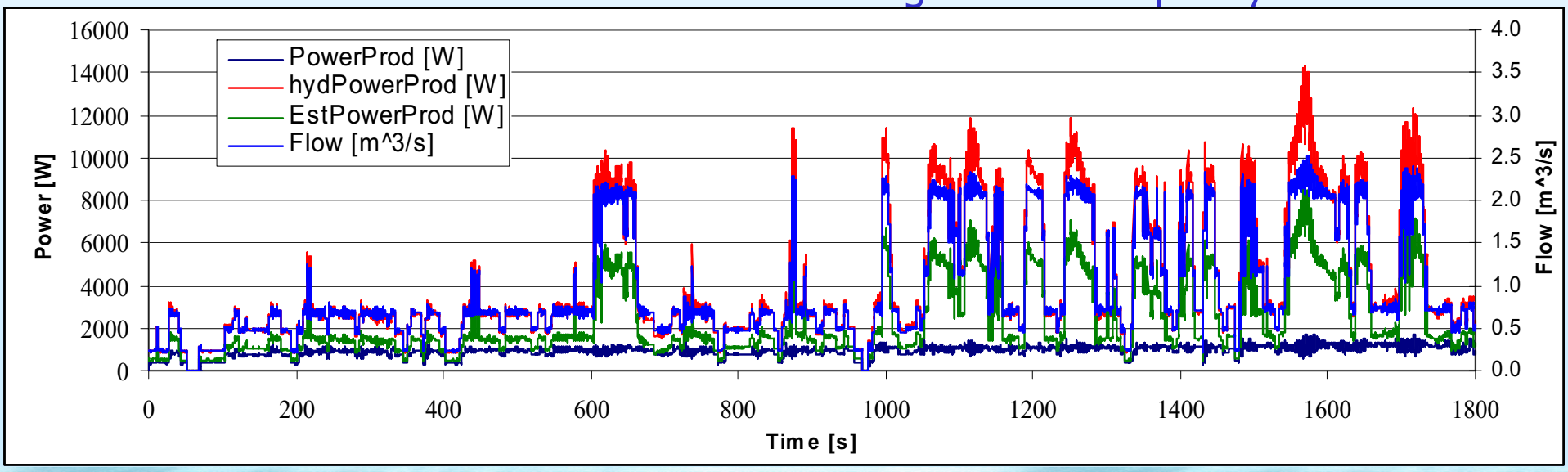
230/400VAC/50Hz

Energy production, example

041213_WD_133:

- Hs = 0.621 m
- FL = 0.454 m
- Crest level ratio: 0.73
- Ave. flow: 1.036 m^3/s
- Ave. Act. Power: 0.92 kW (3.3 %)
- Ave. Est. power: 2.47 kW (8.9 %)
- Ave. Hydr. Power: 4.41 kW (15.9 %)
- Turbine utilization:
  2 4 5 8 9 10:
  99 91 71 40 29 22 [%]

Working near full capacity

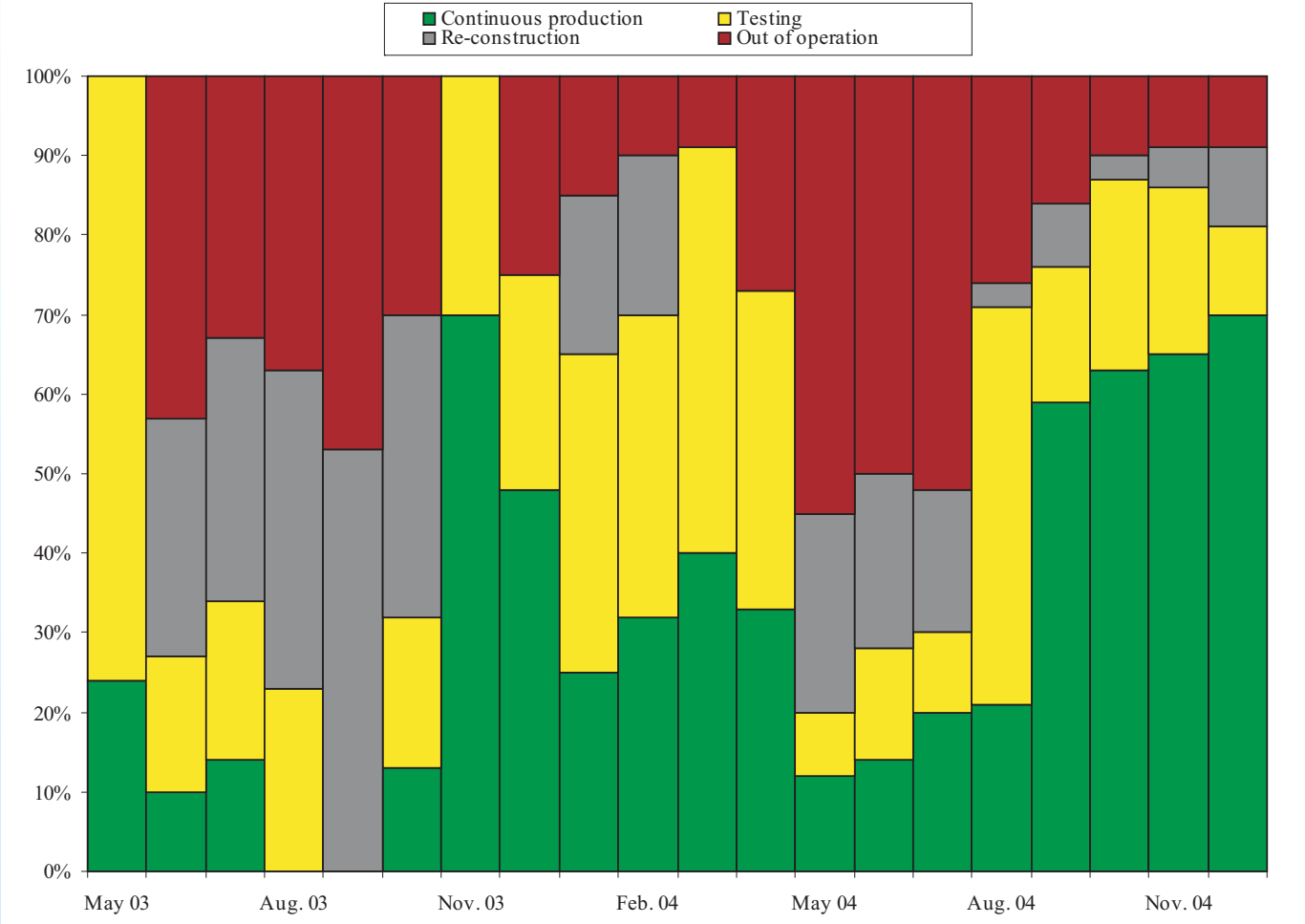


PTO experiences

- No PTO turnkey solution initially available for WD
- WD PTO designed and installed
- A working WD PTO is now a reality
- "Child deceases" pointed out – solvable, but requires engineering
- It is not trivial to take known and proven technology to a new environment
- Since it is unlikely that all problems have been seen yet, further testing at reduced scale and in real sea environments is needed
- Long term testing still required in order to provide reliable data for formulation of O&M procedures

Availability May 2003- Jan. 2005

Power production Test Down time Re-construction



Further developments

Modification of shoulder connection:

- Reduction of forces and movements.
- Hydraulic power take-off to reduce wear.

Improvement of efficiency by refinement of:

- Geometrical design.
- Control algorithms for turbine and power take-off operation.
- Control algorithms for device stability.
- Wave-by-wave forecasting for regulation of turbines.
- Floating level adjustment.

Conservative estimates of effect of refinements (10 – 15 % on each item) justify the stated long term power production rates

Wave climate	36 kW/m
Width	300 m
Yearly production	20 GWh
Efficiency	21 %
Installed capacity	7 MW
Load factor	33 %

Next step

- Multi MW Wave Dragon prototype: Wales
- Research part EU funded: FP6 (STREP)
- Welsh objective one funding for deployment in Wales
- Venture company found (KP Renewables), contract signed
- Design work ongoing

The Wave Dragon Vision

- ☺ Two years operational experience
- ☺ Wave energy absorption performance verified
- ☺ Offshore wave energy is a reality

Thank you for your attention!