Tidal Energy & Technology Current Trends

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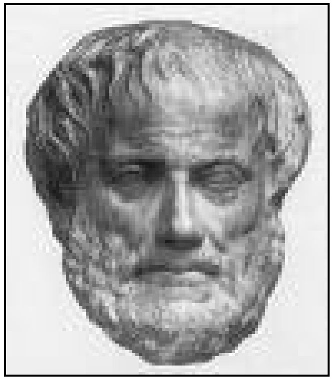
Overview

- Introduction
- Resource
- State of the art
- Projects
- Barriers
- Conclusions

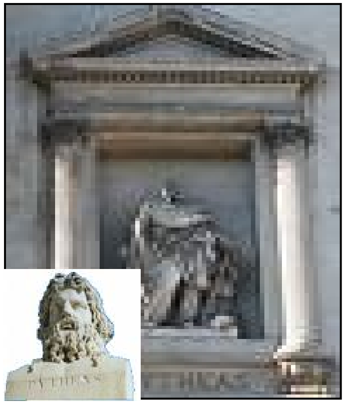
Earliest Tidal Research

~ 350BC



Aristotle
Lyceum
Ancient Greece

ARISTOTLE
Earliest reference on the world on tidal research

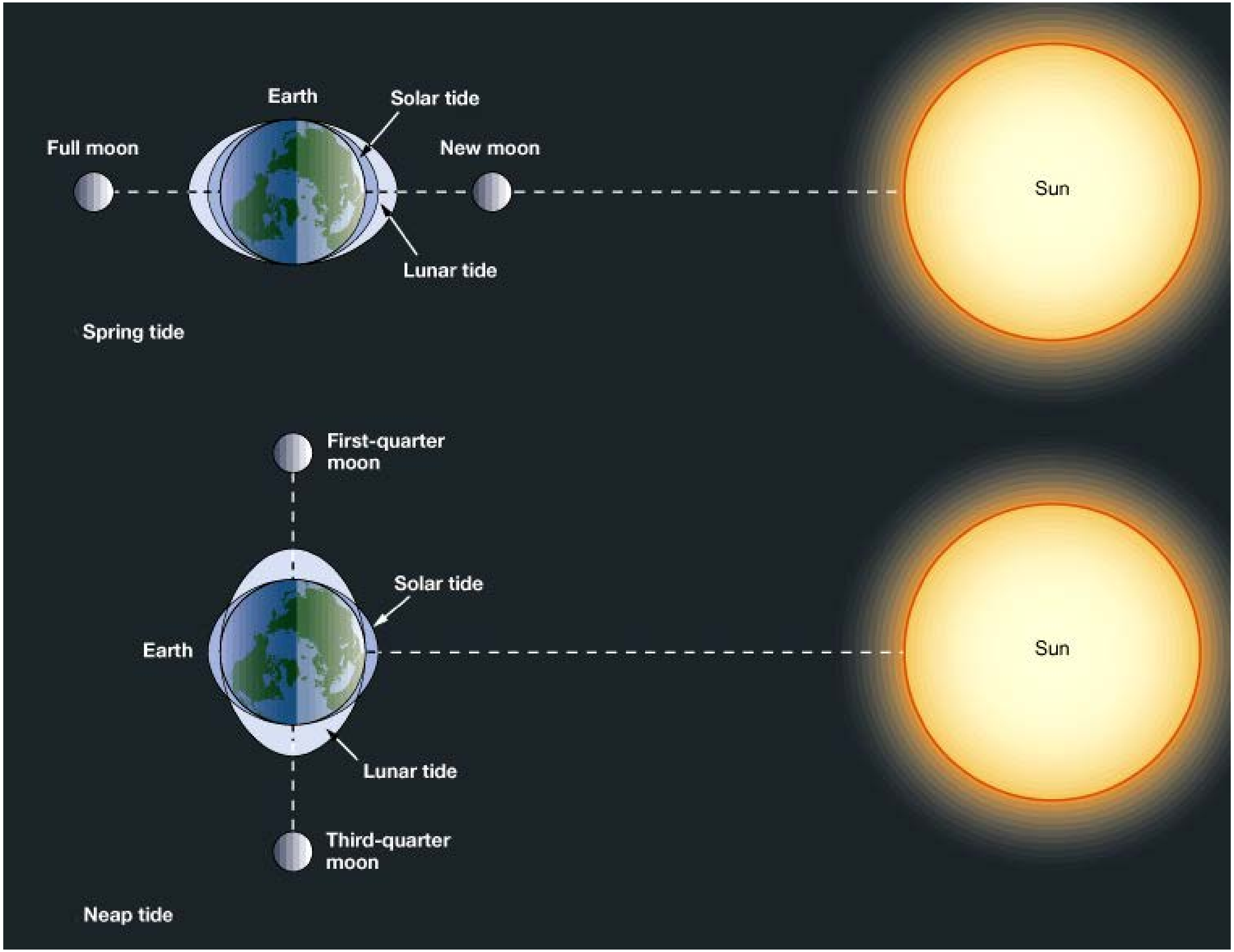


Pytheas
Massalia
Ancient Greece

PYTHEAS
Produced accounts of tidal movements

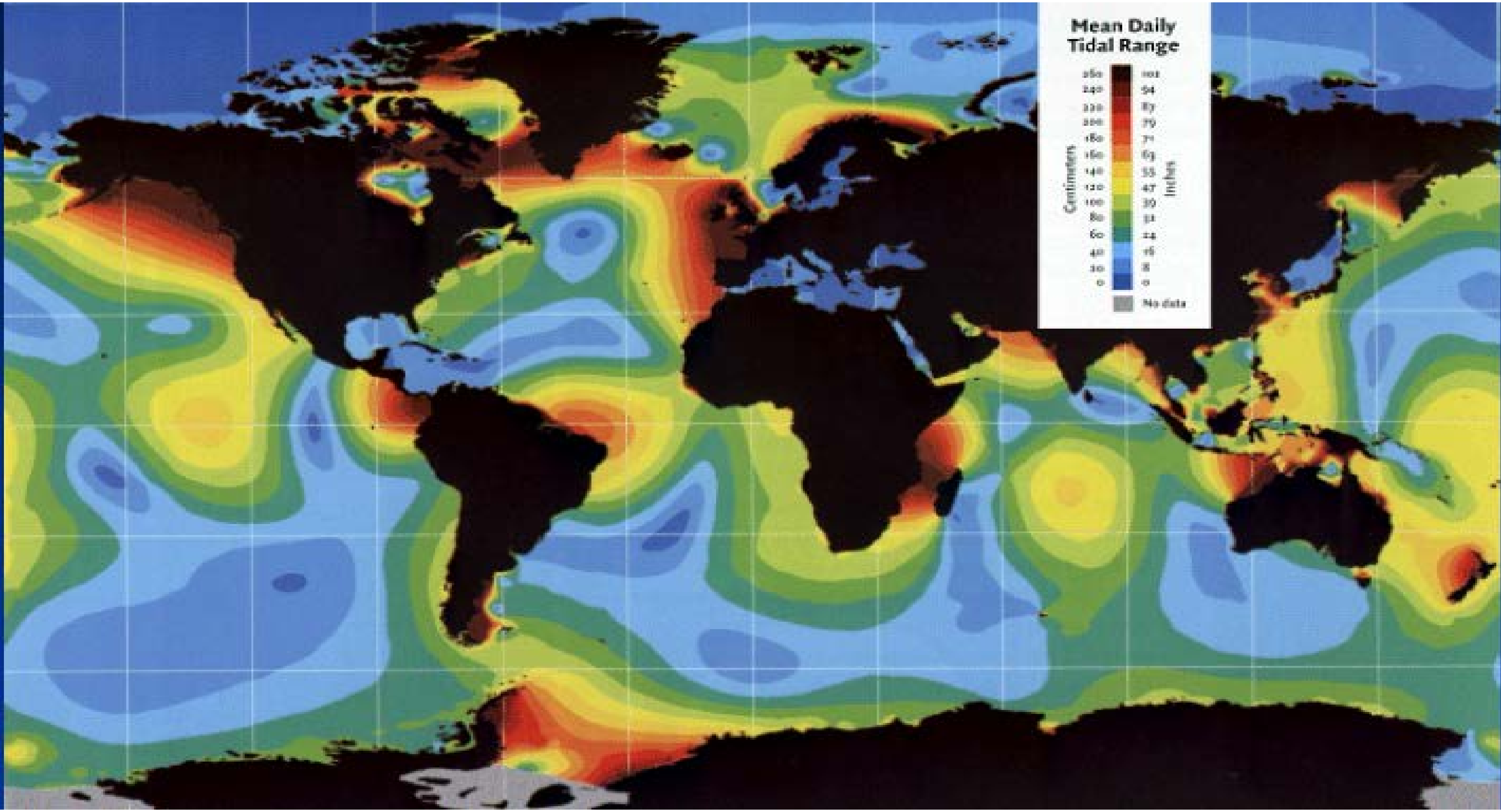
Earth-Moon-Sun Gravity

Tidal energy exploits the **natural ebb and flow** of coastal tidal waters caused principally by the interaction of the **gravitational fields of the earth, moon and sun.**



Global Distribution of Tidal Range

Electric Power Research Institute (EPRI).



Tidal Energy - DECC

- According to DECC, UK, (2014) Wave and Tidal energy offers a predictable and consistent source of renewable energy.
- Developing the potential of marine energy resources will help the UK:
  - a) save around 61 metric tonnes (Mt) of carbon dioxide (CO_2) by 2025 (valued at an estimated £1.1 billion to the UK economy)
  - b) help meet the UK's renewable energy objectives

- Wave and tidal stream energy has the potential to meet **up to 20%** of the UK's current electricity demand, representing a 30-to-50 GW installed capacity.
- Between 200 - 300 MWs of generation capacity may be able to be deployed by 2020, and at the higher end of the range, up to 27 GWs by 2050 (DECC RE Roadmap).

- **The UK is currently** seen as a **world leader** and focal point for the development of wave and tidal stream technologies. With its excellent marine resource and its expertise in oil and gas exploration, the UK is in a unique position to benefit from this type of renewable energy and to develop related wave and tidal stream services. The industry is still in its early stages however, and **further research is needed to determine how best to exploit these assets.**

Tidal Resource

- Worldwide, the tidal resources are considerable and also largely unmapped. However, global resources are estimated at 3 TW.
- The technically harvestable part of this resource, in areas close to the coast, is estimated by several sources at 1 TW (Carbon Trust 2011; Lewis, et al., 2011).
- Argentina, Australia, Canada, Chile, China, Colombia, France, Japan, Russia, South Korea, Spain, the UK, and the USA (Maine/Alaska) have very high tidal ranges. In addition, Eastern Africa has large resources for tidal range.
- For Europe, the resources that are harvestable are estimated at a minimum of 12 GW (EU-OEA), 2010.
- Deployment projections for tidal current up to 2020 are in the range of 200 MW.
- Total tidal current deployment in 2014 was around 6 MW for tidal current (of which 5 MW is deployed in the UK).
- For tidal current technology, the stream speed needs to be at least 1.5-2 m/s.

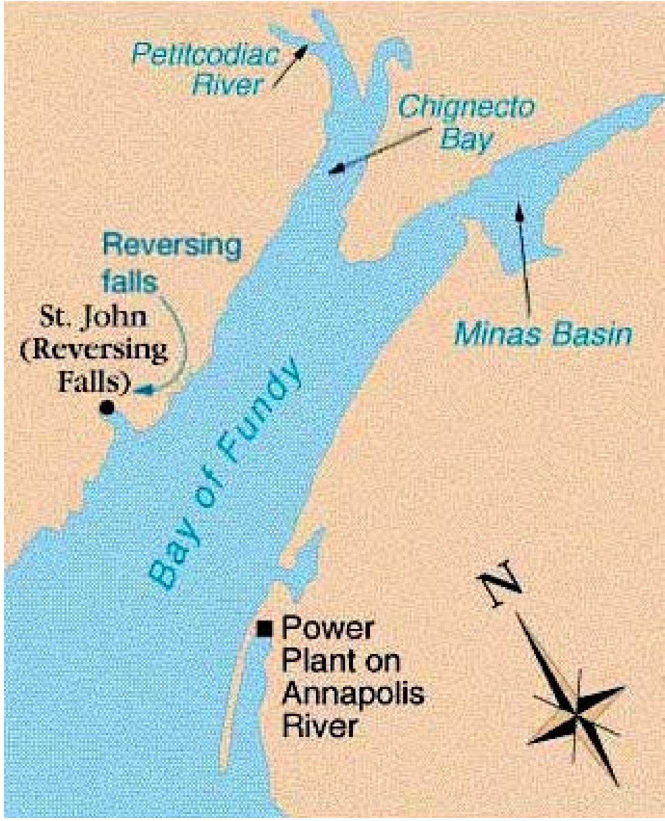
- An advantage of both tidal range and current energy is that they are highly predictable with daily, bi-weekly, biannual and even annual cycles over a longer time span of a number of years.
- Energy can be furthermore generated both day and night and tidal range is hardly influenced by weather conditions.
- Tidal stream is slightly more affected by the weather, but the fluctuations in the long run are lower than, for example, wind and solar.

Potential Energy

The rise and fall of the tides – in some cases up to 16 m – creates **POTENTIAL ENERGY**.

- **Tidal energy is focused by shape and shallowness of bay.**
- **The Bay of Fundy in Canada has the greatest tidal range on the planet.**
- **Maximum spring tidal range in Minas Basin 16.2 m.**

Bay of Fundy tidal bore



Kinetic Energy

The flows due to flood and ebb currents creates **KINETIC ENERGY.**

Siemens MCT Seagen 1.2 MW
Typical Flow at over 3m/s
http://www.marineturbines.com/

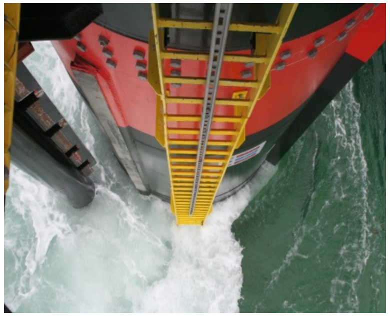
- Power extracted from kinetic energy of flowing water:

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

- Water 800 times denser than air.

- The turbines are similar to designs used for wind turbines, but due to the higher density of water the blades are smaller and turn more slowly than wind turbines.

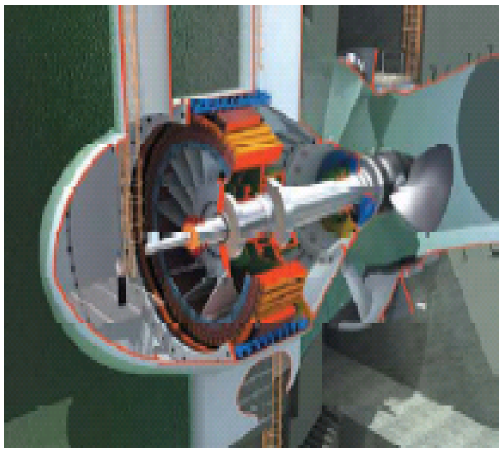
- They have to withstand greater forces and movements than wind turbines.



Technological range

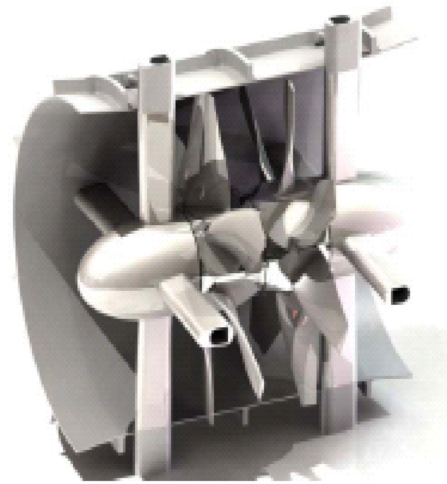
Both forms of energy can be harvested by tidal energy technologies as renewable energy.

← *Increasing environmental impact*



Bi-directional. (La Rance, Alstom)

- Uni-directional operation. (Sihwa, Andritz)
- High axial flow speed.
- 50 metre downstream diffuser.
- High solidity rotor.
- Steady flow conditions.
- Deep cavitation submergence.



(Rolls Royce)

- Bi-directional operation.
- Low axial flow speed.
- Straight walled support structure.
- Twin low solidity rotors.
- Steady flow conditions.
- Modest cavitation submergence.

(Tidal generation)

- Bi-directional operation.
- Low axial flow speed.
- No enclosing support structure.
- Low solidity rotor.
- Unsteady flow conditions.
- Modest cavitation submergence.

Decreasing power density →

Tidal Development

- Tidal energy technologies are found in Europe from ~700 AD.
- Since the 1960s, only five projects have been developed commercially in the period up to 2014.
- However, new technologies have advanced considerably over the past few years and there are a number of ongoing full-scale demonstration projects. More than 40 new devices introduced between the period 2006-2014.
- The major differences among the devices are the turbines, which can be based on a vertical or horizontal axis, and in some cases are enclosed (ducted).
- Full-scale deployment of single turbines have been achieved, and the next step is the demonstration of arrays of turbines (ETI/UKERC, 2014).

Tidal Current Technologies

Main types of Tidal Energy Convertors (TEC):

- **Horizontal Axis**
  - Rigidly mounted
  - Floating and Semi-Submerged
- **Vertical Axis**
- **Hydrofoil**
  - Oscillating
  - Translating
- **Venturi Systems**
- **Archimedes Screw**
- **Tidal Kite**
- **Other**

A GLOBAL CENTRE OF EXCELLENCE IN MARINE ENERGY TESTING AND RESEARCH

http://www.emec.org.uk/marine-energy/tidal-developers/#loaded

- Based on an overview of existing tidal current projects, 76% of all turbines are horizontal axis turbines and 12% are vertical axis turbines (IRENA, 2014).
- In 2011, 76% of all research and development (R&D) investments into tidal current technologies went into horizontal axis turbines, 4% into enclosed turbines, and 2% into vertical axis turbines (JRC, 2013).

http://www1.eere.energy.gov/water/hydrokinetic/listings.aspx?type=Tech

Tidal Current Projects

- Up to 2010, the industry was dominated by **small entrepreneurial companies.**

- But in the last four years **large engineering firms and turbine manufacturer**s like ABB, Alstom, Andritz Hydro, DCNS, Hyundai Heavy Industries, Kawasaki Heavy Industries, Siemens, and Voith Hydro have entered the market.

- Furthermore, companies like GE have also shown an interest and are supplying the electrical power systems for some of the prototypes.

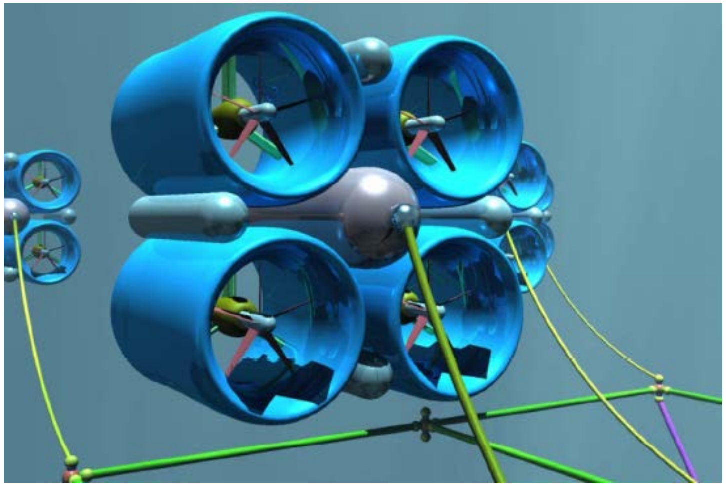
- Also, large **utilities** like Bord Gais Energy, EDF, GDF Suez, and Iberdrola are running demonstration projects.

Ocean Current

- Some tidal current or tidal stream technologies are also used to harvest ocean currents.
- Compared to tidal currents, ocean currents are unidirectional and generally slower but more continuous.
- Ocean current technologies are in an early developmental stage, and no full-scale prototype has been tested or demonstrated yet.
- Ocean currents, although slow are a continuous flow driven by wind patterns and thermohaline circulation.
- Taiwan is interested to harness energy from ocean currents, while studies have been widely undertaken, for example in Florida (Yang, Haas and Fritz, 2012).
- Studies of ideas for floating offshore platforms, are currently being undertaken and thus far, no near future commercial applications have been reported.

Kuroshio Ocean Turbine (TW)

http://www.iam.ntu.edu.tw/



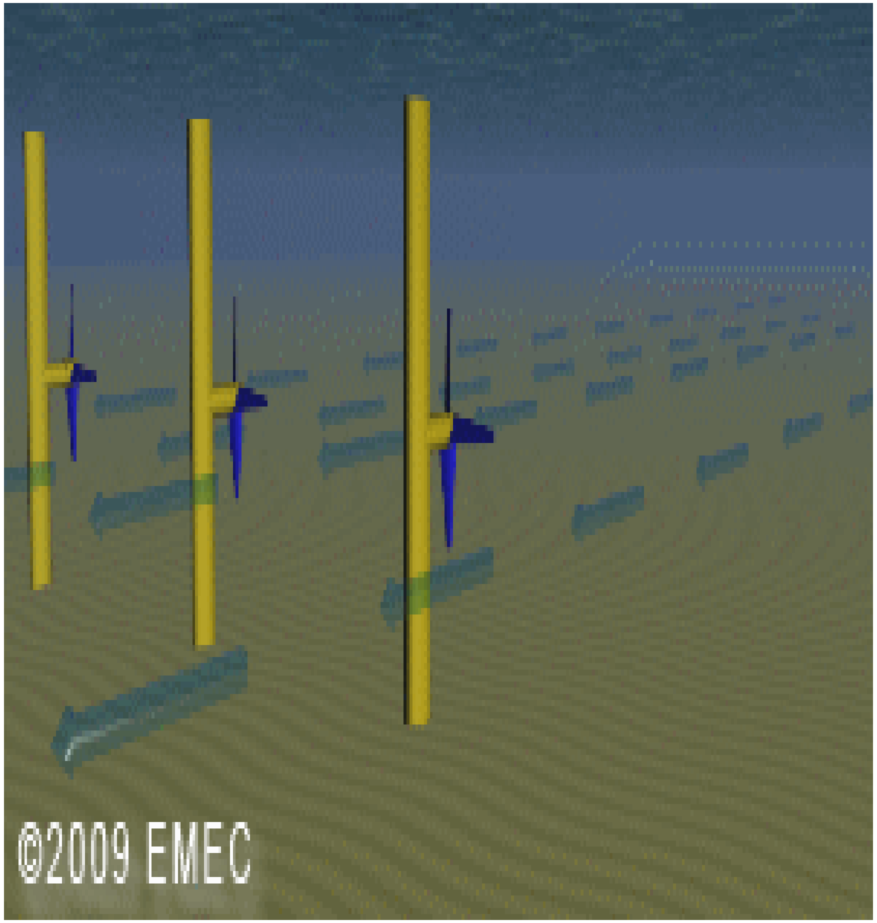
Open Centre turbines

- Most designs use blades that are connected to a central rotor shaft, which through a gearbox, is connected to a generator shaft.
- Open-centre turbines have a different design in that the blades are mounted on an inner, open centred shaft housed in a static tube.
- As the water flows through the shaft, it rotates and electricity is generated.
- The advantage of this design is that it eliminates the need for a gearbox.

Open Hydro

Horizontal axis turbines

- This device extracts energy from moving water in much the same way as wind turbines extract energy from moving air.
- Devices can be housed within ducts to create secondary flow effects by concentrating the flow and producing a pressure difference



Methods to fix the TEC to the seabed

Further to the categories of devices identified above, there is also a range of methods to fix the converter to the seabed:

i) Seabed Mounted / Gravity Base: This is physically attached to the seabed or is fixed by virtue of its massive weight. In some cases there may be additional fixing to the seabed.

ii) Pile Mounted: This principle is analogous to that used to mount most large wind turbines, whereby the device is attached to a pole penetrating the ocean floor. Horizontal axis devices will often be able to yaw about this structure. This may also allow the turbine to be raised above the water level for maintenance. **Siemens/MCT' SeaGen changed from a monopile support structure to a new tripod design.**

iii) Floating (with three sub-divisions):

Flexible mooring: The device is tethered via a cable/chain to the seabed, allowing considerable freedom of movement. This allows a device to swing as the tidal current direction changes with the tide.

Rigid mooring: The device is secured into position using a fixed mooring system, allowing minimal leeway.

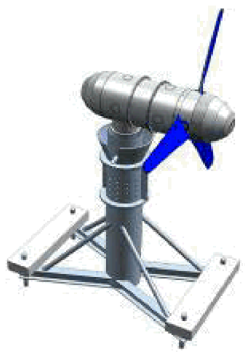
Floating structure: This allows several turbines to be mounted to a single platform, which can move in relation to changes in sea level. **Alstom, is working on turbines with individual components that can be mounted on different kinds of mooring structures.**

iv) Hydrofoil Inducing Downforce: This device uses a number of hydrofoils mounted on a frame to induce a downforce from the tidal current flow. Provided that the ratio of surface areas is such that the downforce generated exceeds the overturning moment, then the device will remain in position.

Of the different tidal current concepts and projects developed so far, 56% uses rigid connection (mostly seabed), 36% uses mooring, and 4% monopiles (IRENA, 2014).

Horizontal Axis Turbines

Rigidly Mounted



Voith Siemens Hydro (Germany)

http://www.hydro.org/news/Weilepp.%20Wave%20Power.pdf

Tidal Generation (UK)

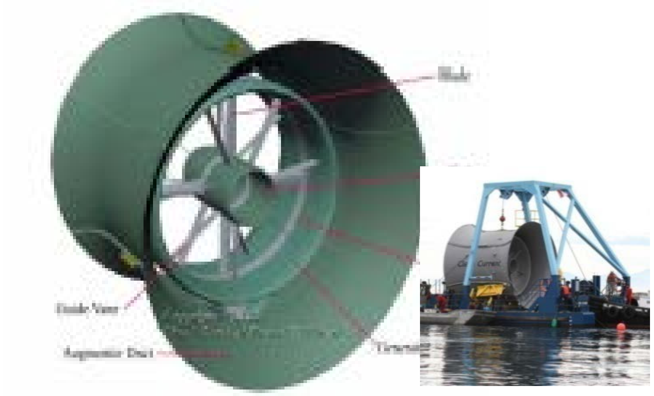
http://www.tidalgeneration.co.uk

KESC Bowsprit Generator /

KESC Tidal Generator (USA)

http://www.kineticenergysystems.com

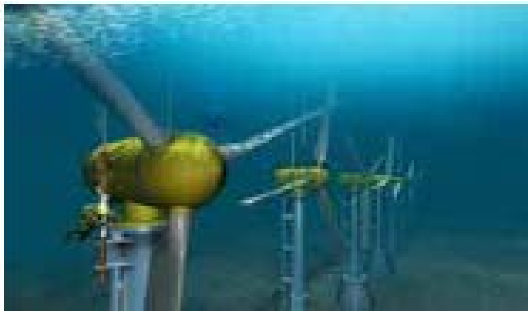
Free Flow Turbine (USA)
http://www.verdantpower.com



Clean Current Tidal Turbine (Canada)
http://www.cleancurrent.com

Horizontal Axis Turbines

Rigidly Mounted



Andritz Hydro Hammerfest

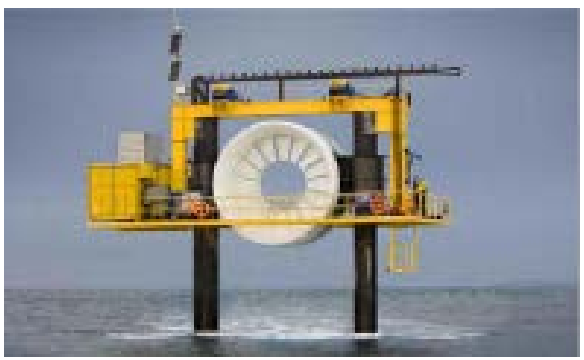
www.andritz-hydro.com

Swanturbines (UK)

http://www.swanturbines.co.uk/

Hydrohelix Turbine (France)

http://www.hydrohelix.fr/

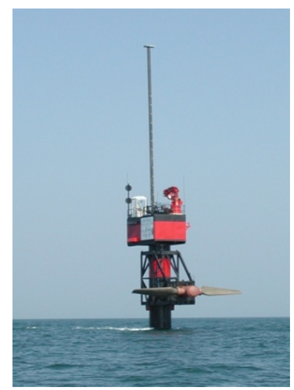


Open Centre Turbine (Ireland)

http://www.openhydro.com

Tocardo (Nederlands)

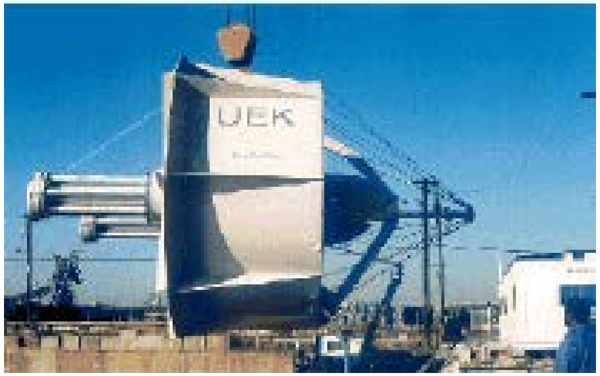
http://www.tocardo.com



Siemens Seaflow (UK) & Seagen (UK)

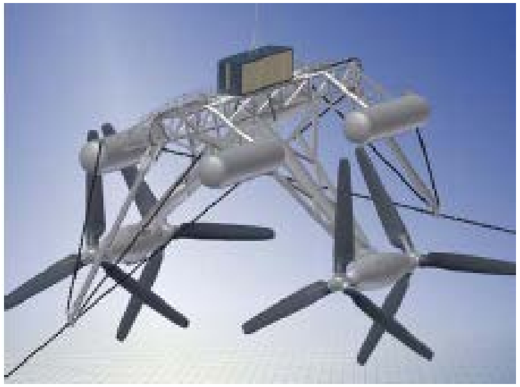
http://www.marineturbines.com

Horizontal Axis Turbines Floating & Semi- Submerged Devices



Underwater Electric Kite (USA)

http://www.uekus.com

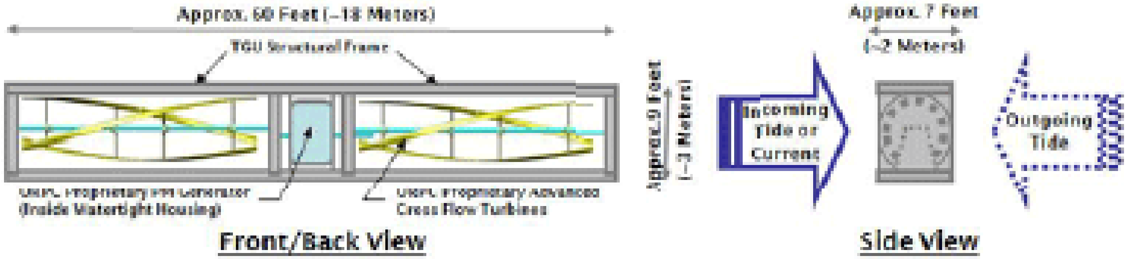


Modril (Norway)

http://www.statkraft.com

Hydro-Gen (France)

http://www.hydro-gem.fr



OCGen (USA)

http://www.oceanrenewablepower.com

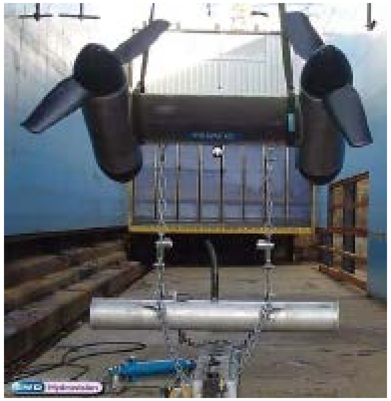
Horizontal Axis Turbines Floating & Semi- Submerged Devices

Evopod (UK)

http://www.oceanflowenergy.com

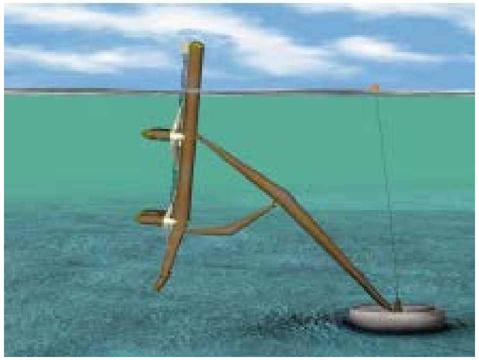
SRTT (UK)

http://www.scotrenewables.com



TidEl (UK)

http://www.smdhydrovision.com



Semi submersible Turbine (UK)

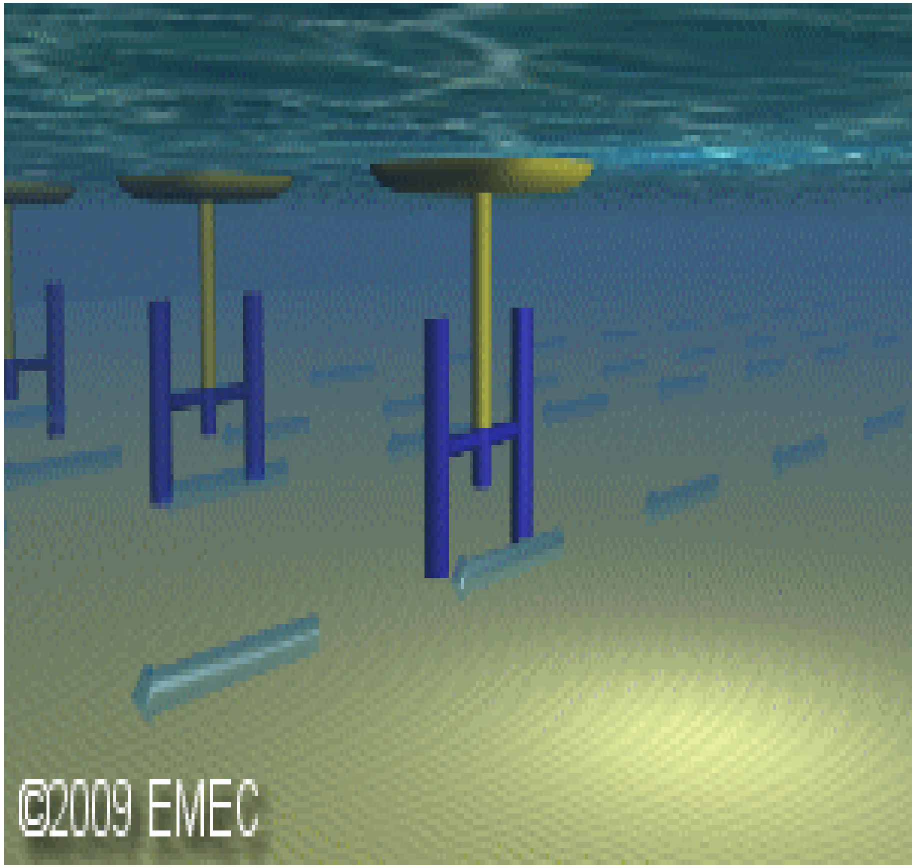
http://www.tidalstream.co.uk

CORMAT(UK)

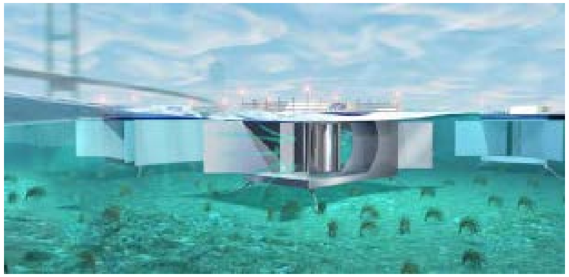
Cameron@esru.strath.ac.uk

Vertical axis turbines

- This device extracts energy from moving water in a similar fashion to the horizontal axis turbines, however the turbine is mounted on a vertical axis.

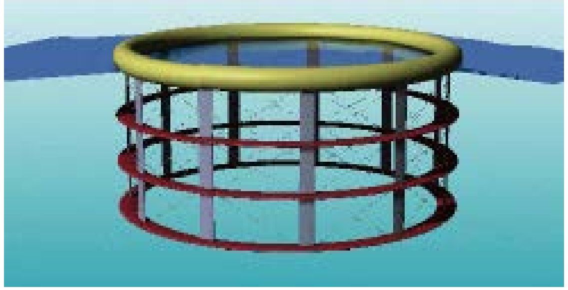


Vertical Axis Turbines



Proteus (UK)

http://www.neptunerenewableenergy.com

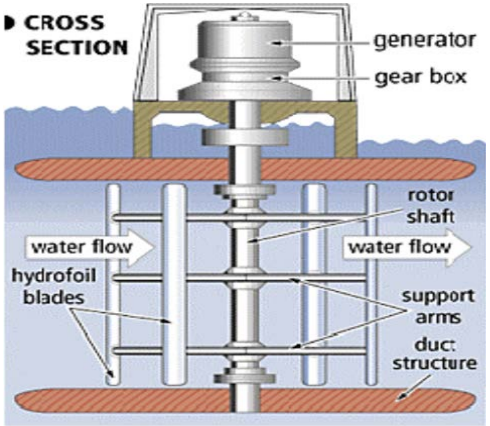


Polo (UK)

http://www.mech.ed.ac.uk

EnCurrent Turbine (Canada)

http://www.newenergycorp.ca

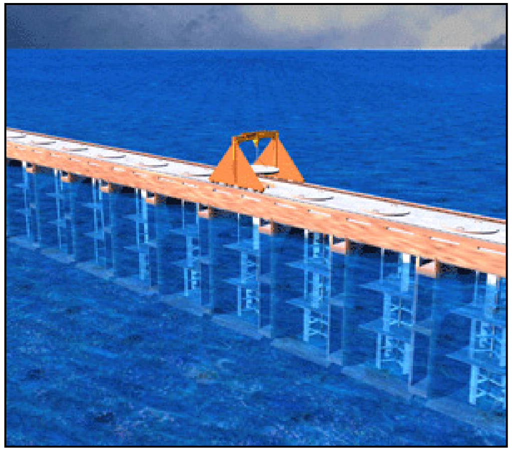


Blue Energy (Canada)

http://www.bluenergy.com

Gorlov Helical Turbine (USA)

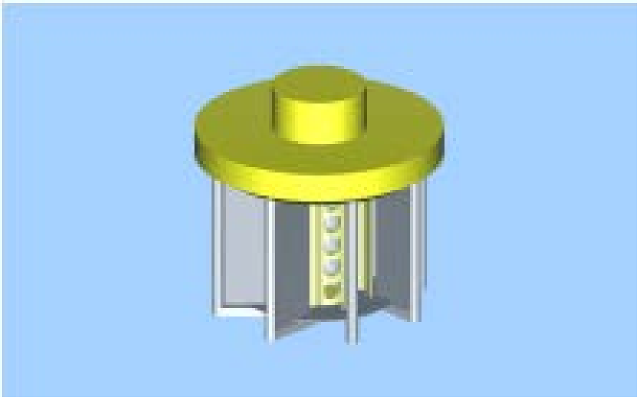
http://www.gcktechnology.com



Kobold Turbine (Italy)

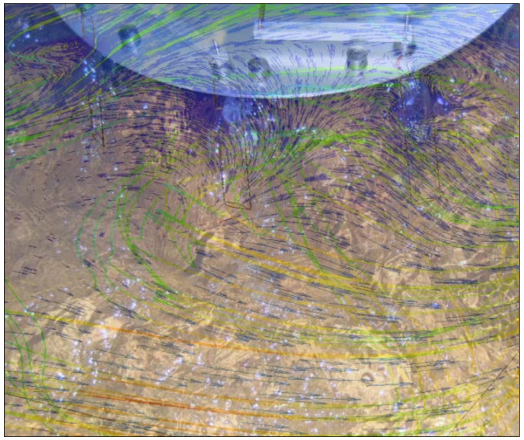
http://www.pontediarchimede.it

Vertical Axis Turbines



Water Turbine (Norway)

http://www.anwsite.com

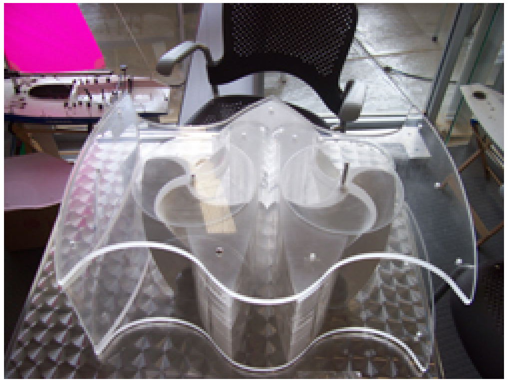


Lancaster University (UK)

http://www.engineering.lancs.ac.uk/REGROUPS/LUREG/home.htm

Water Power Industries WPI (Norway)

http://www.wpi.no



Impulsa (Mexico)

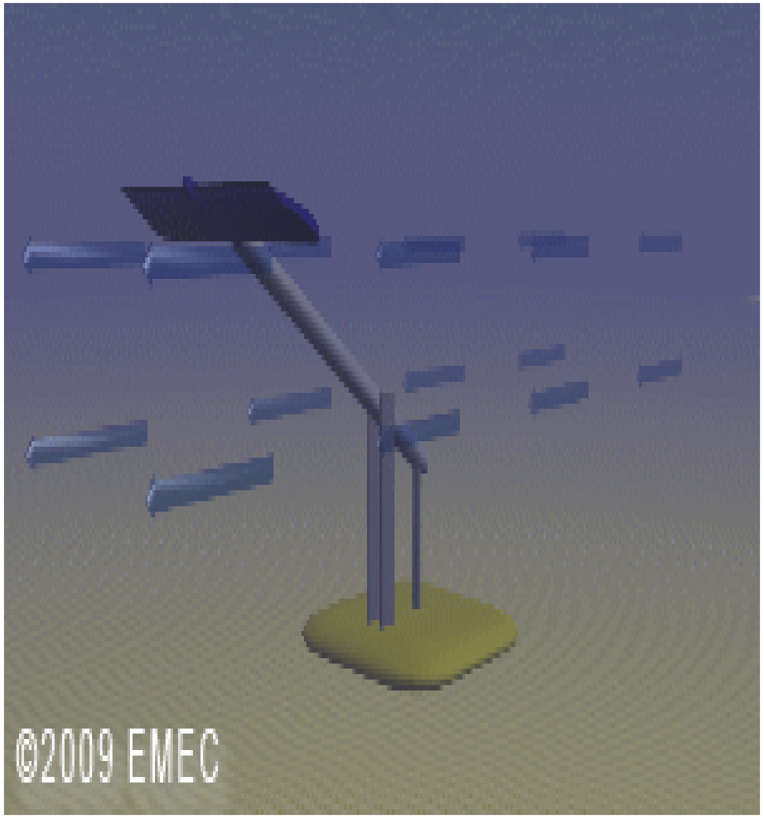
http://www.impulsa4.unam.mx/Defualt_ingles.htm

Alternative Hydro Solutions (Canada)

http://www.alternativehydrosolutions.com

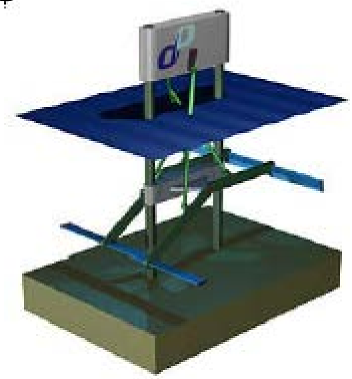
Reciprocating Devices

- Reciprocating devices have blades called hydrofoils – shaped like airplane wings – that move up and down as the tidal stream flows on either side of the blade.
- The up and down movement of the hydrofoils is subsequently converted into rotation to drive a rotating shaft, or connected to pistons to support a hydraulic system for power generation.
- The advantage of reciprocating devices is that the length of the blade is not constrained by water depth, however it also requires complex control systems to pitch the blades correctly.
- Devices without a gearbox are called direct-drive generators.
- There are also proposals to use vortex induced cylinders to generate power in a similar way.
- Around 2% of all R&D investments in tidal current technologies went into reciprocating devices (JRC, 2013).

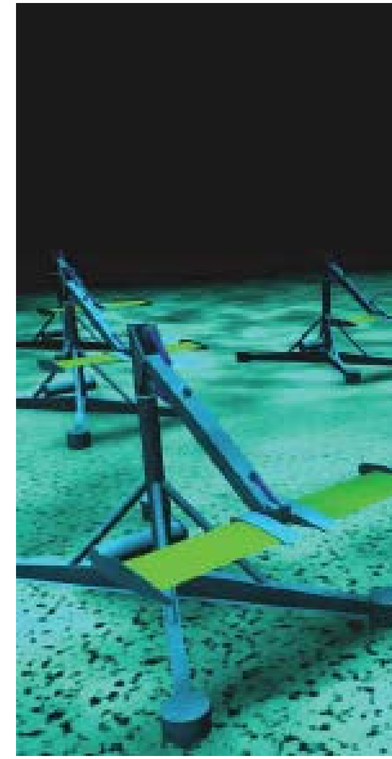


Oscillating & Translating Hydrofoil

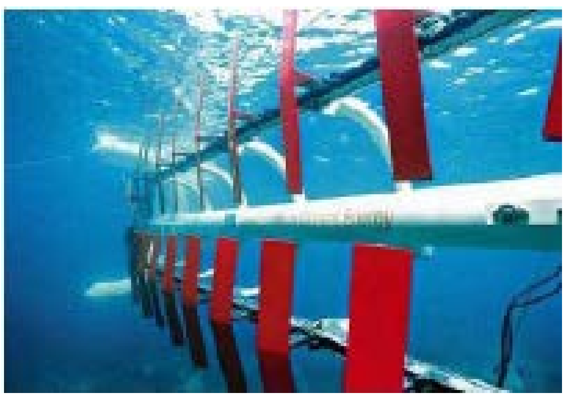
BioStream (Australia)
http://www.biopowersystems.com



Pulse Generator (UK)
http://www.pulsegeneration.co.uk



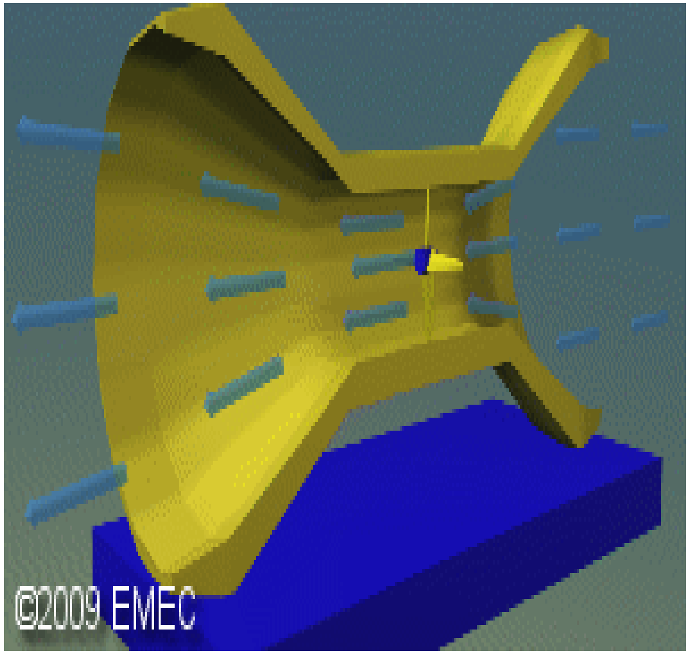
Stingray (UK)
http://www.engb.com

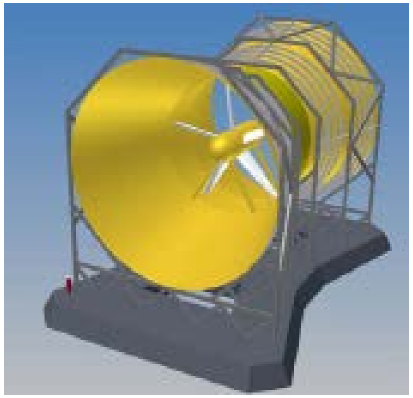


Aquanator
http://www.atlantisresourcescorporation.com

Harmonica (Norway)
http://www.tidalsails.com

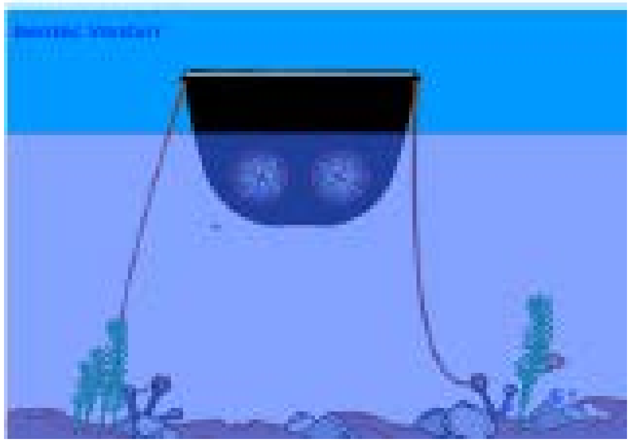
- The blades of horizontal or vertical turbines can also be enclosed within a duct.
- The latter turbines are referred to as Enclosed, Ducted or Shrouded turbines.
- Due to the enclosure, the ocean current is concentrated and streamlined so that the flow and power output from the turbines increases.
- The flow of water can drive a turbine directly or the induced pressure differential in the system can drive an air-turbine.





Rotech Tidal Turbine (UK)
http://www.lunarenergy.co.uk/

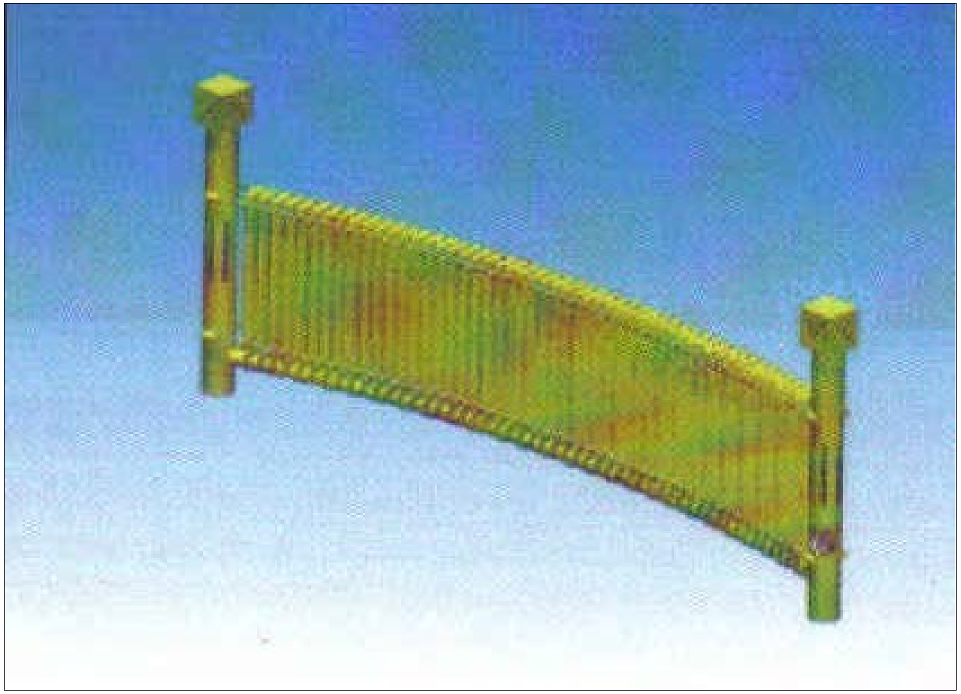
Venturi Devices



Gentec Venturi (New Zealand)
http://www.greenheating.com

Hydro Venturi (UK)

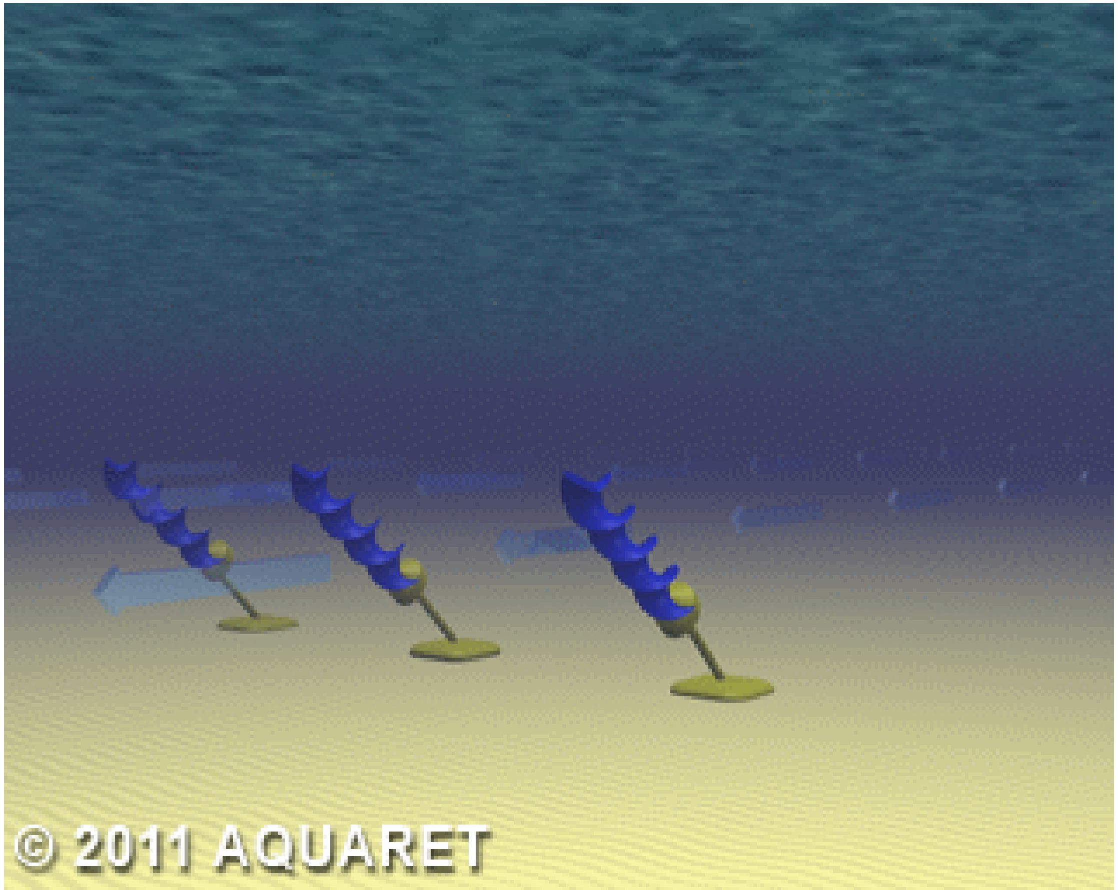
http://www.hydroventuri.com



Spectral Marine Energy Converter (UK)

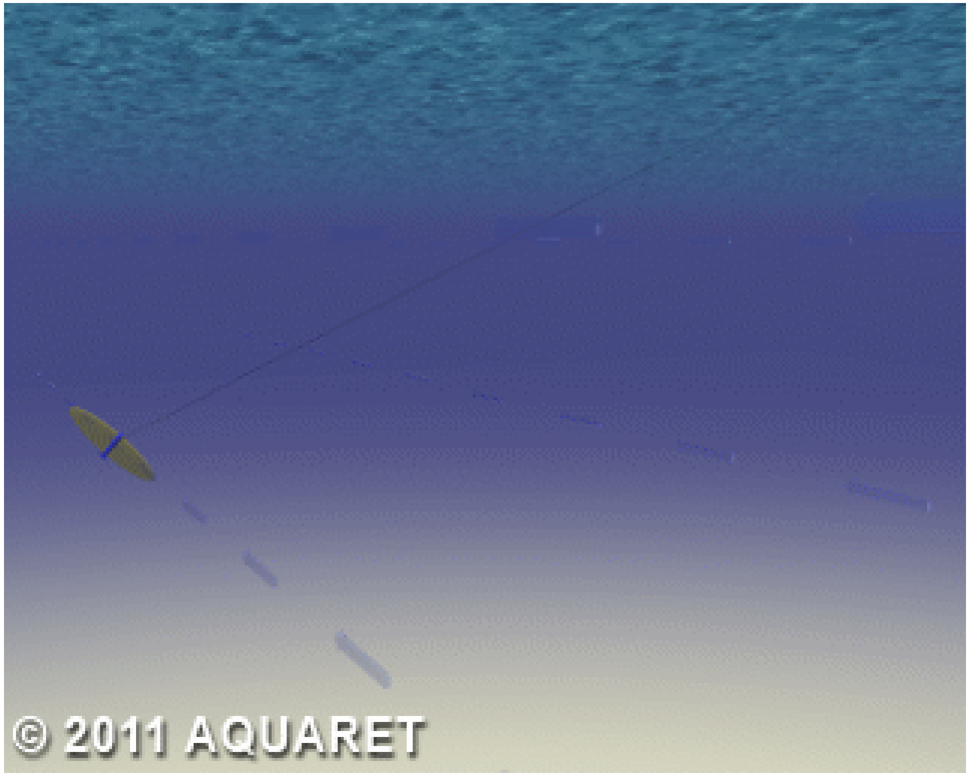
http://www.verderg.com

Archimedes Screw



- The Archimedes Screw is a helical corkscrew-shaped device (a helical surface surrounding a central cylindrical shaft).
- The device draws power from the tidal stream as the water moves up/through the spiral turning the turbines.

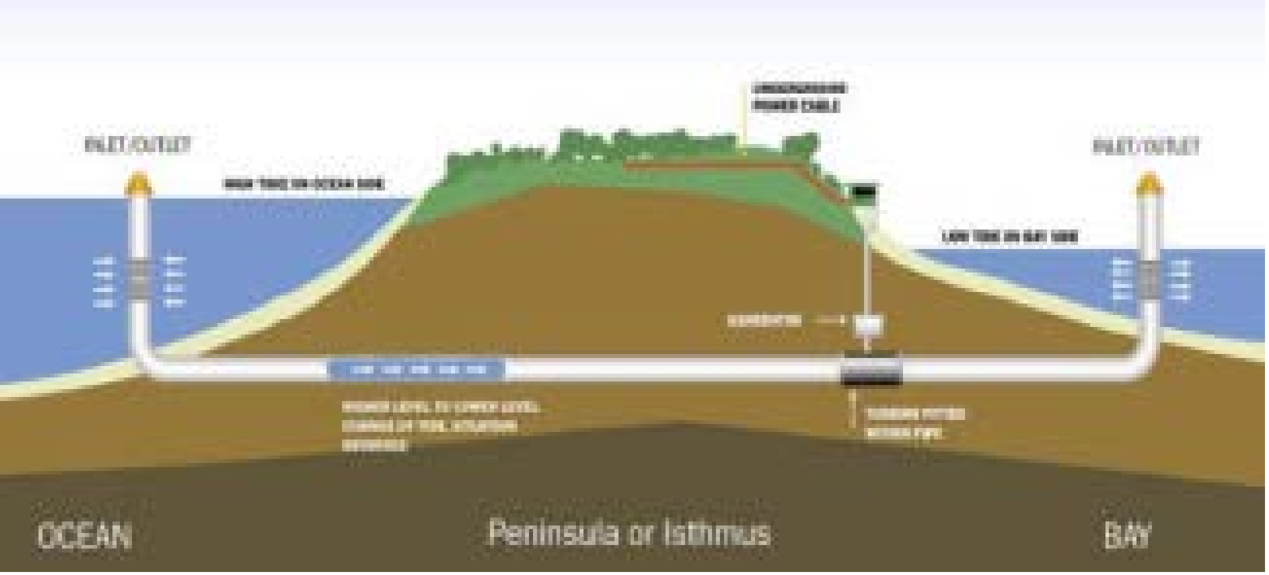
Tidal Kite



- A tidal kite is tethered to the sea bed and carries a turbine below the wing.
- The kite 'flies' in the tidal stream, swooping in a figure-of-eight shape to increase the speed of the water flowing through the turbine.

Other Systems

- This covers those devices with a unique and very different design to the more well-established types of technology or if information on the device's characteristics could not be determined.



Tidal Delay (Australia)

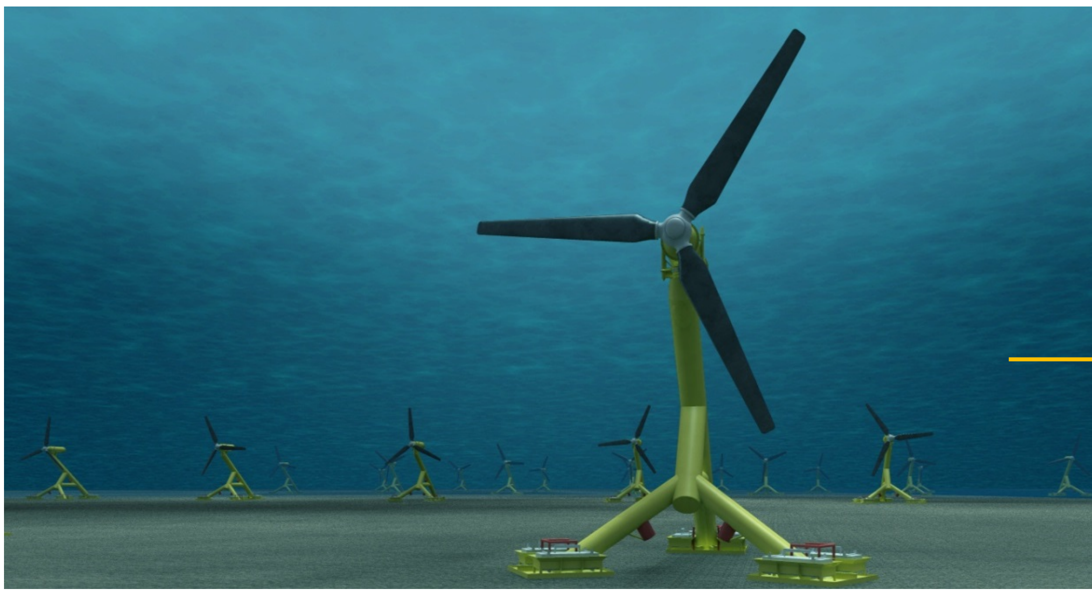
http://www.woodshedtechnologies.com.au

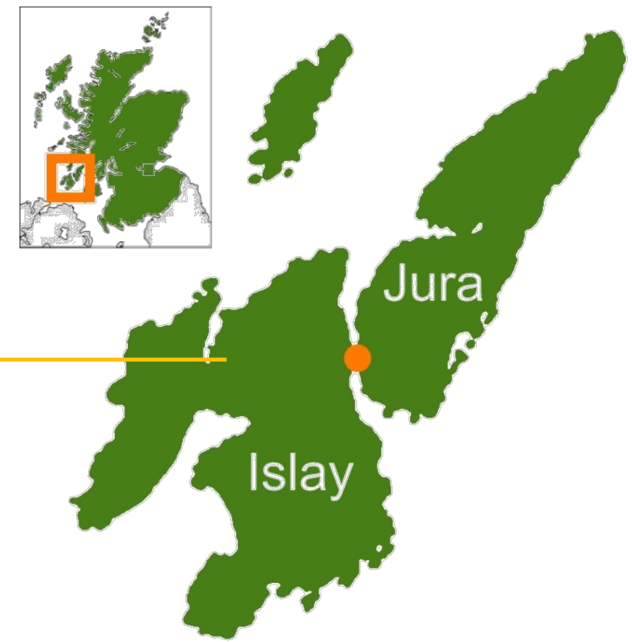
Tidal Current Turbine (Netherlands)

http://www.neptunesystems.net

Array Formation

- Another technical aspect for tidal current technologies is their deployment in the form of farms or arrays.
- Individual generator units are limited in capacity, so multi-row arrays of tidal turbines need to be built to capture the full potential of tidal currents.
- However, turbines have an impact on the current flows, so the configuration in which they are placed is a critical factor to determine their potential yield and output (SI Ocean, 2012).





Phase three:
Pre-commercial array
www.andritz-hydro.com

- *The Sound of Islay project*
- *Project developer is ScottishPower Renewables*

Grid Connection

- Grid connection for tidal current technology deployment requires consideration, turbines need to be connected to each other through array cables (typically 33 kV).

- The array is then typically connected to an offshore substation, which is connected through an export cable (typically 150 kV) to an onshore substation and eventually to the grid (IEA-RETD, 2012).

- With the development of wind parks off shore, there is now considerable experience in developing both offshore AC and DC grid infrastructures.

- Yet, grid connection remains one of the critical aspects for tidal energy deployment as delays and the costs for grid connection could put many projects at risk (RenewableUK, 2013).

Project Developers

- So far, most of the development of this technology is taking place in Canada, China, France, Ireland, Japan, South Korea, Spain, UK, and the USA (Carbon Trust, 2011).
- Most of these countries have at least one open sea test site. In particular, the European Marine Energy Centre (EMEC), based in Scotland, is one of the longest running sites where tidal current turbines have been tested since 2005.
- New test sites are planned in Chile, China, New Zealand, Portugal, Spain, and the USA.
- In the last couple of years, five new industrial companies entered the market by supporting and taking over prototypes close to development:
- Andritz Hydro took over Hammerfest Strom;
- MCT is now also part of Siemens;
- ABB invested in Scotrenewables Tidal Power;
- Alstom acquired Tidal Generation Ltd. (TGL); and
- DCNS took over Open Hydro with projects deployed in Canada, France, and the UK (Scotland).
- Hyundai Heavy Industries has finalised site trials with a 500 kW tidal, and
- Kawasaki Heavy Industries is testing full-scale technologies at EMEC and in Japan.
- Furthermore, GDF Suez is supporting the development of Sabella, an enclosed turbine, in France.

Closest to Commercialisation

- It is difficult to determine which turbines are closest to commercialisation, although it seems that there is a convergence towards horizontal axis turbines.
- Andritz Hydro Hammerfest, Alstom TGL, DCNS Open Hydro, Scotrenewables Tidal Power, MCT/Siemens, and Voith Hydro all deploy horizontal axis turbines of more than 1 MW demonstration units in the sea.
- Furthermore, Atlantis is working together with Lockheed Martin to optimise its new 1.5 MW tidal turbines.
- The turbine has also started being tested in China, where an increasing number of turbines are being developed.
- Of these technologies, the turbines from Andritz Hydro Hammerfest, MCT/Siemens and possibly Alstom TGL have been selected in three European funded demonstration projects for tidal arrays to be operational in the 2014 – 2016 time frame (Jeffrey, 2013).

Further Development

- In April 2014 DCNS OpenHydro and Alderney Renewable announced plans for a 300 MW tidal array.
- However, most work on arrays still focuses on model development (Culley, Funke and Piggott, 2014; Thomson, Whelan and Gill, 2010).

- Aside from advances in applications close to the coast, several smaller technologies are being developed.
- These technologies could also be used for inland applications or as river current generators.
- For example, Tocardo Turbines are in operation in The Netherlands in the North Afsluitdijk and soon also in the Eastern Scheld barrage.
- In the USA, the Verdant turbine was tested in the East River of New York City and Ocean Renewable Power Company is demonstrating its vertical axis turbines near Eastport in Maine.
- Near Australia, HydroGen has been testing its turbines in the Torres Strait.

Closest to Commercialisation?

Siemens MCT SeaGen

Tocardo T100 turbine

Andritz Hydro Hammerfest HS1000

Atlantis Resources Corporation Turbine

Sabella deployed by GDF Suez

Alstom TGL

DCNS OpenHydro

Voith Hydro turbine

Tidal Range Resource

- Worldwide tidal energy potential about 500-1000TWh/year.
- Total tidal range deployment in 2014 was around 514 MW.
- Extensive plans exist for tidal barrage projects in India, Korea, the Philippines and Russia adding up to around 115 GW.

- UK is estimated to hold 50TWh/year.
- UK represents 48% of the European resource.
- Few sites worldwide are as close to electricity users and the transmission grid as those in the UK.
- Department of Energy (DoEn) studies in the 1980s, identified 16 estuaries where tidal barrages should be capable of procuring over 44TWh/year.
- The bulk of this energy yield would accrue from 8 major estuaries, in rank order of scale, the Severn, Solway Firth, Morecambe Bay, Wash, Humber, Thames, Mersey and Dee.

Tidal Range

- Tidal range technologies use: a barrage, a dam or other barrier, to harvest power from the height difference between high and low tide.

- The power is generated through tidal turbines (most of them come from hydropower design, such as bulb turbines) located in the barrage, and their commercial feasibility has been well established through the operation of plants like:
  - In France (240 MW), Canada (20 MW), China (~5 MW) and Russia (0.4 MW) from the 1960s and 1970s.
  - In 2011/2012, South Korea opened the largest and newest tidal barrage (254 MW).

- New technologies developed for tidal range power generation are:
  - tidal ‘lagoons’,
  - tidal ‘reefs’,
  - tidal ‘fences’,
  - and low-head tidal barrages.

Tidal Range

Kislaya Guba, Russia

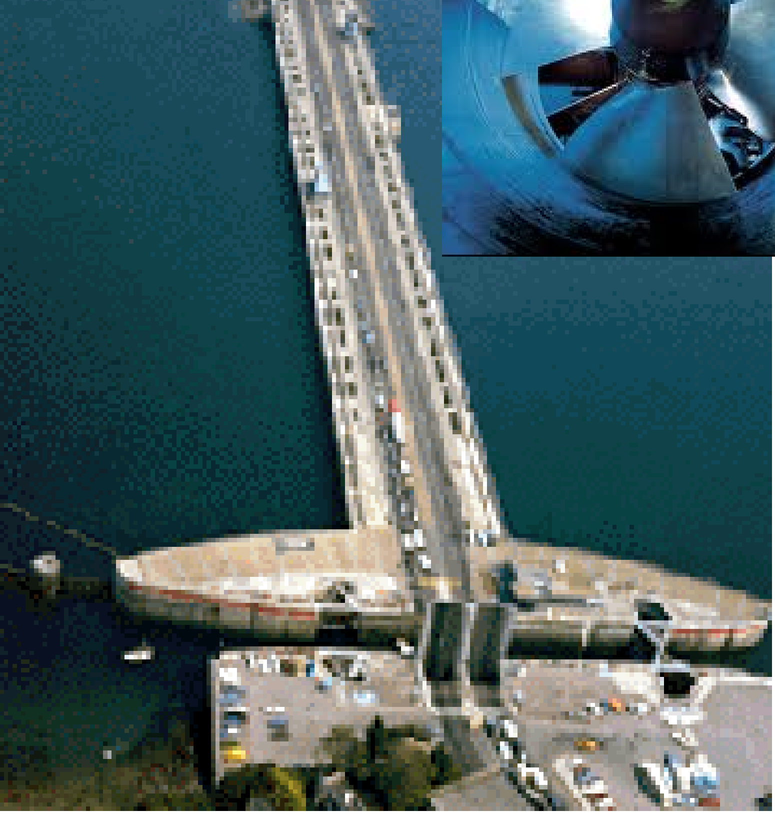
- Existing tidal references world wide include:
  - **La Rance, France, 1967**
    - Alstom Hydro
    - 5.4 m Dia. 24 Turbinesx10 MW
    - 240 MW total capacity
  - **Kislaya Guba, Russia, 1968**
    - 1 Turbine × 0.2 MW
    - 1 Turbine × 1.5 MW
    - 1.7 MW total capacity
  - **Annapolis, Canada, 1980**
    - Andritz VaTech Hydro
    - 7.6 m Dia. Straflo Turbine
    - 1 Turbine x 20 MW
    - 20 MW total capacity
  - **Jiangxia, China, 1980**
    - 1 Turbine × 500KW
    - 1 Turbine × 600KW
    - 3 Turbines × 700KW
    - 3,200 KW total capacity
  - **Sihwa, South Korea, 2011**
    - Andritz Hydro
    - 7.5 m Dia. 10 Turbines x 26 MW
    - 260 MW total capacity

La Rance, France

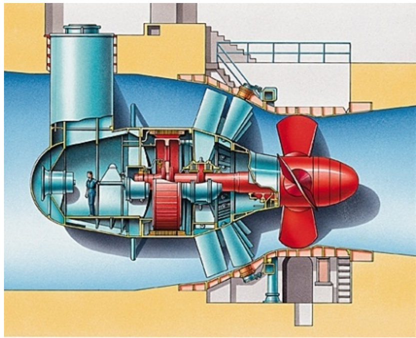
Bay of Fundy, Canada

Sihwa, South Korea tidal power plant 2011

La Rance Tidal Plant France



- Completed 1966/67
- 8 m tidal range
- 330 m long
- 22 km2 basin
- 24 x 5.4 m turbines
- 240 MW total capacity



Design data
D=5,350mm
n=93.75 rpm
H=11m
P=10 MW

La Rance Tidal Barrage Brittany, France

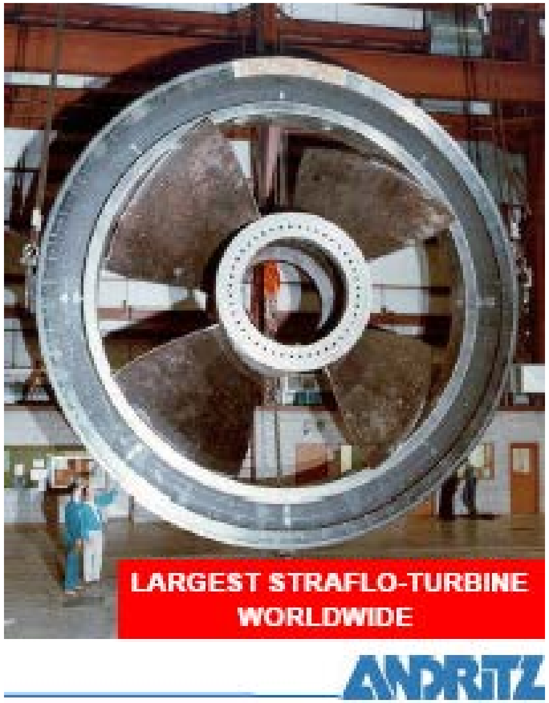
Annapolis Tidal Plant Canada

- Location: Bay of Fundy

- D=7,600mm
- n=50 rpm
- H=7.1m
- P= 20 MW

- 1 Unit

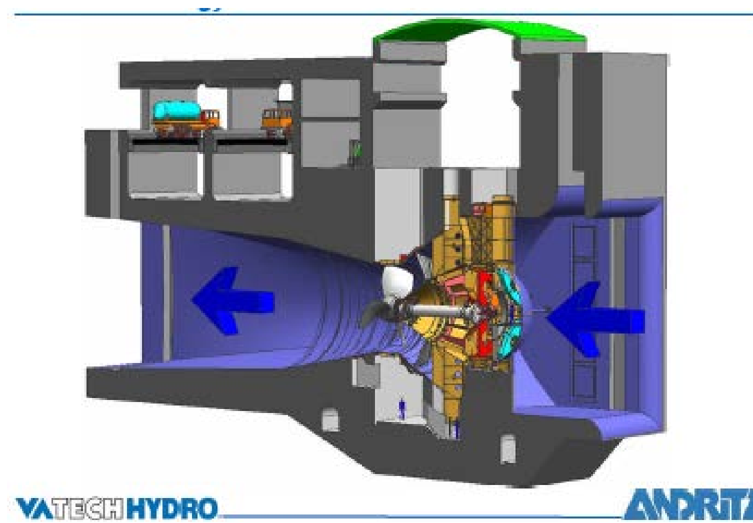
- Contract year: 1980

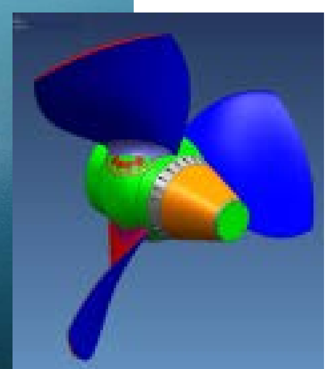


Sihwa Tidal Plant

South Korea

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





Stainless steel runner hub and blade finished machined in VA TECH HYDRO workshops

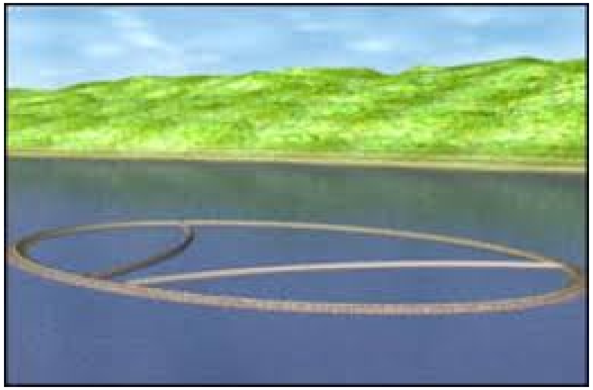
Tidal Reefs Lagoons & Fences

- **Tidal reefs** have a smaller head difference 2-3 m than the conventional 5-10 m used for tidal barrage.
- The advantage of this smaller head difference is a reduced impact on the environment and easier construction due to the lower pressure exerted on the structure.
- On the downside, the lower head would slightly lower full flow efficiency of the turbines.
- **Tidal lagoons** are similar to tidal barrage, except that they are not necessarily connected to the shore but could sit within the ocean.
- Environmental impact assessments of the proposed tidal lagoon in Swansea Bay suggest that lagoons would have lower environmental impacts than tidal barrages.
- **Ultra-low-head tidal techniques** are used for tidal barrage projects like the Grevelingen Lake in the Netherlands that would be the first ultra-low-head barrage, as the tidal difference would be only between 50 cm & 1 m.
- Several low-head tidal techniques are currently being developed, notably by a number of UK universities like Lancaster & companies, & some smaller firms in Canada & France.
- **Tidal fences** consist of a number of individual vertical axis turbines that are connected to each other within a fence structure (Godfrey, 2012).
- The fence itself could be placed between the mainland and a nearby island, or between two islands (as proposed at the San Bernardino Straits, Philippines).
- Thus far, these applications are in their early stages of development and there are no prototypes being tested in the water at present.

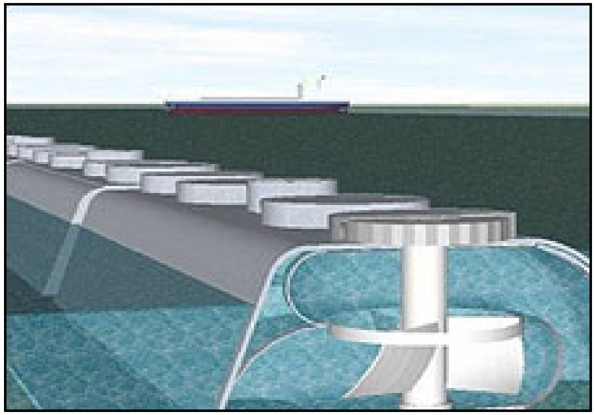
Tidal Barrage Systems

- Single-Basin
- Double-Basin

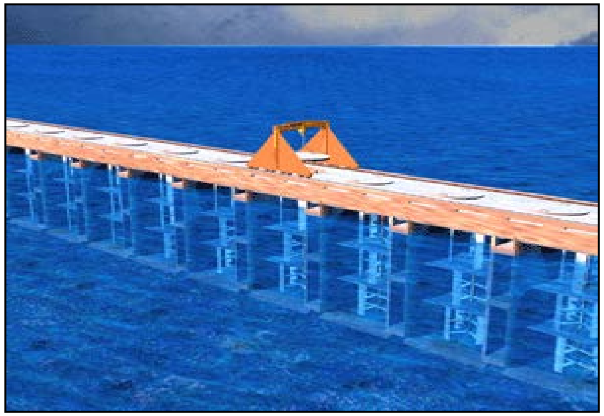
- Tidal Lagoons



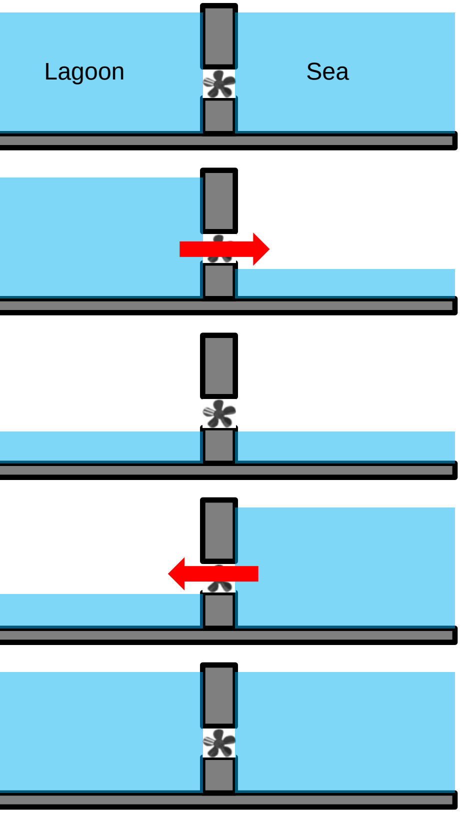
- Tidal Reefs



- Tidal Fences



Tidal Lagoons: Swansea



Starting point; high tide; lagoon full

⇩

Tide ebbs creating a head and generating power

⇩

Low tide; no head

⇩

Tide floods creating head and generating power

⇩

Return to starting point

Swansea Bay tidal lagoon project (Tidal Lagoon Power). Photograph: Tidal Lagoon Power

Swansea Bay Tidal Lagoon, is currently developing a **320 MW lagoon** (Mark Shorrock CEO). The construction of the world's first tidal lagoon power plant in Swansea Bay is scheduled to start in 2015. The 320MW capacity project (with a **design life of 120 years**) will establish a blueprint for a fleet of full-scale tidal lagoons that could between them provide **8% of the UK's electricity**.

PÖYRY Lagoon Costs 2014

- **Tidal lagoon** power projects could be **cheaper than offshore wind and some could be cost comparable to nuclear generation** (based on Tidal Lagoon Power's capital and operating cost estimates for tidal lagoons, and DECC's levelised costs for other technologies).
- The assessment of the central value for the required Contract for Difference CfD strike price for the first three lagoons studied on a volume-weighted average basis is **£111/MWh** (assuming a 35-year CfD duration). Lagoon 1 is **£168/MWh**, whilst for Lagoons 2 and 3 this falls to **£130/MWh** and **£92/MWh** respectively.
- The reduction in required strike prices in moving from Lagoon 1 to 3 is driven primarily by **moving to bigger sites** with greater tidal range **rather than** on an assumption **of technology learning**.
- The levelised cost of electricity for the first three lagoons on a volume-weighted basis is **£100/MWh**.
- The cheapest of the lagoon projects studied, **Lagoon 3, has levelised costs broadly similar to DECC's assessment of the cost of onshore wind, large scale solar PV, nuclear and gas-fired generation.**
- **Tidal lagoons** have an assumed operating **life of 120 years**.

Tidal Generation Options

Most conventional tidal range schemes use bulb turbines, which are comparable to hydropower turbines that are installed in a dam (run of rivers hydro power plant).

Tidal range technology has a number of options for power generation:

- I.) **One way power generation at ebb tide:** The reservoir is filled at flood tide through sluice gates or valves that are closed once the tide has reached its highest level. At the ebb tide, the water in the reservoir is released through the turbines and power is generated. With this single cycle, power is generated for only four hours per day. *Annapolis in Canada is an ebb generation plant.*
- II.) **One way power generation at flood tide:** At flood tide the sluice gates are kept closed to isolate the reservoir while at its lowest level. When the tide is high, the water from the sea-side flows into the reservoir via the turbines, thus generating power. The disadvantage of this cycle is that it has less capacity and generates less electricity, and it may be ecologically disadvantageous as the water level in the impoundment is kept at a low level for a long time. *Sihwa is a flood generation plant.*
- III.) **Two way power generation:** Both incoming and outgoing tides generate power through the turbines. This cycle generates power for four hours twice daily. However, reversible turbines are required. *La Rance is an ebb and flood generation plant*; **bulb turbines can also pump water for optimisation**.

Severn Estuary

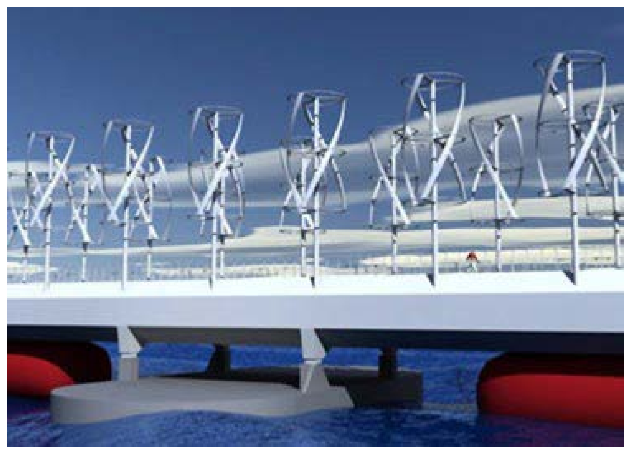
- In 2008 and 2009, a number of exploratory studies were undertaken regarding a tidal barrage in the Severn Estuary (schemes from 8600 MW to 600 MW).
- In 2010, the UK government decided that the barrage would be too risky as costs were too high, including the environmental and ecological issues.
- Several other schemes for technology development for alternatives of so called 'embryonic technologies', had less of an ecological impact, and were thus continued.
- Alternatives to a barrage in the Severn included ideas for 'tidal reefs', tidal 'fences', tidal 'lagoons'.
- Corlon Hafran, a private corporate consortium, re-launched the idea for a tidal barrage in the Severn Estuary in 2010 and has since continued studies.
- In November 2012 another private consortium launched a discussion for a tidal scheme for the Bristol Channel that included a tidal impoundment but also offshore wind and tidal current devices in the Bristol Channel (Regen SW, 2012).
- Another consortium, Swansea Bay Tidal Lagoon, is currently developing a 320 MW lagoon.
- In January 2013, DECC in the UK, published a guidance noting that their "2-year cross-government Severn tidal power feasibility study could not see a strategic case for public investment in a Severn tidal scheme in the immediate term" (DECC, 2013).

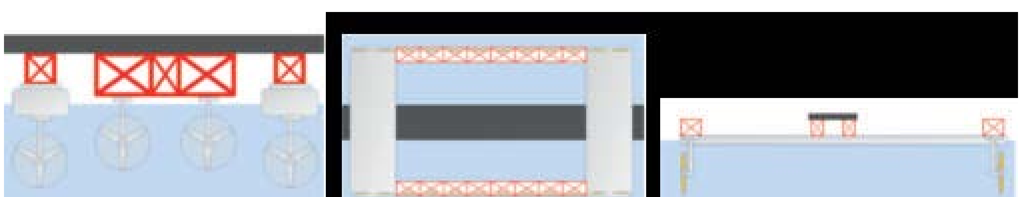
Hybrids & DTP

- Hybrid applications are forms of tidal range technologies that have great potential if their design and deployment can be combined with the planning and design of new infrastructure for coastal zones.
- Project proposals for hybrid applications exist in Canada (British Columbia), China, the Netherlands (Grevelingen), Norway (E39 road project) and the UK (Bristol Channel).
- There are plans for a hybrid form of tidal range and current power generation called 'dynamic tidal power'.
- No full-scale prototype has been tested or demonstrated yet.

Norway North South E39 road

- Coastal Highway Route E-39 planned road trajectory from north to south and Technology survey for renewable energy integrated to bridge considering solar, wind, wave and tidal energy.
- The installation costs of innovative renewables can be reduced, whilst the new structure can be designed in such a way that it best fits tidal generators. Norwegian Public Road Administration (NPRA), 2012.

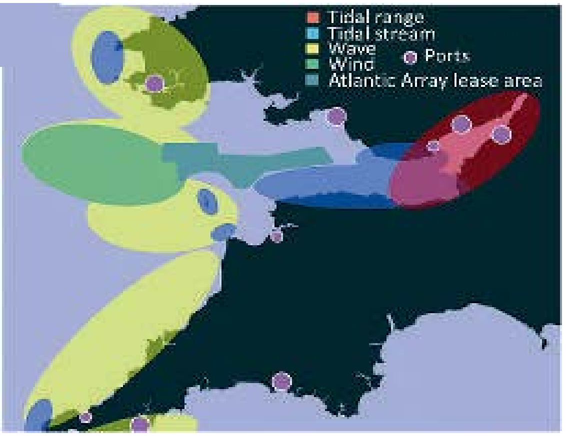




Hybrids & M F Infrastructure

La Rance Tidal Plant - EDF

Grevelingen / Brouwersdam, innovative low head turbines proposed to be installed for testing in 2014

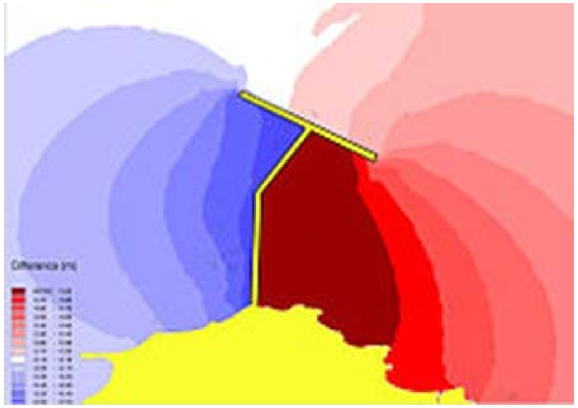


Bristol Channel, map of possible marine energy locations – Regen SW 2012

Sihwa Tidal Power Station – Andritz Hydro 2011

Hybrid Forms

- Hybrid forms of tidal energy can be found in the form of multi-purpose platforms where both tidal current and tidal range technologies are used for electricity generation. These platforms are in an early developmental and innovative stage.
- A recent development is called “dynamic tidal power” (DTP). It consists of a 30-60 km long dam that runs perpendicular to the coast line. At the end of the dam, there is a barrier forming a large “T” shape. The dam interferes with the oscillating tidal waves on either side of the dam, and creates a height difference between the water levels. This height difference creates potential energy, which can be converted into electricity using the low-head turbines that are being used in tidal ranges.
- A technical feasibility study – supported by the Dutch government – for a 8 GW DTP plant in China, is expected to be released in 2015.



Top-down view of a DTP dam. Blue and dark red colours indicate low and high tides, respectively.

Project Developers

- Leading countries are regions with good tidal resources, such as South Korea with tidal range differences of 9 m to 14 m, and Canada at various locations along the Lawrence River.
- Similarly, RusHydro is exploring tidal range projects in Western Australia together with Atlantis Resources.
- Most of these initiatives are typically multi-stakeholder projects, seeking finance from the public as well as private partners.
- Furthermore, current tidal range projects appear to have great benefits in cases where existing dams or compounds are used, and where the objective of energy production is combined with the objective to improve water quality.
- Besides the Sihwa barrage in South Korea, the Netherlands is developing a project in the Grevelingen Lake, and Canada is working on projects in British Columbia, where formerly closed impoundments are being transformed into energy producing impoundments.

Tidal Range Planning

- Tidal plants world wide in the planning process include:
  - Incheon, South Korea, 2017
    - 44 Turbines × 30 MW
    - 1,320 MW total capacity
  - Sekomodo, South Korea,
    - 1540 GWh Annual Output
    - 812 MW total capacity
  - Jindo Uldolmok, S. Korea,
    - Expand to 90 MW of capacity
  - Ansanman, & Swaseongho, S. Korea
    - Both associated with the Saemangeum reclamation project.
    - The barrages are all in the multiple-hundred MWs range
  - Garolim, South Korea
    - 20 Turbines × 26 MW
    - 520 MW total capacity

Additional Potential ~ 2,652 MW

Future Developments

There are many potential tidal barrage sites worldwide:

- **Australia:** Kimberley, Secure Bay.
- **China:** Baishakou, Xinfuyang, Jiangxia near the mouth of the Yalu River is operational, (3.2 MW and it may be expanded). China has in total seven tidal plants with a total capacity of 7.8 MW.
- **France:** Aber-Benoit, Aber-Wrac'h, Arguenon, Frenaye, La Rance, Rotheneuf, Mont St Michel, Somme.
- **India:** Gulf of Kachchh.
- **Ireland:** Strangford Lough, (1.2 MW SeaGen tidal stream system became operational in late 2008.)
- **North America:** Passamaquoddy, Cobscook, Bay of Fundy, Minas-Cobequid, Amherst Point, Shepody, Cumberland, Petitcodiac and Memramcook.
- **Russia:** Kislaya, Lumbouskii Bay, Mezen Bay (15 GW) and Tugar Bay (6.8 GW).
- **South America:** Mexico, San Jose in Argentina, Sao Luis in Brazil.
- **United Kingdom: West Coast -** Severn, Mersey, Solway Firth, Dee, Ribble, Wyre, Morecambe Bay, Dutton and the Wyre estuary. **East Coast -** the Humber, the Wash and the Thames.

Feasibility Studies

- Some of the larger sites with feasibility studies in progress include:
  - The Severn Estuary in the UK, Bay of Fundy in Canada, Mezeh Bay and Tugar Bay in Russia, and the Wash, the Mersey, the Solway Firth, Morecambe Bay, Dee, Ribble, Wyre, Dutton the Thames and the Humber Estuary in the UK.
- The small scale sites of interest from feasibility studies include:
  - Secure Bay in Australia, Sao Luis in Brazil, Garlolim Bay in Korea, the Gulf of Kachchh in India, great potential for further development of tidal power in the Bay of Fundy in Canada: the Minas Basin (over 5 GW) and the Cumberland Basin.
- There are no operational tidal lagoons at present, although a number of projects have been proposed at a variety of scales, particularly in the UK, Mexico and China.

Costs

- The construction costs for 'La Rance' were around USD 340 /kW (2012 value; commissioned in 1966), whilst the Sihwa barrage was constructed for USD 117/kW in 2011. The latter used an existing dam for the construction of the power generation technology.
- The construction cost estimates for proposed tidal barrages range between USD 150/kW in Asia to around USD 800/kW in the UK, but are very site specific.
- Electricity production costs for 'La Rance' and 'Sihwa Dam' are EUR 0.04 /kWh and EUR 0.02/kWh, however these costs are very site specific.
- Tidal range technologies can be used for coastal projection or water management, which would reduce the upfront costs.
- On the other hand, additional operational costs may occur due to the control, monitoring and management of the ecological status within the impoundment.
- Tidal current technologies are still in the demonstration stage, so cost estimates are projected to decrease with deployment.
- It is important to note that costs should not be considered as a single performance indicator for tidal energy.
- For example, the costs for both tidal range and tidal stream technologies can fall by up to 40% in cases where they are combined and integrated in the design and construction of existing or new infrastructure.

Cost indications

- Estimates from across a number of European studies for 2020 for current tidal technologies are between EUR 0.17/kWh and EUR 0.23/kWh, although current demonstration projects suggest the LCOE to be in the range of EUR 0.25-0.47/kWh with the lower range LCOE estimates based on high capacity factors and low capital cost estimates (SI Ocean, 2014).
- The Carbon Trust indicates that the highest current costs, are related to installation (35%), the structure (15%), and maintenance and operation (15%), with installation costs varying greatly according to the location (Carbon Trust, 2012).
- Costs are projected to come down with deployment levels and resource quality as the important determinants.
- Furthermore, technology developers are working hard to increase the capacity factor of arrays from around 25% to 40% and availability factor from 70% to 90% by 2020 (ETI/UKERC, 2014).
- If deployment is in the order of 200 MW by 2020, SI Ocean estimates an LCOE with a central range of EUR 0.21-0.25/kWh (SI Ocean, 2013).
- These estimates are similar to a study by the Carbon Trust, which estimated that the costs for tidal current devices will be around EUR 0.17-0.23/kWh in 2020 (Carbon Trust, 2012).
- Deployment in high or low quality resource area can increase this range to EUR 0.16-0.30/kWh (SI Ocean, 2013).
- Scaling up to around 2-4 GW – assumed to be possible by 2030 – could bring LCOE below EUR 0.20/kWh (Carbon Trust, 2012; SI Ocean, 2013).

Barriers & Drivers

- The greatest barrier to tidal range technology advances are the relatively high upfront costs related to the developments of the dykes or embankments, and the ecological implications of enclosures or impoundments.
- Moreover due to tidal cycles and turbine efficiency, the load factor of a conventional tidal barrage is around 25%, which leads to high cost of energy.
- Improvement in turbine efficiency, in particular innovative reversible turbines for ebb and flood generation, should provide a significant increase in energy yield.
- One important new avenue is the use of tidal range applications to promote ecological improvement.
- In all these solutions (e.g., in the case of the Sihwa barrage or potentially in case of the Grevelingen lake in the Netherlands), the installation of tidal range technology leads to several important societal benefits besides renewable energy.
- These include flood defence, improved environmental and ecological water quality, and fisheries and tourism functions.
- An important new application for tidal range energy under development is one which is focused on harvesting energy from low head tidal differences of less than 2 m.
- For tidal stream technologies, continued support for demonstration and grid connection of larger scale arrays will be critical.
- With these experiences, the materials, operation and maintenance costs can be improved.
- Furthermore, high installation costs of both tidal range and tidal current solutions need to be overcome through capital investments, aiding commercialisation, feed-in tariffs or investment mechanisms in innovation.
- The simultaneous R&D of new infrastructure of flood defences, coastal restructuring, bridge and road construction, also offer opportunities to advance tidal energy technologies.

Technological barriers

- The technological challenge for tidal range is to increase the efficiency of the turbines.
- For tidal current technologies, the basic technologies exist but technical challenges continue to arise due to insufficient experience with materials, working and fixing structures in a harsh environment, demonstration, a lack of information and knowledge regarding performance, lifespan, operation and maintenance of technologies and power plants.
- For tidal current technology to become a real alternative to conventional energy sources, increased attention is required to technical risks in design, construction, installation & operation.
- According to reports of the Crown Estate (2013) and the Carbon Trust (2012), costs need to be brought down to at least 50%, which is comparable to offshore-wind energy generation costs.
- Importing knowledge and experience from other industry sectors, such as offshore oil and gas installations and offshore wind farms, including risk assessments, environmental impact assessments and engineering standards, is of great importance.
- This is not an easy process due to Intellectual Property issues.
- Oil and gas technologies are often not the same as technologies for renewable projects (e.g., high spec, high cost, one-off uses vs. lower cost, mass produced).
- More extensive research on new materials and methodologies, and rigorous testing on new sub-components and complete functional prototypes is still necessary to establish these new technologies.
- For tidal current technologies, costs of fixtures to the seabed, and maintenance and installation costs need to be brought down. Additionally, more experience in deploying arrays is required.

Ecological Impact

- Experiences with artificially closed compounds have demonstrated that the costs of managing an artificial tidal basin (e.g., in the case of La Rance and Cardiff Bay) are high and need careful monitoring and planning.
- The Canadian plants are noteworthy; there was a well-documented discussion from the start of the operation in these plants about the effects on fish and marine life and how to mitigate them.
- This information is currently of high value as ecological issues set important requirements and conditions for the permitting of installations in protected water bodies.
- On the other hand, the re-opening of dams and barriers, often built between the 1950s and 1970s can have great ecological benefits for the water bodies behind them due to a creation of a gradient that is beneficial to aquatic ecology (brackish water) and an increased oxygen content; in such instances, tidal technology can also be used as a tool for water quantity management, whilst generating power.
- A more innovative type of tidal range technology, which does not close impoundments completely, is currently in the developmental phase and will also be of interest DTP.
- The challenge for tidal stream technologies is different. The ecological impacts are deemed to be less than tidal range technologies, but environmental regulators lack the appropriate expertise or tools to assess the environmental risks (Copping, 2013).
- Baseline data of biodiversity in sea waters is limited, resulting in increased costs for evidence gathering and post deployment monitoring (RenewablesUK, 2013).

Industrial Cohesion

- The development of tidal stream technologies has been linked to small and micro enterprises, many of which have been spin-offs from university projects.
- Consequently, there is a lack of cohesion within the industry, with many different designs and a number of small-scale producers.
- However, large turbine manufacturers such as ABB, Alstom, Andritz, Siemens, and Voith Hydro have entered this emerging sector by becoming involved in the start-up phase.
- This new interest is creating the conditions necessary to scale up the existing full-scale demonstration turbines into arrays.
- Since the full-fledged development and operating costs are still not clear, but can be expected to be high, especially during the start-up phase, the projects can become unviable for small and medium enterprises.
- Tidal energy still requires investment and R&D to develop and deploy viable and scalable commercial technology and infrastructure, better understand environmental impacts and benefits, and to achieve market entry.
- Most of the new projects are oriented towards helping bring technologies to a pre-commercial status, promoting easy access to research facilities or supporting the creation of new demonstration sites at sea.
- There remains a lack of knowledge of many different issues including those on various environmental impacts (e.g., mammal interaction or the impacts on the coastline due to tidal dissipation).
- Tidal energy technologies will require similar supply chains to offshore wind and oil and gas.
- The involvement of large and multi-disciplinary industries can be expected to promote synergies, which will generate economies of scale and reduce costs.

New Finance Mechanisms

- Most project costs for tidal stream technologies are provided through government funds, or by technology developers themselves.
- Australia, Canada, France, Ireland (SEAI, 2010), South Korea (Hong, Shin and Hong 2010), and the UK have had active policies to support research and demonstration of tidal current technologies (IEA-OES, 2014).
- Some countries promote a number of selected projects (e.g., in the Netherlands), while others have started a more active policy on marine energies (e.g., feed in tariffs and requests for proposals in the Canada, France, and the UK).
- However, it is still difficult to provide the necessary financial framework conditions in the long term (beyond 2020).
- The need for new finance mechanisms is particularly relevant for the tidal stream technologies that have been tested at full scale, but will require market pull mechanisms to deploy at scale (Bucher and Couch, 2013).
- Possible ways of attracting investments could be by offering tax rewards for investors, by attracting end-users, or by feed-in tariffs that would make high-cost, pre commercial installations more attractive.
- Furthermore, suitable mechanisms for risk sharing or lowering insurance risks could reduce the overall project costs.

Tidal Energy Policies

Country	Tidal energy targets	Ocean energy feed-in tariff (FIT)	Open sea testing centre	Research, Development & Demonstration support
Australia				Support for demonstration projects
Belgium		Eligible for green certificate scheme	1 operational	
Brazil				R&D programme for ocean energy
Canada	Marine Renewable Energy Technology Roadmap	Community FiT for tidal power	2 operational	CAD 4 million, Marine Renewable Energy Enabling Measures Programme
Chile		Special FiT being developed	1 planned	
China	National Ocean Technology Centre (NOTC) is developing 2030 strategic report	Specific FiT for ocean energy	1 under development	Special funding programme for ocean energy (SFPMRE); Establishment of Administrative Centre for Marine Renewable Energy (ACMRE)
Denmark		FiT of EUR 80/MWh (uniform across all renewables)	1 operational	EUR 3.4 million for wave projects 2014-2015
European Commission (EC)	Strategic Initiative for Ocean Energy			NRE300 programme;

Notes: [a] The Renewable Energy Sources Act, or Erneuerbare-Energien-Gesetz (EEG) in German
[b] National Renewable Energy Action Plan
[c] Renewables Portfolio Standard
[d] Renewables Obligation Certificates

Country	Tidal energy targets	Ocean energy feed-in tariff (FIT)	Open sea testing centre	Research, Development & Demonstration support
France	380 MW by 2020	FiT of EUR 150/MWh	2 test sites for tidal energy	Financial support for five demonstration projects
Germany		Tidal power covered under EEG[a]		Research programme for next generation maritime technologies
Ireland	Explicit target in NREAP[b]	Planned FiT of EUR 0.28/kWh	1 operational, 1 under development	R&D budget for tidal energy
Italy	Explicit target in NREAP			
Japan				Ocean energy technological research and development project
New Zealand			1 planned	Marine Energy Deployment Fund (2007-2011)
Portugal	Explicit target in NREAP	FiT halted	1 planned	
South Korea	Specific targets in renewable energy plan	Ocean under RPS[c]		Large and growing R&D fund for tidal power
Spain	Explicit target in NREAP	FiT suspended in 2012	1 operational 1 planned	National and state funding available
Sweden			3 operational	
UK	Explicit target in NREAP	Tidal projects covered under ROC[d] scheme	3 operational, 1 planned	Commercialisation and investment funds; Demonstration scheme;
USA		Eligible for Clean Renewable Energy Bonds and Renewable Electricity Production Tax Credits	2 operational, 1 planned	Grants available for companies

Based on: SI Ocean, 2013; Asia-Pacific Economic Cooperation (APEC), 2013; IEA-OES, 2014.

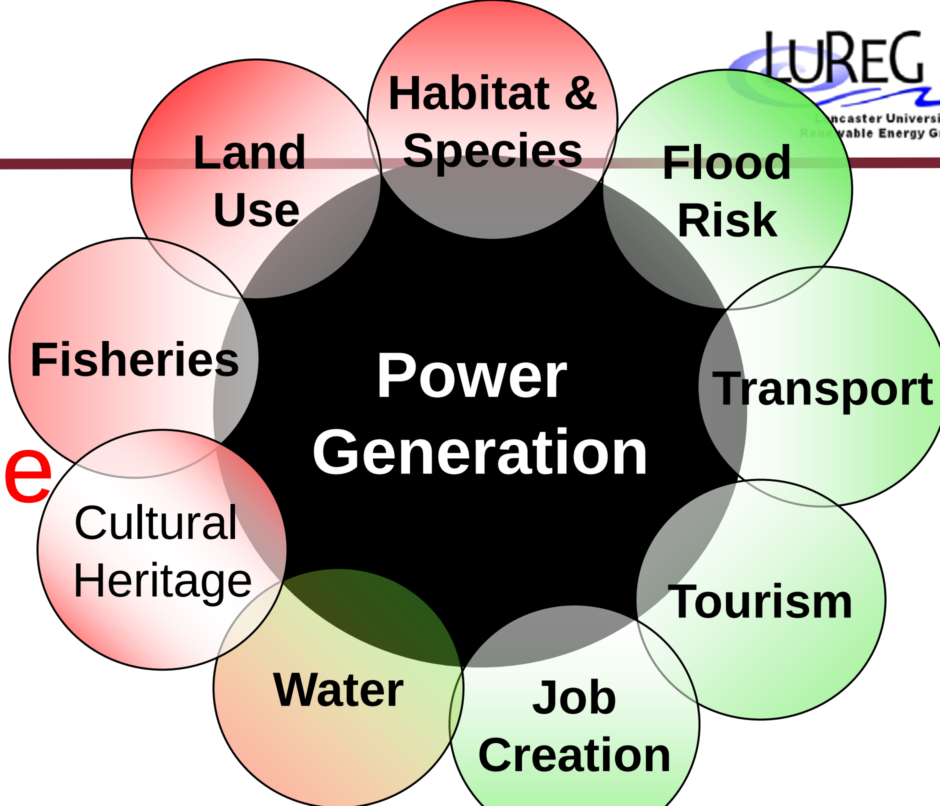
Grid Infrastructure

- For tidal stream technologies, grid connections to onshore grids can also be problematic. Some coastal countries, such as Portugal, the Netherlands, Norway, the South West of the UK and some regions of Spain, have high voltage transmission lines available close to shore, but many coastal regions, where the tidal energy resource is available, lack sufficient power transmission capacity to provide grid access for any significant amount of electricity. A number of open sea test centres have yet to establish grid connections.
- Similar problems have been identified for offshore wind. In Europe, the European Commission together with industry and Member States is supporting the development of an integrated offshore grid structure to deliver offshore wind to consumers, notably through the activities of the North Seas Countries Offshore Grid Initiative (NSCOGI). This takes into account the growth possibilities for offshore wind farms and defines options to build a European offshore grid.
- Port facilities will also be important for further development. Installation, operation and maintenance (O&M) of marine systems is expensive and even more if this will be performed in highly turbulent and changeable waters.
- In order to reduce time and cost on O&M, the alternative of unplugging the tidal energy converters from their offshore emplacement and performing the maintenance at a safe and more accessible port facility, is being considered as a real option. This, together with other auxiliary services would need the appropriate space and port facilities, making it necessary to consider the correct planning and management of infrastructure for the coastal areas where tidal energy represents a real energy alternative.

Planning & Licensing

- Coastal communities and those engaged in more traditional marine activities tend to be critical of the impact of new, innovative technology.
- Planning and licensing processes for ocean energy therefore need to be open and comprehensive enough to take these concerns into account.
- However, in contrast to spatial planning on land, countries generally have limited experience with, and sometimes inadequate governance and rules for, planning and licensing in the marine environment.
- This is particularly true for sensitive areas in relation to environmental protection and nature conservation.
- The lack of processes for guidance, planning and licensing marine activities in areas where many different interests (transport, energy, tourism, fisheries, etc.) coincide, tends to increase uncertainty and therefore a risk of delays or failure in marine projects.
- This can be a barrier to securing investments.
- Early and adequate involvement of stakeholders is also important under these circumstances.
- The challenge, for particularly innovative tidal energy projects, is to develop plans, which from the start significantly mitigate any negative environmental effects.

Multi Functional Infrastructure & Power Generation



- **Barrage schemes** are unique amongst power installations, being inherently **multi-functional** infrastructure, offering **flood protection**, possible **road** and **rail** crossings and significant **amenity / leisure** opportunities, amongst other features.
- Thus, a fully **holistic treatment of overall cost-benefit** is imperative for robust decision-making. It is suggested that, to date, this position has been inadequately addressed in the formulation of **energy strategy**, especially in respect of barrages' potential strategic roles in **flood defense** and **transportation planning**.
- It follows, therefore, that apart from the direct **appraisal of energy capture**, other **complementary investigations** must be sufficiently advanced to enable proper input in decision-making in respect of these 'secondary' functions, as well as the various potentially **adverse issues**, such as **sediment regime change**, impact on **navigation** and **environmental modification**.

Multi Functional Integration

- Tidal range technology being relatively new, most of its projects and work are particularly focused on the technology of the device itself and its direct infrastructure.
- However, for larger schemes, a connection to other factors such as shipping, recreation, water defence and ecological impact could not only bring down installation costs (by better coordination of infrastructure), but also other types of costs and societal acceptance.

a. This is in part demonstrated through the Norwegian Road Administration (2012).

b. The North West Business Leadership Team, proposed the North West Energy Squared Model, a series of multi functional tidal gateways along the North West coast of England (2014).

c. For tidal stream technologies, there are a number of plans for hybrid systems combining floating offshore wind with tidal current technologies (e.g., a 500 kW demonstration plant by MODEC in Japan).

- However, in most cases tidal current technologies do not match well with offshore wind parks as the required strong tides increase the installation costs of the offshore wind parks.

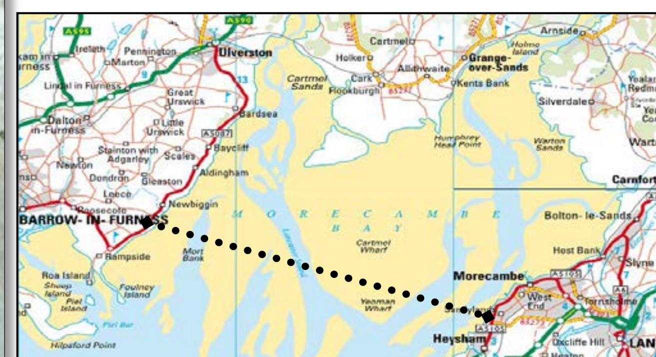
NW Tidal Proposals

Mersey - Peel Energy

Solway - Solway Energy Gateway

Wyre - Natural Energy Wyre

NWBLT - NWEnergy^2 Model



Morecambe Bay - Bridge Across the Bay

Policy

- **Tidal energy policy** has been the **main driver for tidal energy development** as demonstrated by countries such as Canada, France, Portugal, the UK and the USA. Internationally tidal energy policies now form a key component of most governmental sustainable energy policies.

- The principal objective of these sustainable energy policies is to **increase security of energy supply**, while **reducing costs and environmental effects**. This objective can be achieved by diversifying the sources of energy, increasing renewable energy deployment, reducing reliance on fossil fuels, and reducing CO_2 emissions.

- Tidal energy policies generally consist of mechanisms to assist the development of technology such as: **Financial and Tax Incentives, Research and Development Funding, Feed-In Tariffs, Carbon Tax, Mandatory Renewable Energy Targets and Improvements in Planning Process.**

Conclusions

- The **UK** has substantial **potential of tidal** renewable energy generation, to about **20%** of present UK demand.
- **Eight major estuaries** capable of meeting at least **10%** of present electricity demand, employing fully proven technology.
- The **UK** has **tidal stream** practicable potential to about **5%** of present electricity demand.
- **NW** potential from **barrages** at least **5%** of present electricity demand.
- Tidal **barrages** in the estuaries of the **NW** capable of meeting about **50% of the region's electricity** needs.
- **Effective tidal energy policies** and favourable discount rates are critical for the development of tidal energy so it can play a vital role in a sustainable energy future with minimal environmental impact.
- **The Challenge** is for engineers and scientists to deliver UK's marine renewable energy targets
- **The Opportunity** is for the UK to deliver renewable energy with minimal environmental impact
- **Engineers** can solve the problems but **politicians** need to provide leadership, remove barriers and allow sufficient time for some potentially spectacular successes.

Thank you

Tidal Energy & Technology Current Trends

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