World leading Danish frontier within wave power generation

CEO, founder Erik Friis-Madsen Msc, **Wave Dragon**

- *Where is Wave Power generation today*
- *What are the primary objects limiting this power generation source today?*
- *Can any lessons be learned from the wave power generation market introduction?*

- **Technical Potential of Renewable Energy**
- **Predictability and variability for solar, wind, tidal stream and wave**
- **Wave energy device types – four families**
- **Wave energy power plants – any need for energy storage?**
- **Wave Dragon – a floating hydro power plant?**
- **Energy storage for a single Wave Dragon**

Wave Energy Technology.

Strategy for Research, Development and Demonstration 2012

Partnership for Wave Energy

Energiteknologisk udvikling og demonstration

Wave energy increases and subsides slower than wind power and the energy production from waves are more stable. Therefore, a combination will provide a more balanced energy supply than wind power alone. Depending on location, wave energy can be predicted 6-9 hours ahead and with a much large accuracy than wind. Consequently, it is cheaper to integrate in the electrical system.

Ocean Energy Technologies

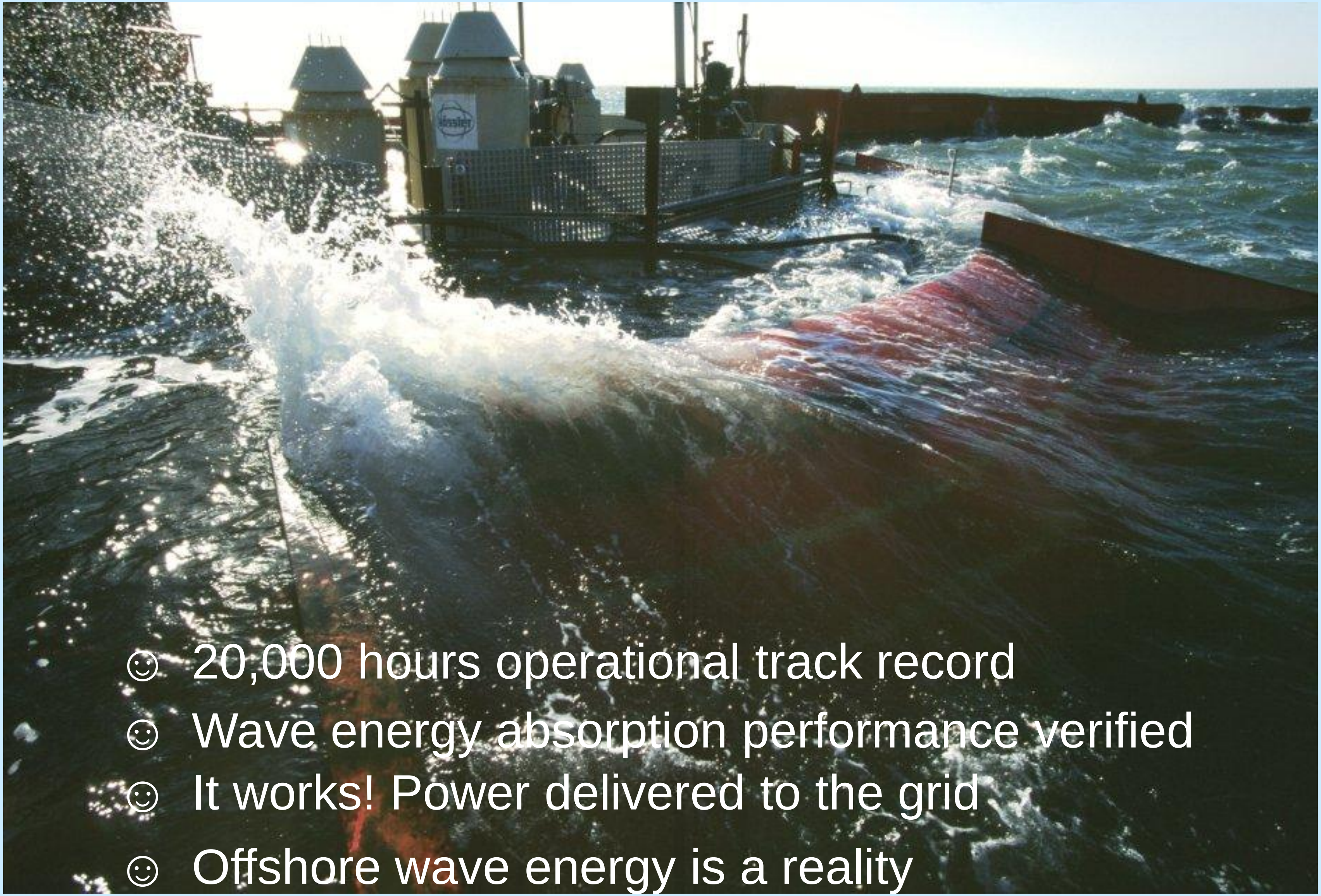
Wave Energy

Wave power captures kinetic and potential energy from ocean waves to generate electricity. Wave energy converters (WECs) are intended to be modular and deployed in arrays. At present there is little design consensus for wave energy devices with no industry standard device concept. Due to the diverse nature of the wave resource it appears unlikely that there will be one single device concept that is used, rather a small number of device types that exploit different regions of this vast resource.

DEVICE TYPE	ATTENUATOR	OVERTOPPING	OSCILLATING WATER COLUMN (OWC)	POINT ABSORBER	OSCILLATING WAVE SURGE CONVERTER (OWSC)
DESCRIPTION	Attenuator devices are generally long floating structures aligned in parallel with wave direction, which then absorbs the waves. Its motion can be selectively damped to produce energy.	Overtopping devices are a wave surge/focusing system, and contains a ramp over which waves travel into a raised storage reservoir.	In an OWC, a column of water moves up and down with the wave motion, acting as a piston, compressing and decompressing the air. This air is ducted through an air turbine.	A point absorber is a floating structure absorbing energy from all directions of wave action due to its small size compared to the wavelength.	An OWSC extracts energy from the surge motion in the waves. They are generally seabed-mounted devices located in nearshore sites.
DIAGRAM					

Figure c: Classification of wave energy converters

Wave Dragon prototype experience



☺ 20,000 hours operational track record

☺ Wave energy absorption performance verified

☺ It works! Power delivered to the grid

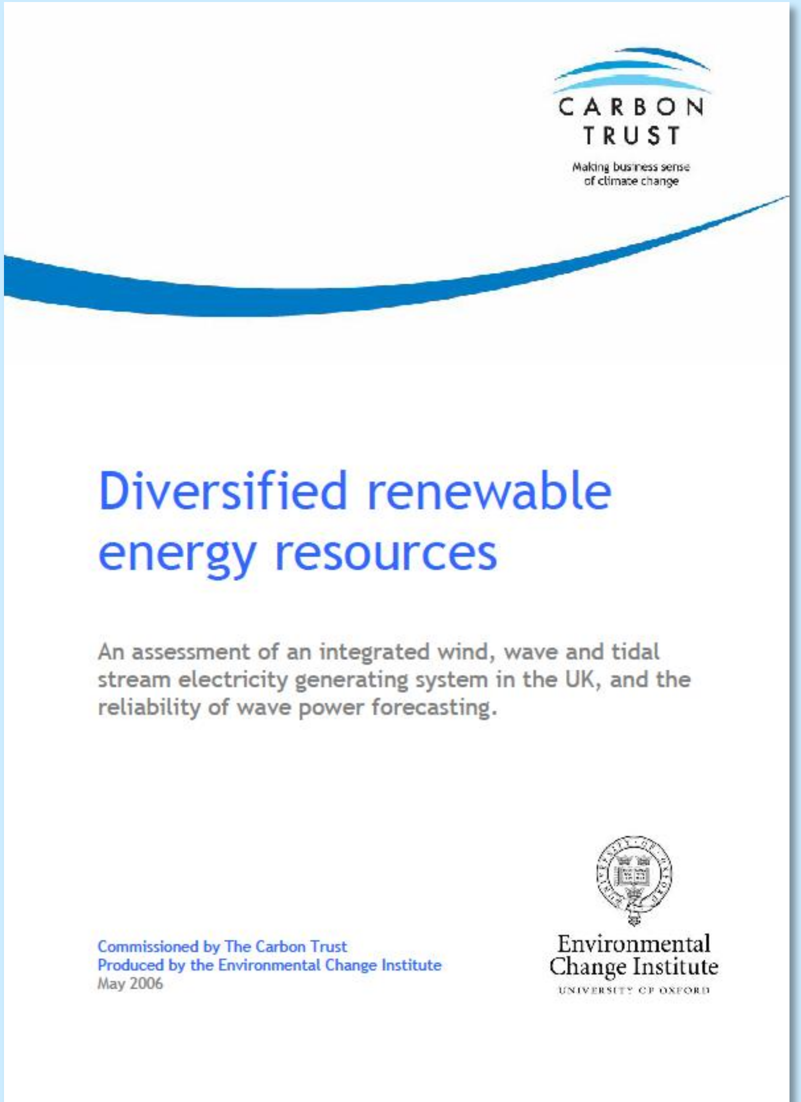
☺ Offshore wave energy is a reality

Technical Potential of Renewable Energy (ExaJoules)

	Bio-mass	Hydro	Solar	Wind	Geo-thermal	Ocean	Total
World	283	50	1,570	580	1,401	730	4,614
Current use	50	10	0.2	0.2	2	0	62.4
Total primary energy supply							420

Source: Federal Ministry for Economic Cooperation and Development and Ministry for the Environment, Nature Conservation and Nuclear Safety: Conference Issue Paper, Renewables 2004 – International Conference for Renewables Energies, Bonn 2004, p.27.

Predictability and variability for (solar), wind, tidal stream and wave


CARBON TRUST
Making business sense of climate change

Diversified renewable energy resources

An assessment of an integrated wind, wave and tidal stream electricity generating system in the UK, and the reliability of wave power forecasting.

Commissioned by The Carbon Trust
Produced by the Environmental Change Institute
May 2006

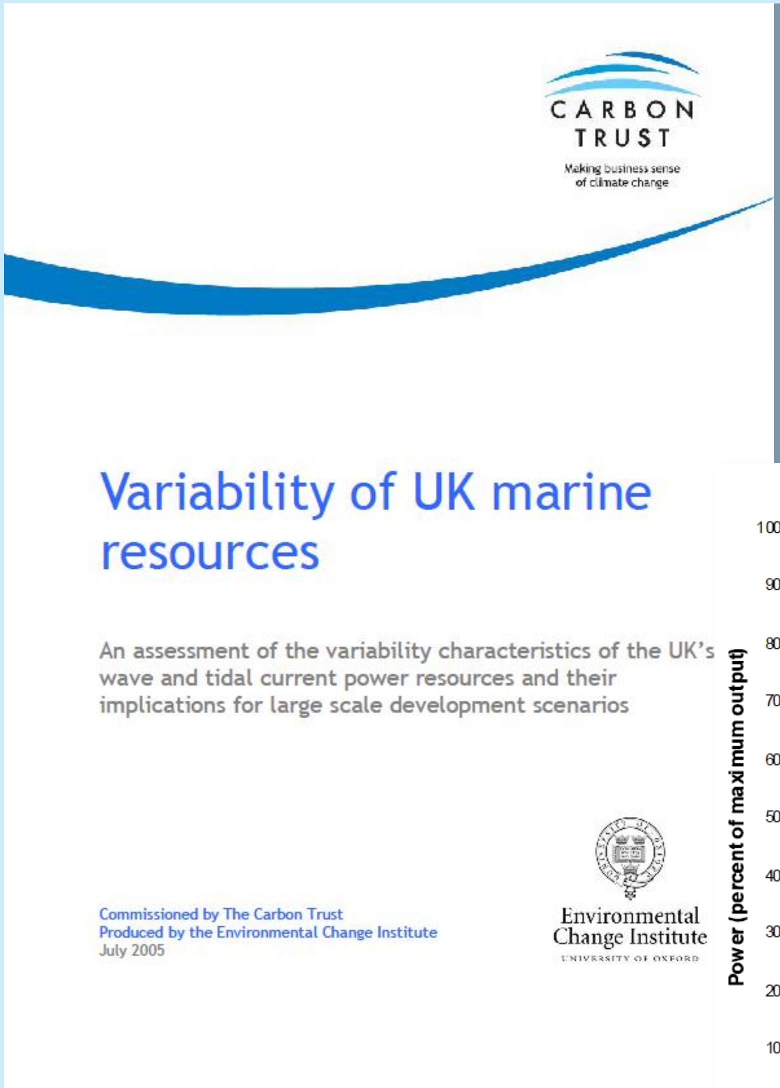
Environmental Change Institute
UNIVERSITY OF OXFORD

Impact on variability

The inclusion of wind, wave and tidal power into a national renewable resource portfolio significantly reduces the hour to hour variability of the renewable electricity supply. The table below shows the variability in supply from the UKI scenario in comparison to that from a tidal stream-only, wind-only or wave-only scenario (variability is expressed as the standard deviation of the hourly change in output as a percentage of installed renewable energy capacity).

Renewable supply	Variability – percent of installed capacity
Tidal stream power only	6.3% - 22.4%
Wind power only	3.2%
Wave power only	2.6%
UKI scenario	**2.0%**

Predictability and variability for (solar), wind, tidal stream and wave

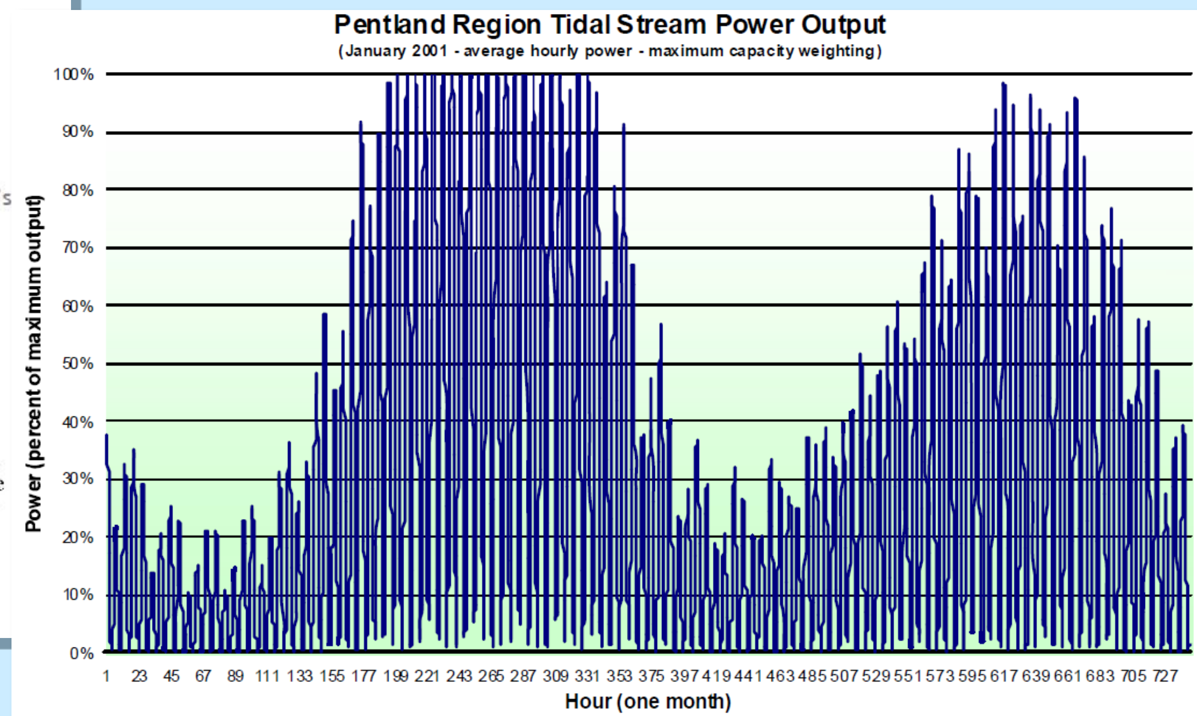

CARBON TRUST
Making business sense of climate change

Variability of UK marine resources

An assessment of the variability characteristics of the UK's wave and tidal current power resources and their implications for large scale development scenarios

Commissioned by The Carbon Trust
Produced by the Environmental Change Institute
July 2005

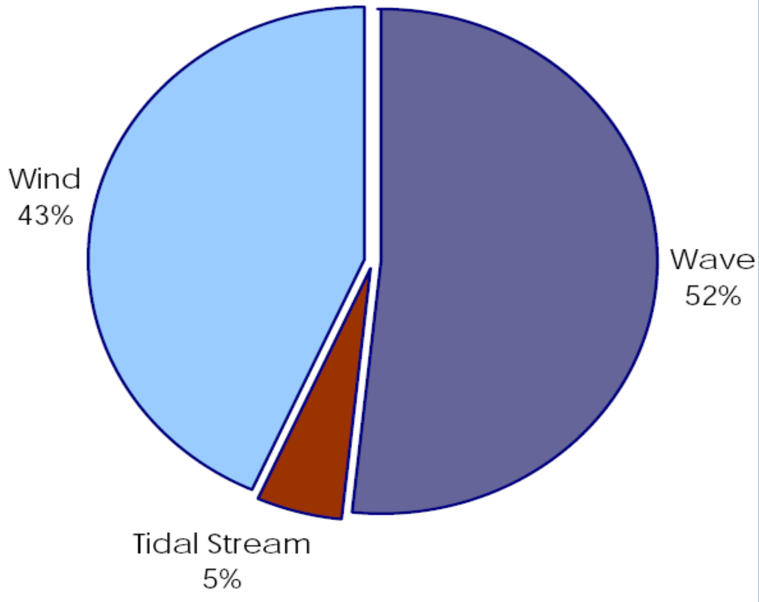
Environmental Change Institute
UNIVERSITY OF OXFORD



Predictability and variability for (solar), wind, tidal stream and wave

A diversified portfolio – UKI scenario

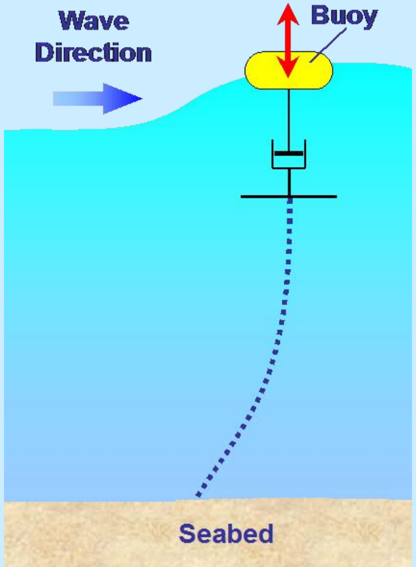
- Wind power – range of sites throughout the UK.
- Wave power – range of sites in three high-energy coastal regions in northern and south-western UK.
- Tidal stream power – range of sites throughout the UK.
- **The contribution of different sites and resources was modelled to achieve low variability in the overall renewable energy supply.**



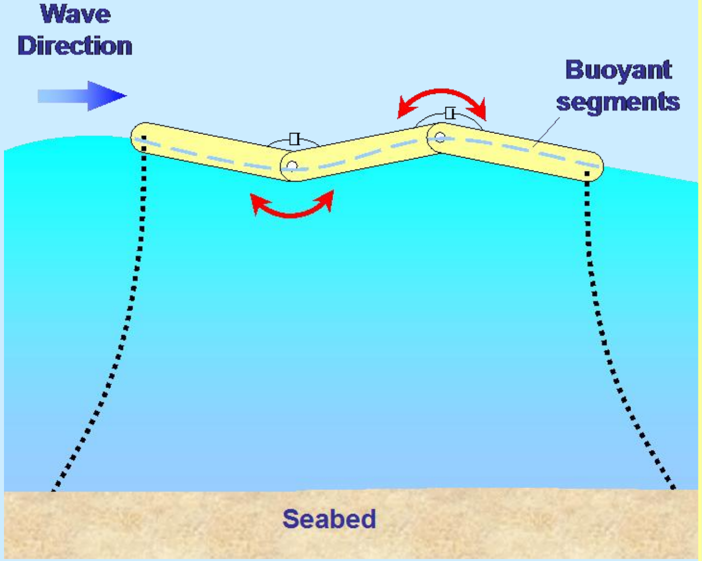
PRASEG – Diversified Portfolios 25 October 2005 – Graham Sinden

Wave Energy Devices: four families

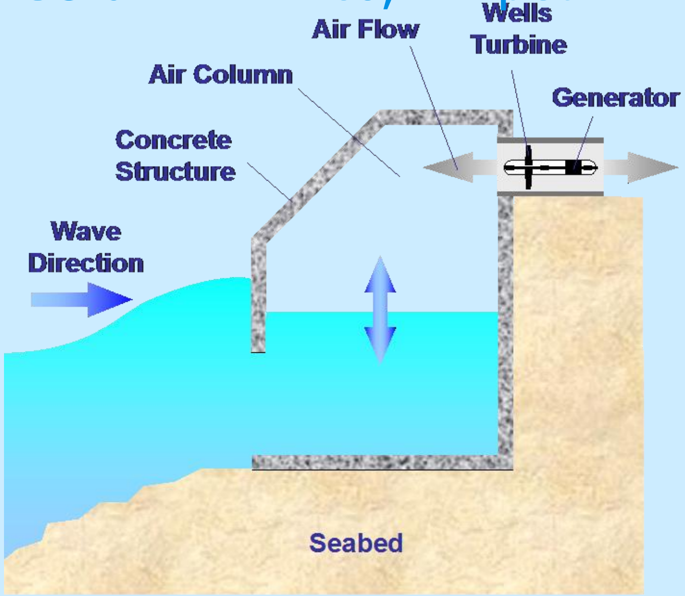
Heaving Devices:
OPT, Aquabuoy



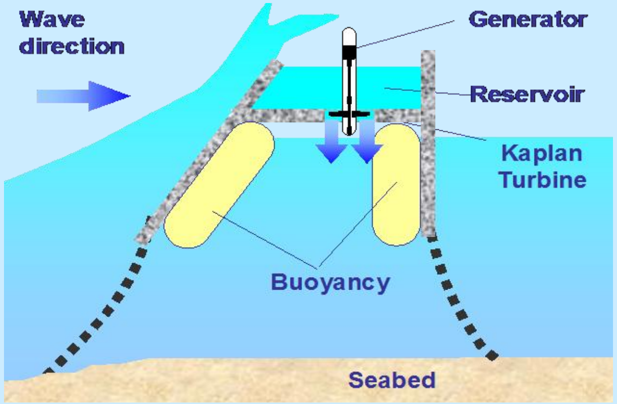
Pitching Devices:
Pelamis, Salter's Duck



Oscillating Water Column:
Pico, Limpet



Overtopping Devices:
Wave Dragon



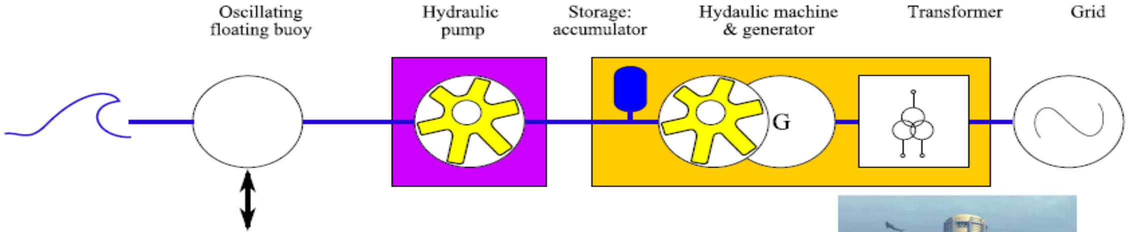
IES

Is the Wave Dragon really a wave energy converter ?

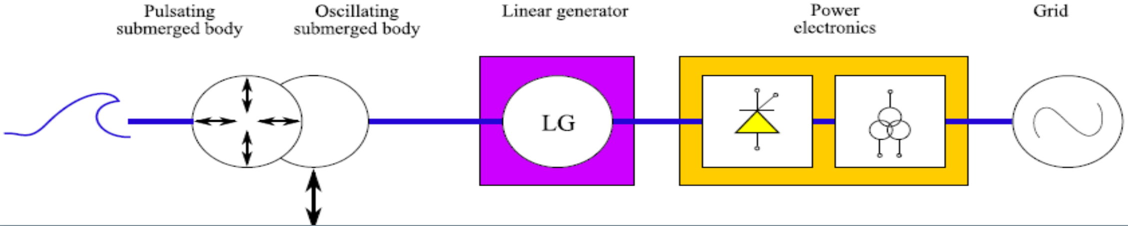
…and other puzzling conundrums

Alexandra Price
Supervisor: Robin Wallace

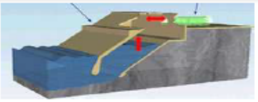
- Floating buoy: buffered drive

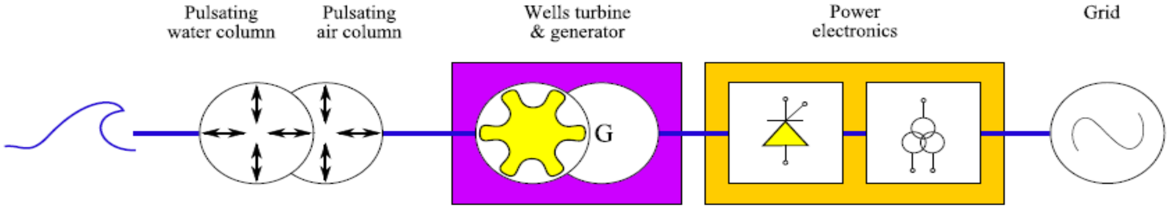


- Submerged buoy: direct drive

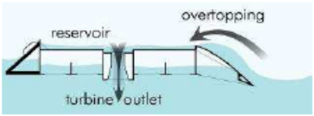


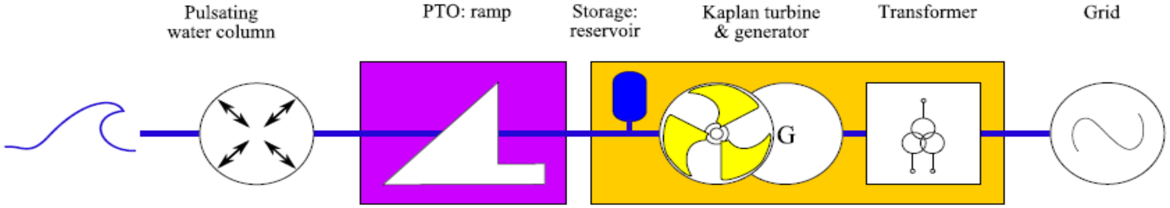
- Oscillating water column





- Overtopping device

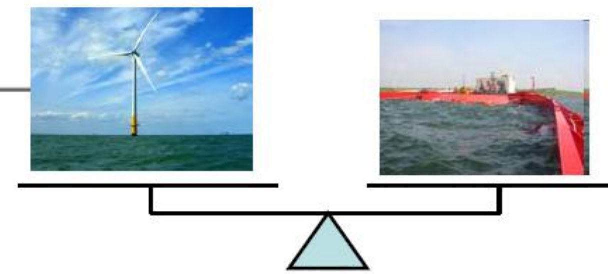




Wave energy power plants – any need for energy storage?

Number/size of WECs to match energy of 1 WT

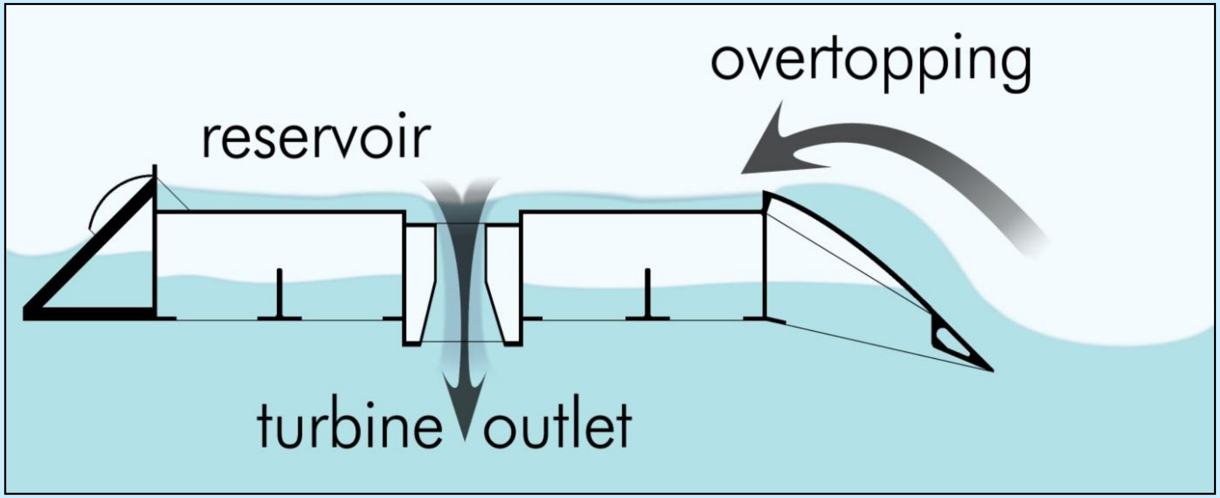
Category	Sub category	Number of WECs required	Required total width
OWCs		7	200
Overtopping devices		1	300
Wave activated bodies	Small low-draft heaving buoys	150	750
	Larger heaving buoys	12	230
	Sea bed mounted pitching devices	8	165
	Floating pitching devices	14	340
	Surging/heaving/ pitching devices	13	400
	Yawing/heaving	8	1100



Centrale Nantes
CNRS
NTNU

A. Babarit
9th EWTEC – Southampton – September 5th-9th, 2011

The Wave Dragon Technology

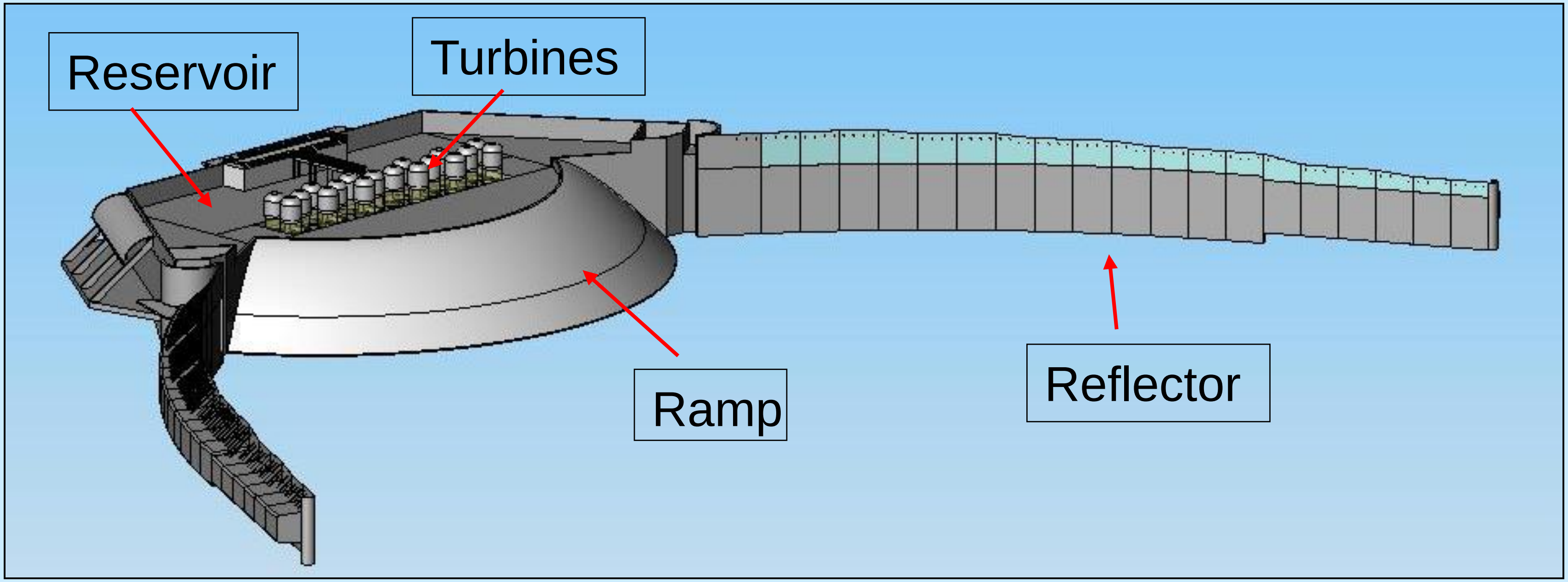


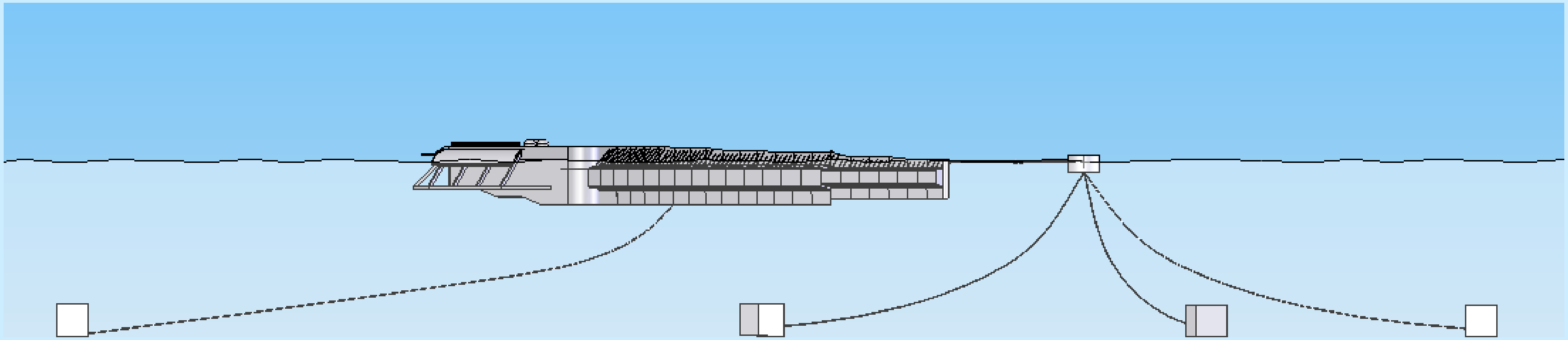
Absorption
- Wave energy focusing
- Overtopping

Storage
- Above sea level reservoir

Power-take-off
- Low-head variable speed propeller turbines
- PM generators & frequency inverters

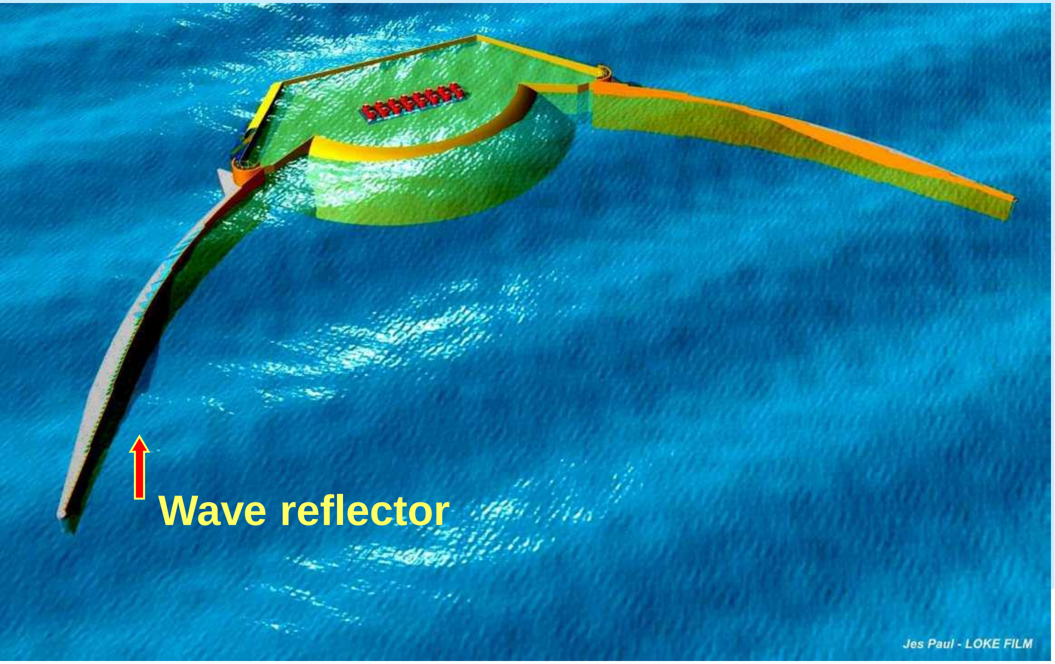
The Wave Dragon Technology



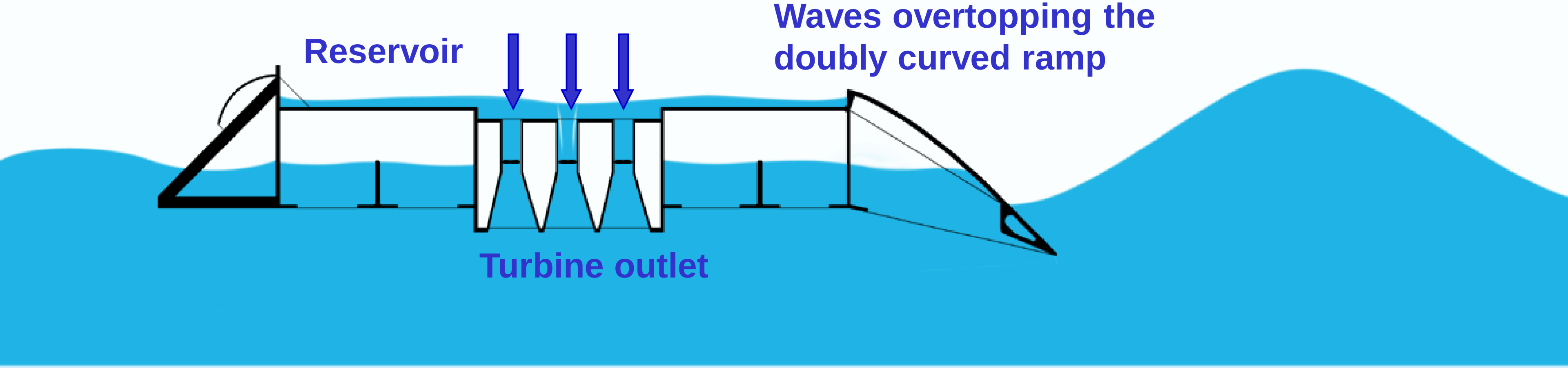


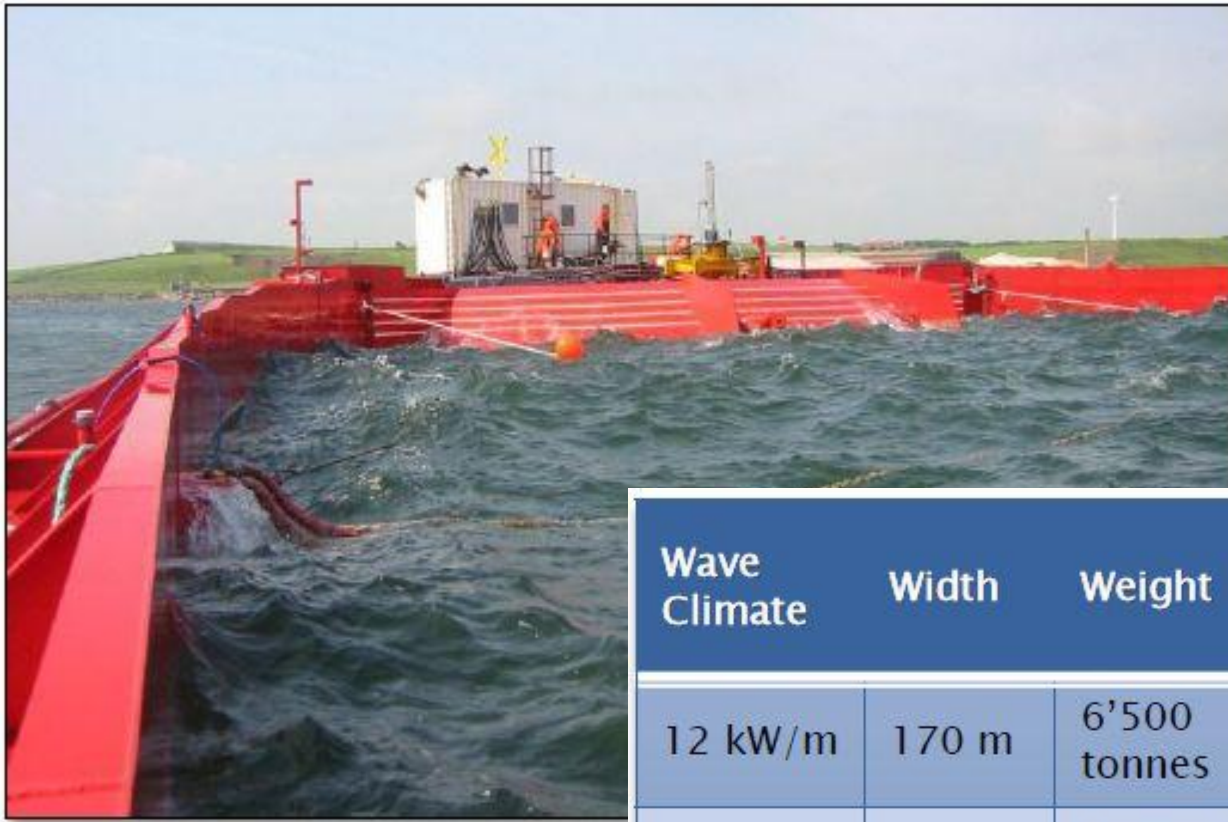
Floating Barge + River Hydro Power Station = Wave Dragon

Wave Dragon principle



Climate	Power -	Production
12 kW/m	1½ MW	4 GWh/y/unit
24 kW/m	4 MW	12 GWh/y/unit
36 kW/m	7 MW	20 GWh/y/unit
48 kW/m	12 MW	35 GWh/y/unit



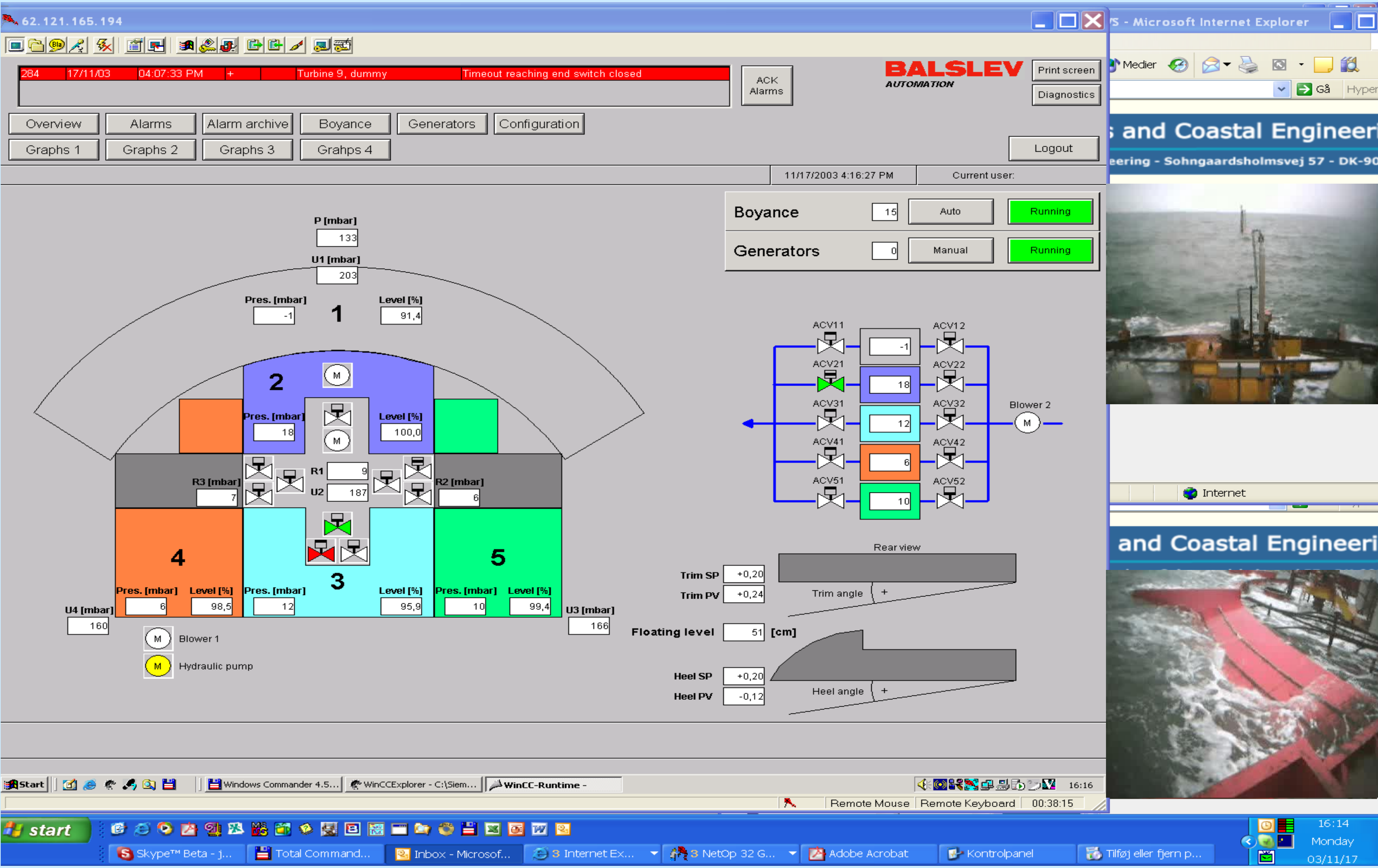


57 m wide 200 tonnes Wave Dragon prototype with 7 turbines deployed and connected to the grid in 2003 as worlds first floating WEC

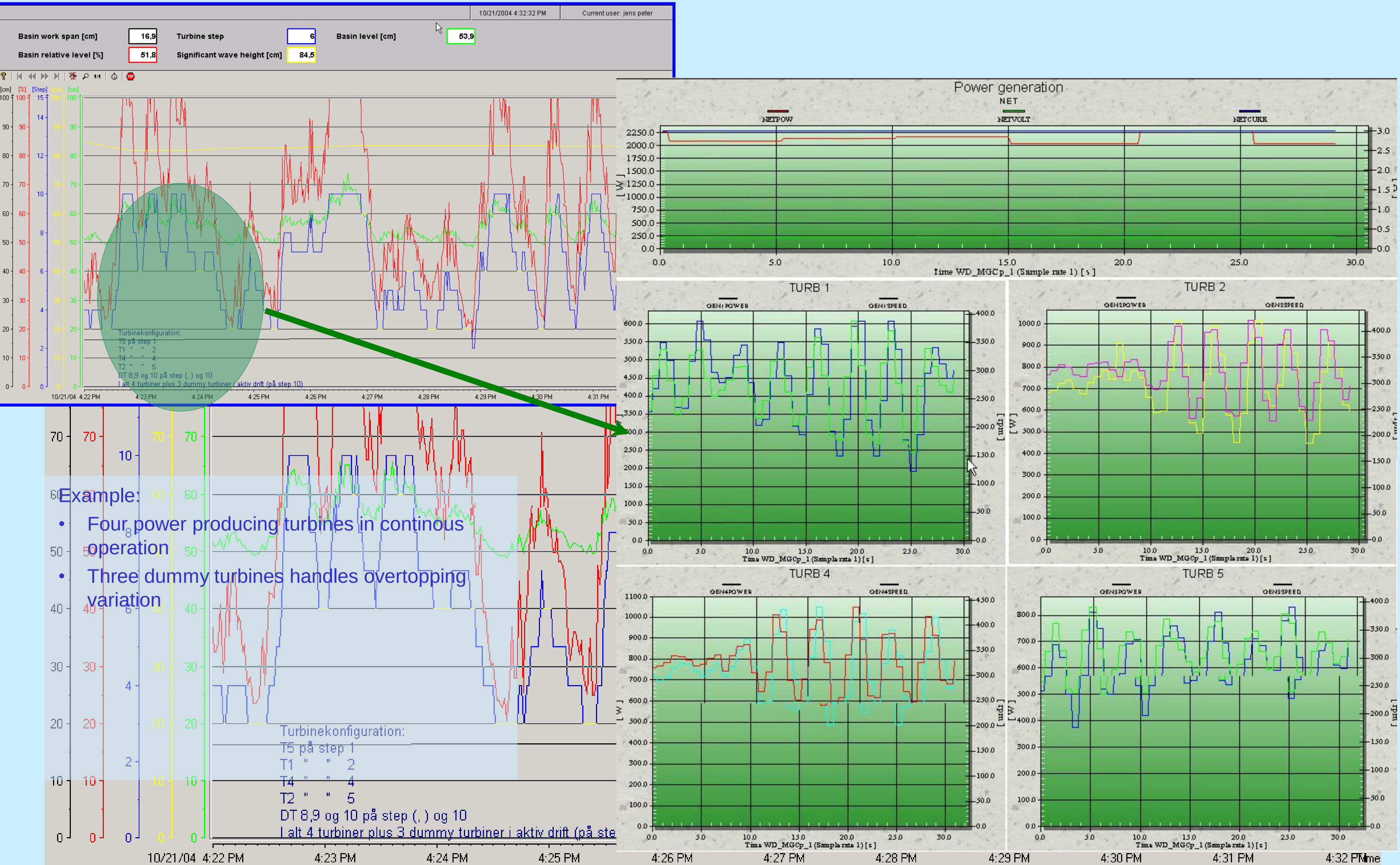
Wave Climate	Width	Weight	Turb.	Rated Power	Yearly Production
12 kW/m	170 m	6'500 tonnes	8	1.5 MW	4 GWh
24 kW/m	260 m	22'000 tonnes	16	4 MW	12 GWh
36 kW/m	300 m	33'000 tonnes	16-20	7 MW	20 GWh
48 kW/m	390 m	54'000 tonnes	16-24	12 MW	35 GWh

Full scale Wave Dragon device sizes

Remote control



Turbine operation and power production



Example:

- Four power producing turbines in continous operation
- Three dummy turbines handles overtopping variation

Energy storage for a single Wave Dragon

Flywheel Technology (1:4)

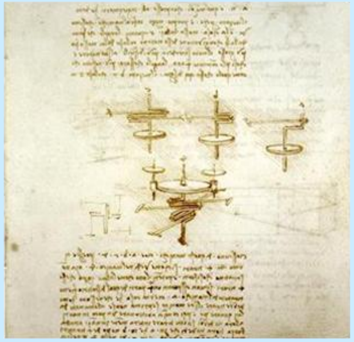
What is a flywheel?

A flywheel is a rotating mechanical device, which is used to store rotational or in technical terms kinetic energy. Flywheels have a significant moment of inertia and thus resist changes in rotational speed. The amount of energy stored in a flywheel is proportional to the square of its rotational speed. Energy is transferred to a flywheel by applying torque to it, thereby increasing its rotational speed, and consequently its stored energy. Conversely, a flywheel releases stored energy by applying torque to a mechanical load, thereby decreasing its rotational speed.

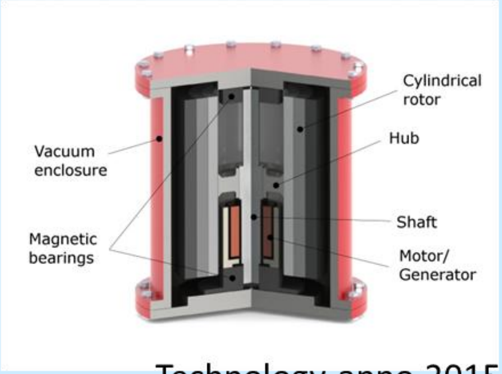
On the right the flywheel technology development from the renaissance to today.

For online info please visit -

http://www.youtube.com/watch?v=mz_7UF4KQpk



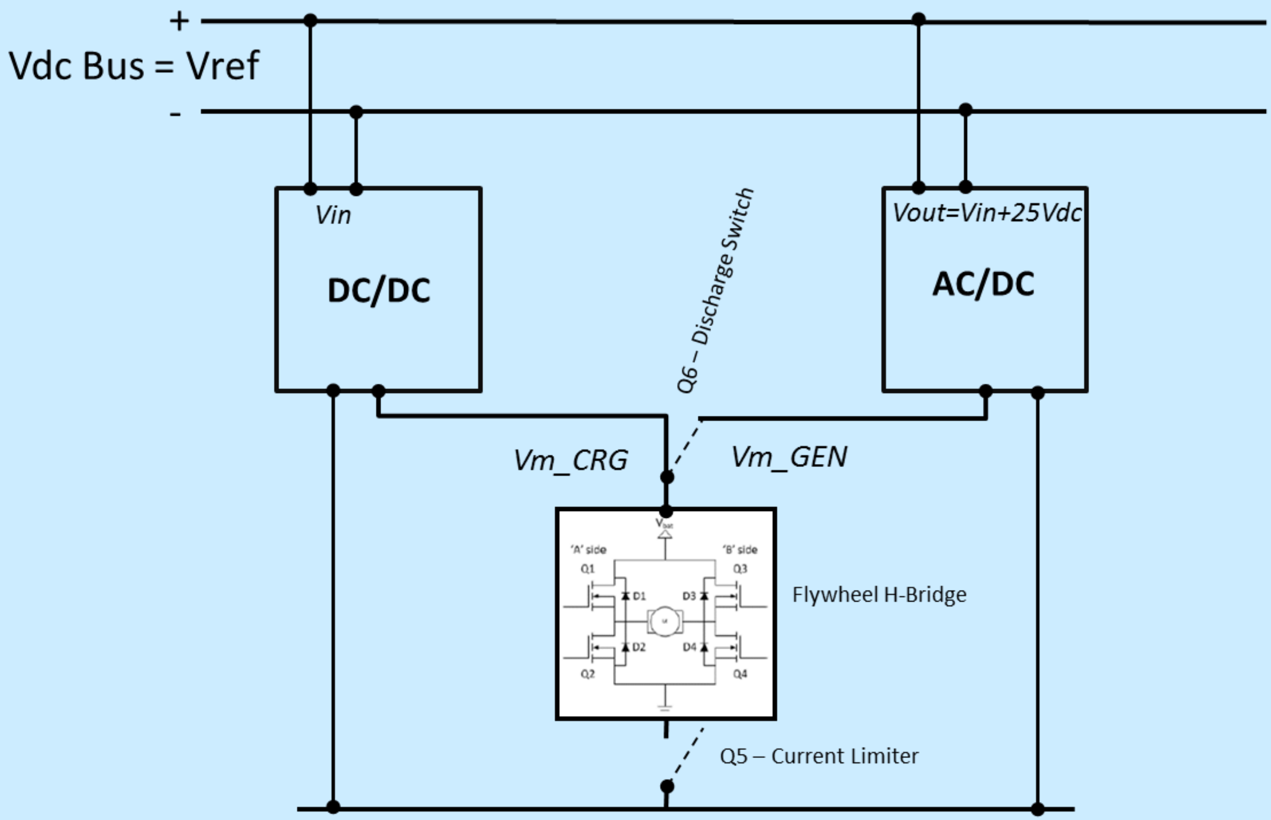
Leonardo *da Vinci*
(1452-1519)



Technology anno 2015

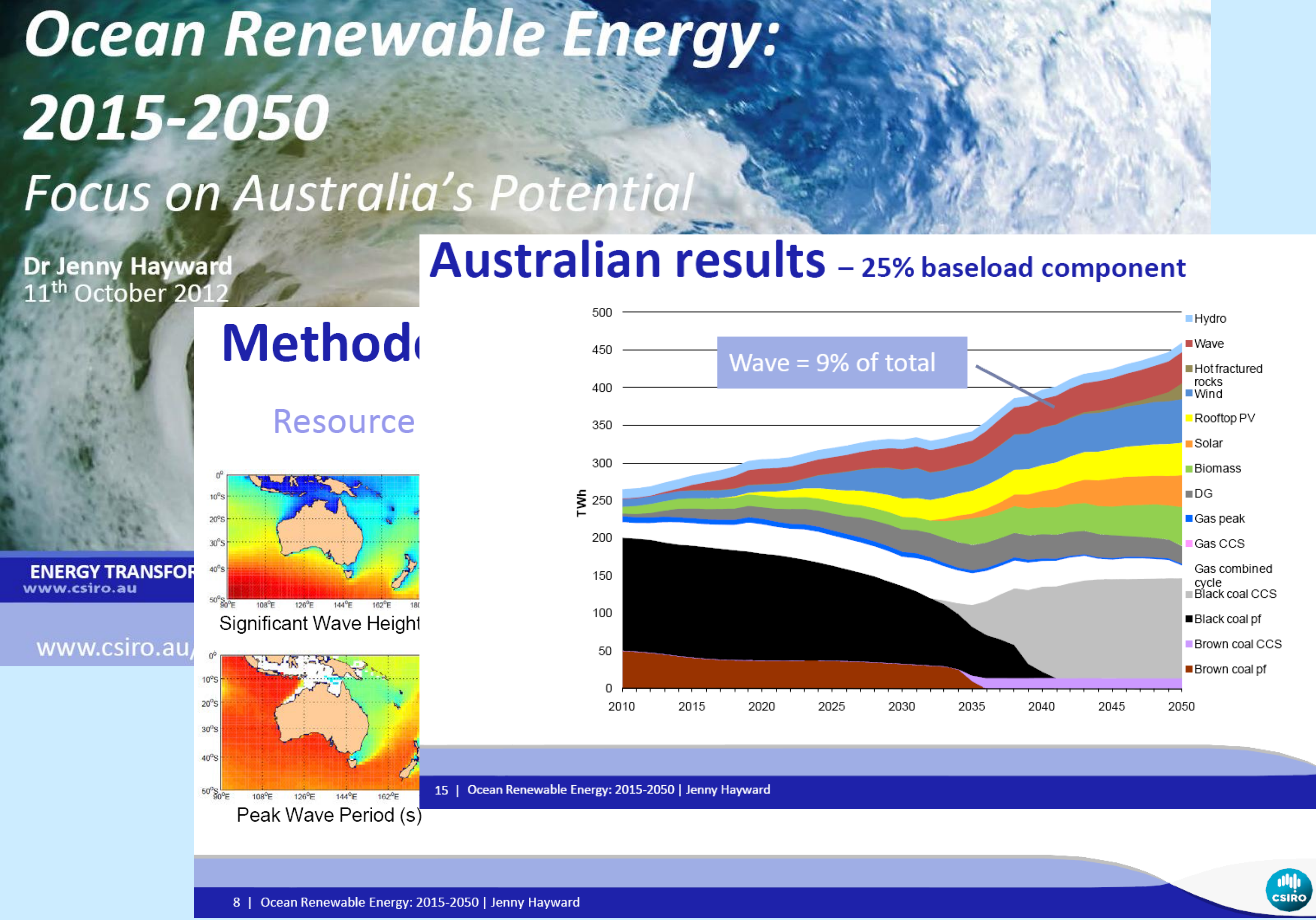
Energy storage for a single Wave Dragon

Principle drawing
- for connection to DC bus system




Wave Dragon
Multi-MW Ocean Energy Power Plant

Back up slides


Ocean Renewable Energy:
2015-2050
Focus on Australia's Potential
Dr Jenny Hayward
11th October 2012
ENERGY TRANSFOR
www.csiro.au
www.csiro.au/
Method
Resource
Significant Wave Height
Peak Wave Period (s)
8 | Ocean Renewable Energy: 2015-2050 | Jenny Hayward
Australian results – 25% baseload component
Wave = 9% of total
TWh
Hydro
Wave
Hot fractured rocks
Wind
Rooftop PV
Solar
Biomass
DG
Gas peak
Gas CCS
Gas combined cycle
Black coal CCS
Black coal pf
Brown coal CCS
Brown coal pf
15 | Ocean Renewable Energy: 2015-2050 | Jenny Hayward
CSIRO

Islay 70 kW

Tapchan, Norway

Trivandrum, India

Sakata Breakwater, Japan

SDE, Israel

OSPREY

Flap Device, Japan

Takenaka, Japan

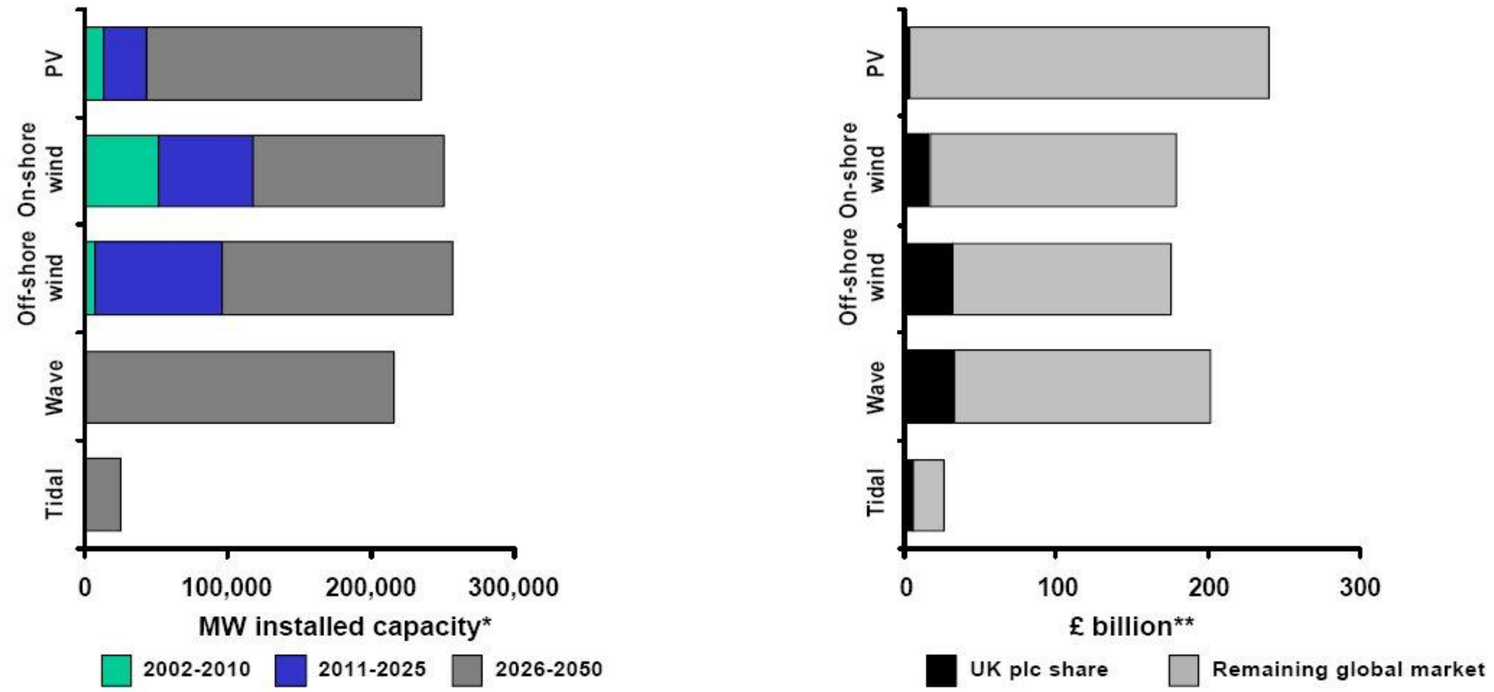
Fixed wave energy devices

Floating wave energy devices

dti | CARBON TRUST | RENEWABLES INNOVATION REVIEW

Wave and tidal stream could develop into significant global markets by 2050 which the UK, as current leaders in this emerging technology, would be well placed to exploit

Possible shape of global renewable electricity market, 2050



Note: * Estimates for global capacity additions from IEA, BTM, WEC, DTI estimates; ** Based on undiscounted cummulated installed capex and opex revenues, taking into account IEA and PIU experience cost curve predictions. Estimates of UK share are from Carbon Trust workshops with industry experts.

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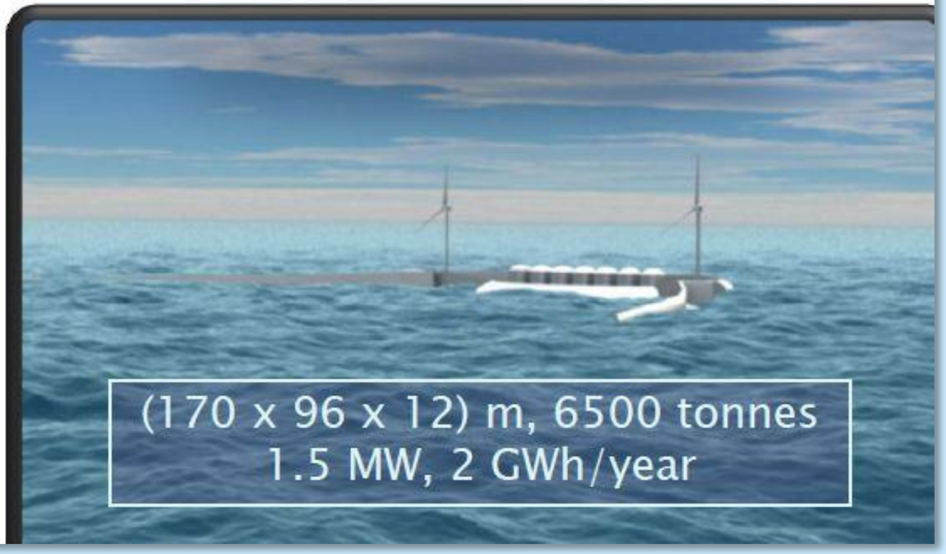
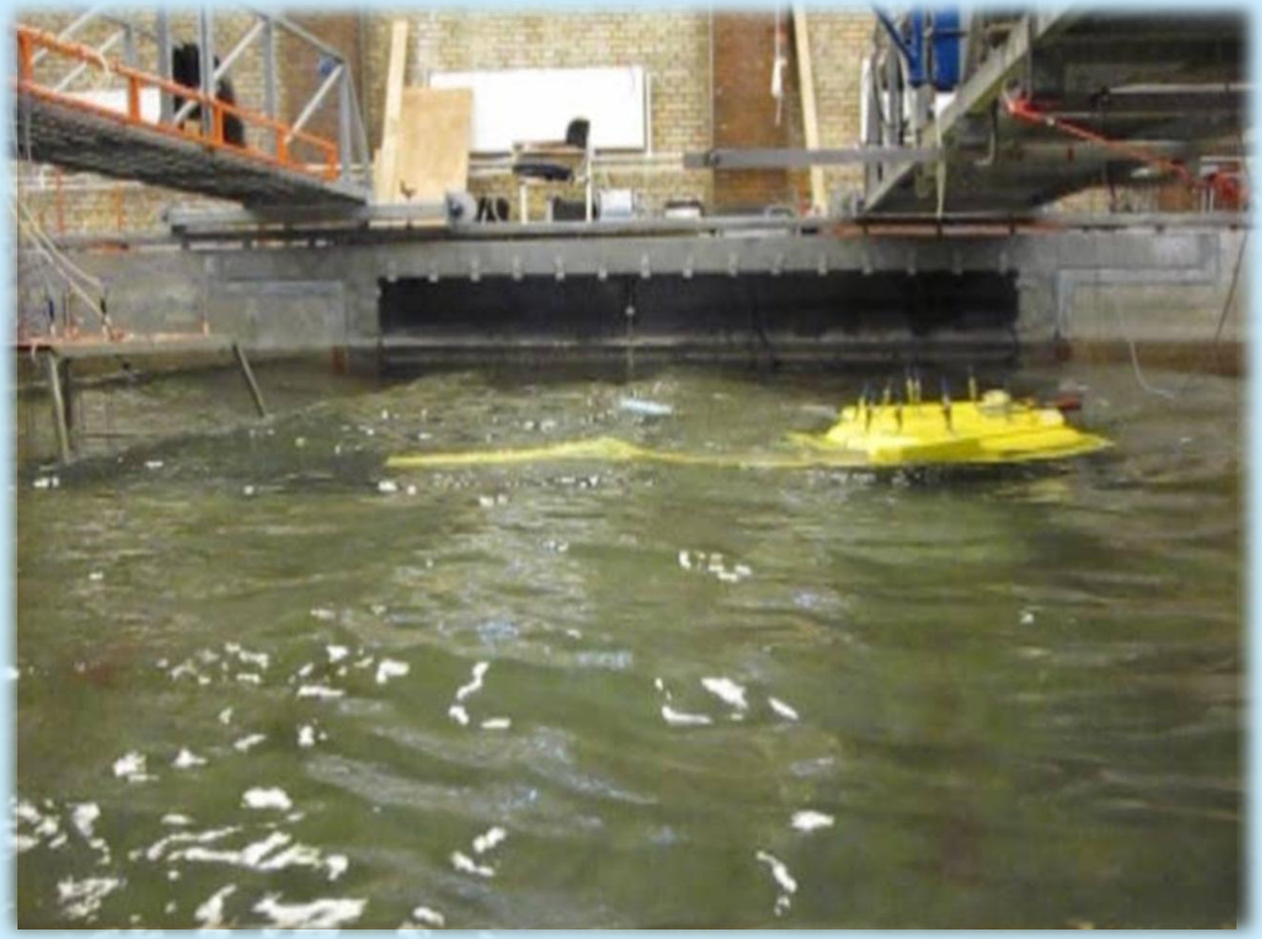
Wave Dragon – Development

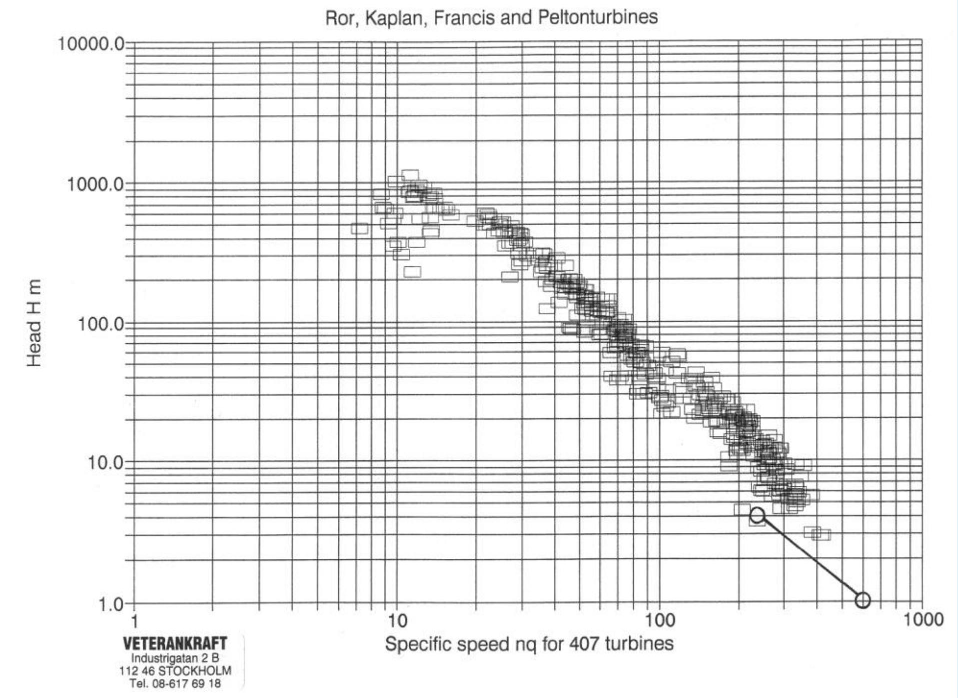


1:50 Model test 100 year wave

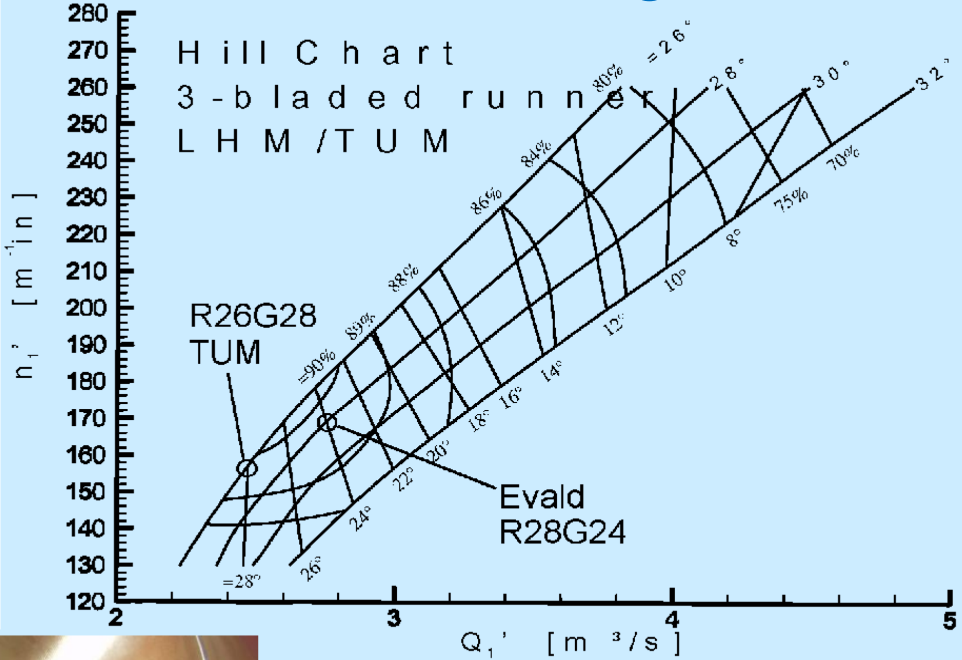


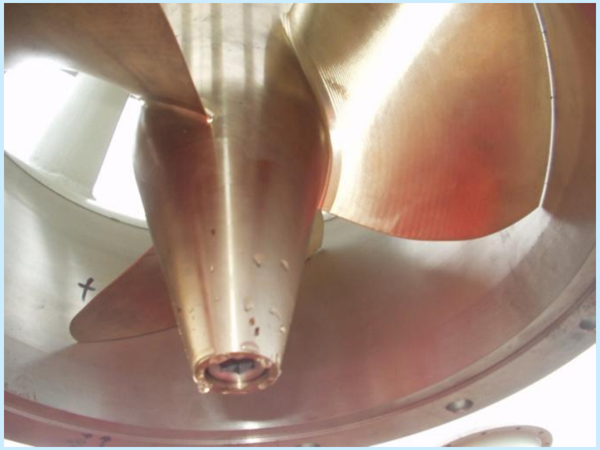

BERYL A CONDEEP
BRENT B CONDEEP
BRENT D CONDEEP
FRIGG TCP-2 CONDEEP
STATFJORD A CONDEEP
STATFJORD B CONDEEP
STATFJORD C CONDEEP
Mobil Exploration
Norway Inc.
Water depth: 146m
Installation: 1984
GULLFAKS A CONDEEP
Statoil
Water depth: 135m
Installation: 1986
TROLL CONDEEP
Norske Shell A/S
Water depth: 302.9m
Installation: 1995
HEIDRUN TLP
Conoco
Water depth: 350m
Installation: 1995
Dr. techn. Olav Olsen a.s
CONCRETE PLATFORMS – DESIGN EXPERIENCE

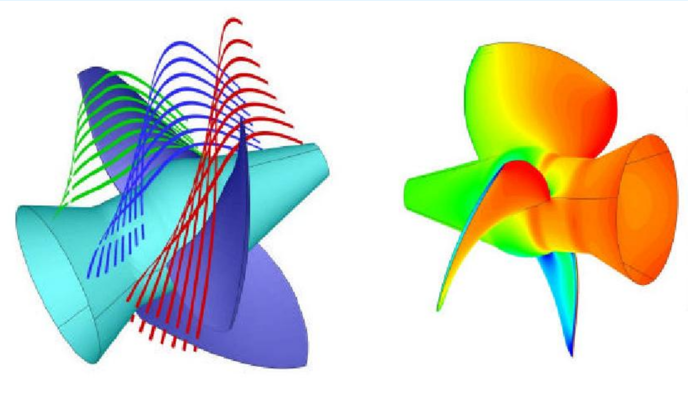
Operational Experience



Turbine Design







Cylinder gate turbines running

Ice and WEC’s is a bad combination!

The prototype was designed for a 3 year life time, but was not scrapped until 2011 after more than 8 years of operations.

How visible is a WD power plant?

Seen from 100 feet above sea level and at a distance of 5km

Under the horizon at a distance of 10km

Wave Dragon Advantages

- **Offshore**

  Low environmental impact. No visual impact, fewer international designations.

  High wave energy resources. Seabed friction causes great loss of energy in depths below 30 m.

  Plenty of suitable sites.

- **Overtopping**

  Non-resonating structure. Lower risk of damage in largest sea states as structure does not move, largest waves pass over device.

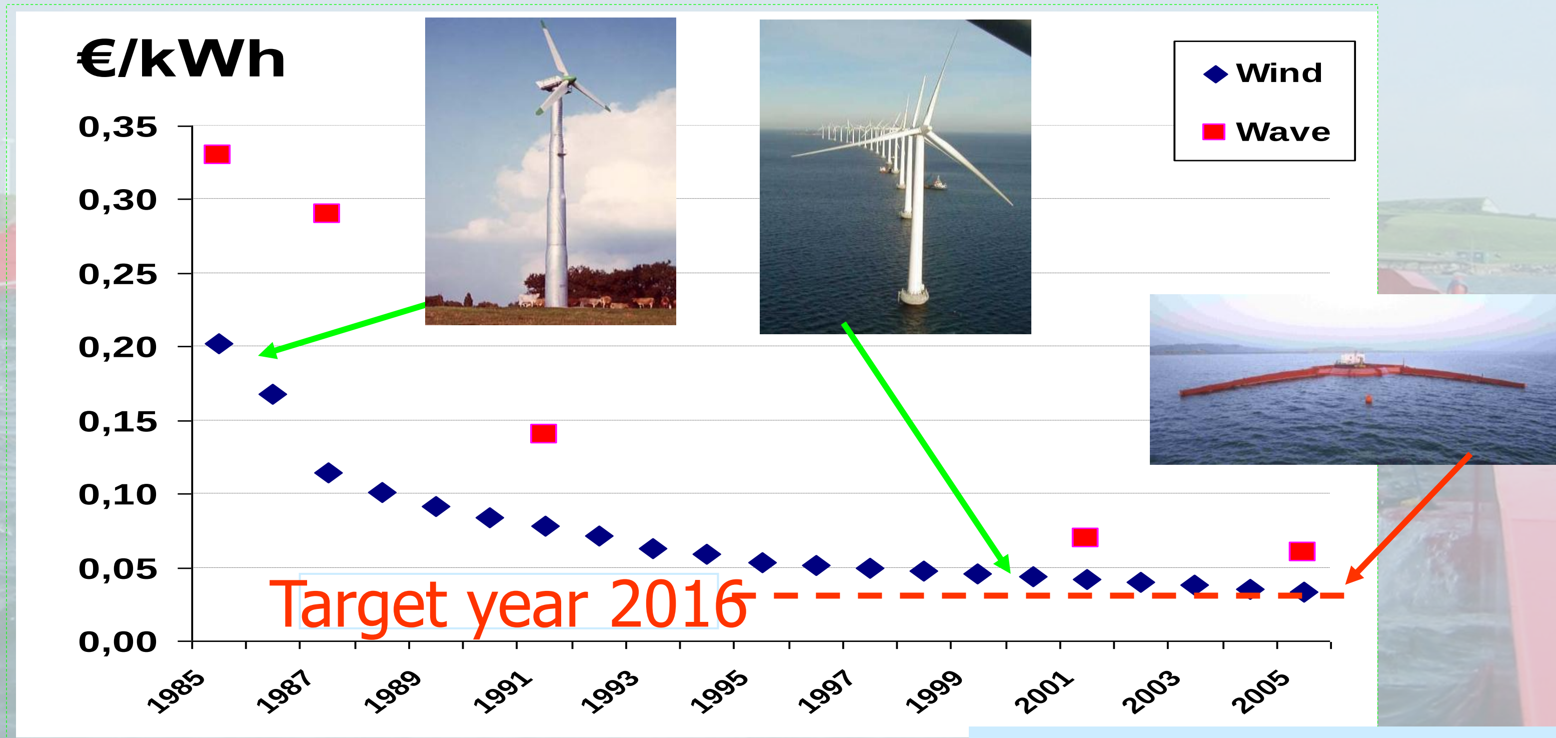
  Scaleable. Size can be increased to give performance improvements.

  Large-sized. Ease of access for maintenance, can host wind turbine.

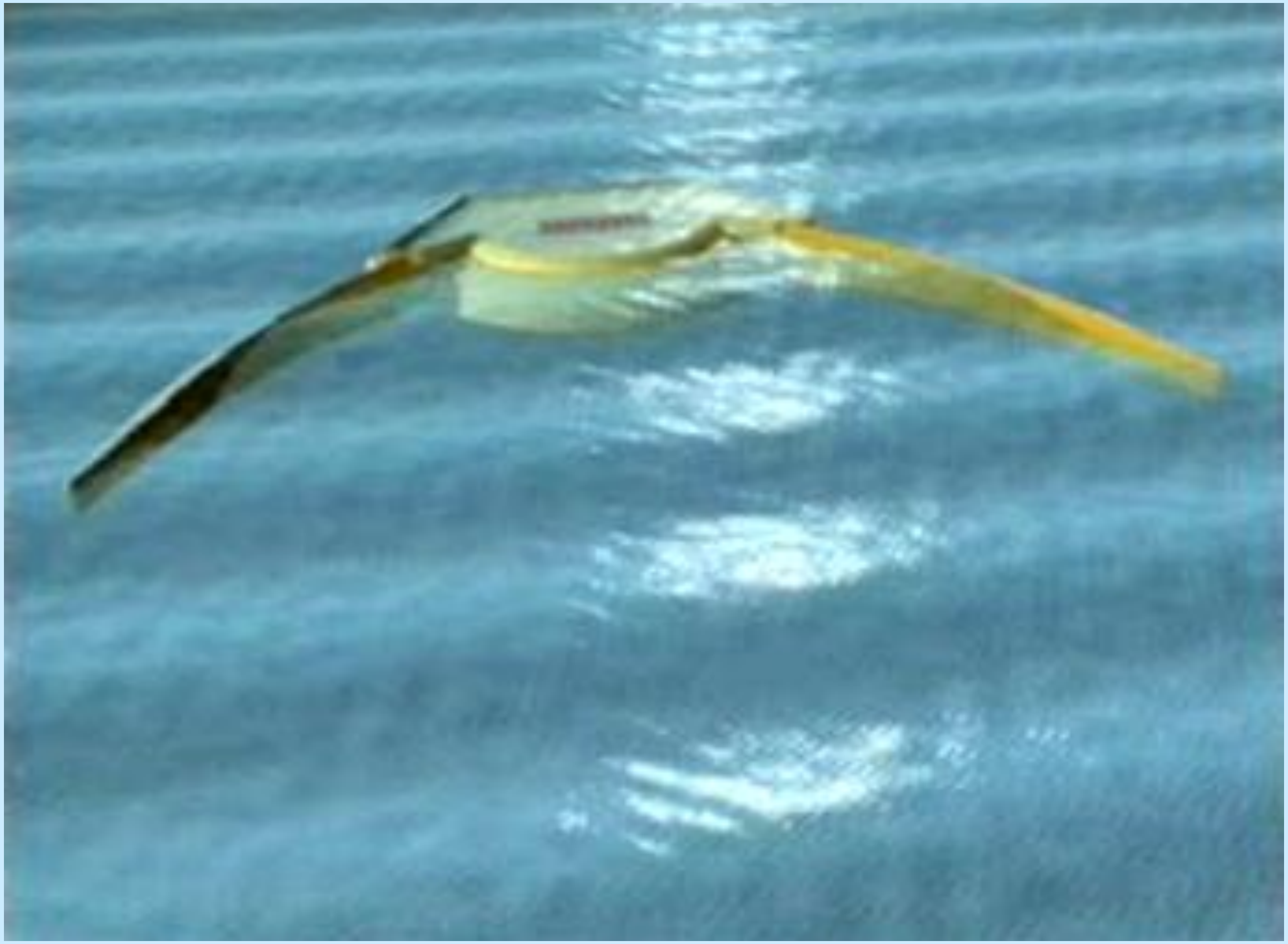
  Passive survival mode. Long life and low O&M costs

Wave Dragon objectives

To develop Wave Dragon to a power plant unit of 1.5 to 12 MW with a production price of 0.04 €/kWh



Source:
EU Wave Net 2002 and Risø



Animation: **LOKE film**