SUPPLEMENT TO THE HISTELEC NEWS

AUGUST 2007

"WATER POWER & SEVERN BARRAGE REVIEW"

Two of our members, Mike Hield and Glyn England have produced articles pertaining to the Severn Barrage as prelude to the talk by David Kerr of Sir Robert MacAlpine on 10th October.

WATER POWER by Mike Hield

Introduction

Normally a report on a talk is done after the event, but in the case of the talk on "The Severn Barrage" I thought a preliminary briefing would be of interest. My own interest arises from a career in SWEB as an electrical distribution engineer and my leisure activity as a dinghy sailor and yachtsman.

History

Man used water power as long ago as 200 BC for grain milling and water pumping, around 1100 AD for "Fulling" woollen cloth and later for processing metals. From about 1700 mathematicians and engineers started to analyse the workings of the water wheel and came to realise that the weight of water in the wheel was more significant than the impact from the flow. Isaac Newton (1642-1727) established his Second Law of Motion - i.e. Force is equal to rate of change of Momentum. Leonhard Euler (1707-1783) a Swiss mathematician developed his equation of motion for non-viscous flow. Daniel Bernoulli (1700-1782) defined three forms of energy in a fluid ie. height, velocity and pressure; these being interchangeable and the total constant. These ideas formed the basis for analysing the performance of turbines, fans and pumps.

Tidal Mills were very rare as they needed to be away from damaging waves and also the relative small size of the mills made them impracticable for large tidal ranges. In 1779 a mill existed on the River Trym about a third of a mile from its junction with the River Avon. Hence Sea Mills as the area is known today, but the original name may have been Saye Mills; Saye being a fine serge-like cloth, which was the product of the mill. Over on the East coast a fine old tide mill is still working at Woodbridge, Suffolk on the River Deben.

In Wales on the upper north-eastern arm of Millford Haven there is a large tidal mill on the Eastern Cleddau at Blackpool east of Haverfordwest. This mill also benefits from the river running down from Mynydd Presseli hills. All these mills are in very well sheltered positions. The first water turbine, as opposed to an open water wheel, was developed in France in about 1800 by Benoit Fourneyron. The important difference was that all the blades contributed to the energy all the time, the turbine runner ran completely submerged and the power was delivered by a fast rotating vertical shaft.

James Thomson, brother of Lord Kelvin, invented the Vortex turbine and patented it in 1850. It had adjustable guide vanes and the blades were curved. It was a highly effective and efficient turbine.

In Devon from 1906 until 1934 water wheels or turbines were installed at Buckfastleigh, Ivybridge, Holsworthy, Tavistock, Mary Tavey and Morwellham. Scotland benefits from abundant rainfall collected in lakes and rivers at high altitude. In 1896 the British Aluminium Co installed five water driven d.c. generators totalling 3750 kW at the Falls of Foyers and in 1909 11 Pelton wheel generators at Kinlochleven totalling 25725 kW. Aluminium in those early days was almost a precious metal.

In 1932 a proposal was made for a Severn Barrage upstream from Avonmouth. In 1943 A.T.Starr in his text book *"Electric Power" wrote "The Severn Barrage which was estimated to be capable of producing 500,000 h.p. (373 MW) during a 10 hour day with a peak capacity of 1000,000 h.p. In order to overcome the disadvantage of ebb and flow there were to be two reservoirs involving pumping during high level periods. The large cost of the necessary constructional work has prevented as yet the exploitation of the scheme."*

In the 1950's the CEGB began to consider the idea of pumped storage whereby water was pumped to a high level at times of low electrical demand to be used to drive generators to meet sudden peak demands on the system at other times. Dinorwig in Wales was opened in 1984 and all the plant is installed inside a mountain and is the largest of its kind with 6 x 340 MW turbine/generators - motors/pumps. The Rance Barrage in N.W. France near St.Malo was completed in 1967 and comprises 24 10MW bulb type turbines - total 240MW. The turbines are of the axial flow type and generate on both flood and ebb tides.

Time and Tide

The following diagram illustrates the terminology of tidal heights which are now expressed in Metres.

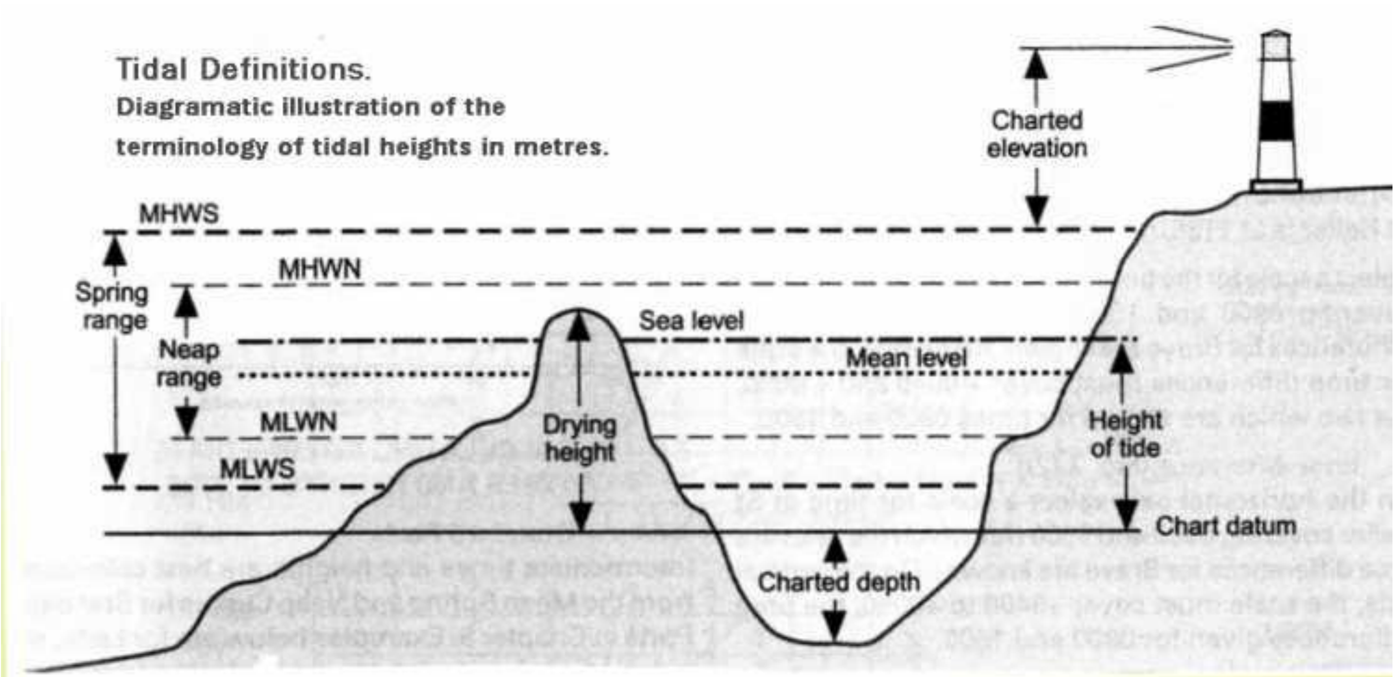


Chart datum is the reference level above which heights of tide are predicted and below which charted depths are measured. The datum used for most British ports is the lowest sea level predicted under average meteorological conditions for that port unlike the land mapping datum for the ordinance survey which is fixed for the whole U.K. and is based on mean sea level.

Range is important for tidal barrages and is the difference in height between successive High and Low waters. Tides arise from the gravitational pull of the moon and sun on the major oceans of the world. The biggest tides occur when the sun, moon and earth are on the same axis and are called spring tides and occur about every two weeks. In the intervening week the sun - world - moon axis become at right angles resulting in a reduced gravitational pull on the oceans. These tides are known as neap tides and the range is about 64% of the spring range. In the Bristol Channel spring tides occur in the evening and early morning and neaps at midday and midnight. Tidal predictions are for average conditions and in practice can be affected by meteorological conditions such as atmospheric pressure and gales.

So why are tides in some locations much higher/lower than the general levels? The main reason is the shore configuration e.g. the coast of South Wales and England together with the shelving sea bottom. The narrowing and shelving would not affect the level if the rate of rise was very slow but for the momentum of the thousands of tons of water entering at speeds up to 4 or 5 knots. Other effects occur in long closed estuaries and channels which have a natural wave resonance period which when coinciding with the tidal period gives a large amplification of the tide. Together with changes in tidal heights come tidal currents or tidal streams. Off Portishead streams reach 4.8 knots at springs and 2.6 knots at neap tides. Near Lynmouth on the N.Devon coast, streams reach 4 and 1.9 knots, and here a marine current turbine of 300 kW has recently been installed. For those unfamiliar with the definition of a knot it is a speed of 1 nautical mile per hour - approx. 1.15 mph. or 0.5 metres per second.

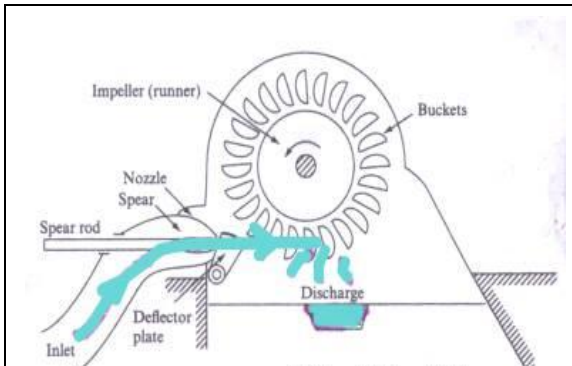
Water Turbines

With the introduction of Marine Current turbines which are still under development there are now four types of

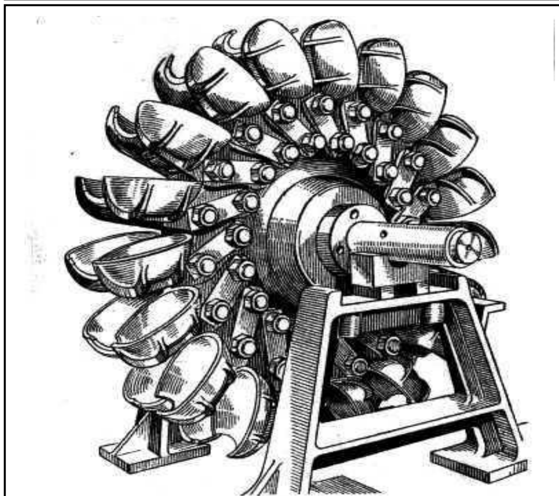
1. The Pelton Wheel - Impulse type
2. The Francis Reaction Turbine - Radial Flow
3. The Kaplan Reaction Turbine - Axial Flow
4. Marine Current Turbine - Propeller - Not Enclosed

1. The Pelton Wheel

After the old fashioned open water wheel this the earliest type and was invented in America by Lester A. Pelton in the 1870's. Water is delivered at high pressure and all the energy is applied by one or two high velocity jets impinging on a series of buckets mounted on the rim of a wheel. The buckets run at just under half the velocity of the jet{s) and for electric generation the speed must be constant and is controlled by a special long tapered Spear and Nozzle which reduces the flow volume without reducing the velocity. To cater for a sudden loss of electrical load the jet is diverted from the buckets with a Deflector Plate. The Pelton Wheel is high speed and smooth running and needs a high head of water but not necessarily a high volume.

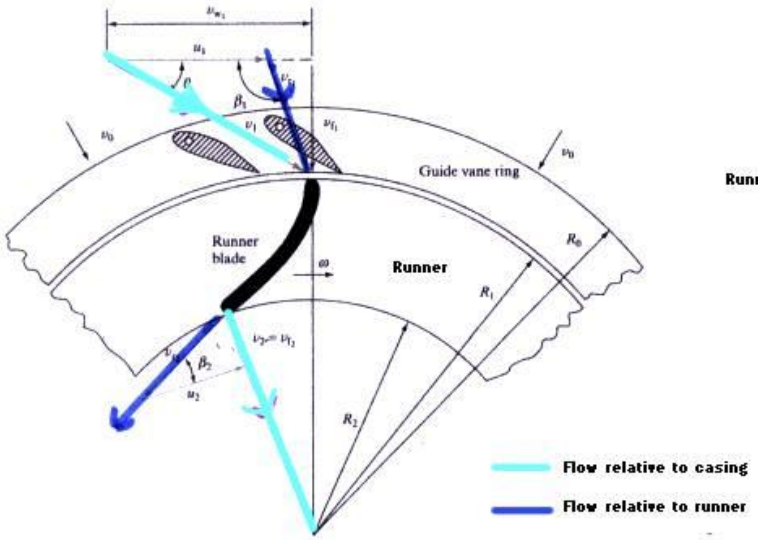


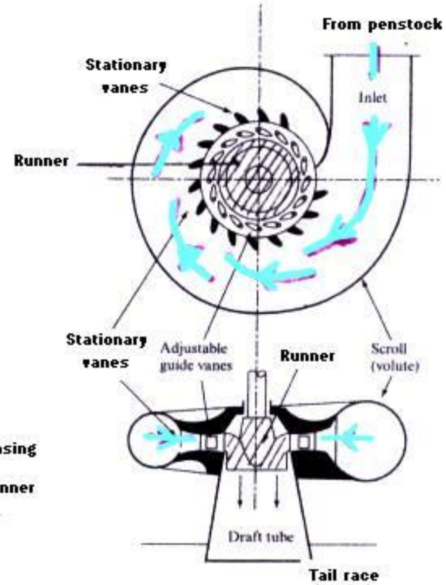
Pelton Wheel (1)


Pelton Wheel (2)

Reaction Turbines - Francis and Kaplan

The Reaction concept is not as obvious as that of the impulse concept of the Pelton Wheel. The water approaches a set of curved blades mounted on a shaft and glides over them thereby changing direction and so imparting pressure on the blades due to centrifugal force, i.e. the force experienced by a passenger in a car when turning very fast. The water enters the blades nearly at a tangent and for the highest efficiency leaves the blades radially and at a reduced velocity.

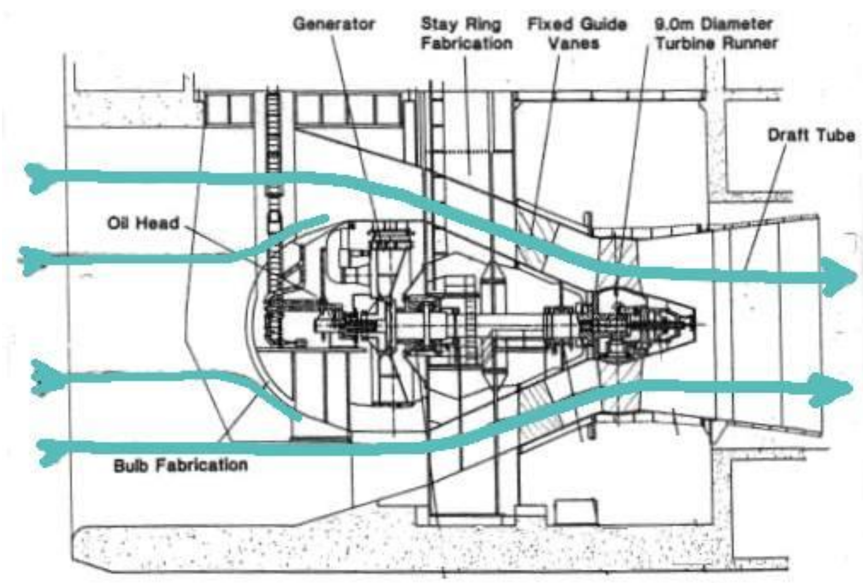




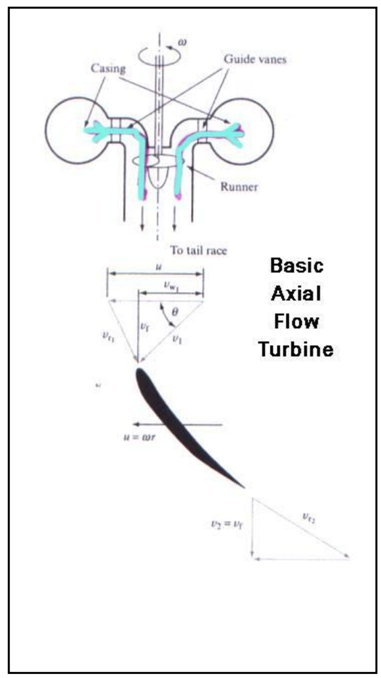
Francis Turbine

2. The Francis Turbine

In this turbine which was invented by an English engineer J.B.Francis (1815 - 1892) water is delivered into a volute casing which completely surrounds the runner and is under pressure as well as velocity. The water is guided through both fixed and adjustable veins in the casing and glides onto the runner blades at an angle. The water then turns in the runner to exit parallel with the axis of rotation. Load changes are catered for by the adjustable vanes. Sudden load changes are dealt with by a bypass valve or a surge tank. The Francis is used in very large ratings for example 340 MW for the Dinorwig pump storage scheme.



Kapeller Turbine Generator



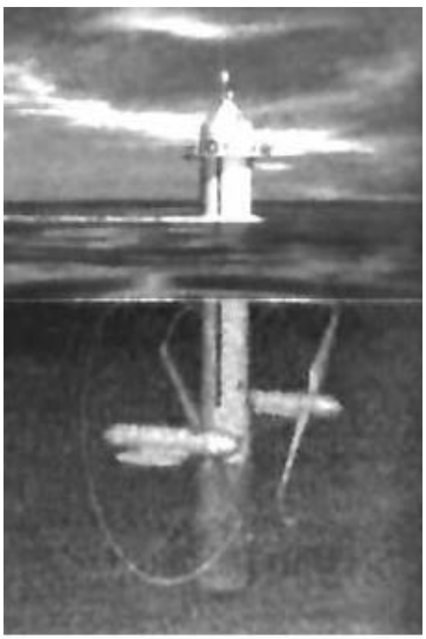
3. The Kaplan Turbine

This was a development of the Francis by an Austrian Professor Victor Kaplan in 1913. A basic axial flow turbine with fixed guide veins and runner blades suffers a rapid fall of efficiency at part loads. This is overcome in the Kaplan turbine which has adjustable blades in the runner. With this arrangement a wide range of high efficiency may be achieved at varying power levels. Kaplans run from very low heads up to 400m.and at ratings up to about 40MW (proposed Severn Barrage).

Usually hydro-generators of the Francis and Kaplan type have vertical shafts, this enables the electrical generator to be well above the water. The Severn Barrage proposal follows the arrangement used at the Rance barrage with the machine axis horizontal and turbine and generator totally submerged in a large bulb. This layout leads to a simple clean water flow over propeller-like blades hence the name Kapeller.

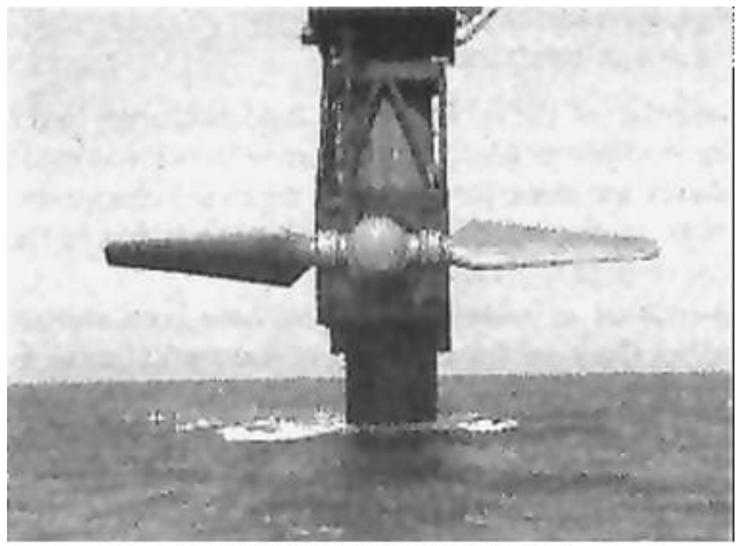
Marine Current Turbines

These turbines are a recent development and are aimed at using the strong flow of water in certain places without building a barrage or dam. The arrangement is rather like an inverted wind turbine with long narrow blades submerged in the water. Obviously the civil engineering costs are minimal but two fundamental issues arise. Firstly the velocity of the current available is limited to about 6-7 Knots at spring tides at the best locations; the power available is proportional to the current velocity cubed for a given diameter. The other basic problem is that the power efficiency of any propeller whether in wind or water in an unbounded free flow is limited to just under 60%. This is before any other inefficiencies due to drag actions on the blades and mechanical losses. An example is the new Marine Current Turbine now being installed at Strangford Lough in N.Ireland . This is rated at 1.2MW and has a blade diameter of 20 metres. The Kapeller turbines proposed for the Severn Barrage are rated at 40MW and have an overall diameter of about 25 metres, runner diameter about 9 metres.



Marine Current Turbine (2)

Artists impression of Twin Rotor
(Image Marine Current Turbines Ltd)



Marine Current Turbine (1)
(Image Marine Current Turbines Ltd)

Summary

	Pelton Wheel	Francis Turbine	Kaplan Turbine	Marine Current
Type number w (rad)	.05-.04	.4-.2.2	1.8-4.6	-
Operating Head	100-1700	80-500	0-400	zero
Maximum Head	53	40	40	0.3-1.2
Highest Efficiency	93	94	94	40?
Regulating Mechanism	Spear Nozzle Deflector Plate	Guide Vanes Surge Tanks	Blade Stagger	Blade Feather

The Type number enables various forms of turbine to be classified. The lower the number, the higher the speed of rotation. Pelton wheels are used for high heads and low volumes and most early turbines were of this type. The high speed is well suited to electric generation. Francis turbines are used for medium heads and are the type usually used for pump storage schemes. Kaplans can be used for very low heads and large volumes and are the type proposed for the Severn Barrage. Marine current turbines are under development.

References

1. Introduction of Fluid Mechanics – Nakayama & Boucher
2. Reeds Nautical Almanac
3. Fluid Mechanics – Douglas, Gasiorek, Swaffield & Jack (5th Edtion)
4. Science of Wind and Water – Kay
5. Energy Paper No.57 The Severn Barrage Project : General Report 1989 HMSO

SEVERN BARRAGE REVIEW by Glyn England

The Government's Energy Review (The Energy Challenge), published in July 2006, included a commitment to a study of the potential of tidal power in the UK, and a review of proposals for the Severn Estuary tidal resource. A novel step has been to hand over responsibility for the whole study to the Sustainable Development Commission (Chairman--Jonothan Porritt). Funding for this activity would come from the Department of Trade and Industry, the devolved administrations in Scotland and Wales, and the South West Regional Development Agency.

The study project includes assessments of UK tidal power resources, the available technologies and the implications for electricity supply. Specifically in relation to the Severn, the studies will consider the barrage proposals and alternatives, the environmental constraints and the impacts on local communities. It is intended to include the financing options. Further details of the project scope are available on www.sd_commission.org.uk. which also carries updates on progress.

The research phase in which consultancies and academic institutions were contracted to produce evidence-based reports on these issues is complete and a major stakeholder and public engagement programme is underway.

A session in Cardiff on 29th March was attended by some 50 participants, including representatives of fishing, wildlife and harbour interests, the Severn Tidal Power Group and the Renewable Energy Association. A report of the meeting (61 pages) is available on the Commission website. On tidal power in general, opinions were collected on benefits and disbenefits. For the Severn particularly, the classic Strengths, Weaknesses, Opportunities and Threats analysis was used, groups of participants being asked to examine tidal barrages and alternatives, tidal lagoons and tidal stream submerged turbines. It is impossible to summarise the many, often conflicting, opinions recorded in the meeting report but here are a few comments.

There seems to be an innate human characteristic that makes it easier for people to envisage the destructive effects of change generally, and major projects in particular, than to make the imaginative leap and look at the totality of effects, both good and bad.

For example, there are pessimistic comments, fearful for the future of the docks at Portishead, Cardiff, Newport and Sharpness if a barrage were built. Making an imaginative leap, is it possible to envisage highly efficient and environmentally attractive barge trains, upstream of the dam, having the reverse effect? If experience of the, much larger, Tennessee Valley Authority Scheme in the USA is any guide, new routes for trade could be established between South Wales and Southern and South Western England? Could some of the cars imported into Portishead be transhipped to Sharpness by barge with considerable environmental gain? And is there scope for holiday traffic and a car ferry between South Wales and Weston-Super-Mare? I trust the Commission has the views of a farsighted marine transport expert.

Somewhat similarly, concerns are expressed about possible loss of biodiversity and damage to salmon fishing. These are important topic but one needs to look at possible gains as well as possible losses. I am sure the Commission will have obtained factual information about the La Rance Tidal Power Station, near St. Malo, where there is now 40 years of operating experience. Biodiversity in a marine environment is a complex subject and I am not qualified to make judgements. I have, however, seen studies that show that the estuary has become a breeding and nursery area for many species of fish, and that it has a stable population of fish which need to pass from fresh to salt water and back again to complete their life cycle. It is significant that the estuary has been designated under the intergovernmental Convention on Wetlands (RAMSAR Convention), on the grounds of its importance to water birds, particularly fish eating birds like gulls, guillemots and auks.

A participant, rightly, points out that EdF has not built a second tidal power plant. If I recall the French view correctly, it is that no other estuary in France has the appropriate characteristics. The one scheme that was examined was intended to harness the tidal flows between the mainland and the Channel Islands. This involved very long dams and proved too costly. This might, however, be a good location for tidal stream turbines if field trials are satisfactory,

A meeting, similar to the one held in Cardiff, has taken place in Scotland and it is reported that there has been a workshop for local authorities from around the Severn as well as a number of local discussions.

While this has been going on, the Government has published an Energy White Paper. During earlier work, Malcolm Wickes, the then Energy Minister, expressed some doubts about how far the energy future could be left to market forces. These doubts are not reflected in the White Paper. In the Section on Electricity Generation -- Investment Framework, the commitment to a market based approach is made clear. If this means the Government sees no role for itself, this is not good news for major projects. Such projects, and the Severn Barrage is a good example, have substantial externalities, with benefits and disbenefits accruing to the community as a whole. These form no part of a company profit and loss account and, therefore, no part of any project assessment made by the company.

The Report on the whole study is now expected in September. It is likely to advance substantially our knowledge of the Severn Estuary and the prospects for electricity generation. In the light of recent events, it will probably contain an evaluation of the extent to which a barrage would mitigate the tidal element in the risk of floods to the City of Gloucester. I think it quite likely, however, that it will recommend more study of this, much studied, renewable energy source.

Glyn England

July ‘07