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IET The Knowledge Network

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Ocean Energy: the Wave of the Future

The Institution of *Engineering and Technology* Seminar on

Engineering a Safer Global Climate: The Power Sector's Response

Monday, 8 September 2008
The IET, Savoy Place, London, UK

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Lancaster University
Renewable Energy Group
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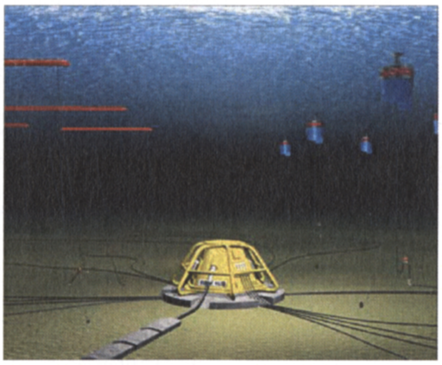
Overview

- Introduce wave energy
- Brief review
- Present State of the Art
- Repeat for tidal energy
- Conclusions
- Apologies but can only briefly touch on wide range of technologies



Wave Hub

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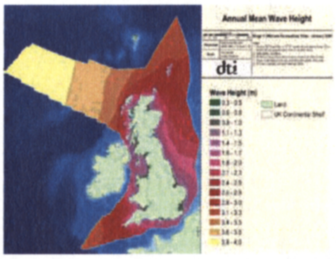
UK and Worldwide Wave Energy Resource

- Worldwide practical resource estimated 2000-4000 TWh/year
- UK practical resource estimates:
  - Offshore 50 TWh/year
  - Near-shore 7.8 TWh/year
  - Shoreline 0.2 TWh/year

(Future Marine Energy The Carbon Trust)

- UK consumption 350 TWh/year
- Power at specific site:
  - Power per metre crest length
  - Annual Mean Wave Height

The Global Wave Resource in kW per metre of crest. (courtesy of PWR Ltd)



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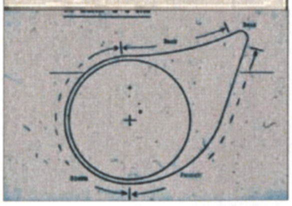
Wave Power Salter Edinburgh Duck

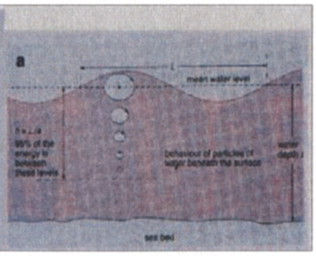

University of Edinburgh BULLETIN Light from the Face of the Deep?

- Salter, S H
- "Wave power"
- Nature, 1974
- **249,** 720-724

Prof Stephen Salter



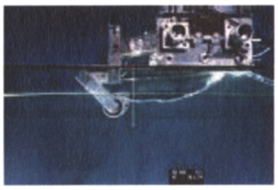
The Salter Edinburgh Duck



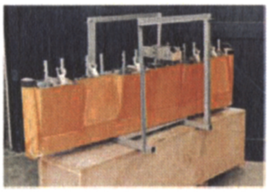
Duck & Lancaster Flexible Bag

- Some of the earlier ideas were extensive machines in which the phase diversity of the waves from collector to collector produced a large measure of equilibration (Duck, LFB).

Prof Steven Salter
Edinburgh University



Salter Edinburgh Duck
Edinburgh University



The Lancaster Flexible Bag
Lancaster University

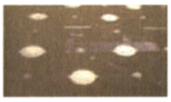
Prof Michael French
Lancaster University

- This arrangement seems likely to produce the lowest power costs (array WECs).

Research at Lancaster University

- Began in 1978
- Developed several devices:
  - Flexible Bag
  - Flounder
  - Frog
  - PS Frog
  - Frond
  - Pushmi
  - WRASPA

Lancaster Flexible Bag



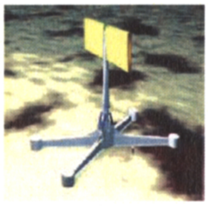
Flounder

Lancaster Flexible Bag Attenuator

CRM PS Frog

Early PS Frog

PS Frog 5



Frond

- Research continues towards developing surging point absorbing WECS

Wave Energy Converter Systems (WECS)

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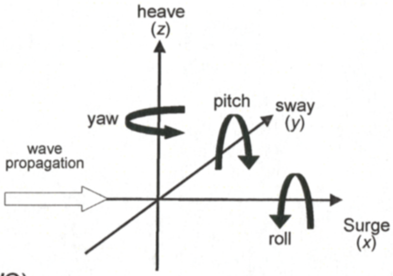
- Three main device types:
  - Shoreline
  - Near-Shore
  - Offshore

- Methods of power extraction
  - Heave
  - Pitch
  - Surge
  - Overtopping
  - Oscillating Water Column (OWC)



Shoreline WECS

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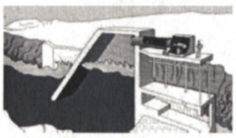
- Location – On shore or shoreline

- Promising technologies include:
  - Energetech – OceanIlnx (Australia)
  - LIMPET OWC (Scotland)
  - Pico OWC (Portugal)
  - TAPCHAN (Norway)

LIMPET OWC (Scotland))
Siemens Voith Wavegen



OWC Operation Drawing

Energetech – OceanIlnx (Australia)

Pico OWC Portugal

Near-shore WECS

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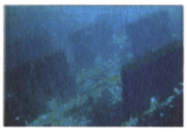
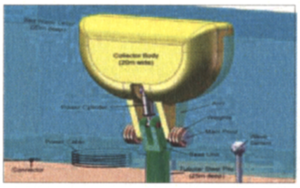
- Location – Water depths up to 40m
- Promising devices include:
  - WRASPA
  - Wave Rider
  - Wave Roller
  - Wave Rotor
  - OSPREY
  - Oyster



Wave Roller



WRASPA

Aquamarine Oyster

Wave Rider

Wave Rotor

Wave Rotor

Offshore WECS

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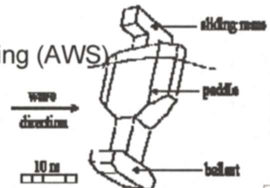
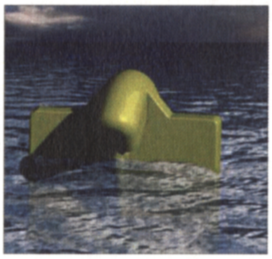
- Location: Water Depths > 40 m
- Promising Devices:
  - Archimedes Wave Swing (AWS)
  - Pelamis
  - PS Frog
  - Wave Dragon



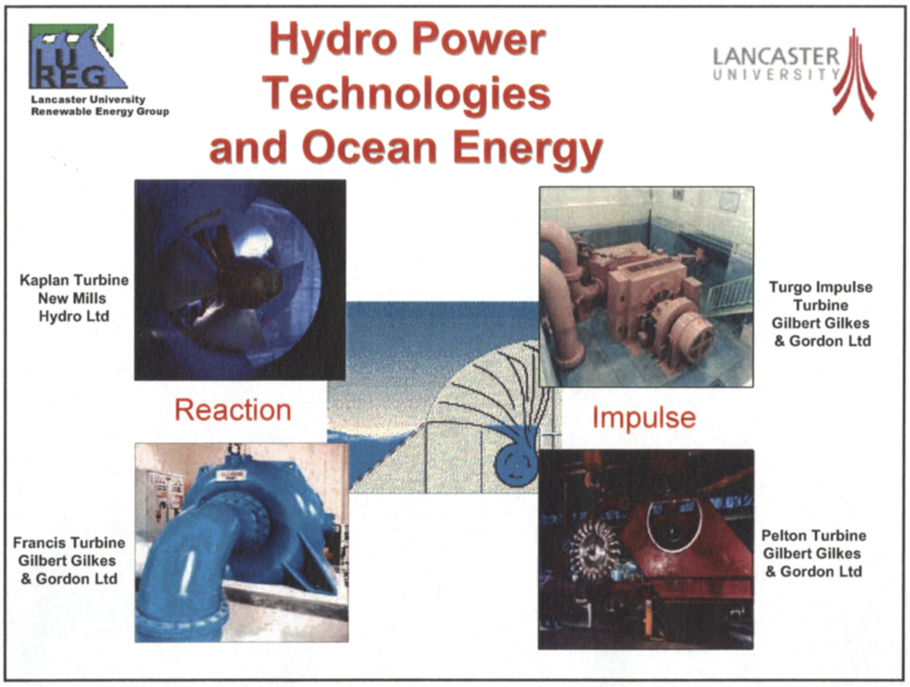


PS Frog 5

Pelamis PWP Ltd

Wavedragon

Archimedes Wave Swing (AWS)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Hydro Power Technologies and Ocean Energy
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Kaplan Turbine New Mills Hydro Ltd
Reaction
Francis Turbine Gilbert Gilkes & Gordon Ltd
Turgo Impulse Turbine Gilbert Gilkes & Gordon Ltd
Impulse
Pelton Turbine Gilbert Gilkes & Gordon Ltd


LU REG
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WAVE DRAGON
ULTRA LOW HEAD TURBINES
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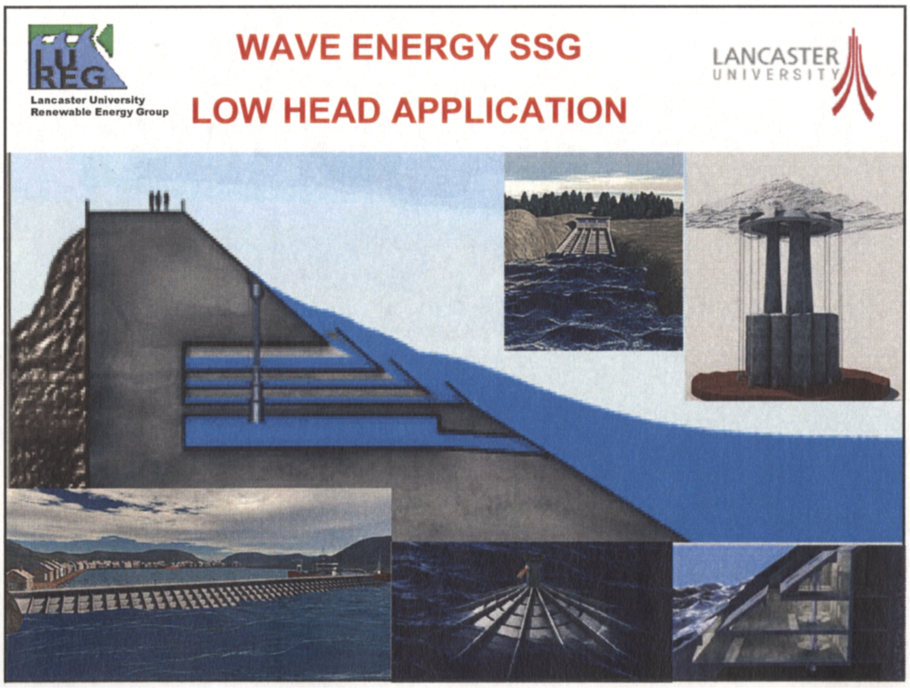
overtopping
reservoir
turbine
outlet


WAVE ENERGY SSG
LOW HEAD APPLICATION
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HIGH HEAD APPLICATIONS
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Collector Body (20m wide)
Excellent Engineering Solutions
WEIR
STRACHAN & HENSHAW
WRASPA - Lancaster
OSCILLATOR
PELTON WHEEL & GENERATOR
SUB STATION
SEA RETURN
SEA WATER PISTON
FLOW LINE
AQUAMARINE OYSTER
AQUABUOY FINAVERA

Tidal Energy Resource

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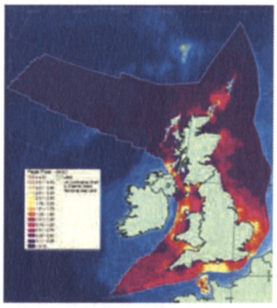
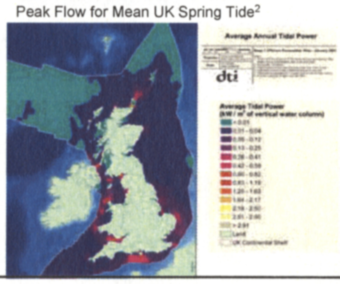
- Tides depend on position of moon and sun in relation to the earth – provide a highly predictable source of power
- 18TWh/year technically extractable tidal stream resource in UK – could meet 3-5% of energy demand[1]
- Power extracted from kinetic energy of flowing water:

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

- Water 800 times denser than air, so require lesser flow rates



Peak Flow for Mean UK Spring Tide[2]



[1] *Carbon Trust. "Future Marine Energy". January 2006.*

[2] *DTI. "Atlas of UK Marine Energy Resources" 2004.*

Types Of Tidal Turbine

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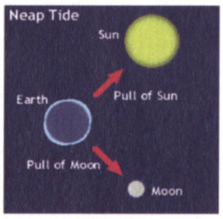
- Barrage / Dam
- Venturi Systems
- Oscillating Hydrofoil
- Vertical Axis Turbines
- Horizontal Axis Turbines
- Ducted
- Other

- **Lunar Month = 29.53 Days**



- **Neap Tide (¼ Moon & ¾ Moon)**

- **Spring Tide (Full Moon & New Moon)**

Barrage / Dam

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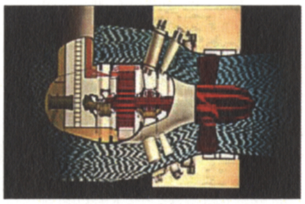
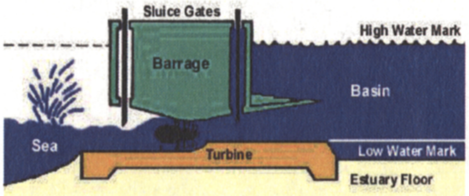
- Across Estuaries/Rivers/Islands
- Manmade pools / Lagoons
- Existing tidal references world wide:
  - La Rance, Alstom, France, 1967
  - Annapolis, Andritz VATECH Hydro, Canada, 1980
  - Sihwa, Andritz VATECH Hydro, South Korea, 2005



La Rance Alstom Kaplan Turbine



Schematic Diagram of a Barrage using a Kaplan Turbine

La Rance Tidal Barrage France

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- Location: Saint Malo, Brittany
- D=5,350mm
- n=93.75 rpm
- H=11m
- P=10 MW
- 24 Units
- Contract year: 1967

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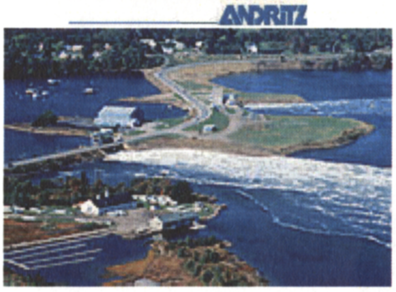
Annapolis Tidal Plant Canada

- Location: Bay of Fundy
- D=7,600mm
- n=50 rpm
- H=7.1m
- P=19.9 MW
- 1 Unit
- Contract year: 1980



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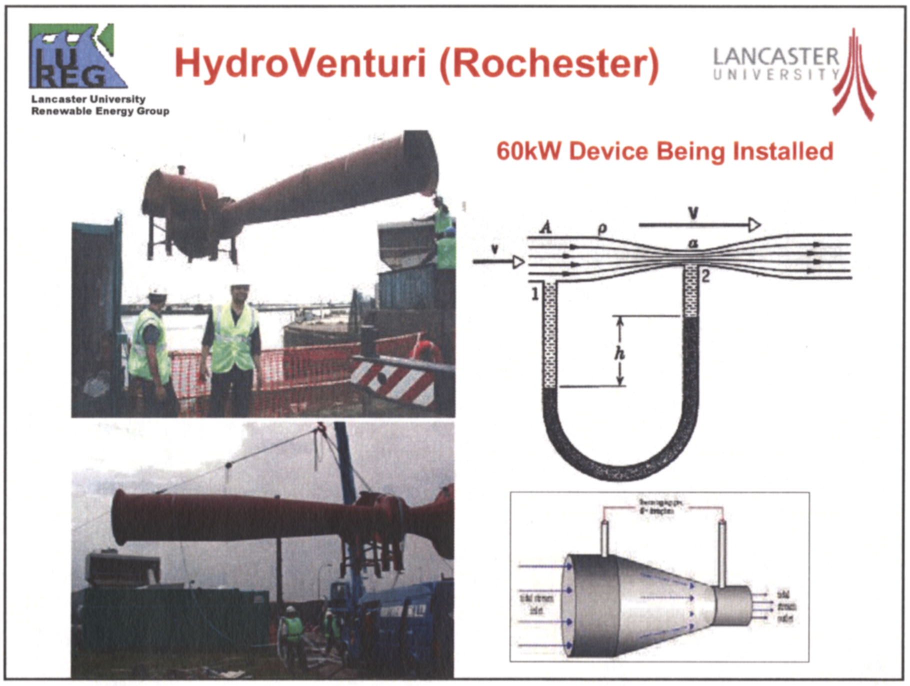
Sihwa Tidal Plant South Korea

- Location: Sihwa Tidal Plant
- D=7,500mm
- n=64.3 rpm
- H=5.8m
- P=26 MW
- 10 Units
- Contract year: 2005

Bird's eye view of Sihwa tidal power plant to be completed in 2009 © DAEWOO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HydroVenturi (Rochester)
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60kW Device Being Installed
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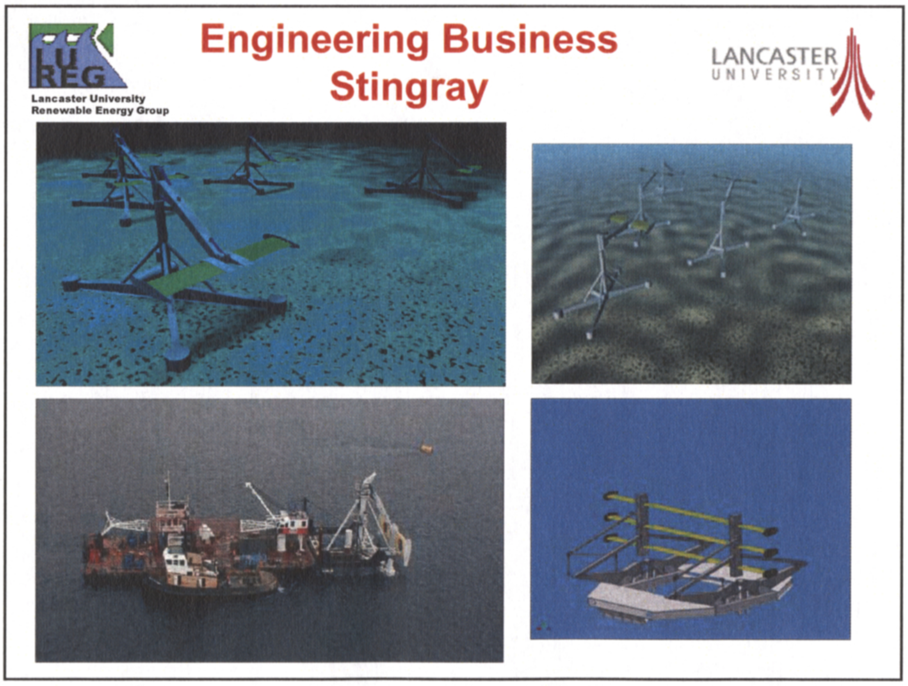
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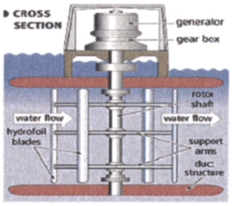
Vertical Axis Tidal Turbines

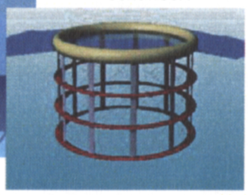
- Vertical axis can provide a larger swept area than horizontal axis, exploit a market niche for shallower locations.
- Most schemes are lift based (Darrieus), but smaller ones can be drag based (Savionus).
- Key Vertical Axis schemes to date –
  - Blue Energy, Canada (fixed pitch, tidal fence, tidal lagoon).
  - Gorlov, USA (helix shape, claims greater efficiency).
  - Enermar, Italy (blade allowed to oscillate 10° from tangential, 100kW full scale prototype connected to grid).
  - Salter, Polo UK (variable blade pitch).



Blue Energy Canada

Gorlov USA

Enermar Ponte Di Archimedes



Salter Edinburgh Polo

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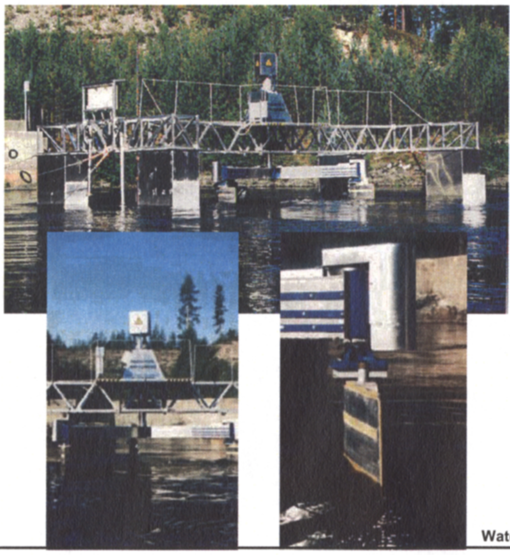
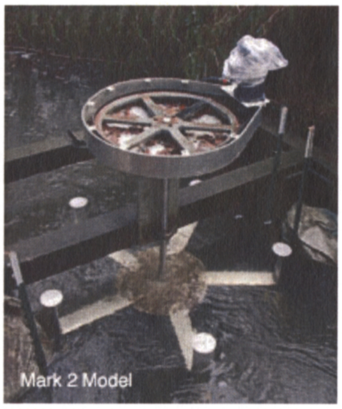
Other Vertical Axis Devices include:



Water Power Industries (WPI) - Norway



Alternative Hydro Solutions - Canada

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Horizontal Axis Turbine
MCT SEAFLOW & SEAGEN 1.2 MW

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Commercial Demonstrator

Some key features:-

- 2 x 600kW rotors:16m diameter
- installed on steel pile
- rotors and nacelles raised above sea level for maintenance
- transformer and electrical connection to grid in accessible and visible housing at top of pile
- deployment in arrays or "farms". of hundreds of turbines

Marine Current Turbines Ltd (MCT) Seagen 1.2 MW

Seaflow installed 30 May 2003
rotor dia. 11m
rated power 300kW
pile dia. 2.1m
water depth 24m $\pm$ 5m

Marine Current Turbines Ltd (MCT) Seaflow

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Other Horizontal Axis Turbines include:

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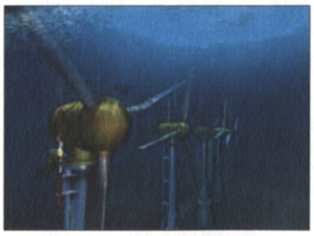
- Underwater Kite
- Hammerfest Strom
- Open Hydro
- SMD Hydrovision -TidEl

SMD Hydrovision TIDEL

Underwater Kite



Hammerfest Strom - Norway

Open Hydro

Underwater Kite

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Tidal Stream Technology State of the Art

1.Systems of more than 1000kW: potentially commercially viable		
MCT (UK) – Seagen	1.2MW	2008
2.Systems of more than 100kW		
MCT (UK) – Seaflow single axial flow rotor	300kW	2003
Hammerfest Stroem (Norway) - Blue Concept – single axial flow rotor	300kW	2003
3.Small systems of less than 100kW actually tested at sea		
IT Power / NEL / Scottish Nuclear (UK) - single axial flow rotor	10kW	1994
Engineering Business (UK) Stingray - reciprocating hydrofoil	150kW	2002
Open Hydro (Ireland) - unconventional ducted axial flow rotor	35kW ~75kW	2003 ~ 2007
Verdant Power (USA) - fixed pitch axial flow rotor	35kW	2005?
Ponte di Archimedi (Italy) - Kobold Turbine - Darrieus rotor	25 kW	2004
UEK (USA /Canada) - twin ducted axial flow rotors	40kW?	2002?
Clean Current (Canada) - single axial ducted flow rotor	80kW?	2007
4.Developers with small-scale physical models tested in laboratories		
Lunar Energy (UK) / R1000 or R1500 – ~1/20 model tank tested	1 MW	?
SMD Hydrovision (UK) / TiDel - 1/10 model tank tested	1MW	?
Swan Turbines ~1 kW model tested	350kW	?
5. Developers with no practical testing so far		
Scottish & Southern Energy / RTVL Neptune - proposed 2MW twin axial flow rotors	2MW	?
Tidal Generation - proposed 1 MW single axial flow rotor	1MW	?
Tidal Stream - proposed group of 4 axial flow rotors	2MW	?
plus 20+ others		

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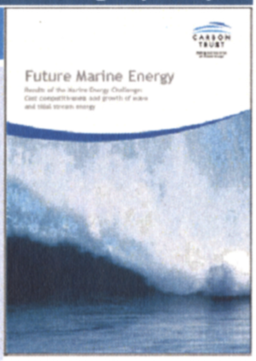
Delivery Aspirations

The Carbon Trust Marine Energy Challenge (MEC)

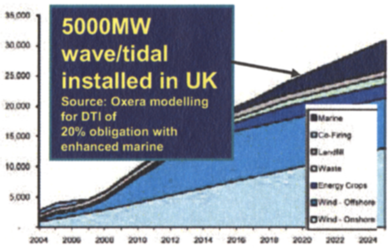
Technology developers

- AquaEnergy Development UK
- Clearpower Technology
- Ecofys
- Embley Energy
- Lancaster University
- Ocean Power Delivery
- Seavolt Technologies
- Wave Dragon



The Carbon Trust Report CTC601 (2006)

- By 2020, up to 5 GW generating capacity could be installed across Europe
- Large share could be in UK, supplying ~3% UK demand and abating up to 7 $MtCO_2$/year



UK projected development

500-1,000 MW by 2015

3.5% of UK electricity by 2025 (5,000 MW)

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Conclusions

- Ocean Energy is a developing technology with design convergence on tidal but not on wave. Today's technologies will help solve the immediate needs, but we need to work hard nurturing tomorrow's low carbon technologies today.
- Deployment at scale is much more demanding and long-term than initial deployments of a technology and the route to success is to follow the steps of smaller to larger scale closely (University Lab/NaREC/EMEC/Wave Hub).
- Funded technologies can have downsides (long-term prospects / work / survive / be reliable) and possibly unfunded technologies could offer excellence in design. Investors, sponsors and government need to distinguish between these devices coordinating activities and requesting technical assessments before offering support.
- Engineers can solve the problems but politicians need to provide leadership, remove barriers and give us sufficient time for some potentially spectacular successes.

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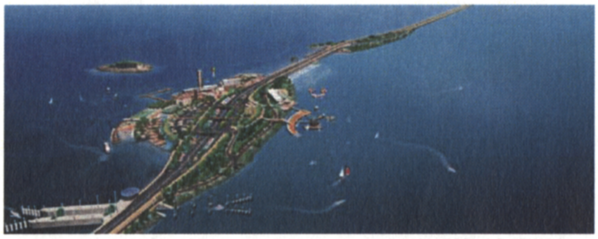
"We must look to the course of the sun and the moon and ensure that we do not miss it!"



Bird's eye view of Sihwa tidal power plant to be completed in 2009 © DAEWOO

Wavedragon

Marine Current Turbines Ltd (MCT) Seagen 1.2 MW

Pelamis PWP Ltd

Thank you

Wavedragon Kaplan Turbine

Annapolis Andritz Turbine

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