ENV-5022B
Low Carbon Energy: 2016 - 17
Tidal Power

Websites: http://www2.env.uea.ac.uk/energy/energy.htm
www.uea.ac.uk/~e680/energy/energy.htm

Recipient of James Watt Gold Medal

CRed
carbon reduction

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Tidal Power

- **Tides arise from the rotational motion of the earth**

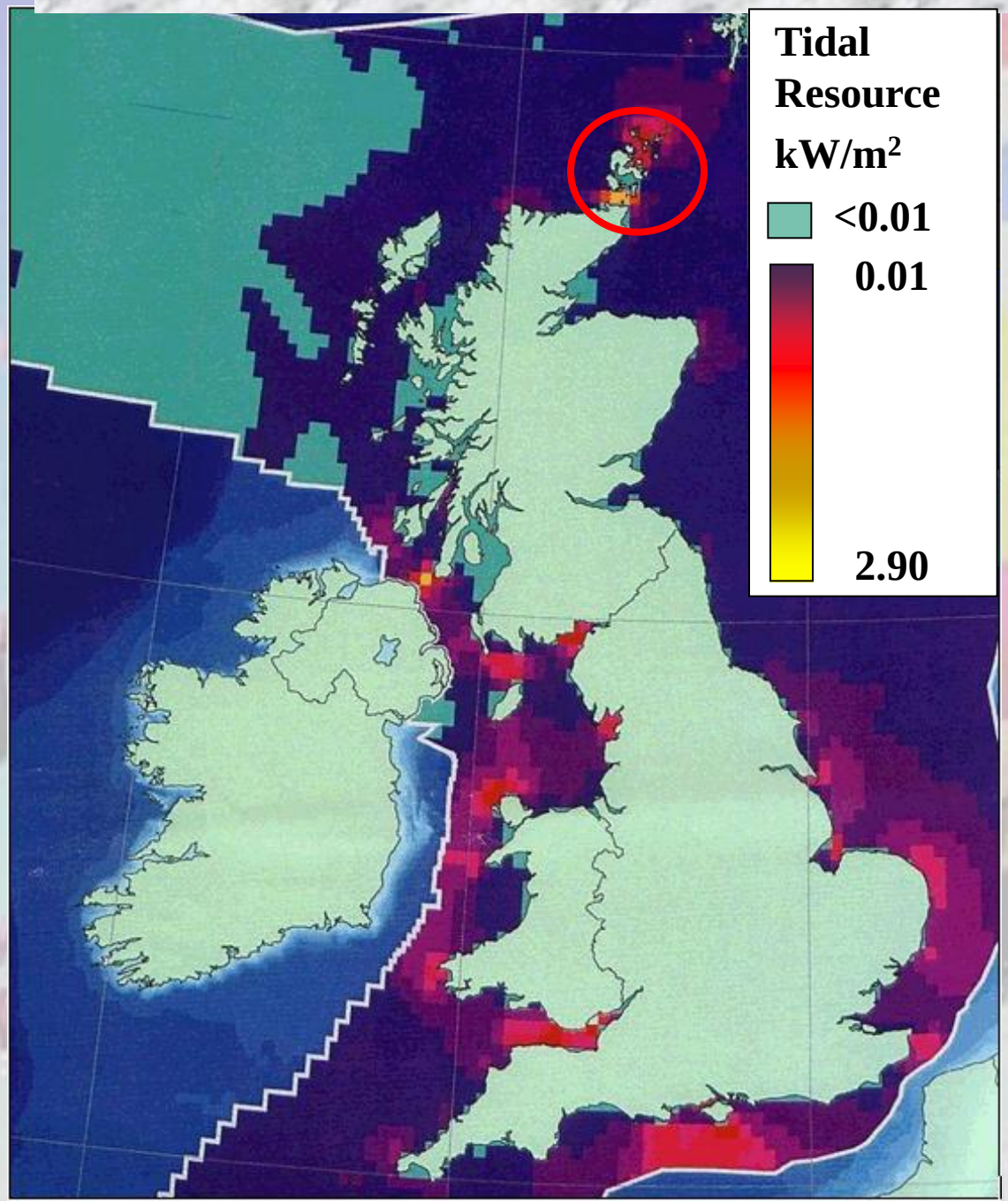
  > differential gravitational field set up by the Earth, Moon, and Sun.

Several different tidal cycles:-

- **a semi-diurnal cycle - period 12 hrs 25 mins**
- **a semi-monthly cycle - (i.e. Spring - Neap Tides) corresponding with the position of the moon.**

  Sun, Earth and Moon in approximate alignment >> Spring Tides,
- **a semi-annual cycle - period about 178 days which is associated with the inclination of the Moon's orbit. Causes highest Spring Tides to occur in March and September.**
- **Other long term cycles - eg a nineteen year cycle of the Moon.**
- **Spring Tides have a range about twice that of neap tides, while the other cycles can cause further variations of up to 15%.**

Tidal Power – The Resource



Resource is measured in terms of kW/m² of vertical column of water

Tidal Power

- The Tidal range is amplified in estuaries, and in some situations, the shape of the estuary is such that near resonance occurs – e.g Severn Estuary, Wash, Mersey.
- Other good locations for tidal energy – between islands
  - Race of **Aldernay**
  - **Pentland Firth**
  - **Eynhallow Sound in Orkney**
  - **Fall of Warness, Orkney**

Tide Mill at Woodbridge in Suffolk worked for several hundred years until finally closed in 1960s

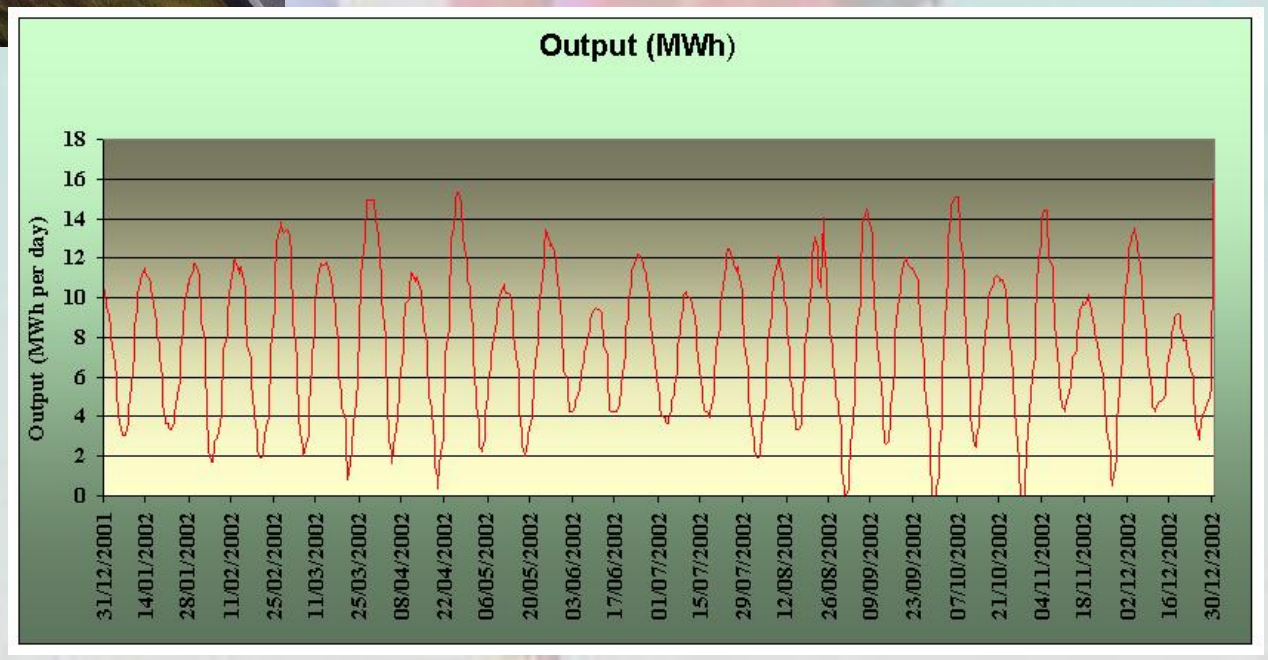
Tidal Power – Possibilities

- Churchill Barriers, Orkney

Tidal Power – The Resource

Example of possible scheme in Orkney:

Potential Output from 40 x 5m diameter turbines in one Churchill Barrier over whole of 2002



Average demand for one house in Orkney ~ 12 kWh per day

Tidal Power

- **A barrage placed across such an estuary can affect the resonance conditions :**
  - **can enhance or suppress potential range,**
  - **careful modelling is needed.**

- **Potential power is approximately proportional to area impounded and the square of the tidal range. Thus about 4 times as much power can be generated at spring tides as at neap tides.**

- **For the Severn Estuary it has been found that**

$$P = (0.0398 * A)^{0.97}$$

Where A is impounded area and P is annual energy in TWH

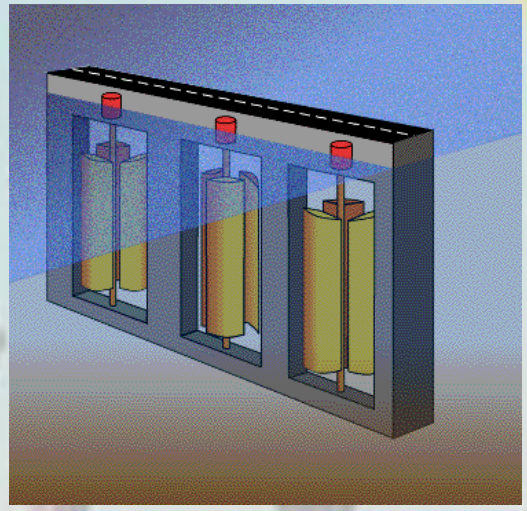
Tidal Power

- Barrage Schemes – a barrier is constructed across an estuary

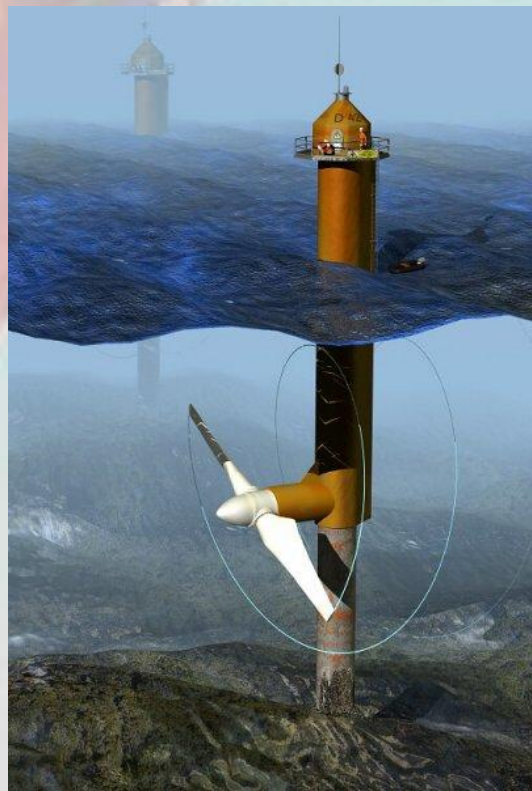
La Rance – only sizeable plant in world – 240 MW

Constructed in 1966

- **Tidal Stream (under water turbines)**
- **Tidal Fence (a variant of Barrage and tidal stream)**



Unlike barrage does not provide for a road link.

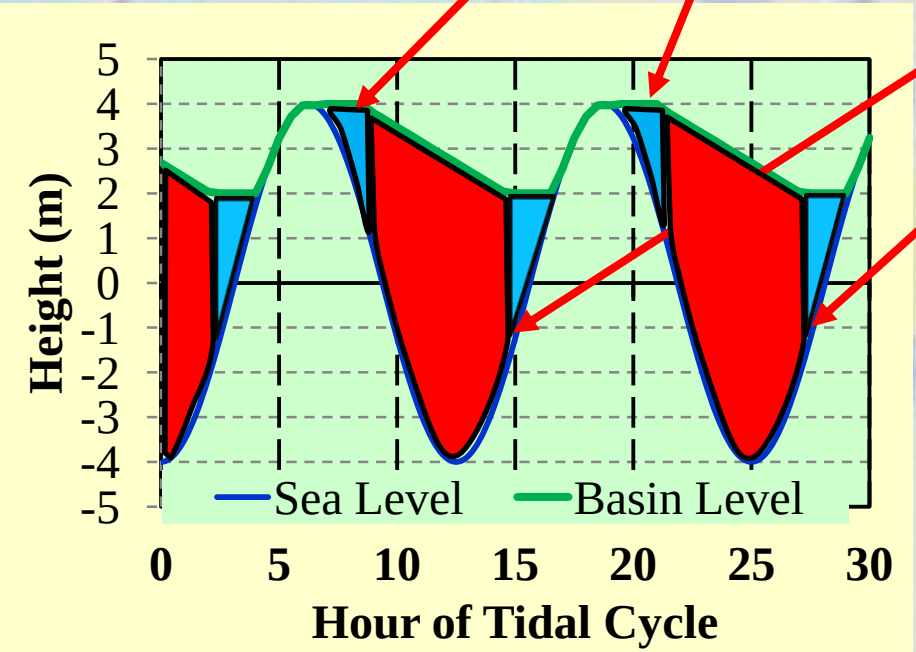


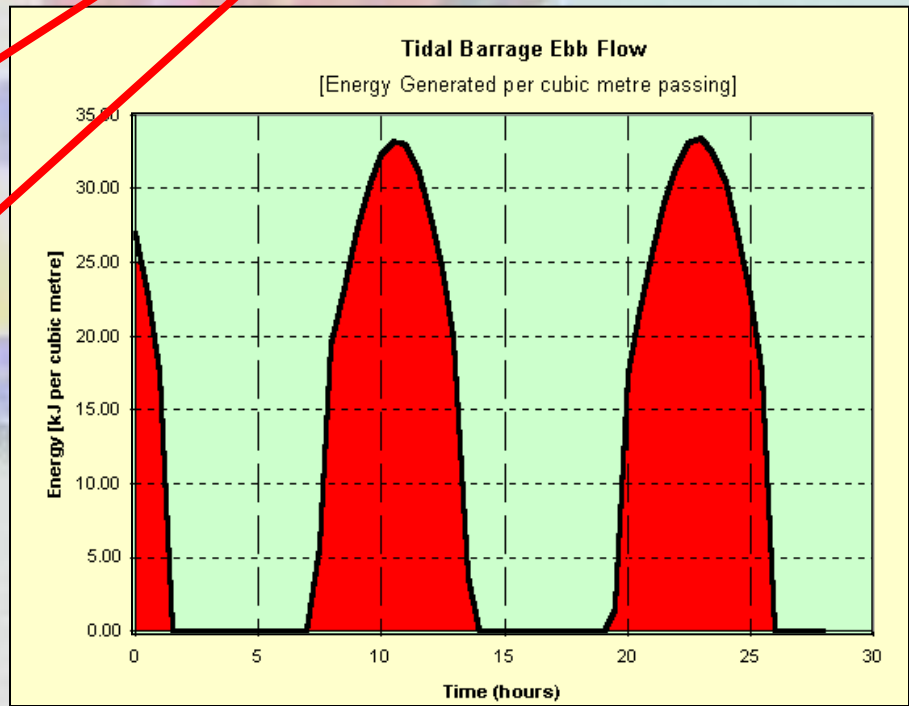
- **Tidal lagoons (a variant of barrages)**

Tidal Power – Barrage Schemes

Ebb Generation Flow:

- **Basin fills as tide rises through Sluice Gates**
- **Sluice Gates closed at High Tide and basin level held until tide falls to provide sufficient head difference.**
- **Generation ceases when head difference falls below critical level**
- **Generation is restricted to ~ 6 hours in any tidal cycle**
- **Predictable but since tides are on 12.5 hour cycle generation may not coincide when needed most.**
- **Mean basin level higher than natural situation – issue for wading birds**

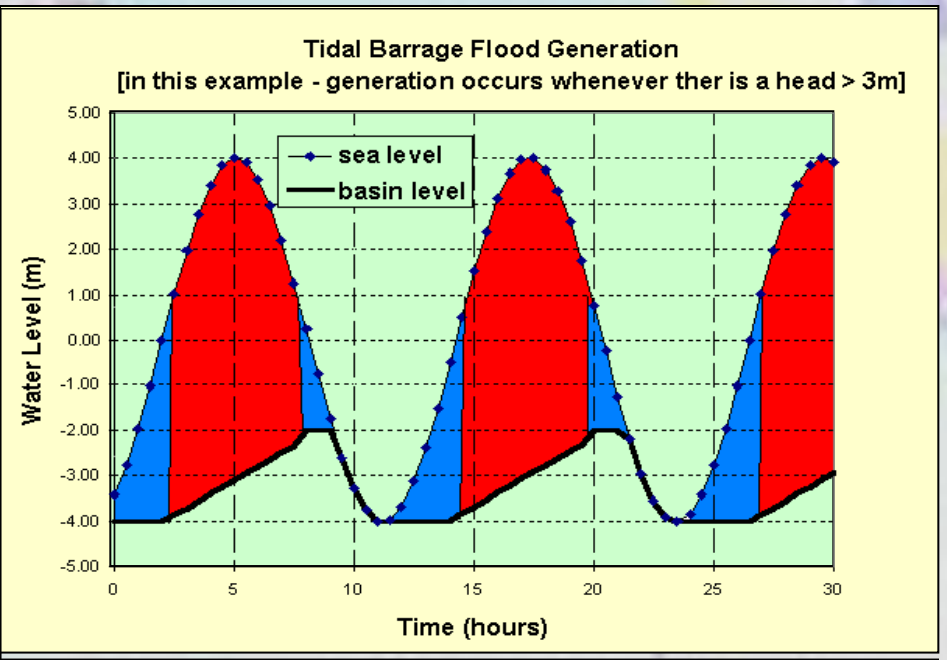


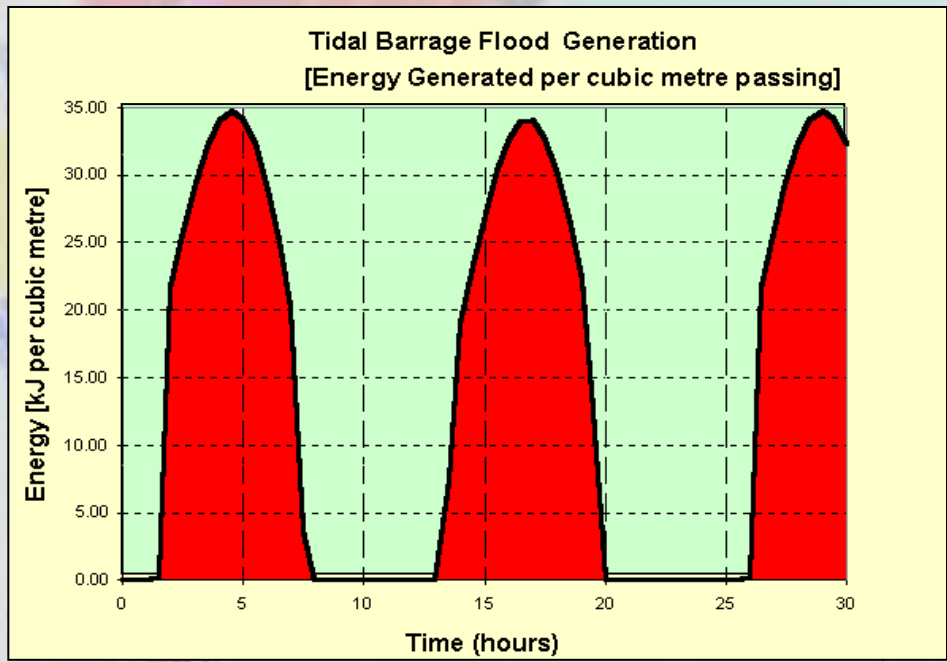


Tidal Power – Barrage Schemes

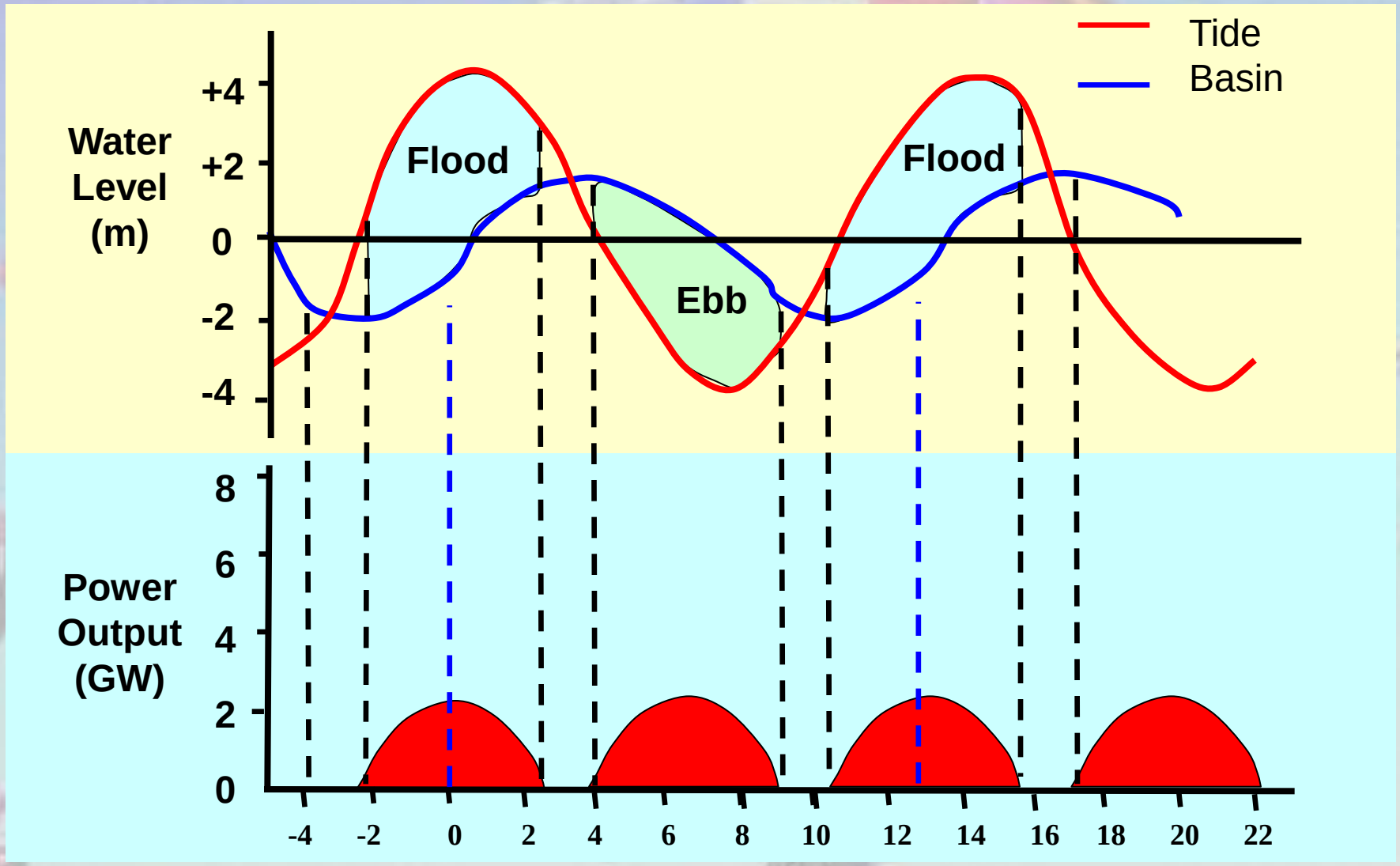
Flood Generation Flow:

- Basin is empty at low tide
- Sluice Gates closed and no generation until tide level rises to provide sufficient head
- Generation occurs as water flows into basin ceases after high tide when head difference falls below critical level.
- Sluice gates opened to drain basin at low tide
- Generation is restricted to ~ 6 hours in any tidal cycle
- Generally less generation than on Ebb mode.
- Mean basin level lower than natural situation – problems for shipping





Tidal Power – Barrage Schemes – Two Way Generation



- Example shows possible power from a Severn Barrage Scheme
- Less Power than EBB scheme, but better distribution through day

Tidal Power – Severn Barrage Scheme

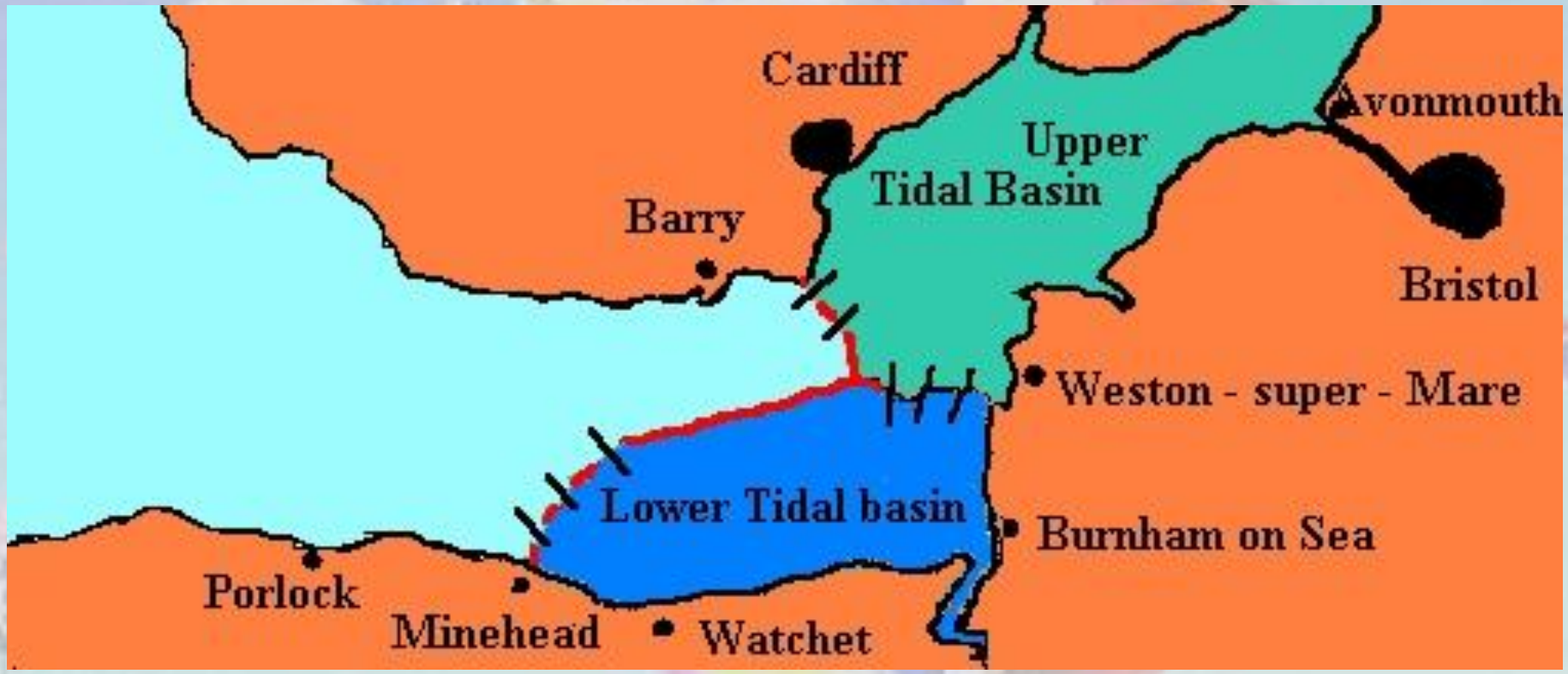
- **Single Basin – derived from Bondi Report EP46**

Opportunity to build this at time of Second Severn Crossing was missed – part of cost could have been from provision of new road link.

Location would be further downstream, but benefit now from a further additional road link is limited.

Tidal Power – Severn Barrage Scheme

- **Double Basin – based on DECC Consultation 2009**



- **Upper Basin filled at High Tide**
- **Lower Basin emptied at low tide**
- **Could provide power on demand**
- **Could incorporate pumped storage – not costed in design**
- **Would provide better access for shipping through upper basin (albeit via locks)**
- **Would increase time of mud flats for wading birds in lower basin (albeit slightly displaced in location)**

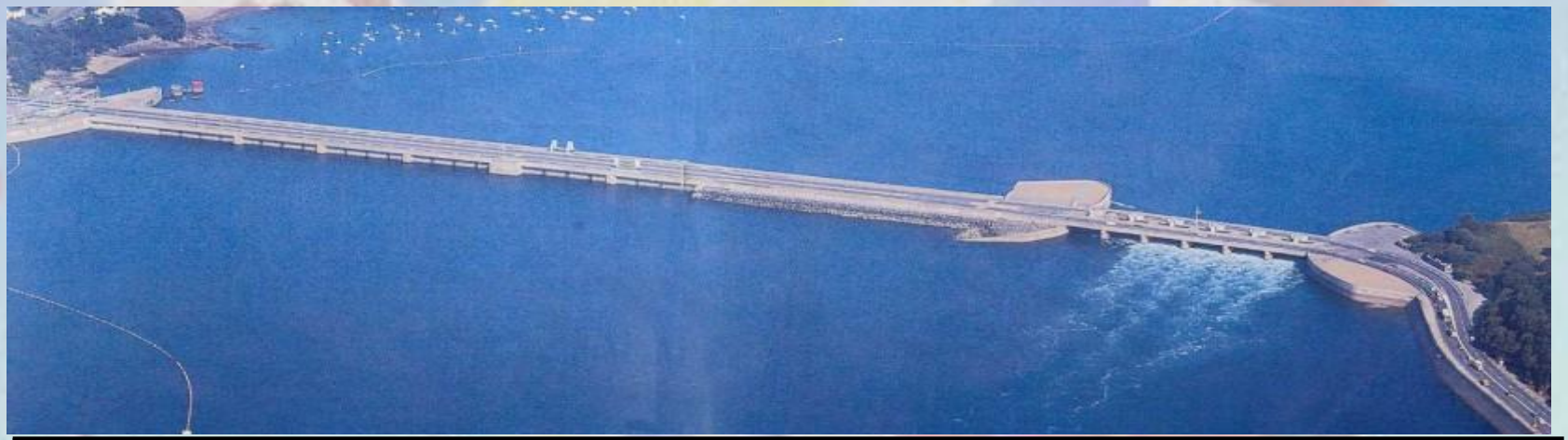
Tidal Power – Severn Barrage Scheme

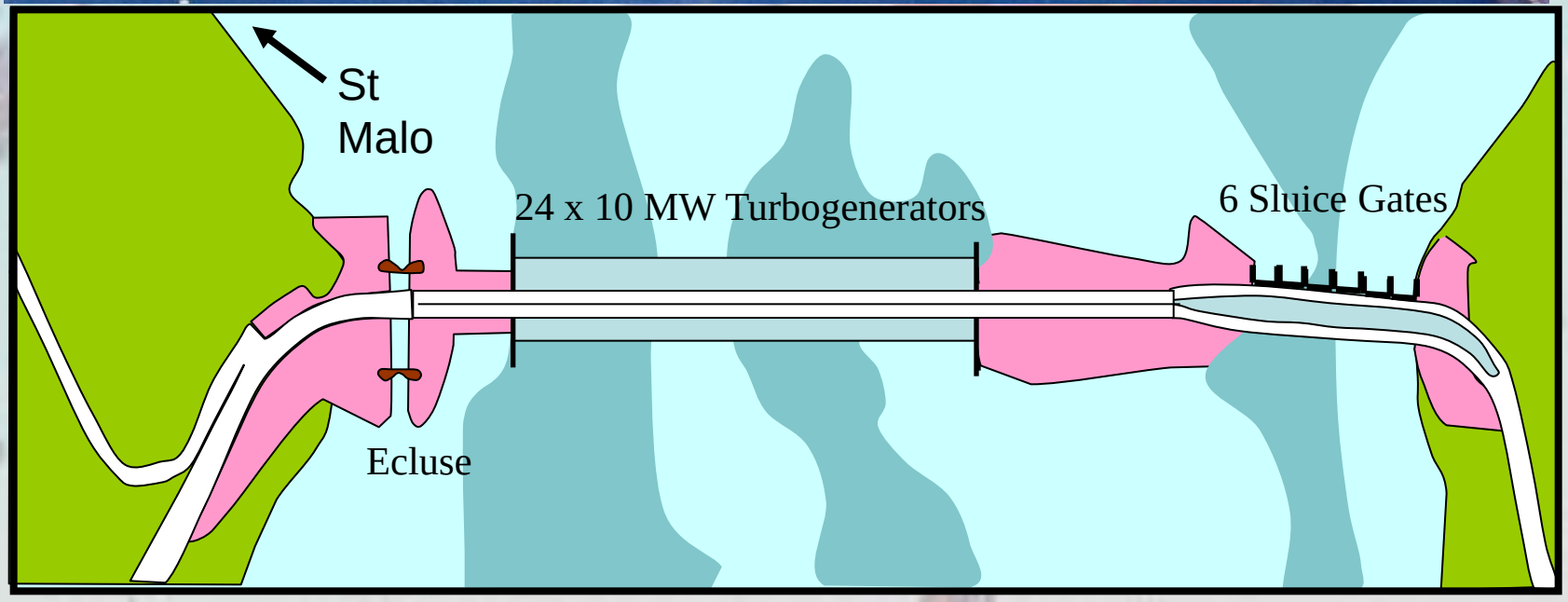
Minehead Barrage – DECC Consultation 2009

- **Large Single Barrier -would provide greatest generation, but would also cost much more, but may, overall be more cost effective over its lifetime.**

Tidal Power – Barrage de la Rance, St Malo

- **Constructed in 1966 – 240 MW peak output**

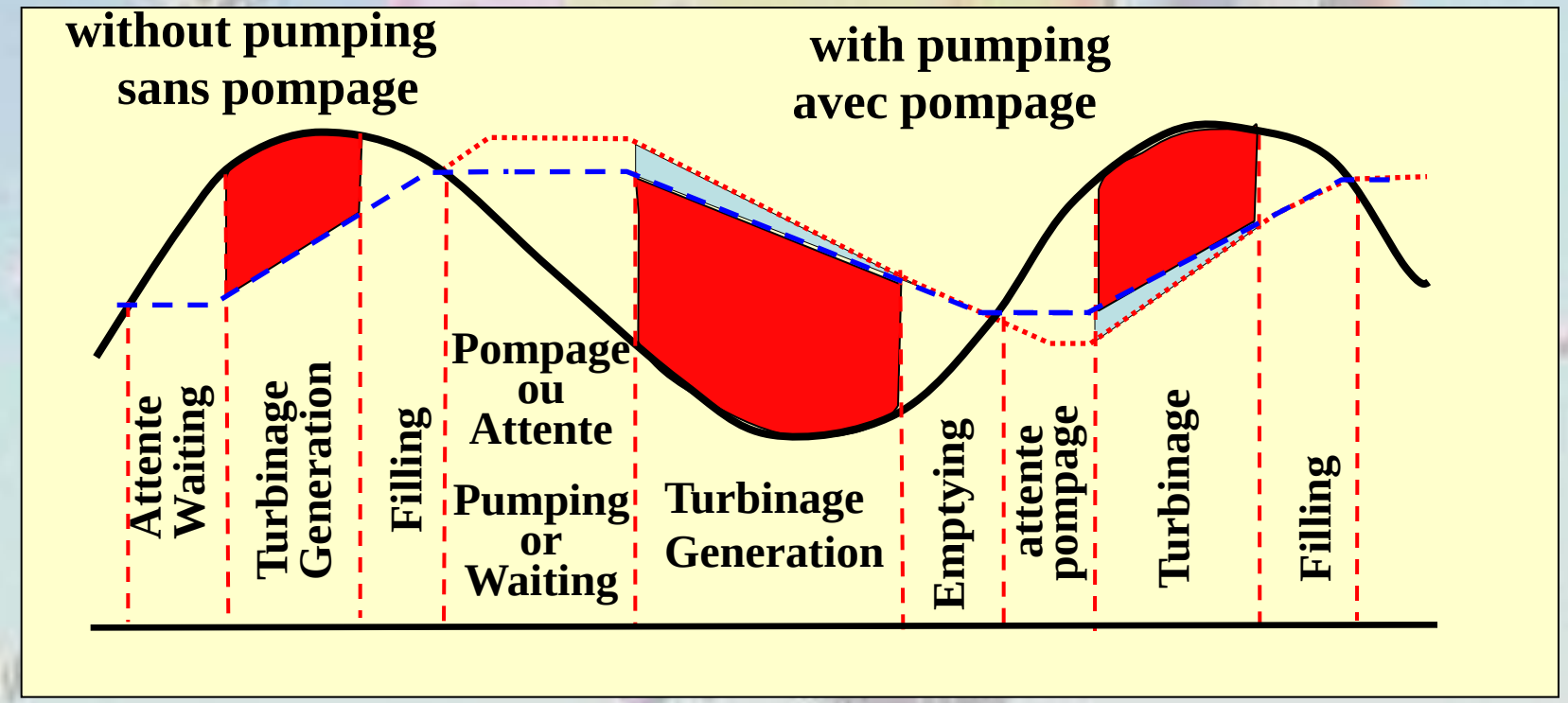




Tidal Power – Barrage de la Rance, St Malo

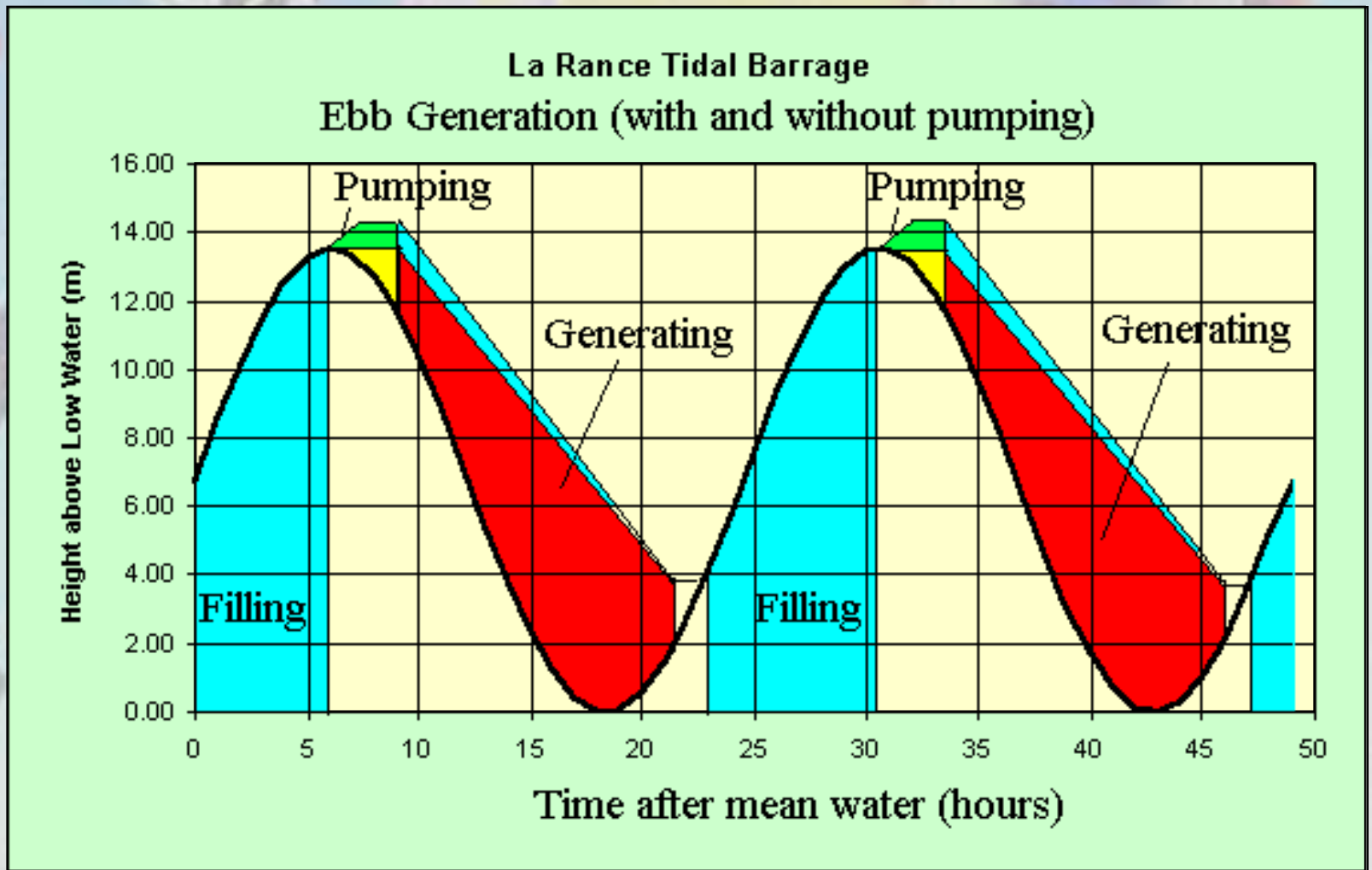
Two way generation

Flood **Ebb**

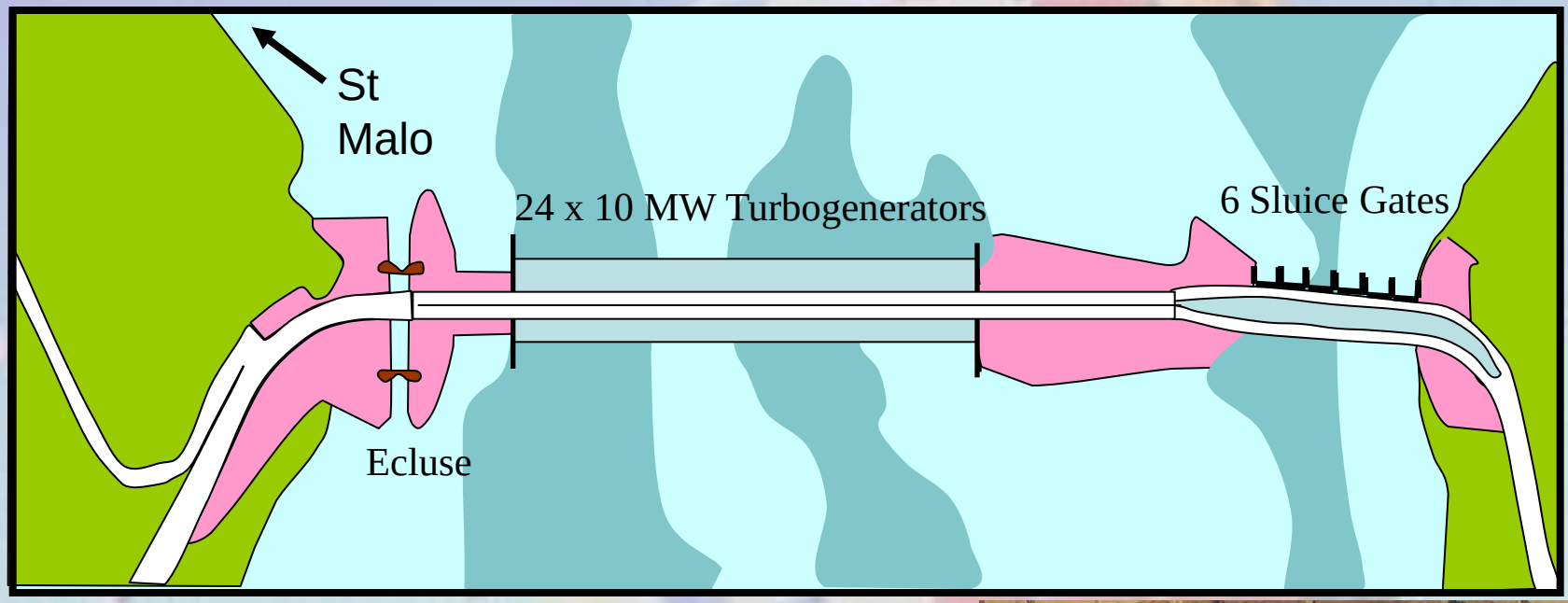


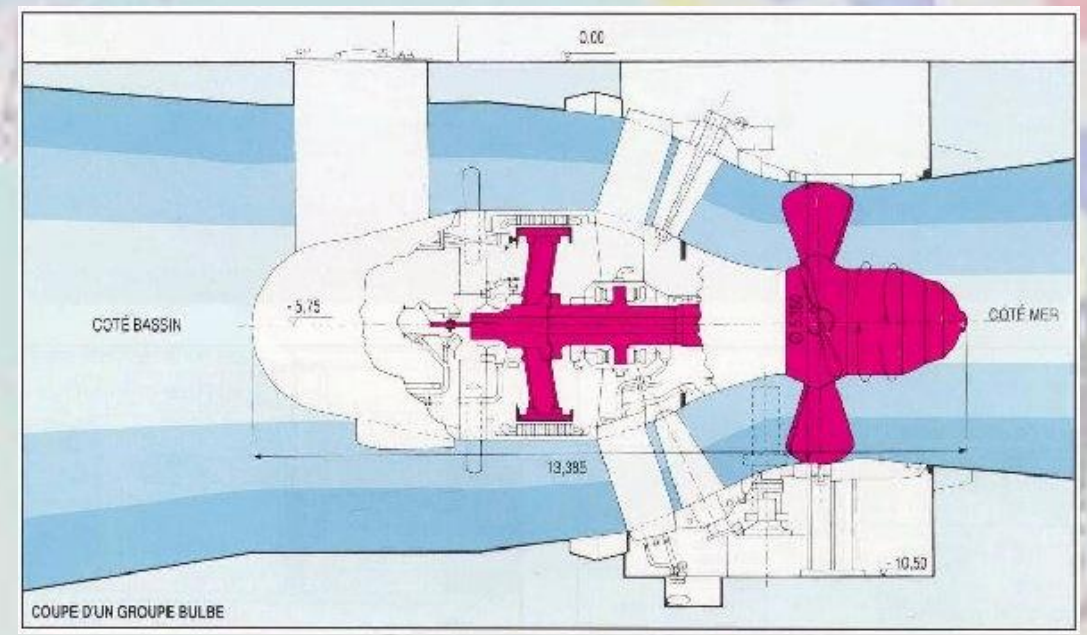
Tidal Power – Barrage de la Rance, St Malo

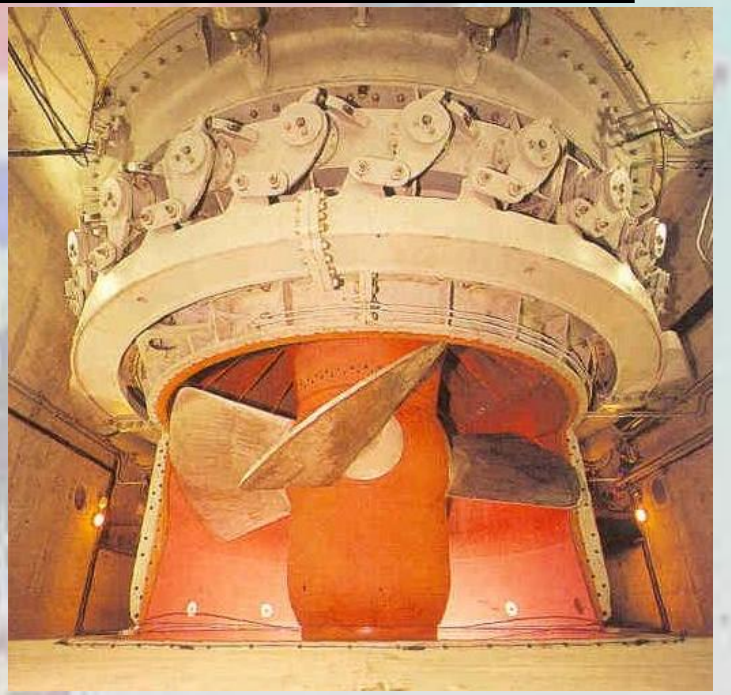
- Can use pumping at high tide to enhance output.
- Pumping not done if it coincides with peak demand
- Pumping is done over low head – generation over higher head – hence a net energy gain.



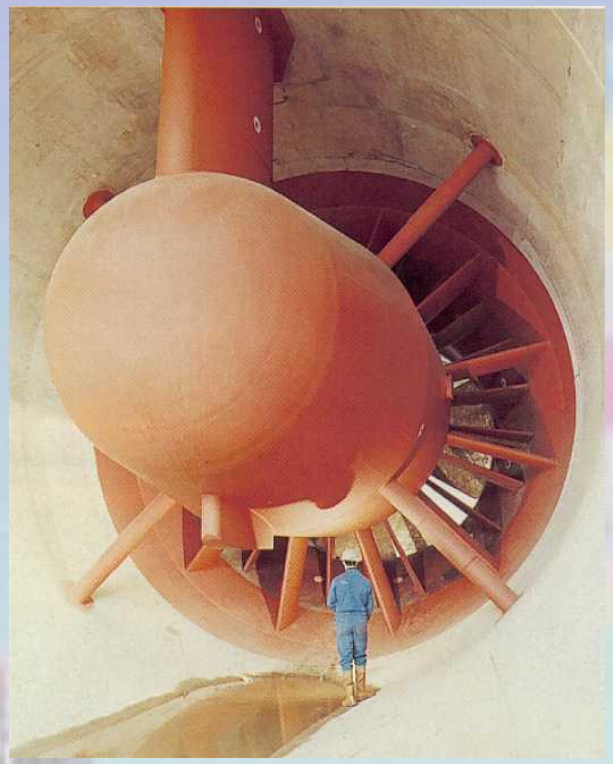
Tidal Barriers – La Rance

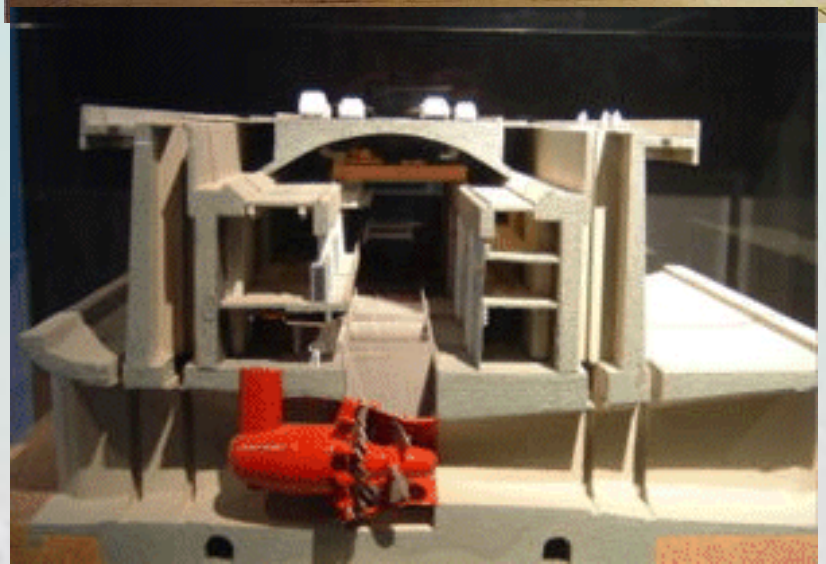






Tidal Power – Barrage de la Rance, St Malo





Tidal Power – Barrage de la Rance, St Malo

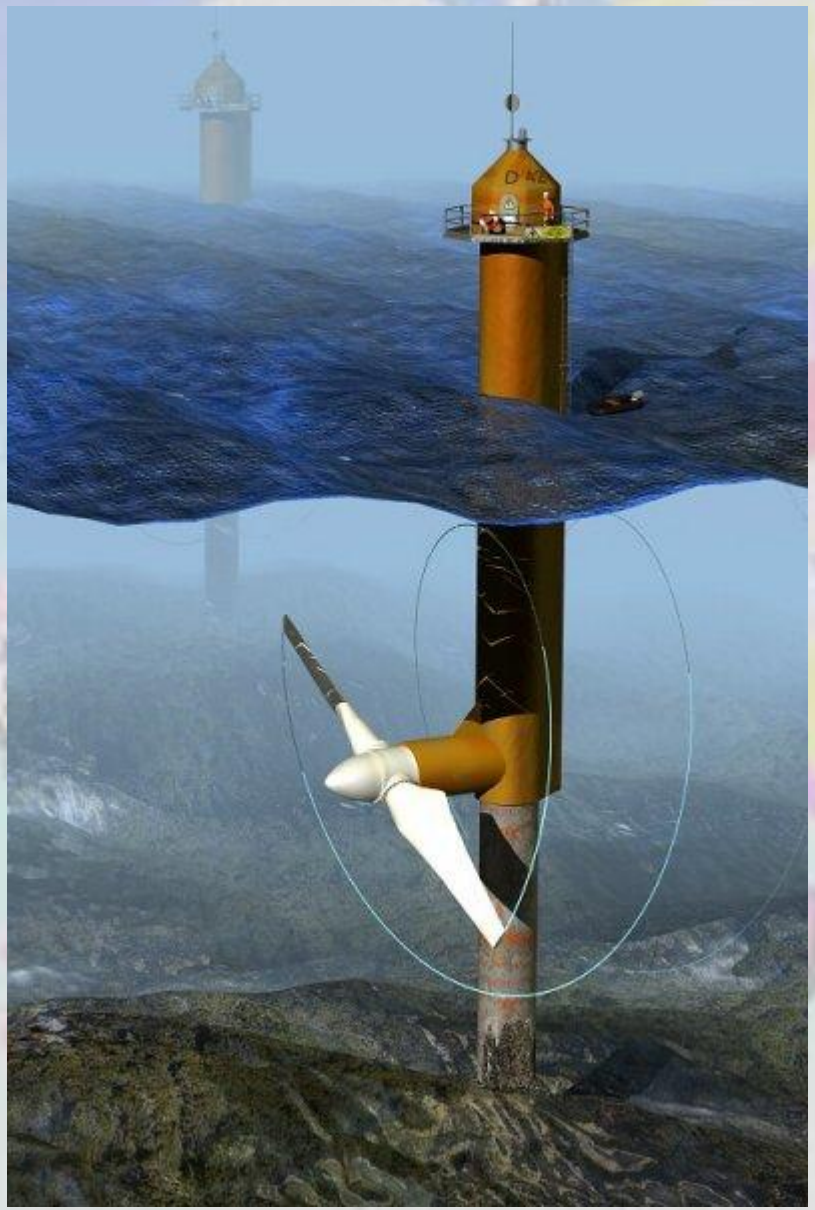
Vortices created during generation at La Rance

The Sluice Gates

Energy Field Course 2001

Tidal Power – Tidal Stream

Under water Turbines



First Open Hydro device installed in Orkney in 2007. Later designs sit on sea bed

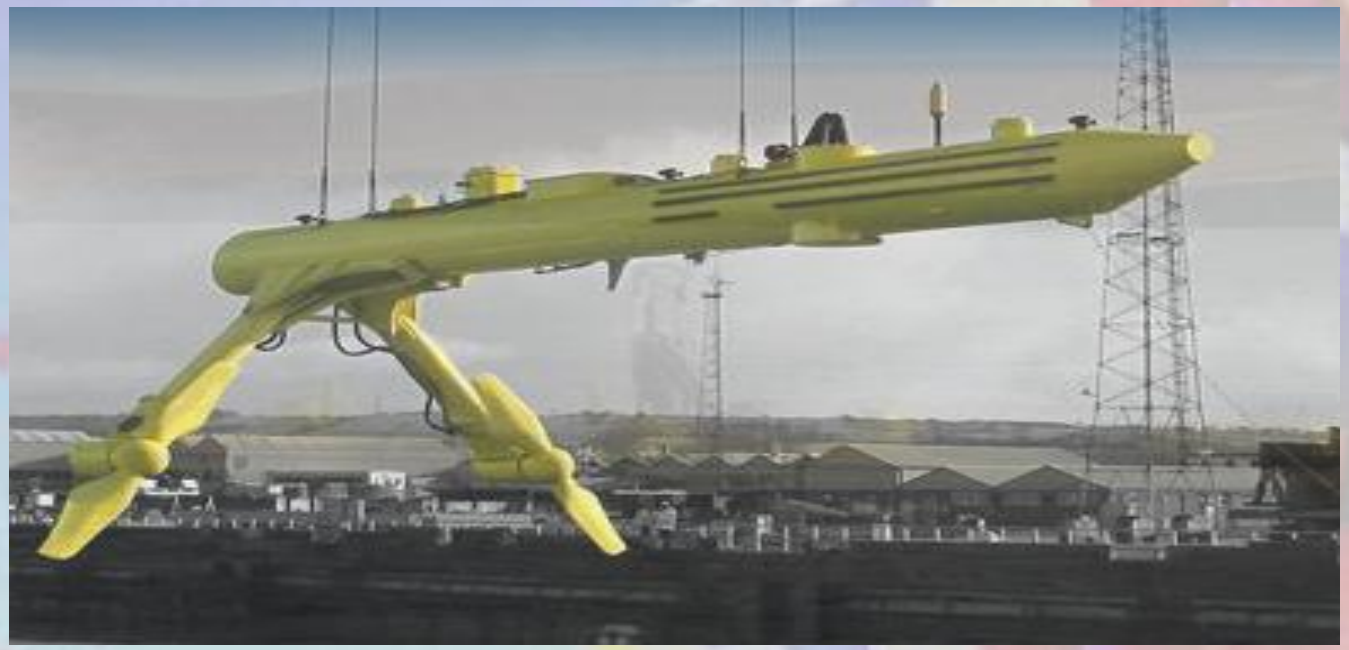
Link to BBC Webpage

Tidal Power – Tidal Stream

Grid connected device in Northern Ireland

1MW Tidal Stream Alstom device on Hatston Quay, Orkney in April 2013.

Tidal Stream Scot Renewables – 250 kW – late 2012



Video of device

There is no sound to this video, but it demonstrates some of technicalities of the device

Tidal Power – Tidal Lagoons

A derivative of barrage

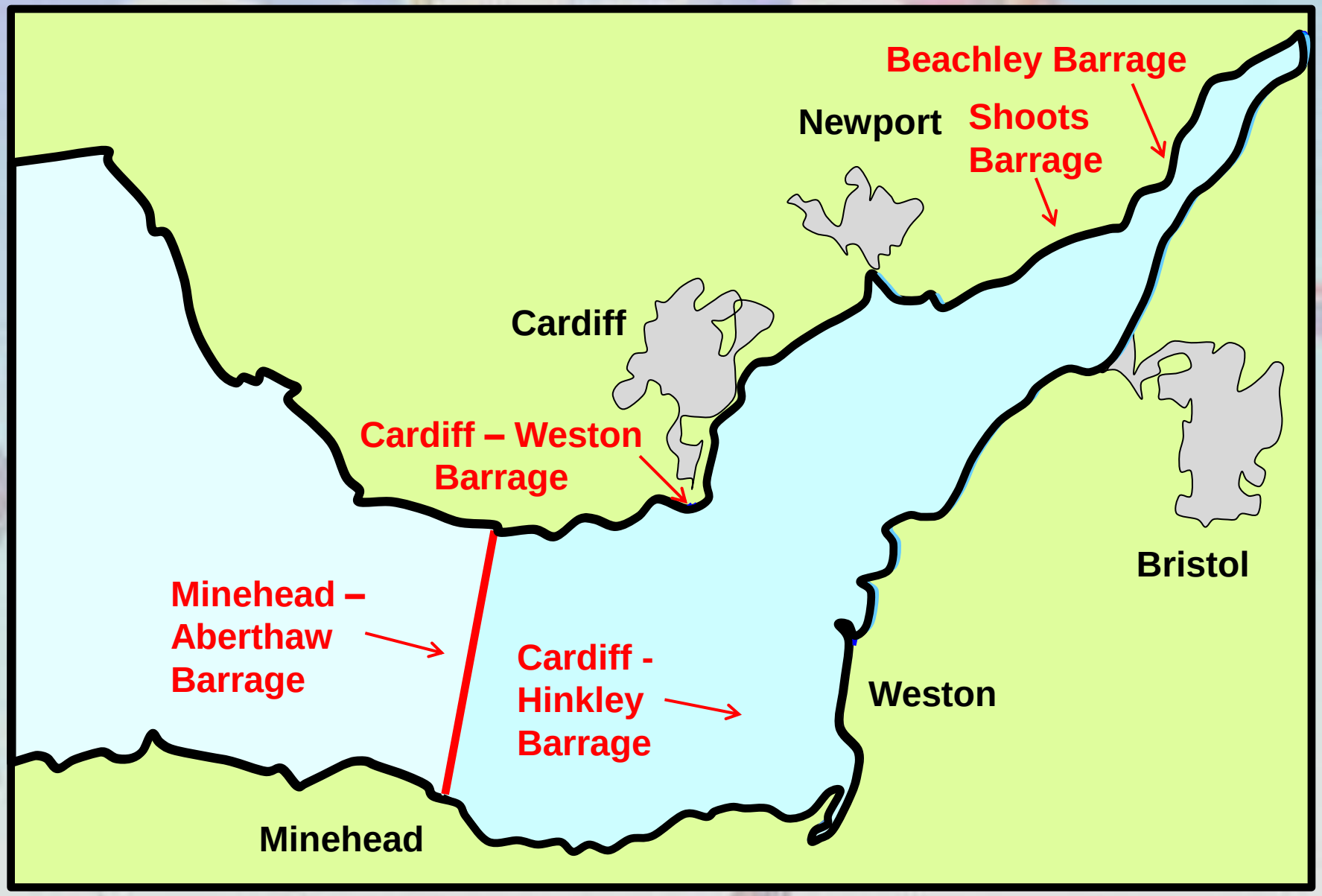
- Create a lagoon surrounded by a barrier
- Allow water to flood into lagoon and then generate through turbines.
- Could have two lagoons – as double barrier scheme.
- Claimed it could have higher load factor and less Environmental Issues
- Would require a lagoon of 115 sq km and a barrier length of 60+km – [much longer than barrage – material issues??]
- Would require 200 million tonnes of rock fill – about 10 times that of basic barrier scheme.
- Would generate no power until complete (all or nothing)

Tidal Power – Basic Theory

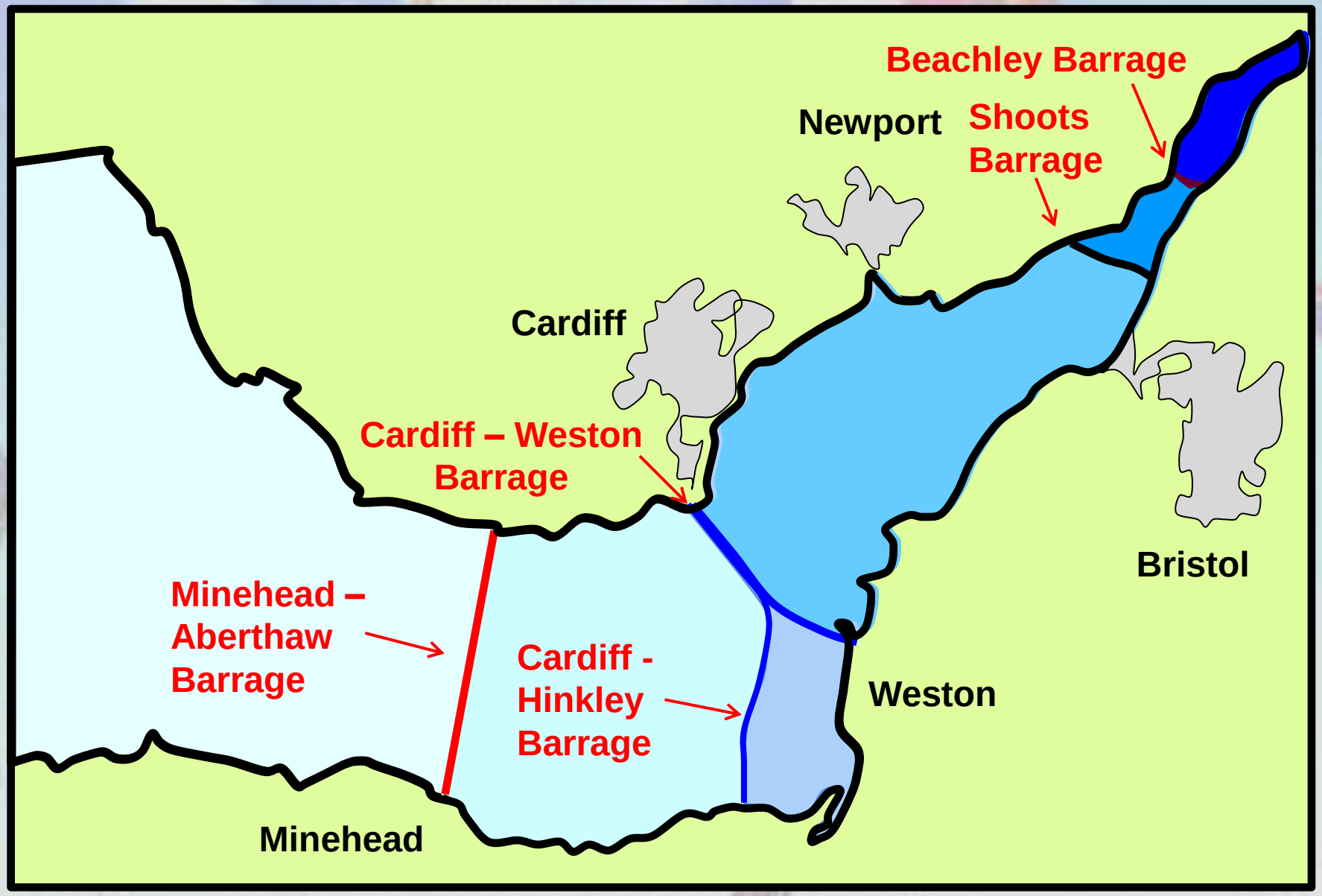
- Barrier Schemes rely on potential energy
- **Energy available = mgh x volume flowing**
- **But kinetic energy = potential energy**
- **i.e. $mgh = 0.5\ m\ V^2$ (v = velocity) or $V = \sqrt{2gh}$**
- **Mass flowing = density x volume**
- **m = density x cross section area x velocity**
- **$m = \rho\ \pi\ R^2\ V$ (R is radius of turbine)**
- **So energy available = $0.5 . \rho\ \pi\ R^2\ V . V^2 = 0.5\ \rho\ \pi\ R^2\ V^3$**
- **Allowing for efficiency η_{act}, actual available energy**

  $= 0.5\ \eta_{act}\ \rho\ \pi\ R^2\ V^3$
- **Tidal Stream devices rely on kinetic energy**
- **Formula is same as for Wind Turbines**
- **i.e. Energy Output = $0.5\ \eta_{act}\ \eta_{betz}\ \rho\ \pi\ R^2\ V^3$**
- **η_{betz} is the Betz Efficiency = 59.26%**

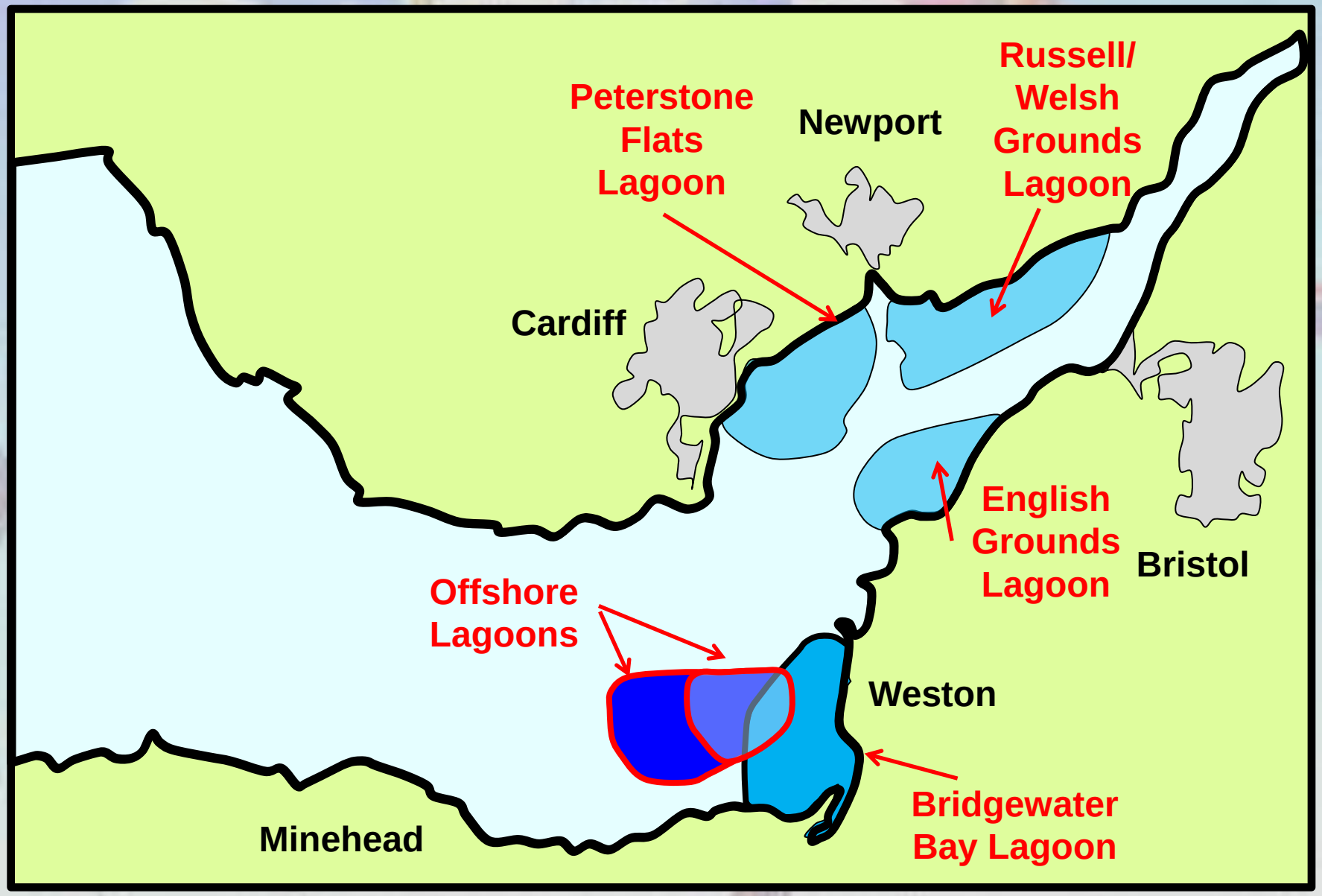
Proposed Schemes 2009 - Barriers



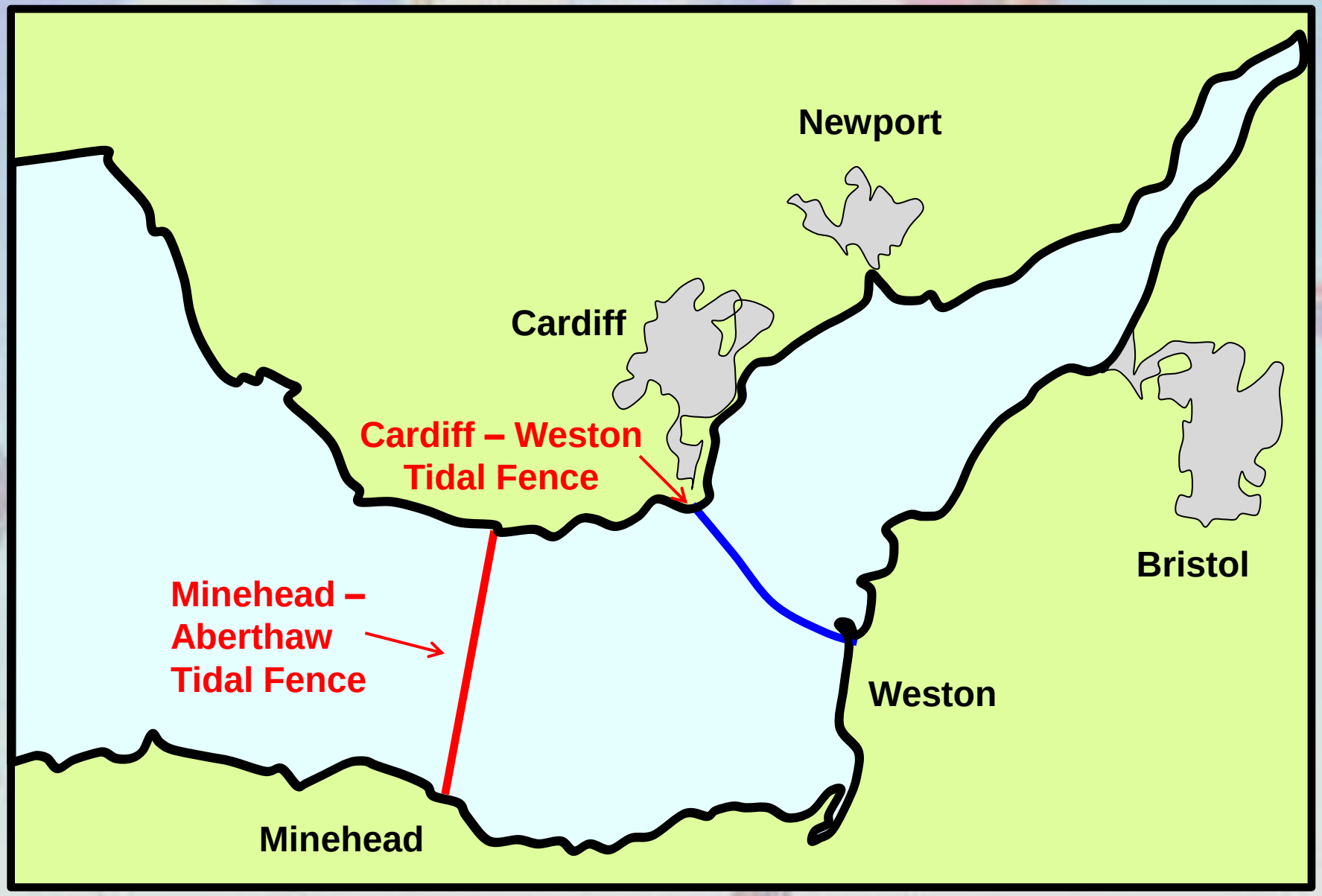
Proposed Schemes 2009 - Barriers



Proposed Schemes 2009 - Lagoons



Proposed Schemes 2009 – Tidal Fences



Comparison of Different Schemes

In 2010 Government postponed plans for development indefinitely

		Installed capacity	Annual Generation	Earliest operation	capital cost	Cost per unit
		MW	TWh		£bn	p/kWh
B1	Outer Barrage from Minehead to Aberthaw	14800	25.3	2022	29	7.3
B2	Middle Barrage from Hinkley to Lavernock Point	~9950	19.3	2021	21.9	7.82
B3	Middle Barrage (Cardiff - Weston)	8640	16.8	2020	18.3	7.39
B4	Inner Barrage (Shoots Barrage)	1050	2.77	2019	2.6	6.69
B5	Beachley Barrage	625	1.59	2018	1.8	8.21
F1a	Tidal Fence (Cardiff - Weston)		0.7	?	4.4	40.47
F1b	Tidal Fence (Minehead -Aberthaw)		3.3		6.3	14.33
L3a	English Grounds Tidal Lagoon		1.41	2018	3.1	11.35
L3b	Welsh Grounds Tidal Lagoon	1360	2.31	2019	2.6	11.27
L3c	Peterstone Flats	1120	2.33	2019	3.3	9.03
L3d	Bridgewater Bay	1360	2.64	2020	3	8.29
L3e(i)	Offshore Tidal Lagoon 1	1360	2.6	2020	5.8	12.86
L3e(ii)	Offshore Tidal Lagoon 2	760	1.32	2019	3.5	15.05

- **Tidal Fences are unknown technology so uncertainty over operation date.**
- **For comparison Sizewell B generates ~8.0 TWh per annum.**
- **Data do not consider potential advantages of double barrier scheme with pumped storage – something which will be needed with more renewables**

A simple Cost Benefit Analysis of the benefits of a double basin scheme

- **In 1979, construction of Dinorwig Pumped Storage Power station (1800 MW) was started and cost £0.45bn**
- **Compared to January 1979, the RPI in Mar 2016 was 488.6, i.e. prices were nearly 5 times those in 1979.**
- **Thus the cost of similar station today would be £2.2bn or £1.22m per installed MW.**
- **If 50% of capacity were available as pumped storage,**
- **The Minehead – Aberthaw basin if made a double basin would provide same capabilities as spending £7bn elsewhere on alternative pumped storage**
- **something which will be needed with increased renewable generation such as wind**
- **A holistic approach is needed**

See
http://www.independent.co.uk/opinion/letters/letters-tidal-power-1517932.html

Swansea Bay Lagoon Proposed Scheme

Abertawe

Stop Press: 20th April 2017

There are fears the General Election could push the Swansea Bay Tidal Lagoon start date back a year to 2019

- **Received planning consent mid 2015. Capacity 320 MW projected generation 500 GWh/year. Projected Cost £1.3bn**
- **Discussions ongoing regarding support continuing but a suggest Strike Price of £96.50 /MWh compared to £92.50 /Mwh for Hinkley Point.**
- **Significantly more than onshore wind and solar.**

Link to videos of scheme

ELECTRICITY MARKET REFORM – Contract for Difference

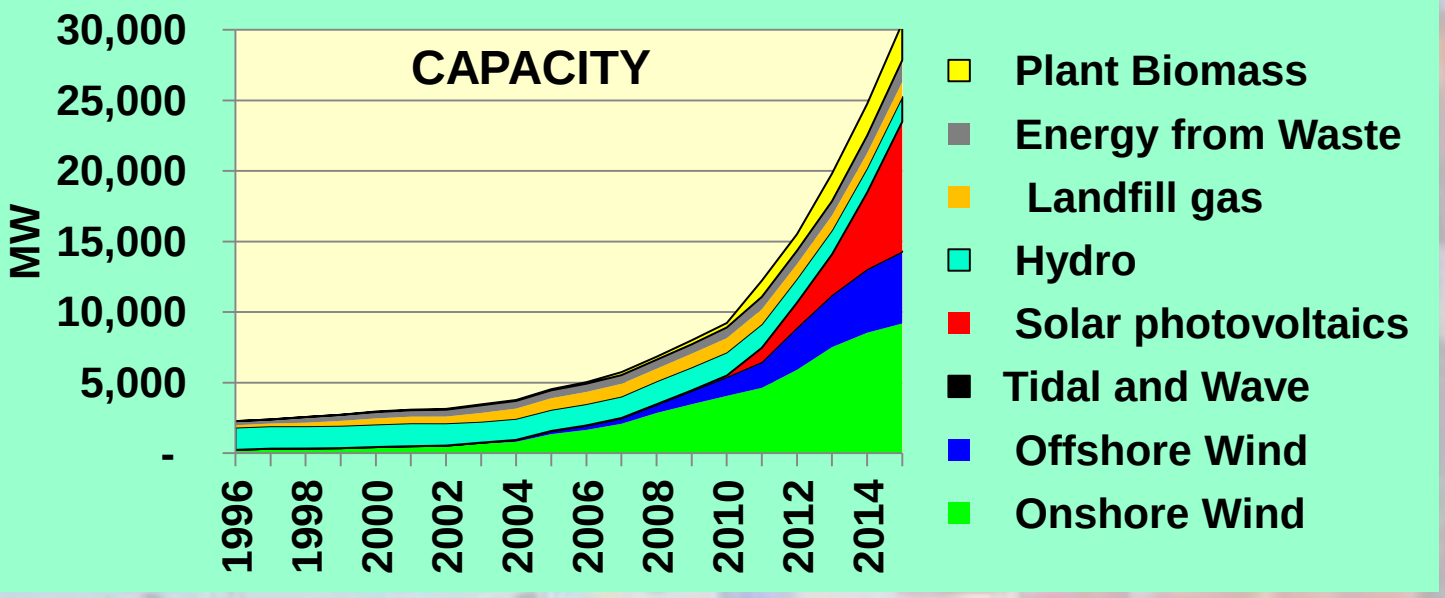
	Draft Strike Prices (£/MWh)			Actual Strike Prices (£/MWh) ***	
	2016/ 17	2017/ 18	2018/ 19	2017/ 18	2018/ 19
Offshore Wind	150	140	135	119.89	114.89
Onshore Wind	100	95	95	82.50	79.23
Sewage Gas	85	85	85		
Large Solar PV	120	115	110	82.50	79.23
Tidal Stream	305	305	305		
Tidal Barrage	Current Discussions suggest 96.50				
Wave	305	305	305		
Nuclear	92.5				

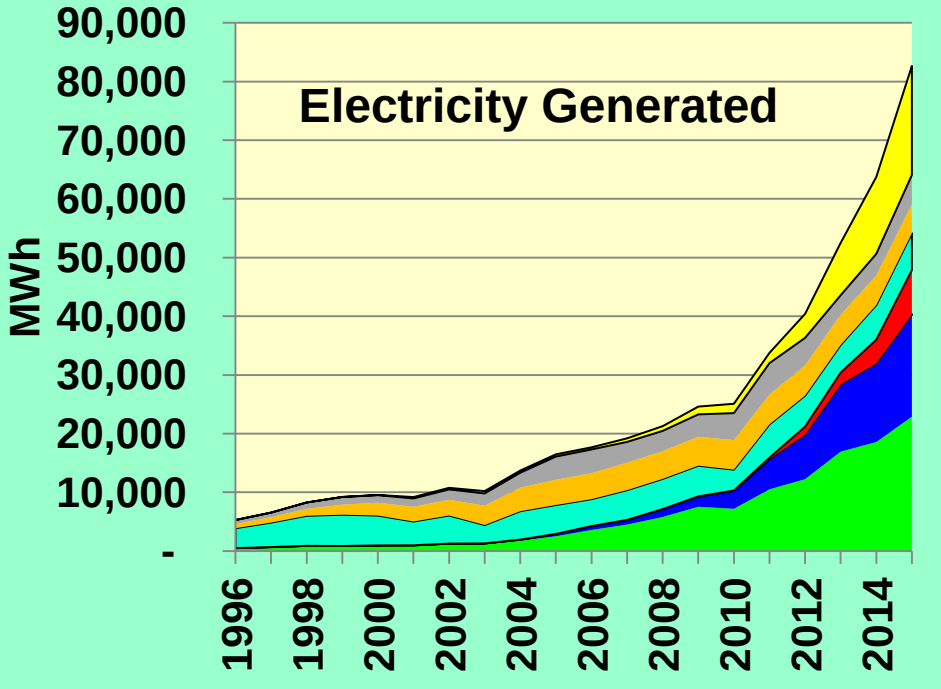
See: **Electricity Market Reform: Delivering UK Investment**
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209276/EMR_Spending_Review_Announcement_-_FINAL_PDF.pdf

***** Results of Auction Round 1**

Round 2 Auction expected shortly.

Comparison of Peformance of Renewable Energy

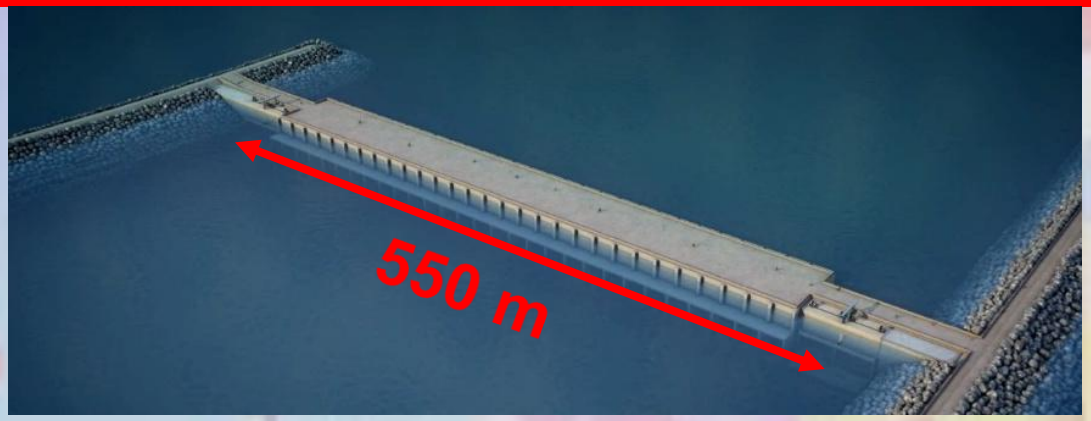




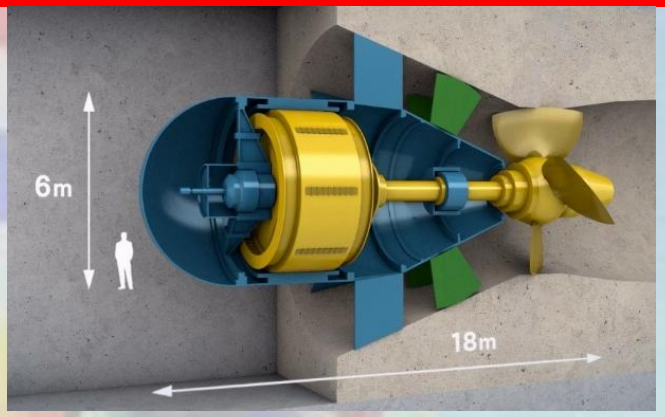
Load Factors – Average over 5 years

Onshore Wind	25.9%
Offshore Wind	34.7%
Tidal and Wave	4.8%
Swansea Bay projected	17.8%
Solar photovoltaics	8.6%
Hydro	37.1%
Landfill gas	55.0%
Energy from Waste	44.8%
Plant Biomass	27.6%

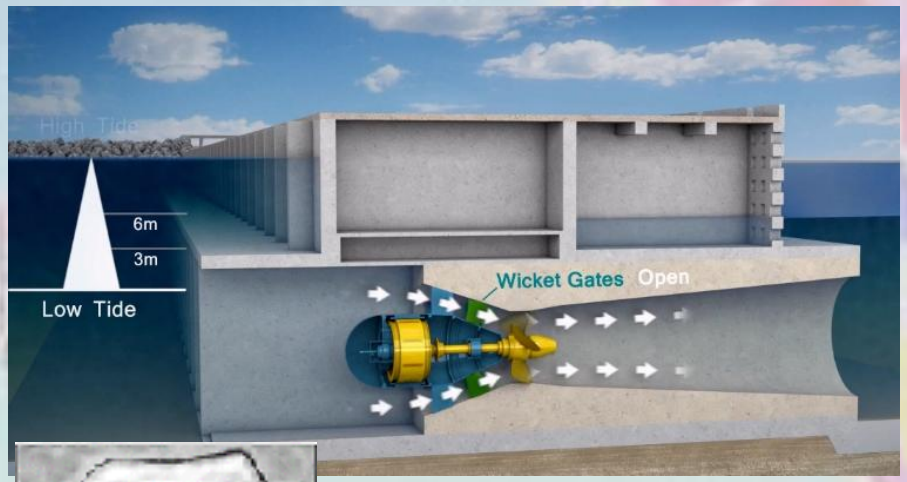
Abertawe Bay Lagoon Scheme

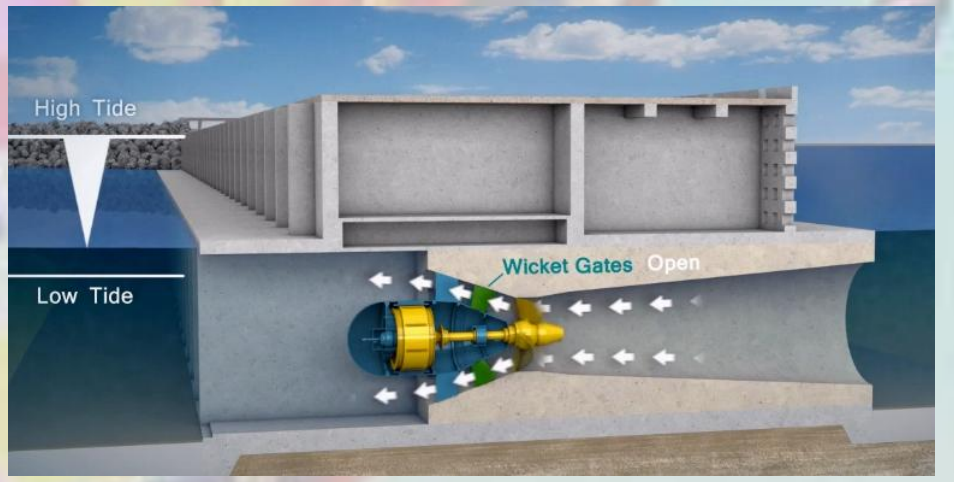


26 X 16 MW Turbines



Turbine Section





And Finally

"If you do not change direction, you may end up where you are heading."

“（直译）：“如果你不改变，你将止步于原地。”

Lao Tzu (604-531 BC) Chinese Artist and Taoist philosopher

Tidal Stream Future Resource

Location	Annual Output (GWh/yr)	Installed Capacity (MW)
Channel Islands	1817	533
Orkney and Shetland	1045	318
Western Isles	1119	325
Pentland Firth (Orkney)	8120	2292
South West	1229	368
Total	13330	3836

13300 GWh is equivalent to 3.7% of UK electricity demand

In comparison the UK has currently installed 13650 MW* of wind turbines

*** Capacity installed by 8th April 2016**