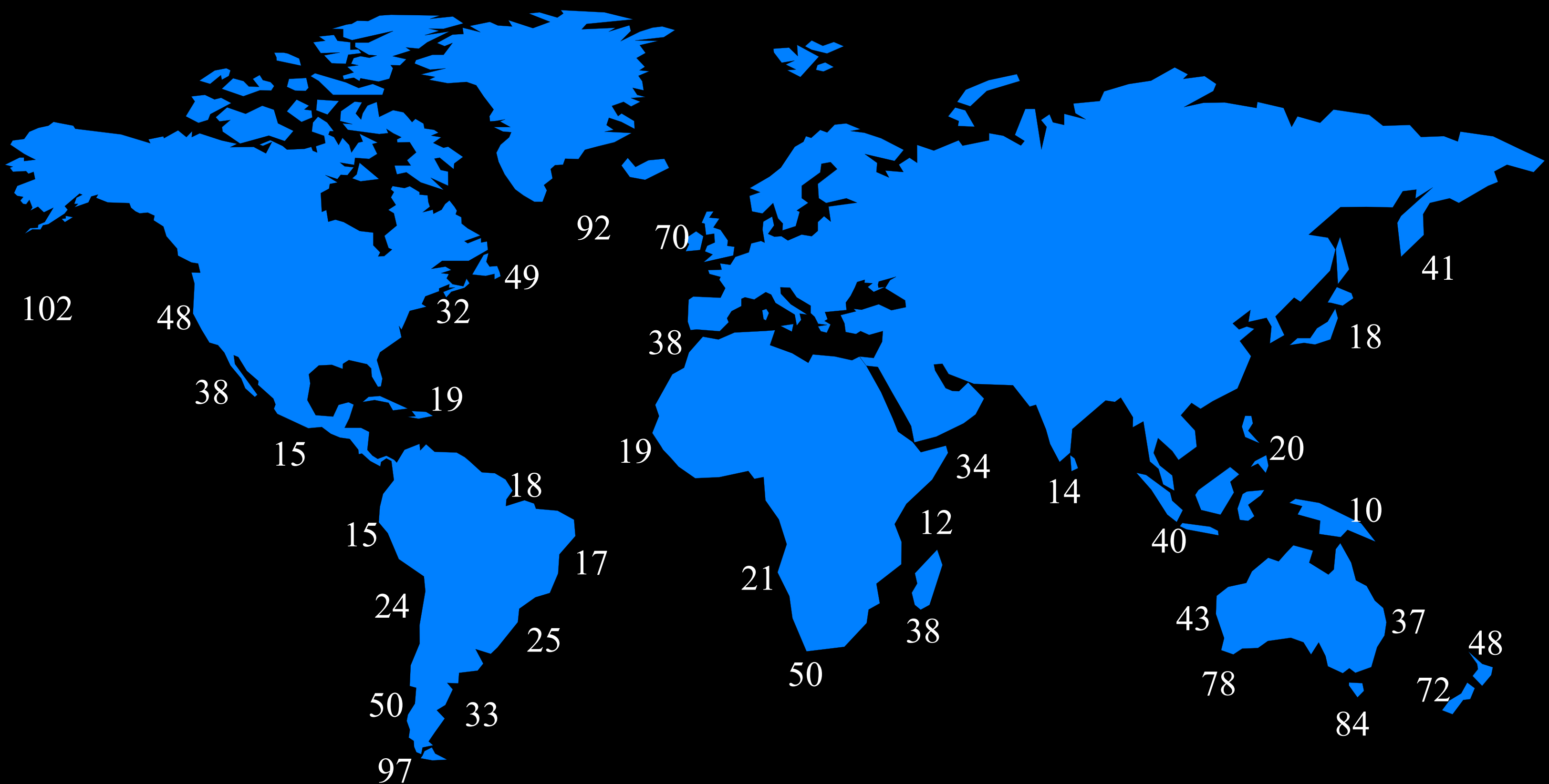
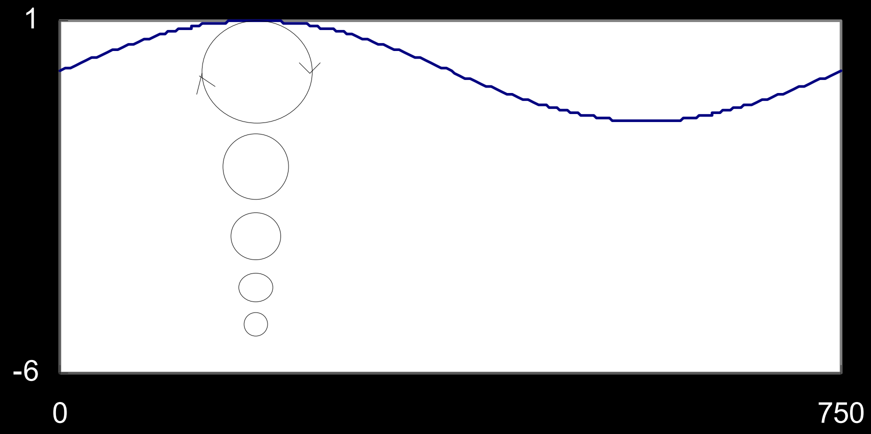

Wave
Energy

Global ocean wave energy resource



Annual average in kW/m width of wave

Wave energy



- For travelling ocean waves, water particles move in circular orbits, the radius of the orbit decaying exponentially with depth.
- In shallow water, the orbits distort into ellipses, with velocities generally well below 1 m/s.
- The relative motion is moderate, frictional (viscous) effects are small and dissipation of energy as the wave travels along is minimal.
- A surface wave is an efficient energy carrier: energy gathered in storms is stored and transmitted over hundreds or even thousands of km.
- Wave energy will be more constant than the wind energy from which it is derived.

Wave energy

- Period for waves passing a reference point:

$$T = \sqrt{\frac{2\pi\lambda}{g}}$$

$\{ \lambda$ = wavelength

- Power, P, per metre length of wave front:

$$P = \frac{\rho g^2 a^2 T}{8\pi}$$

$\{ a$ = amplitude

- In storms waves reach a maximum steepness:

$$\frac{a}{\lambda} \cong 0.03$$

Wave power devices

- Requirements:
  - operate reliably in a hostile, corrosive environment where maintenance access may be problematic;
  - provide a means for efficient conversion of the low-frequency (~0.1 Hz) cyclic wave motion into a useful energy form (most commonly electricity);
  - survive the 50-year storm condition at the chosen site.

- Extreme storms in deep water can produce waves over 30m high, with energy flows of several MW/m of wave front.

- Moorings for deep-water systems are a particular concern. Wave energy converters, unlike offshore oil platforms, are designed to react with the waves and will experience very large structural loads.

- A device may be moved into shallow water near the shore but then the smaller waves and their directional nature significantly reduce the available mean power.

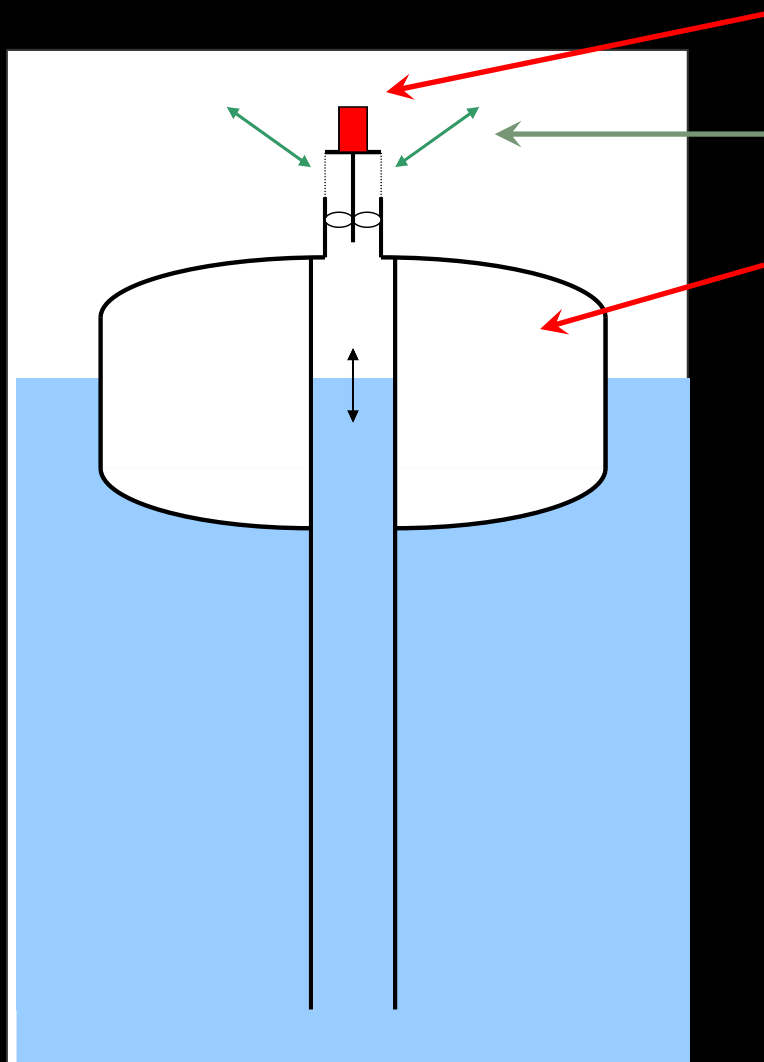
Device classification

- Passive – designed to guide the waves to spill over into elevated reservoirs, which then drain through conventional low-head hydraulic turbines into the sea.
- Relative motion – between structural parts with the motion employed to transfer a working fluid around a circuit to drive a rotary machine.
- Oscillating water column – where sea water is admitted to a chamber which is vented to the atmosphere

Significant events

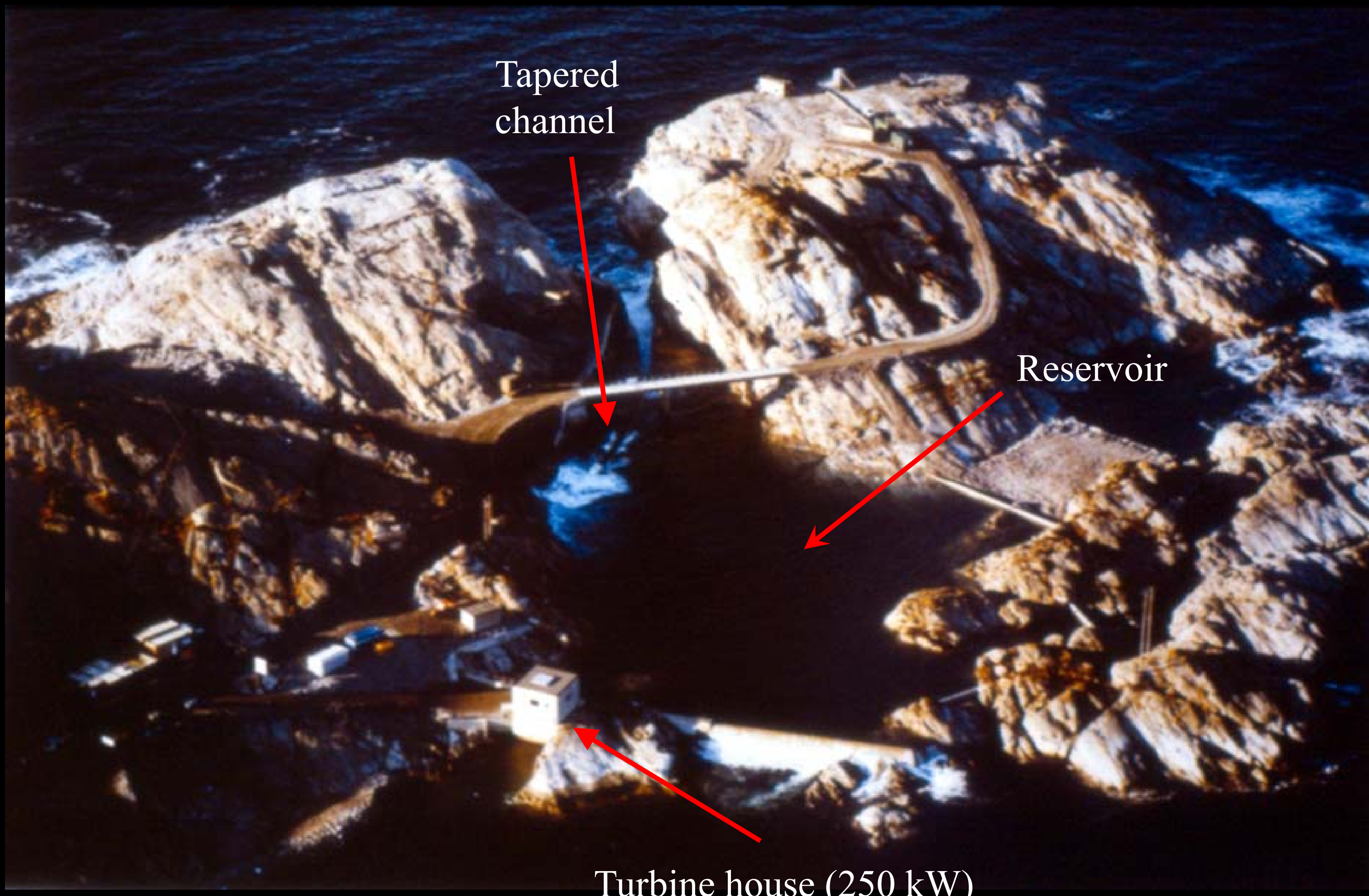
1965 Japan	Wave-powered navigation beacon developed by Masuda. 50W oscillating water column device (OWC). Several hundred constructed and deployed around Japanese coastline.
1985 Norway	Two prototypes constructed: a 500 kW OWC and a 350 kW passive device. OWC destroyed in storm in 1988.
1985 Scotland	Prototype 75 kW OWC constructed at shoreline site on Islay. Satisfactory operation; decommissioned 1999.
1995 Scotland	Osprey 2 MW prototype OWC constructed. Device damaged by storm during installation and removed from site. Replacement planned but abandoned due to unforeseen problems with site.
1998 2003 Scotland 2004 Europe 2006 Portugal	Two 500 kW OWC shoreline installations given clearance to proceed with EC research funding. Locations Islay, Scotland, and Pico in the Azores. Both commissioned in 2001-02. Construction of full-scale 750 kW Pelamis prototype for trial deployment at EMEC. Sea trials of Archimedes Wave Swing off Portugal and Wave Dragon over-topping device in Danish waters. Agreement for first wave energy 'farm' using Pelamis machines.

Masuda buoy

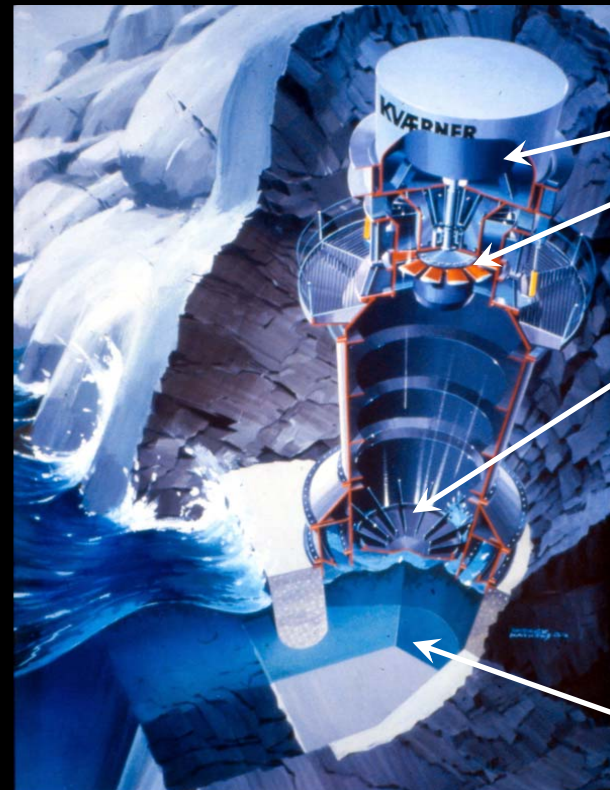


- Japanese wave-powered navigation buoy, introduced in 1960's.
- Overall diameter 3m.
- Air turbine and 60W generator powered by oscillating water column.
- Output stored in lead-acid batteries.

Tapered channel wave power plant



Norwegian OWC



Generator

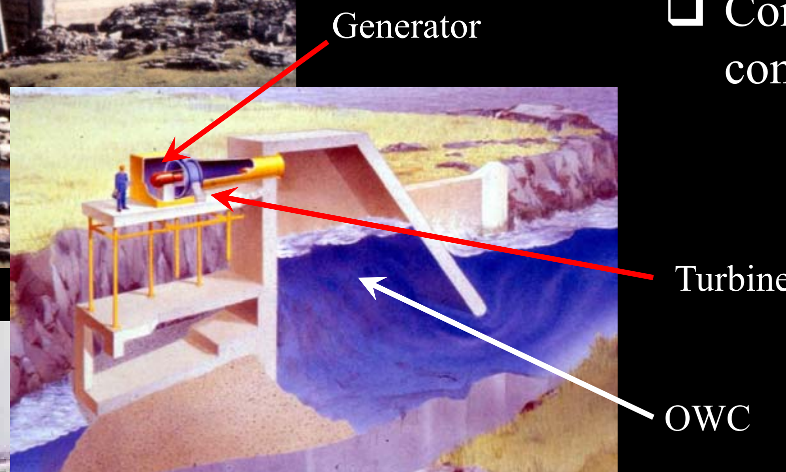
Wells turbine

Circular splash guard with annular space for air flow to turbine

OWC chamber

- 500 kW prototype single-rotor Wells turbine on shoreline near Stavanger.
- Concrete OWC chamber topped by steel tubular tower.
- Constructed 1985, destroyed by storm in 1988.

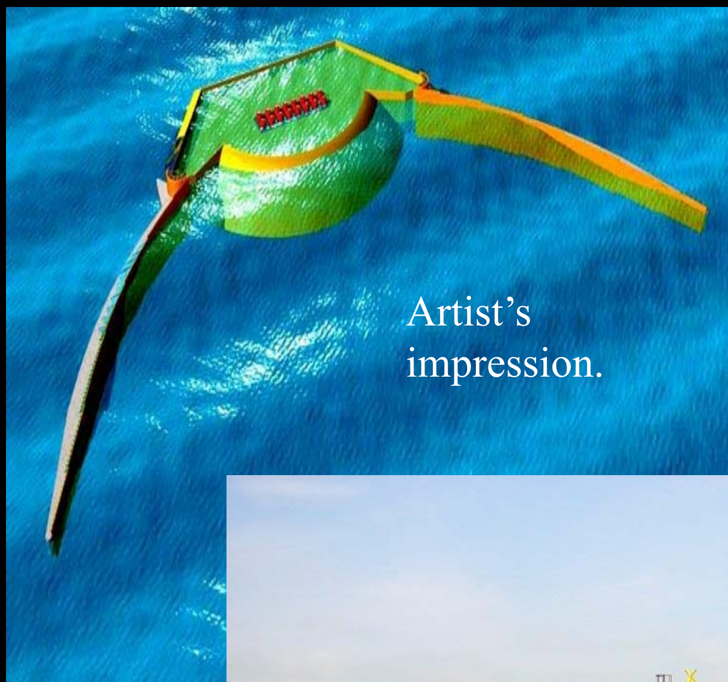
OWC, Islay



- ❑ Prototype OWC device, Portnahaven, Islay.
- ❑ Wells turbine and generator rated at 75 kW.
- ❑ Constructed in 1985, de-commissioned in 1999

- ❑ Limpet: 500 kW system installed near Portnahaven.

Wave Dragon

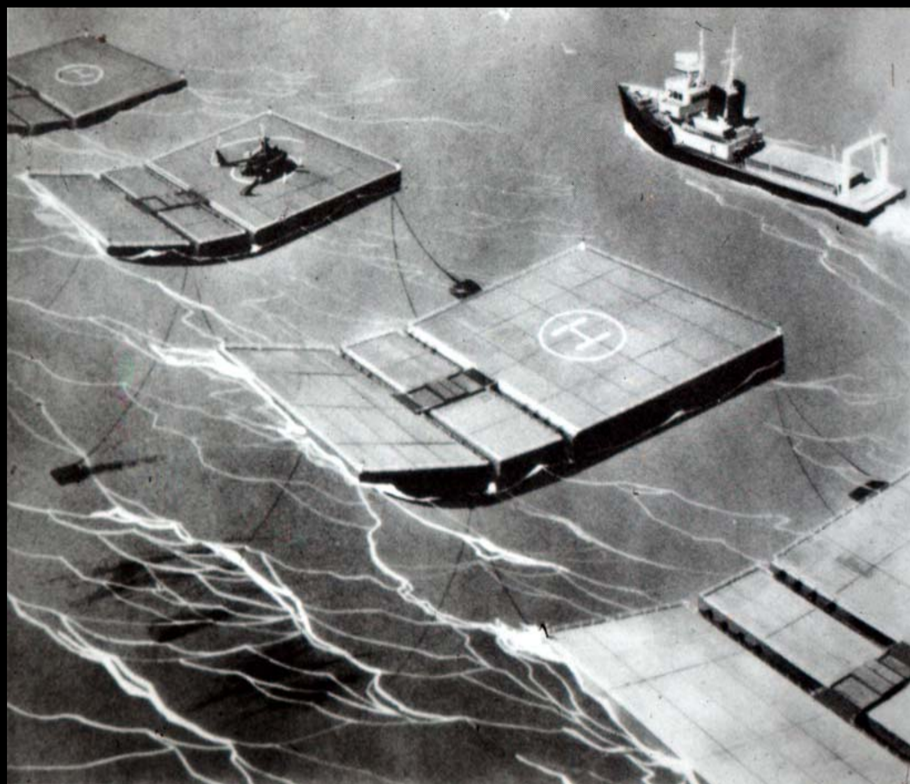


Artist's impression.

- Danish design.
- Arms amplify incoming waves, which spill over into a central chamber.
- Power take-off by simple low-head hydro power technology.
- At full scale, would be 260 m wide and develop up to 4 MW.

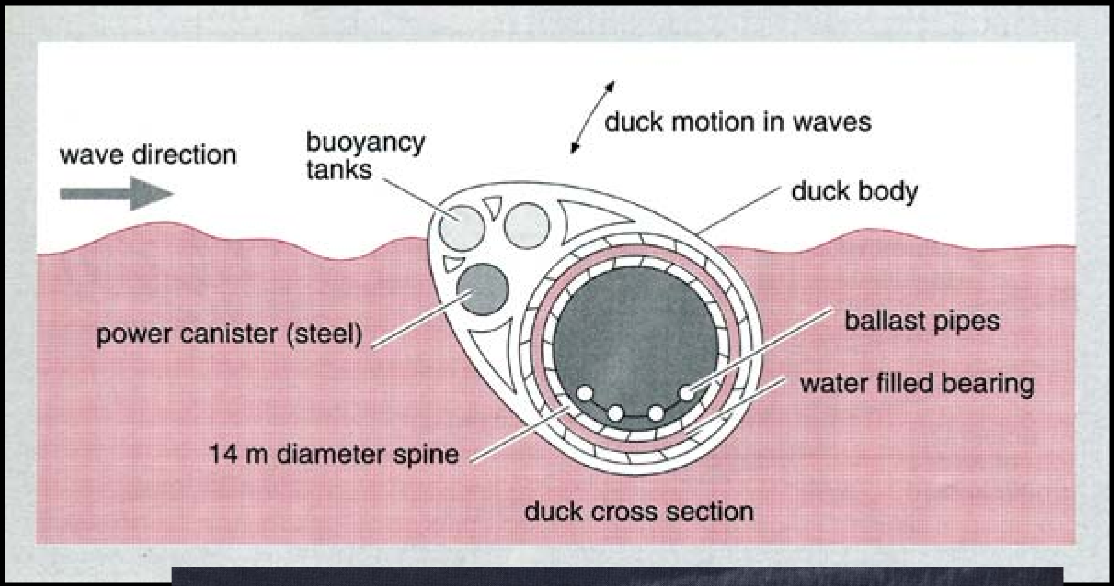
- A 1/4.5 scale prototype Wave Dragon during sea trials off the Danish coast in 2003.

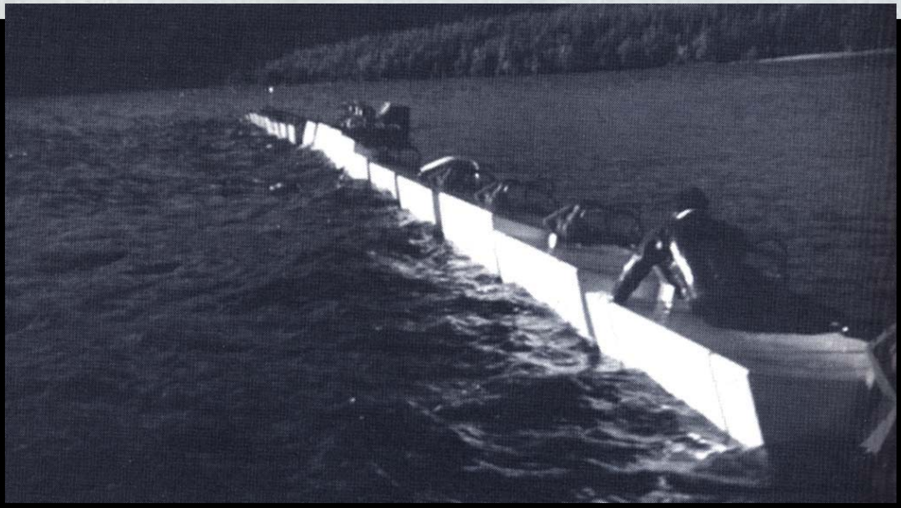
Cockerell raft wave energy converter



- Funded under UK wave energy programme in the 1980s.
- Segmented raft flexes under wave action.
- Power take-off using high-pressure hydraulics.
- 1/10-scale prototype tested in the English channel

Salter’s Duck





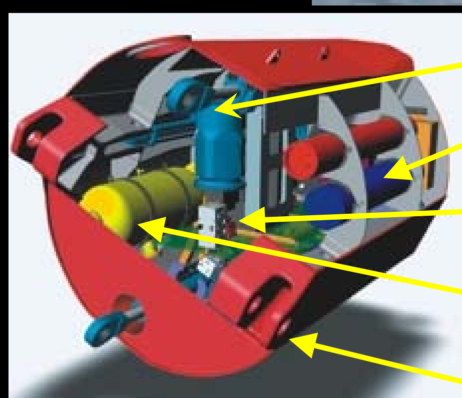
- ❑ Funded under UK wave energy programme in the 1980s.
- ❑ Angular motion between duck and spine actuates hydraulic pumps for power take-off.

- ❑ Testing of ducks at about 1/10 scale in Loch Ness, late 1980s.
- ❑ Each duck is free to take up its own angular position relative to the common spine.

Pelamis

- 1/7 scale model in sea trials in the Firth of Forth near Edinburgh, 2001

power conversion module



Pelamis 750 kW prototype

Ocean Power Technology's PowerBuoy

- 3 m diameter buoy on trial in Hawaii, 2009.
- A floating "point absorber" with a submerged reaction plate.
- Hydraulic power take-off.
- Various sizes have been produced.

- Larger version showing reaction plate.

Aquamarine Power's Oyster

- ❑ UK company based in NI.
- ❑ Sea-bed mounted, partially buoyant oscillating plate with hydraulic power take-off.
- ❑ Shallow-water device (10 to 12 m for this prototype, rated at 315 kW).
- ❑ Sea water is pumped to on-shore hydro turbine.

- ❑ Illustration of an array of Oyster devices.

- ❑ Oyster 1 prototype on test at EMEC (Orkney) in 2010.

Conclusions

- Ocean wave energy is a major global resource but exploitation presents an engineering challenge which has yet to be overcome.
- Fundamentally different devices have been proposed and the best path remains unclear.
- Shallow water demonstration systems have been appearing throughout the world but the production of significant amounts of energy requires deep water installation. The success of devices such as Pelamis is crucial to future large-scale exploitation.
- Costs during the early stages of development cannot possibly compete with conventional sources, and must be subsidised if an industry is to grow.
- Production is likely to be far from demand centres, so reinforcement of the electricity grid will be required and transmission costs will be substantial.
- Other issues: weather effects, maintenance, marine animal impacts, reduced sea access, noise and visual impact.