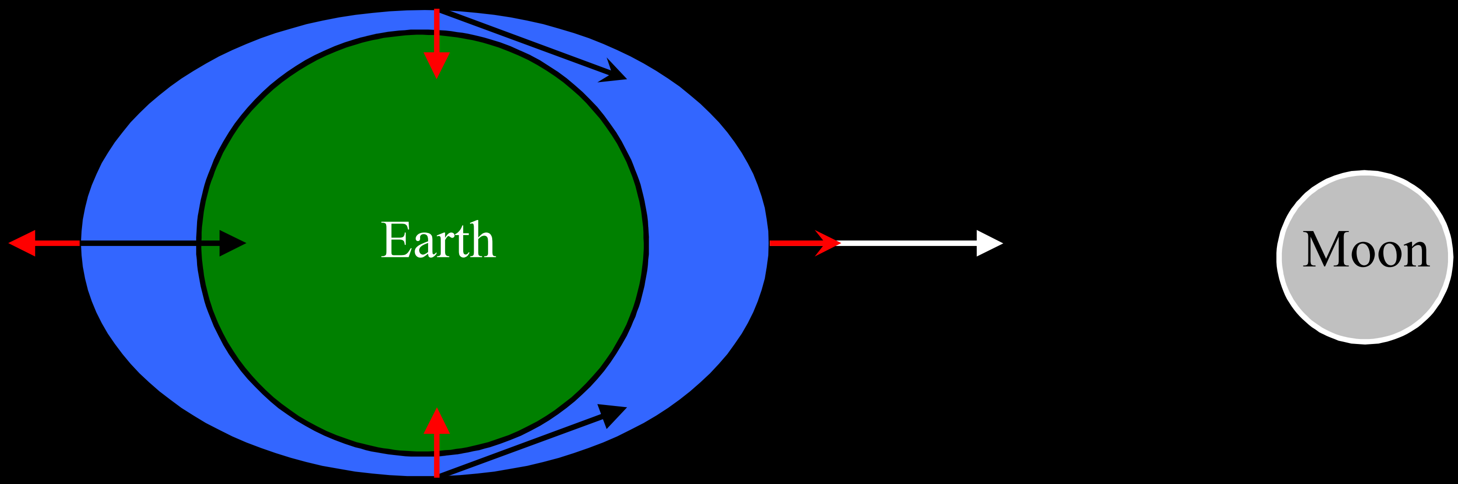
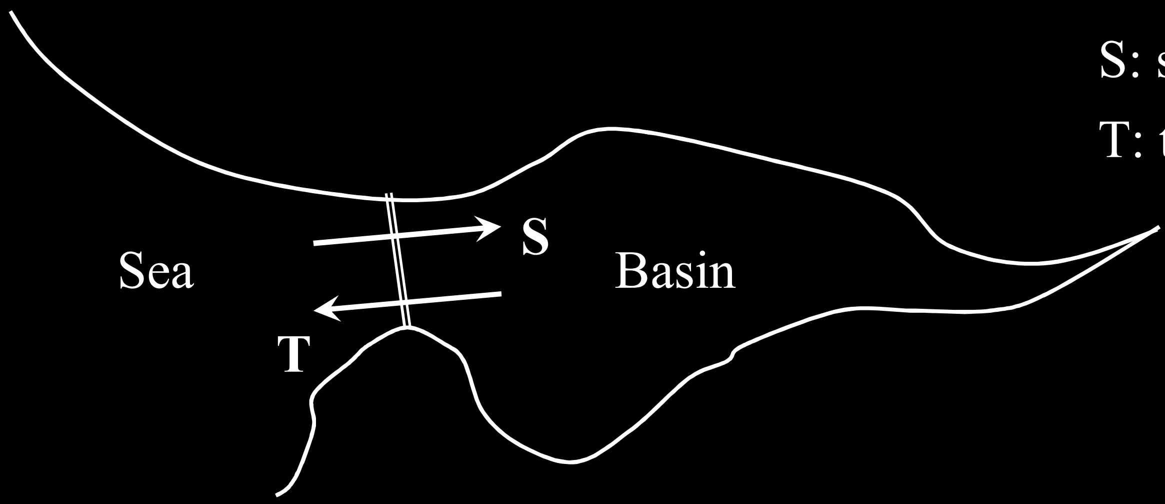
Tidal Energy

Gravity and the tides



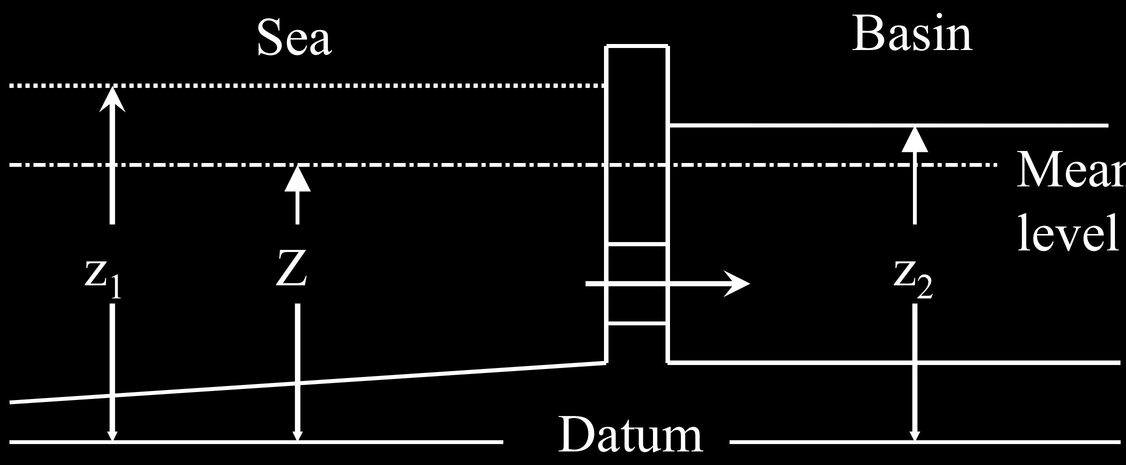
- Lunar cycle has a period of about 12h 25min.
- Tidal range would be very small (about 0.5 m) if the earth were covered in water. But the land masses interfere, and create large ranges in some parts of the world.
- Two power extraction methods: tidal range and tidal stream.

Tidal range: single-effect barrage system

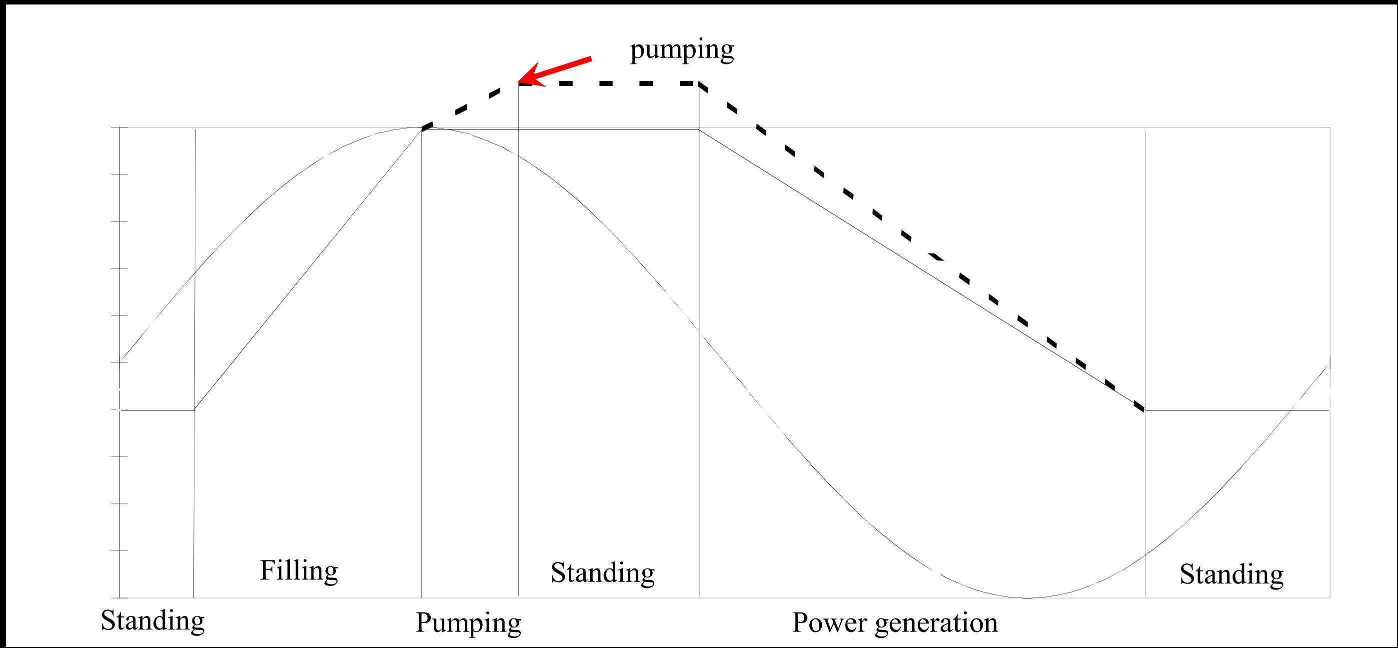


S: sluice gates

T: turbines



Operation of a single effect barrage system



- Basin is filled through the sluices until high tide; sluice gates are closed.
- There may be pumping using grid electricity to raise the level further.
- Turbine gates closed until the sea level falls to create sufficient head across the barrage.
- Gates opened and turbines generate until the head is again low.
- Sluices are opened, turbines disconnected and the basin is again filled.

La Rance tidal barrage system, France

Photo credit: *Popular Mechanics*, December 1997.
Top picture shows water flowing from left to right.
Bottom left shows project while under construction.
Right picture shows turbine assembly and baldes.

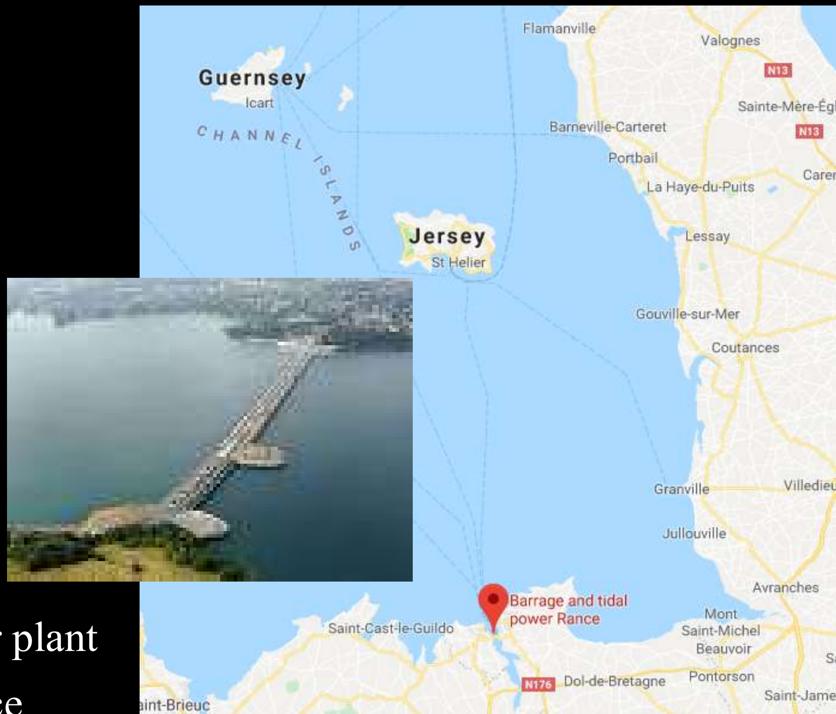
Power: 240 MW (from 24 turbines)

Annual generation: 500 GWh

Tidal range: 8 m

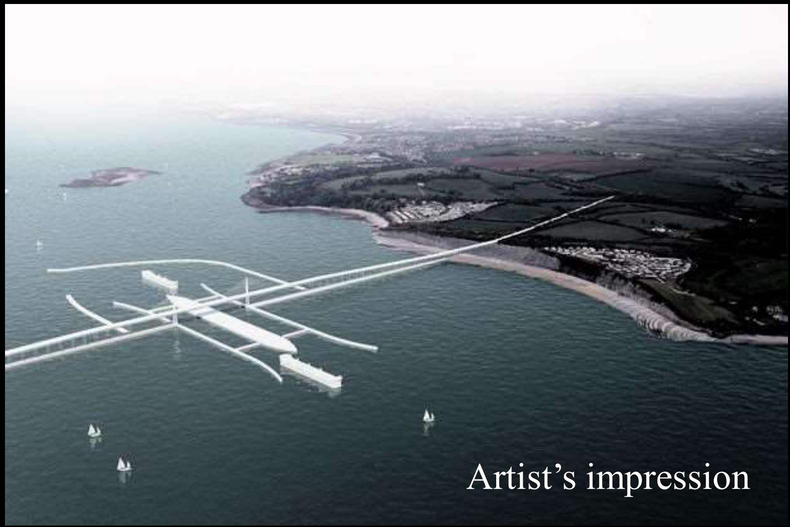
Capacity factor: 28%

Length: 700 m

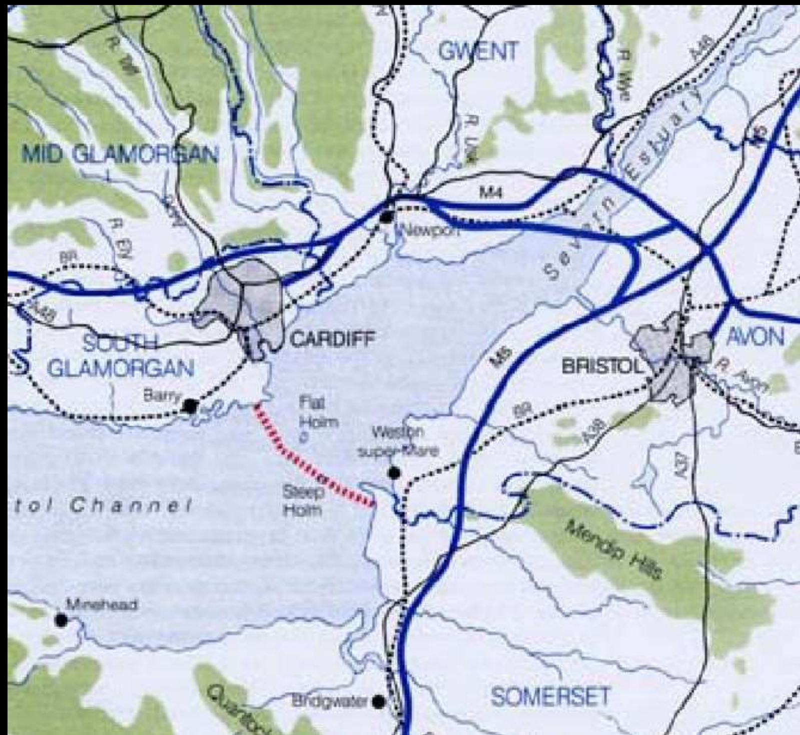


- ❑ Location: Brittany, France
- ❑ Completed 1967
- ❑ Capital cost €94.5 million
- ❑ Operated initially as an experimental power plant
- ❑ Owned and operated by Électricité de France

Proposed Severn barrage, UK


Artist's impression

- ❑ Length: 16 km
- ❑ Tidal range: 10 m
- ❑ Rated power: 7 – 12 GW

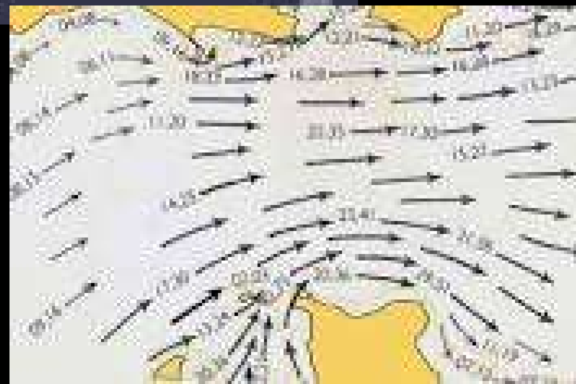


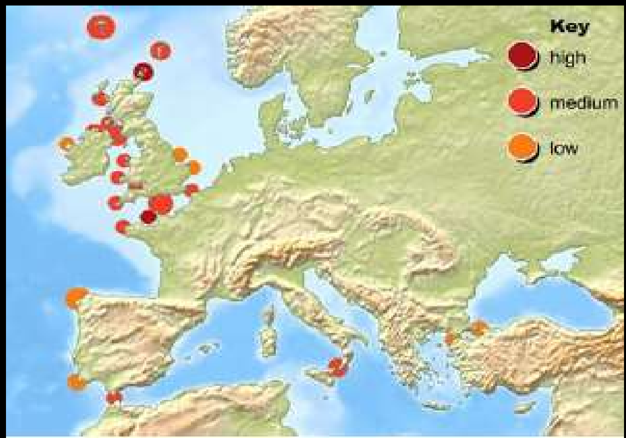
Arguments against:

- ❑ Estimated cost: £34 billion
- ❑ Scale and impact would be unprecedented
- ❑ Major environmental impacts
- ❑ Other significant resources exist in the UK

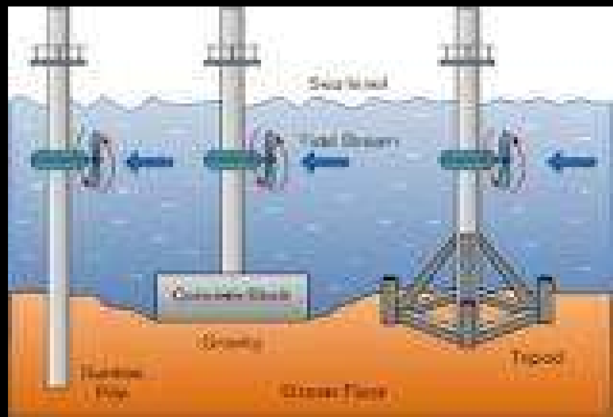
Tidal stream power extraction

- Conversion technology still immature.
- Proposed designs offer a wide variety of configurations and mooring arrangements.
- Three major contenders:
  - horizontal-axis turbines
  - vertical-axis turbines
  - oscillating hydrofoils
- Pentland Firth estimated at ~1.9 GW or ~40% of the total Scottish demand.





Aqua-RET 2012

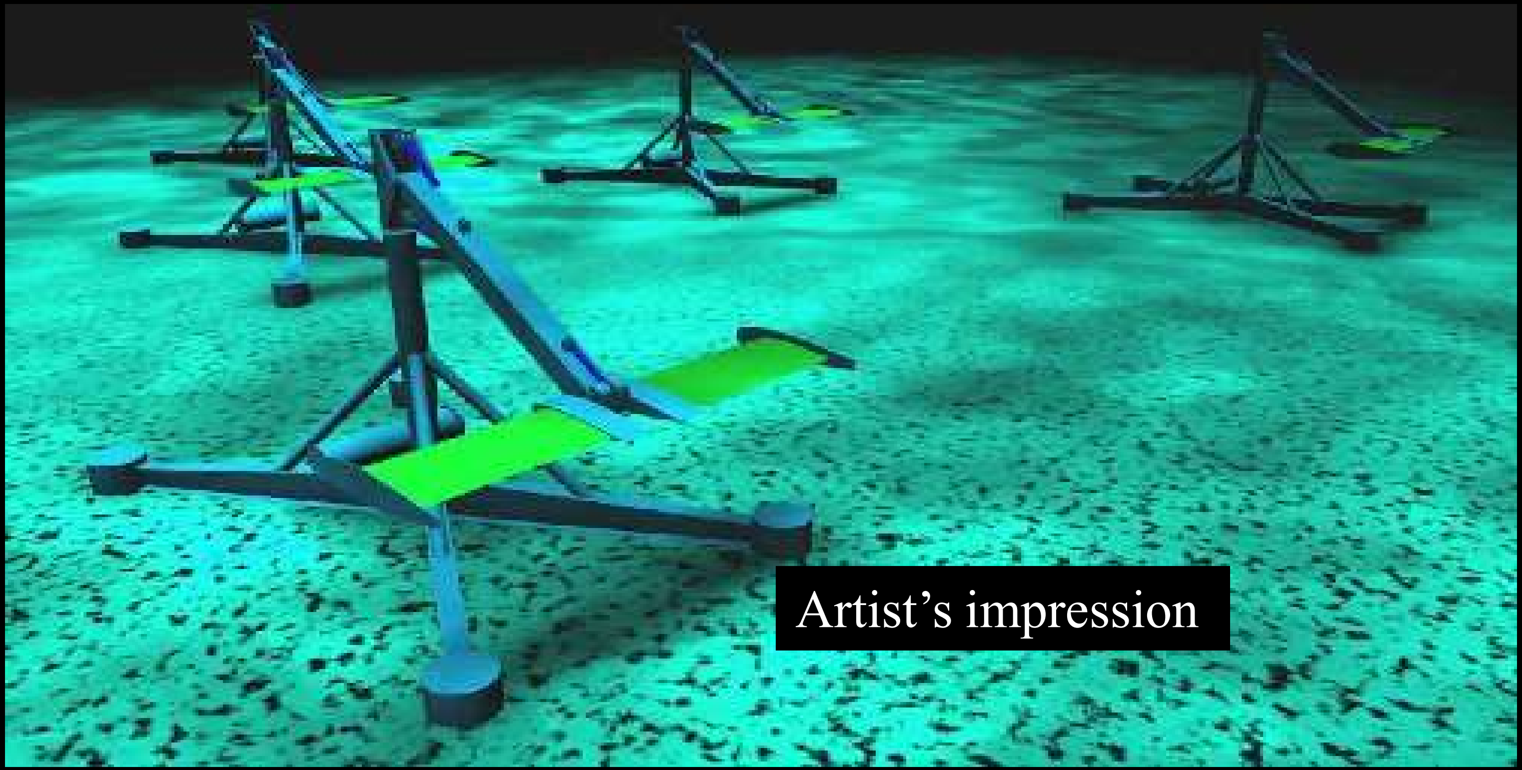


European Marine Energy Centre (EMEC)

http://www.emec.org.uk/

- Established in 2003, located in Orkney
- Provides developers with accredited, open-sea testing facilities
- Maintains 14 grid-connected test berths and associated infrastructure

Stingray

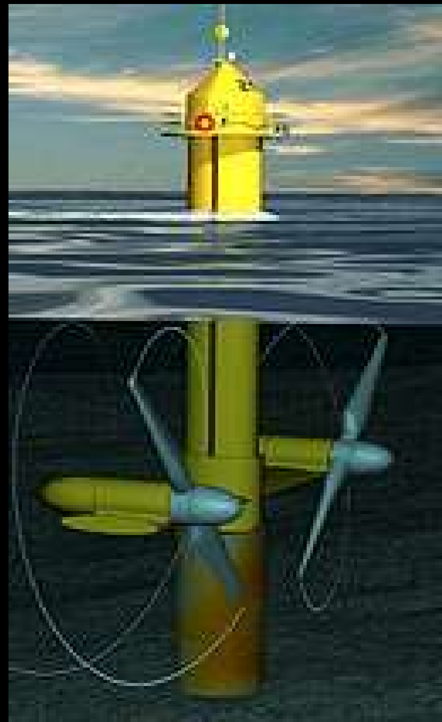


- Employs an oscillating hydrofoil.
- Hydraulic power take-off system.

Stingray trial in Yell Sound, Shetland, September 2002

- Device produced 90 kW output in a 1.5 m/s current.

Testing of prototype turbine near Lynmouth, Devon.



- Project managed by Marine Current Turbines Ltd.
- 300 kW rating - 2 blades, rotor diameter 11 m.
- No yaw mechanism and no electrical connection to shore.

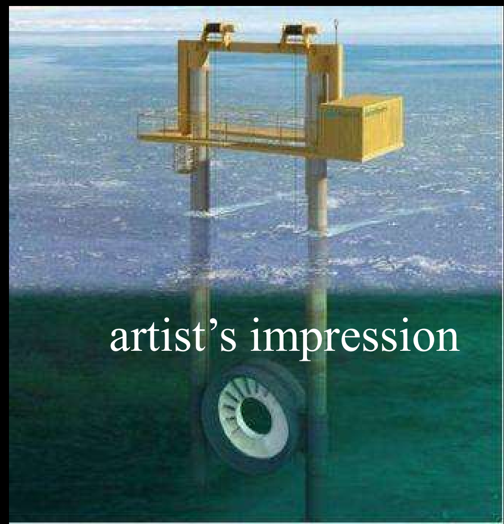
- Artist's impression of a twin 2-bladed installation.
- Rotors contra-rotate to minimise the reaction torque on the structure.

Strom AS, Norway

- Rated at 300 kW, rotor diameter 20 m.
- Deployed in fjord near Hammerfest in 2003.
- Turbine has a tripod supporting framework with gravity ballast.
- Joint venture with ScottishPower to deploy a proposed10 MW farm in the Sound of Islay, Scotland.

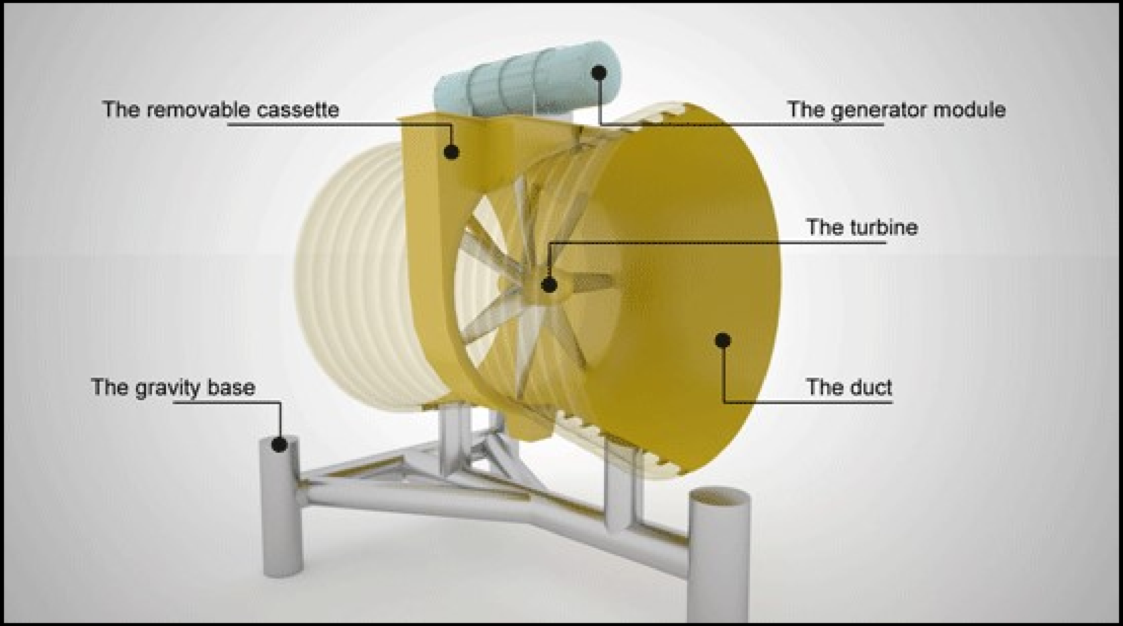
Open Hydro

- Hub-less design with a permanent magnet generator around the rotor rim.
- Rigidly mounted, accepts bi-directional flow.
- Prototype device has been evaluated at EMEC.
- Further demonstrator planned for Bay of Fundy, Nova Scotia.



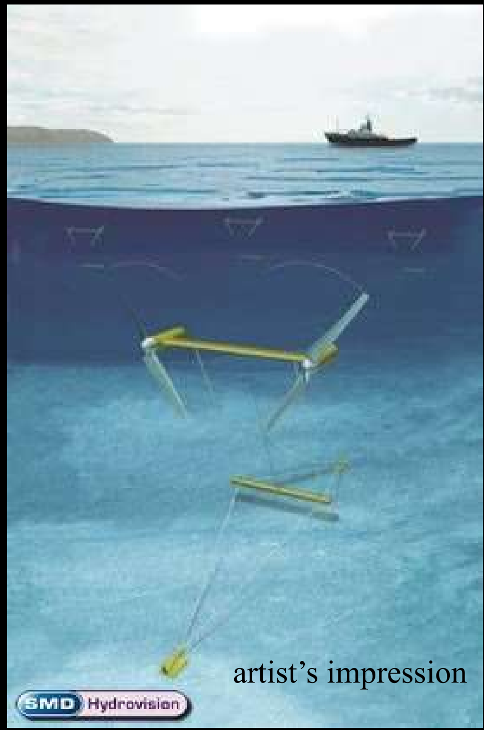
artist’s impression

Lunar Energy



- Bottom-mounted, bi-directional device.
- Turbine and generator can be extracted from main structure for servicing.
- 1 MW prototype tested at EMEC in 2007.
- 8 MW farm proposed in joint venture with EON UK.

SMD Hydrovision



artist's impression

- Main picture shows 1/10 scale turbine on test site at NAREC UK.
- Features a moored buoyant structure for use in deep water.
- Full scale device has 2 rotors of 15m diameter, rated at1 MW.

SeaGen

- Designed by Marine Current Turbines Ltd.
- Rated power output 1.2 MW.
- Twin 16m diameter rotors on a piled supporting column.
- Installed in Strangford Lough, Northern Ireland, 2008.

Voith Hydro

- 110 kW prototype.
- To be tested in S Korean waters in late 2010.
- 1 MW version to be produced in 2011 for trials at EMEC.

Atlantis Resources Corporation

- Australian group with links to Norway and the UK.
- Bi-directional, single-rotor machine, 18m diameter.
- Atlantis AK1000 1 MW turbine to be tested at EMEC in 2011.

artist's impression

MeyGen

http://www.bbc.co.uk/news/uk-scotland-24100811
viewed September 2013

- Consent obtained for installation in the Pentland Firth, between Orkney and Scottish mainland.
- AR1000 turbine has a rotor diameter of 22.5 m, weighs 1,500 tonnes, and is rated at 1MW.
- Aspiration: 400 turbines generating 398 MW.

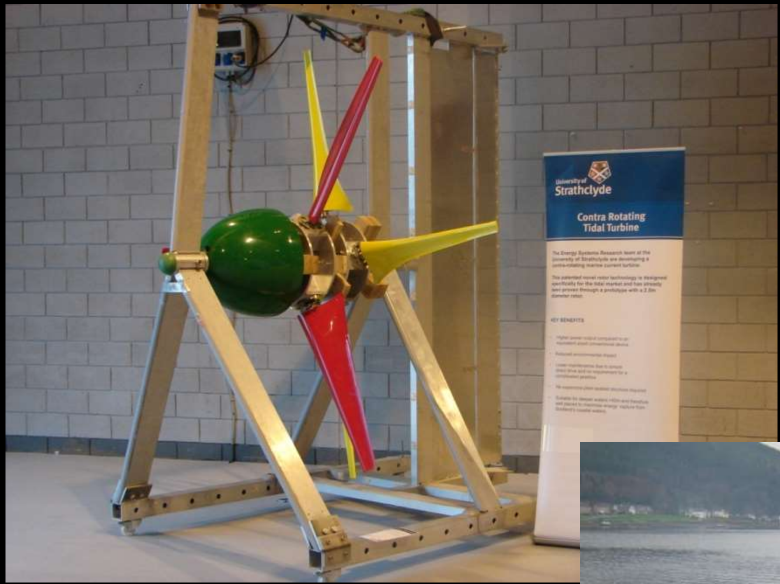
"August [2017] proved to be a world record month, providing enough energy to power 2,000 Scottish homes from just two turbines [700 MWh]. "
(David Taaffe, Project Director as quoted in the Independent)

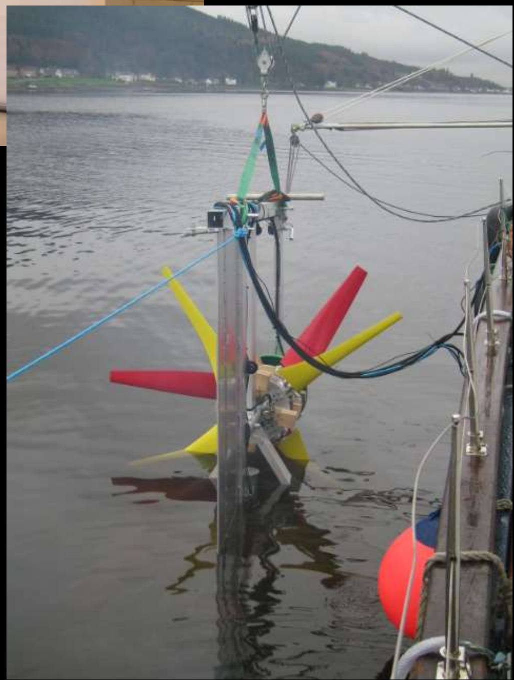
Alstrom

Deployment at EMEC

- 22 m long nacelle
- weight 150 tonnes
- 3 pitchable blades, 18 m dia.
- buoyant to allow towing
- deployed in a water depth of about 40 m
- rotates around vertical axis
- reached full nominal
- power of 1 MW in January 2013 at EMEC
- endurance and reliability tests underway

ESRU/ Nautricity: CoRMaT

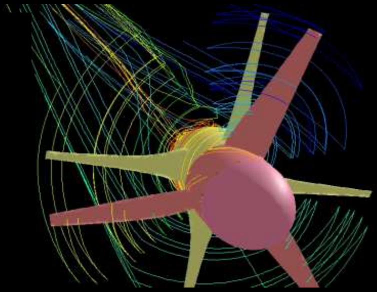




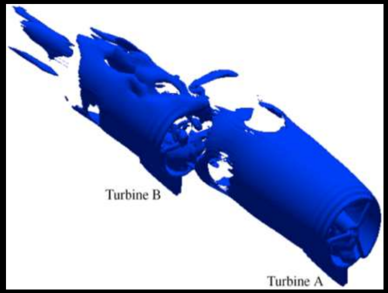
- Contra Rotating Marine Turbine (CoRMaT).
- 2.5 m diameter contra-rotating turbine prototype.
- Tow-tank tested and sea trialled in the Firth of Clyde and Sound of Islay.

CoRMaT characteristics

Two closely spaced dissimilar rotors move in opposite directions.

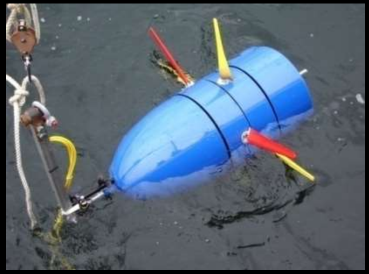


Reduced Capital Cost
- No expensive moorings or pilings required
- Commercially viable even at small generating scale

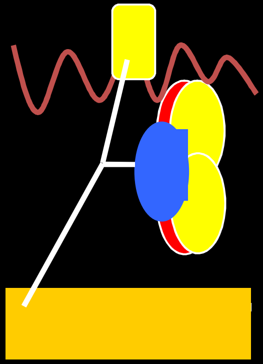


Reliability
- Direct drive generator eliminates need for gearbox
- No complex blade pitch control

Ease of Maintenance
- Easy to deploy and recover
- Small number of simple sub-assemblies



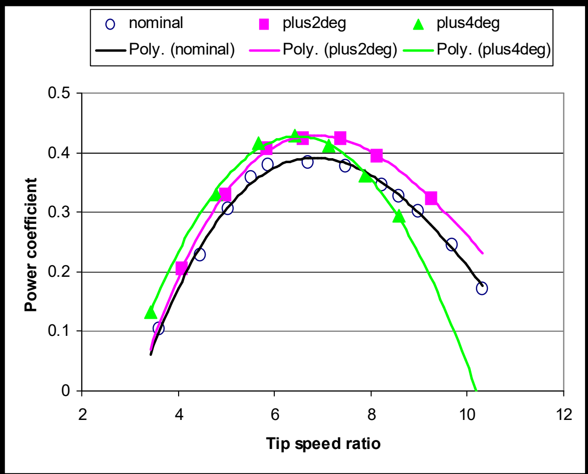
Efficient
- Increased energy capture compared to single rotors
- Always optimally oriented to tidal flow
- Increased deployment density due to decreased wake effects



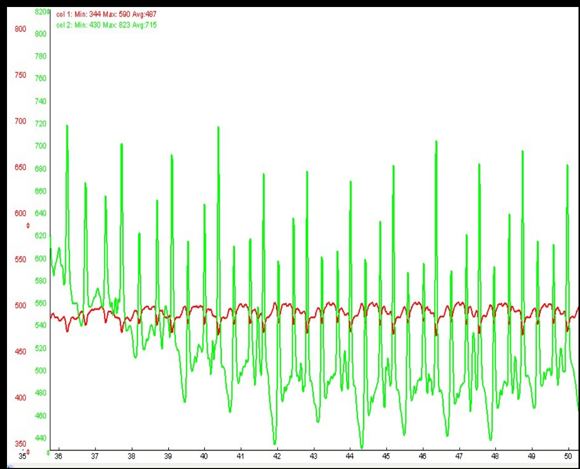
Wide operating envelope
- Suitable for deployment in water depths from 8- 500m where maximum tidal energy harvest is likely

CoRMaT test results

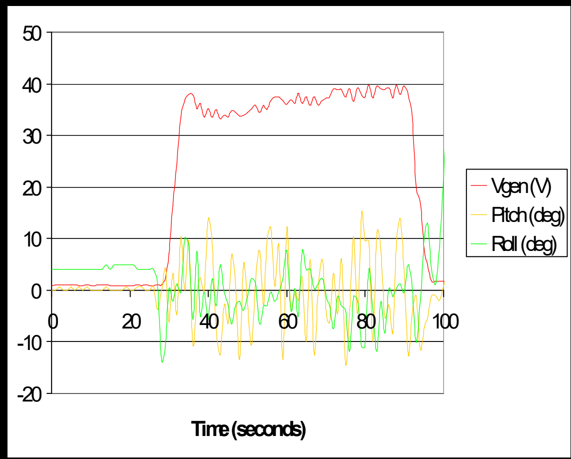
1: Tow-tank tests confirm neutral buoyancy



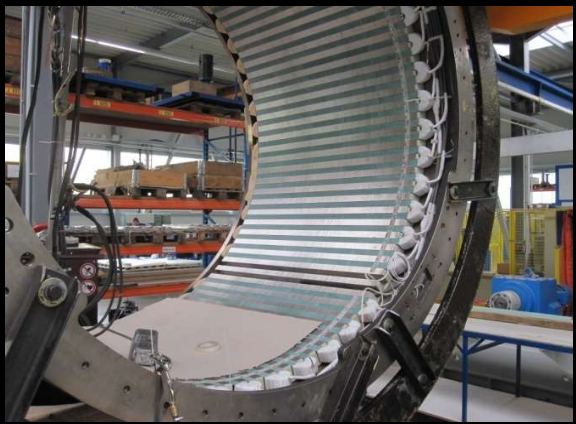
2: Sea trials confirm dynamic stability ...



3: ... and enhanced power output



CoRMaT 750 kW device manufacture



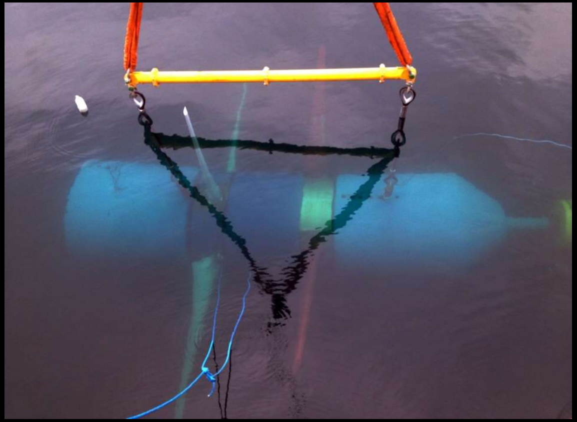
- ❑ GFRP Blades – Airborne, Netherlands
- ❑ Contra-rotating radial PMG – Smartmotor, Norway

CoRMaT assembly and pre-testing



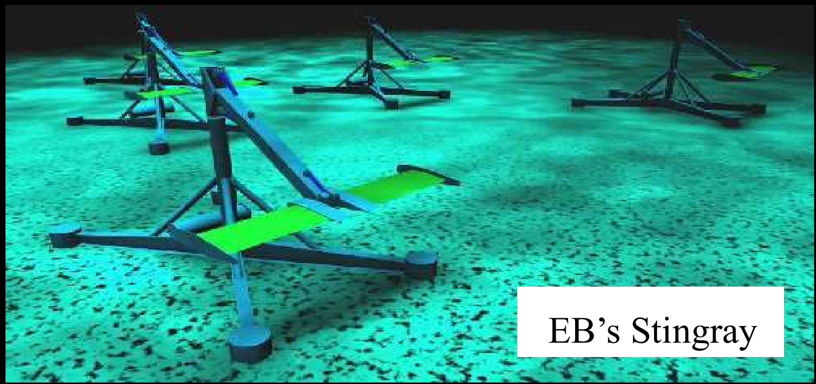



CoRMaT deployment at EMEC – September 2013

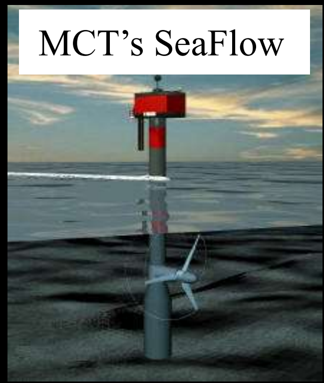


Challenges

… oscillating aerofoil driving hydraulic accumulators

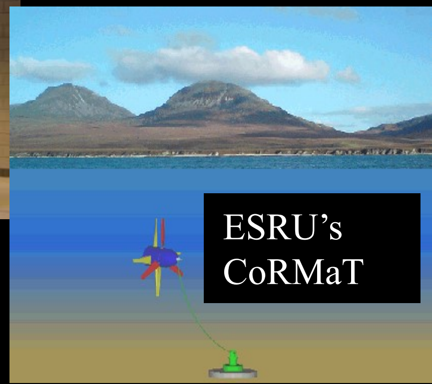

EB's Stingray

… horizontal axis turbine evolved from wind technology


MCT's SeaFlow


MCT's SeaGen

… contra-rotation, tethered

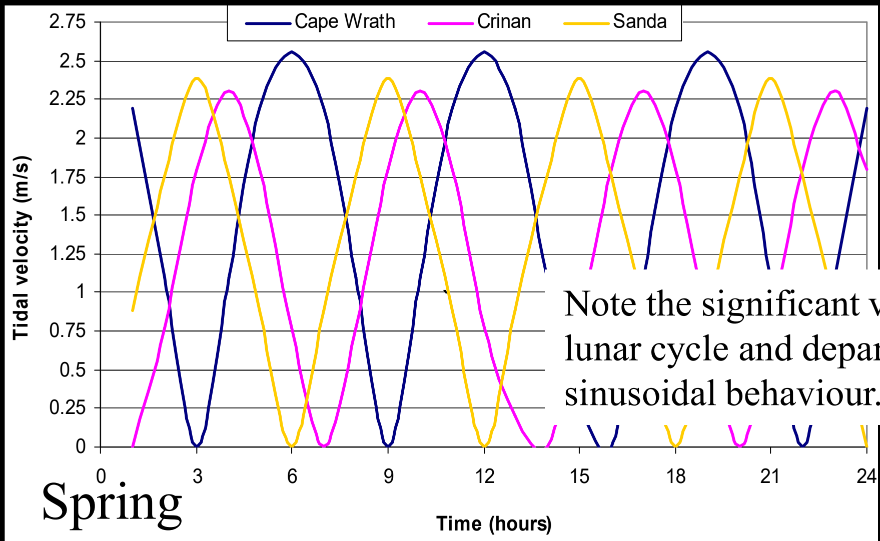

ESRU's CoRMaT

- ❑ Reduce capital cost.
- ❑ Limit corrosion and abrasion.
- ❑ Maintenance and safety issues.
- ❑ Power take-off at low rotation speed.
- ❑ Gearing reduction/elimination.
- ❑ Power transmission/grid access.
- ❑ Land access and use.
- ❑ Phased operation of different sites.
- ❑ Maritime & aquaculture impact.
- ❑ Overcome vested interest.
- ❑ Key question: given the daily and monthly velocity variations, can phased tidal stream sites be employed to provide predictable, firm power?

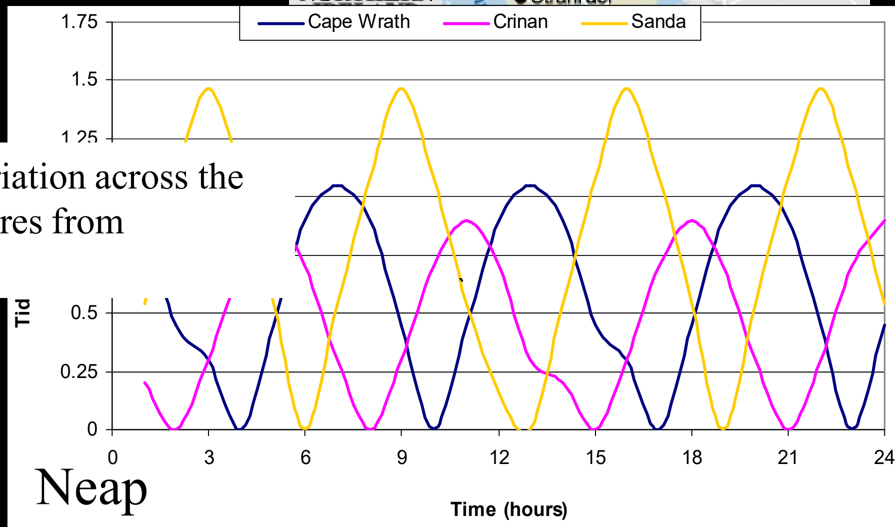
Synchronised tidal stream farms

- 3 Scottish coastal sites investigated:
  - Cape Wrath
  - Crinan at the Sound of Jura
  - Sanda off the Mull of Kintyre

- Hourly stream velocities taken from Admiralty charts



Note the significant variation across the lunar cycle and departures from sinusoidal behaviour.

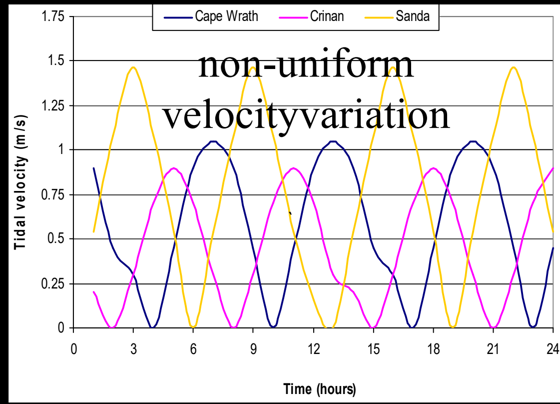


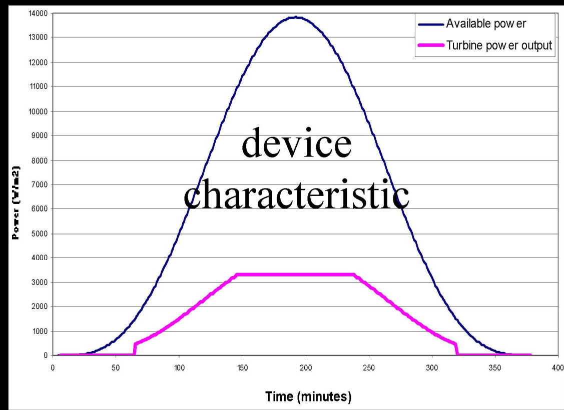
Spring and Neap tide daily velocity variations at the 3 sites

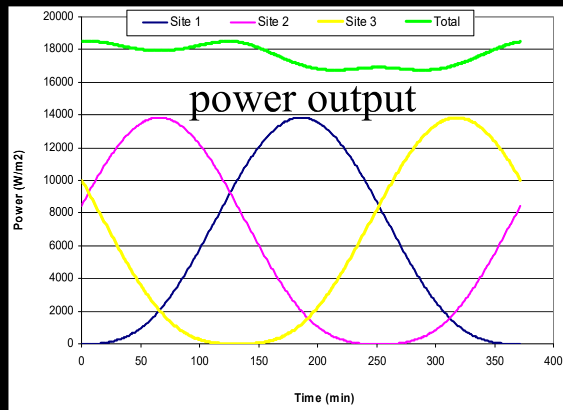
Synchronised power output

Assumptions:

- ❑ Turbines operate in an open stream environment.
- ❑ Dynamic loading ignored (as caused by velocity shear, stream misalignment or wave action).
- ❑ Turbulence effects ignored.
- ❑ Turbine has a cut-in stream velocity, with enforced idleness at slack water.
- ❑ Above a rated stream velocity power is held constant.
- ❑ Device sized for maximum power extraction.
- ❑ Available power given by $P = \frac{1}{2} \rho A V^3$ (ρ the fluid density, A rotor swept area and V stream velocity).
- ❑ Turbine $C_p = 0.3$, cut-in @ 1 m/s, cut-out @ 2.5 m/s).

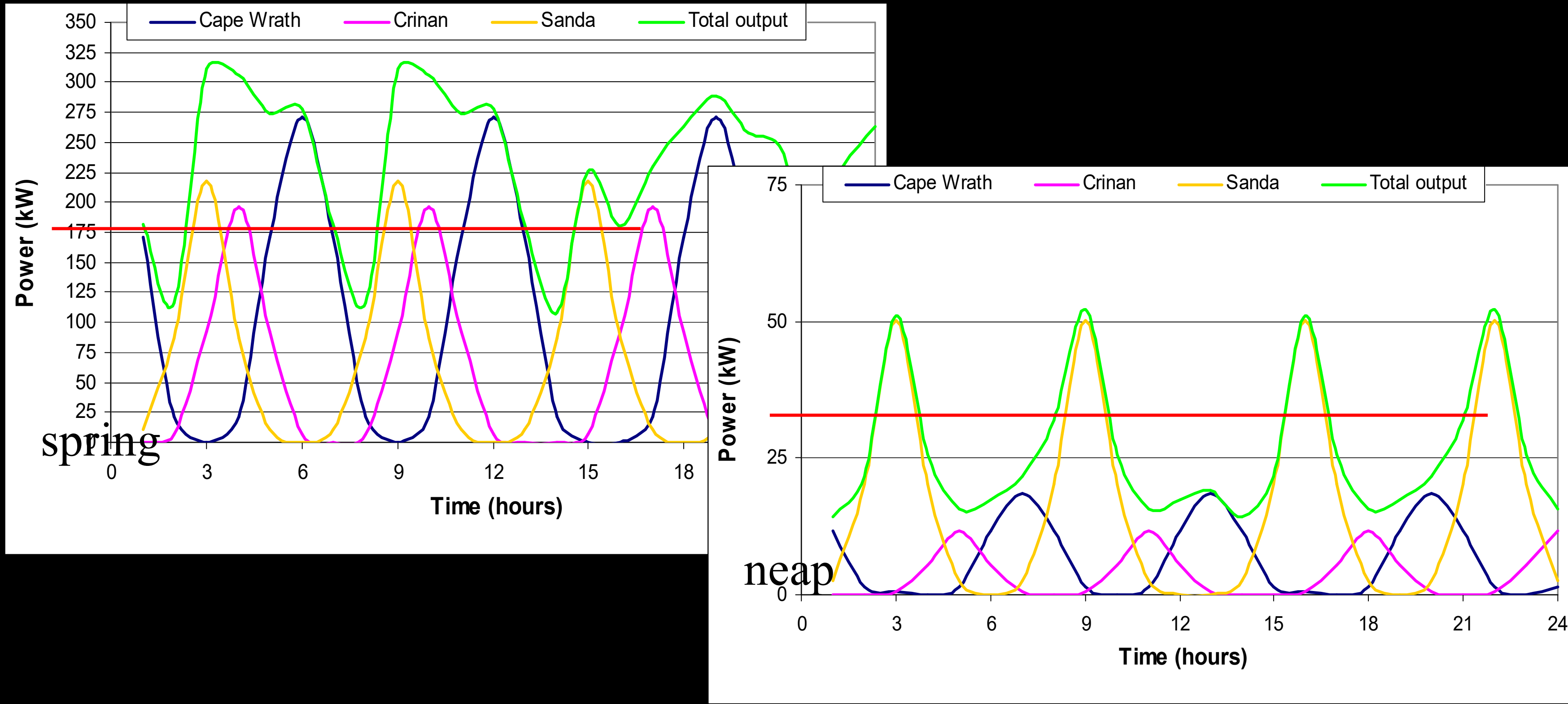






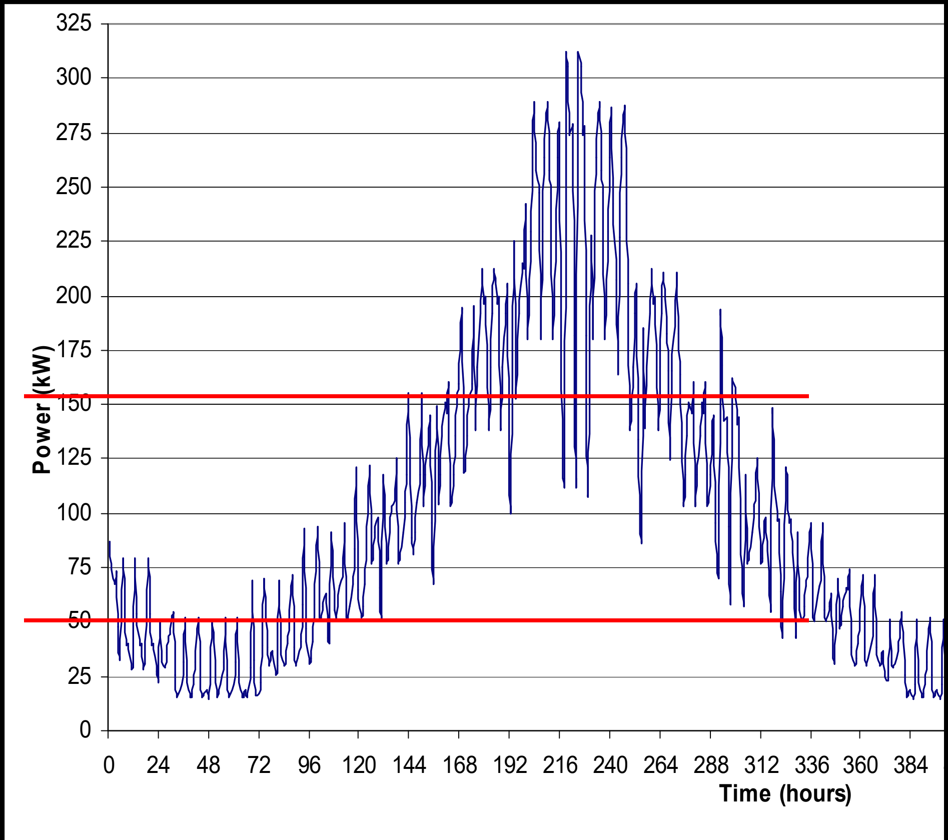
ME927 Tidal energy

Site and aggregate power output



- ❑ Spring tides: a significant base load is evident - about 1/3 of peak.
- ❑ Neap tides: the outputs are much lower at about 1/4 of peak.
- ❑ Changes between successive cycles are evident - Sanda is cycling at a higher frequency, a phenomenon that will reverse at another point in the lunar cycle.

Power output fluctuation over the lunar cycle



Options:

- ❑ size turbines to restrict the maximum output to that experienced during neap tides;
- ❑ size turbines for the average monthly output and introduce other sources of energy to meet the shortfall;
- ❑ size turbines for the spring tide condition and introduce long term (weekly) energy storage so that the excess capacity during near-spring tides can be stored for later use.

- ❑ Variation between spring and neap tide power production shown here over a half-month period.
- ❑ Fluctuations in output due to the lunar cycle affect all sites simultaneously.

Conclusions

- Some level of base load provision can be achieved via the phased operation of dispersed tidal current power stations.
- Difficulties arise due to the non-uniformity of site velocities.
- The natural variations that occur between successive tidal cycles (daily and monthly) produce a significant irregularity in aggregate power output.
- The predictability of tidal power output may be regarded as a major asset in energy supply management.
- The twice-daily cycle may be smoothed by the use of hydraulic pumped storage, or the phased operation of conventional hydro power plant.
- The lunar cycle induced variation in power output may be accommodated by complementary sources of energy or energy storage.
- Linking widely dispersed sites will place extra demands on the network.
- Accurate data are needed to predict the performance of systems of this kind.

- See tutorial questions for typical tidal range and stream calculations.