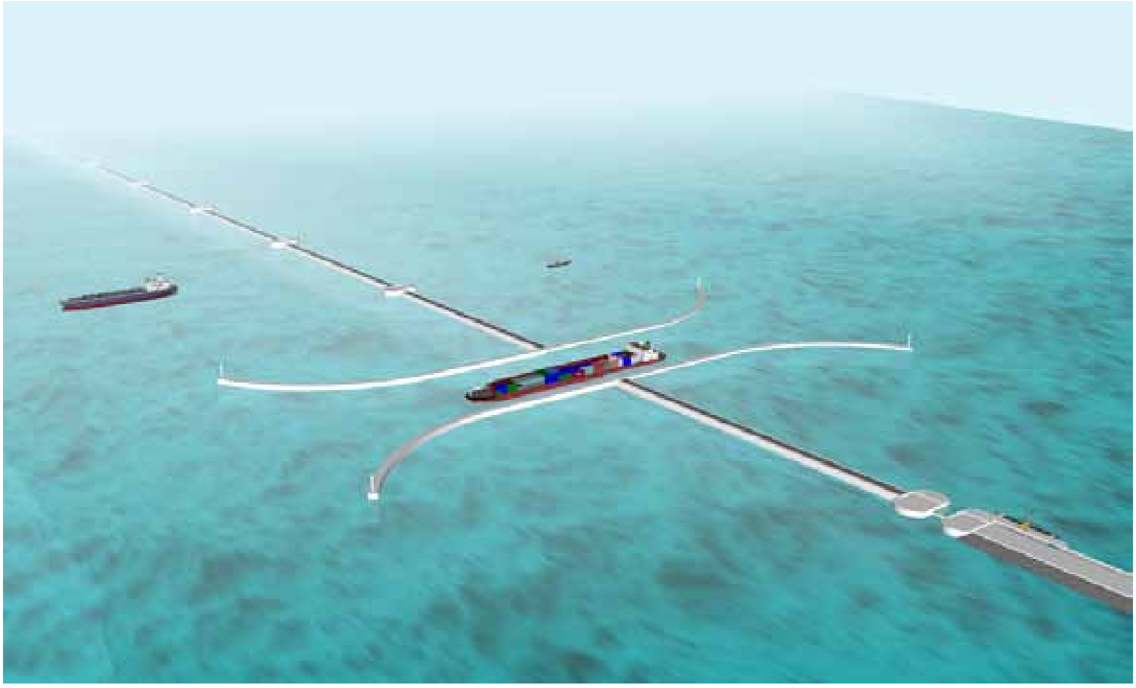
EVANS TIDAL POWER REEF

FOR THE SEVERN ESTUARY

'AN INTRODUCTION'

Schematic view of a 20 metre reef turbine
(man to same scale)



Aerial view of how the reef might look

SEVERN TIDAL POWER REEF

REVISION 4

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to harness the potential of the Severn estuary.

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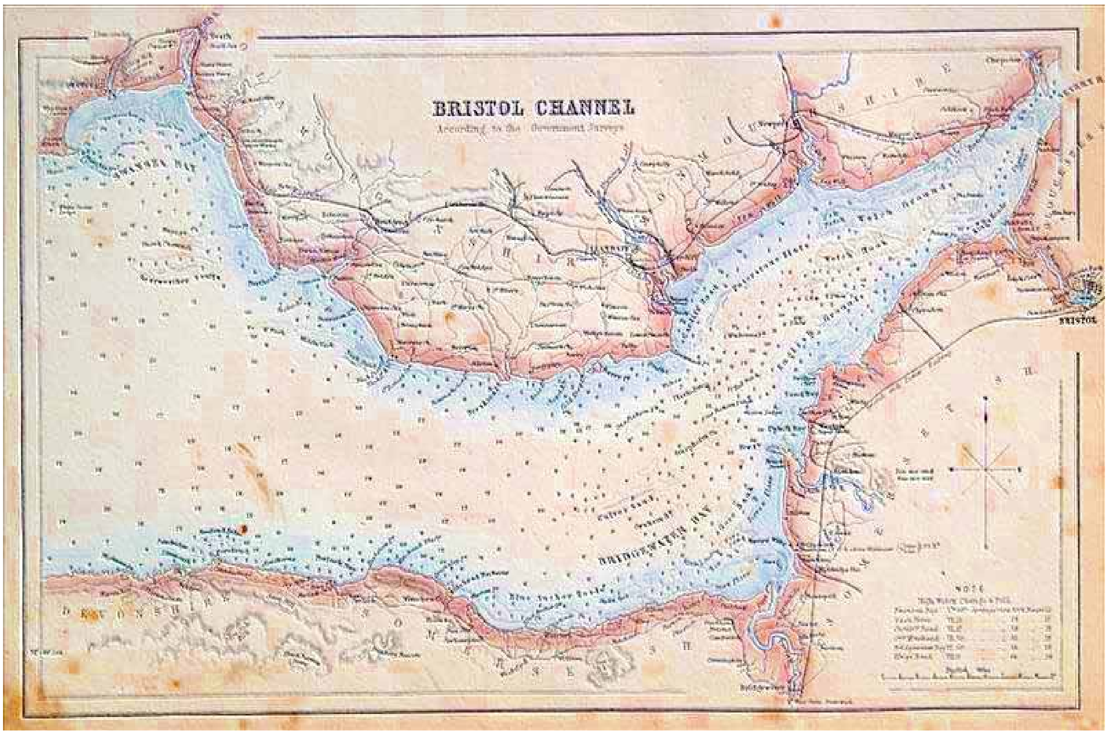
BACKGROUND & SUMMARY

The Severn Estuary has the second highest tidal range in the world. There is huge potential to harness this power and many proposals have been put forward throughout the last 100 years. Most of these schemes (tidal range technology) work by blocking off the estuary or lagoon with a dam/barrage, and by delaying the tides, these barrages produce a significant difference in water level between the inside and the outside of the dam in order to operate the hydroelectric turbines. These proposals are both expensive and environmentally damaging. The damage is mainly caused by changes to water flow patterns and levels within the estuary. This in turn impacts on the mudflats and salt marshes and their bird populations. More recent developments in tidal stream technology (extracting kinetic energy) are also expensive and give a significantly lower power output.

The REEF system, is a totally new concept and embraces the challenges and conflicts associated with large infrastructure projects in environmentally sensitive areas **before**, rather than after the engineering design stage. The REEF is based on a relatively light impounding structure spanning the 12-mile estuary that maintains a small but constant head difference between the outer sea level and the inner estuary when the tide is coming in and the reverse when the tide is going out. Introducing only a short delay to the natural tidal cycle avoids almost all the adverse environmental consequences of a large fixed barrage of the type proposed between Cardiff and Weston Super Mare. The REEF proposal has already had positive feedback and support from a wide range of environmental groups.



The favoured location for the REEF is between Minehead in Somerset and Aberthaw in South Wales. A recent study conducted by consultants W.S.Atkins suggests that a REEF type structure in this location could yield an annual energy output as much as 50% greater than a ‘conventional barrage’ located between Weston Super Mare and Cardiff. Such a structure it also concluded, would also be significantly cheaper and faster to build and would have significantly less environmental impact when compared to a conventional ‘barrage’ between Cardiff and Weston.

The water turbines used in a barrage scheme, are usually unidirectional, so a significant portion of the civil engineering cost is associated with sluices and by-pass channels to let the tide into the inner basin, but this is ‘dead investment’ in that it does nothing to increase the energy output and actually dissipates energy in friction. The REEF system uses bidirectional turbines and a ‘differential head’ of less than three metres to minimise environmental damage and maximise the utilisation of the plant. The power output is lower but the operating period is longer, making it easier to integrate with the National Grid. Around 600 water turbines with diameters between 15 and 20 metres diameter will be required to generate up to 6000MW.

Navigation has always and will continue to be vital to the community and commerce along the Severn estuary. To consider installing conventional ship locks that would cause significant delays to the passage of ships is unrealistic. Bristol Ports now account for over 12 million tons of freight annually and has embarked on a £600m development of a new ‘Deep Sea Container Terminal’, so only an innovative solution to the passage of very large containers ships with minimal delays will be acceptable, and this is what the REEF offers.

Large marine infrastructure projects of this kind are complex to finance, on account of the high ‘front end investment’ and lead-time until the first revenues. The REEF addresses both these issues firstly by shortening the build time by about 60% and secondly by allowing power generation to start well before the project is completed. It will be also be possible to reduce the financial risks during the construction phase by designing a project that can use many sub-contractors simultaneously and a supply chain that is flexible and broad based.

The REEF is not so much a ‘power station built in the sea’ as a chain of ships or floatable structures sitting on the seabed. The key to reducing both short-term risk and ‘future proofing’ the whole project is flexibility. By separating physically and if necessary financially, the provision of the infrastructure (a seabed foundation) and the movable ‘power generation modules, many partners can easily be combined and thus reduce individual risks.

Mulberry Harbour, a project involving similar technology was built in secret during WW2 in only 6-months and installed in Normandy over a period of a few weeks; it is therefore not unreasonable to assume that with our present knowledge of offshore structures and project planning that we are able to build a not dissimilar scale of project in a time scale of a few years rather than the ten to fifteen years for a ‘conventional barrage’ or a nuclear power plant.

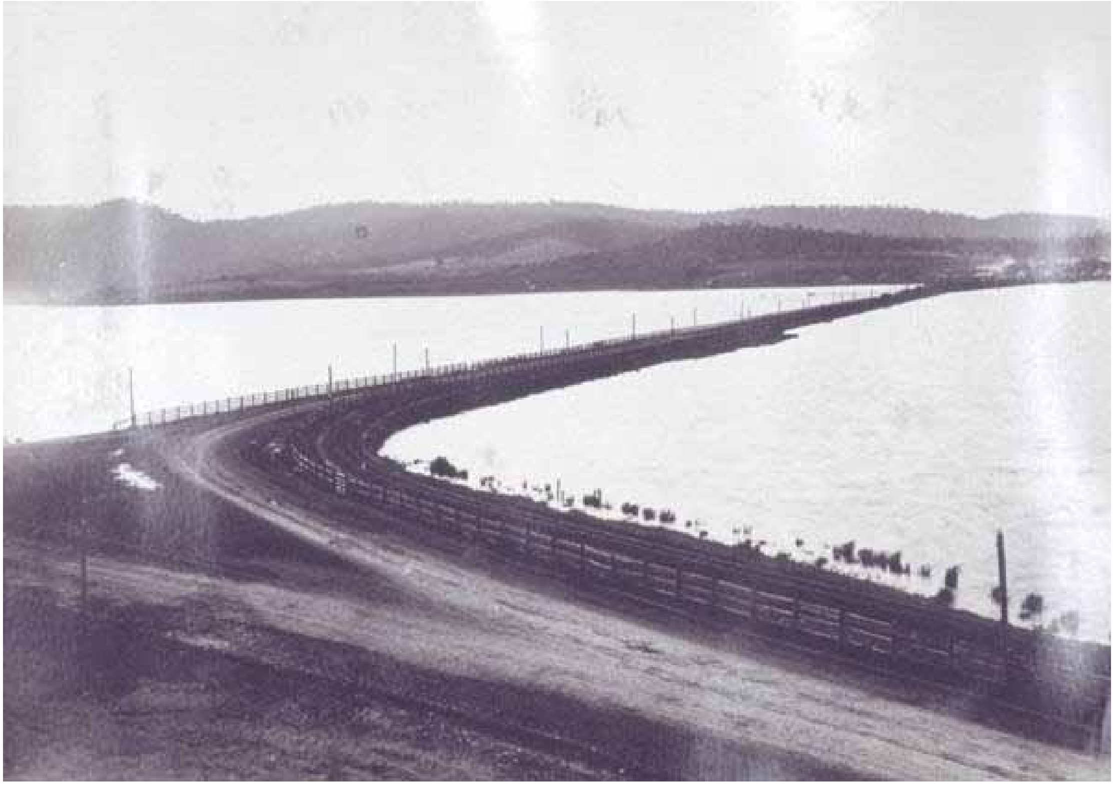
Galvanising the many interested groups and the ‘nation’ behind this project is important, I see it as essential that a significant part of the capital investment and ‘direction’ comes from the people of Britain. Both the Welsh and the English have major parts to play and would benefit from very significant numbers of jobs both during construction and for ongoing maintenance. My personal objective is to bring together the constituent parts of a major ‘green energy project’ that we could be proud to leave for future generations instead of a stockpile of spent nuclear waste.

This concept has such subtle flexibility and such energy and environmental rewards that the nation should feel it would be a huge detriment to the country as a whole if this project were not constructed.

A project of this nature in this location needs to address 5 main criteria:

1) Constant energy supply
2) Limitation on environmental impact
3) Minimising construction cost
4) Minimising construction time
5) Creation of a beneficial infrastructure & employment for substantial numbers of companies.

This is the only scheme out of all the proposals that can fulfil **all** these main criteria in a very positive & beneficial way for all. **Therefore one can conclude that this scheme is the only proposal that is truly viable.**



SECTION 1 - The Concept

The advantages of the ‘TIDAL POWER REEF’ concept over other proposed schemes to harness the potential of the Severn estuary are that:

The REEF approach to tidal power generation opens up the prospect of abundant ‘green energy’ without the environmental damage and without major impact on freight shipping movements.. The main objectives of the REEF System are to be environmentally benign, and yet generate the greatest output of renewable energy of any of the tidal power proposals in the World. From the outset the needs of the wildlife, migratory fish and navigation have been taken into account. Previously projects have focused on providing maximum energy supply with little regard to their impact on the environment and shipping movements. Post design solutions to reduce these impacts have often been incorporated with minimal success.

Conventional barrages cause massive disruption to the water levels and flow patterns within the estuary. This results from the highly localised and intermittent discharges from the turbines. The impacts of such disruption are many and complex and may be very detrimental to the environment as well as to navigation. In addition, the power generated comes in two peaks in every 24 hours that adds to the problems of regulating the National Grid system, rather than alleviating them as the REEF can do.

The REEF design is much more subtle and accommodating to the environment. It could be likened to a sunken necklace of concrete caissons containing the turbines that can generate or pump in either direction. The REEF is not a static entity; it is a series of components that adjust with the tides to facilitate the different man-made uses and environmental requirements of the Severn estuary.

The REEF is based on a relatively light impounding structure spanning the estuary that maintains a small head difference of between two and three metres between the outer sea level and the inner estuary when the tide is coming in and the reverse when the tide is ebbing.
The introduction of only a short delay to the natural tidal cycle avoids almost all the adverse environmental consequences of a large fixed barrage of the type proposed between Cardiff and Weston Super Mare.

Standard and proven engineering systems have been proposed as a starting point for the REEF wherever possible, though more ‘innovative’ designs may have significant advantages and need to be developed alongside the main programme. I started by gathering information on the environmental impacts in order to create a ‘design envelope’ in which the engineering is constrained, in much the same way that the ‘North Sea operating environment’ defined the new technology for building oil platforms 40 years ago.

Environmental impact has in the past been seen more as a series of mitigating measures rather than an integral part of the engineering design. A reasonable balance has to be struck between the local environmental impact and the wider benefits of ‘green energy’ generation.

Smaller quantities of material will be required to build the REEF, so the cost and environmental impacts on land and sea will be reduced. The REEF will be comprised of several different types of structure, each optimised for the depth of water, the function and environmental impact. Ease of construction and maintenance will be a high priority in the engineering designs.

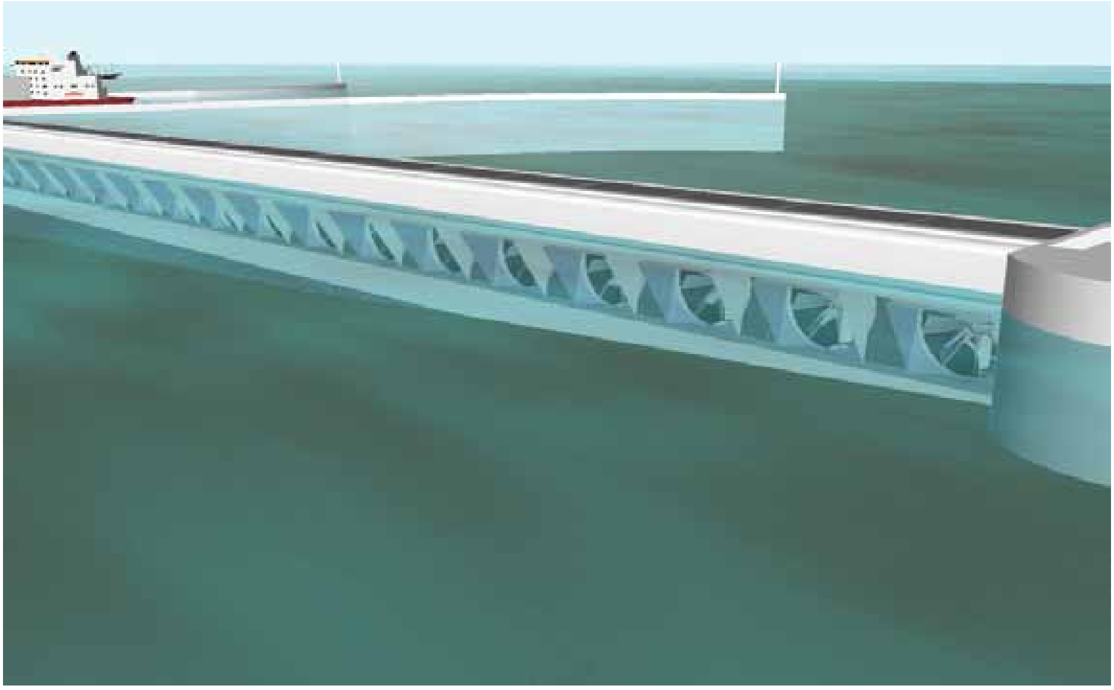
The REEF uses many smaller output turbines that will have slightly lower full flow efficiency but which run under ‘ideal design conditions’ for almost the whole of the operating period. Variable speed operation may be worthwhile on all or some of the turbines when the differential head falls below two metres. The ‘coarse’ flow regulation of the system is achieved by simply stopping or starting individual turbines to maintain the required head differential. Different turbine types and layouts are feasible, provided they meet the main design criteria above of working efficiently at very low head, being fish friendly and having a similar cost per installed MW as conventional water turbines.

The longer generation period makes it easier to match peak generation with peak demand. Furthermore, a relatively small increase of head of around half a metre over the nominal operating head, will enable the scheme to operate at an overload capacity to meet peaks for short periods, or to ‘swing the ‘generation period’ by an hour or so to match a peak in demand. The considerably greater storage capacity offered by the outer REEF further enhances this feature of the project because the percentage change in water level/tidal phase is much less significant and within the range variations that you would expect from factors such wind direction.

a) LOCATION

The route for the proposed ‘Severn Tidal Power REEF’ (a low differential head system) would run from Warren Point just east of Minehead in Somerset, to Breaksea Point near Aberthaw power station in South Wales. This route is proposed in order to obtain as much energy as possible from the tides but without encroaching on the Exmoor or Glamorgan Heritage Coasts and to provide as much flood protection for the low lying areas of Somerset as possible, and all without damaging the environment.

The length of the REEF would be just under 20km (12 miles). This route encloses an area of estuary that is almost double that enclosed by the Cardiff – Weston barrage. This larger volume of water can generate significantly more power despite the tidal range being smaller. This location would offer, according to the recently published study by Atkins, up to 30TWh/annum, which is about a 50% more electricity production than the proposed Cardiff-Weston barrage.



A section of power modules

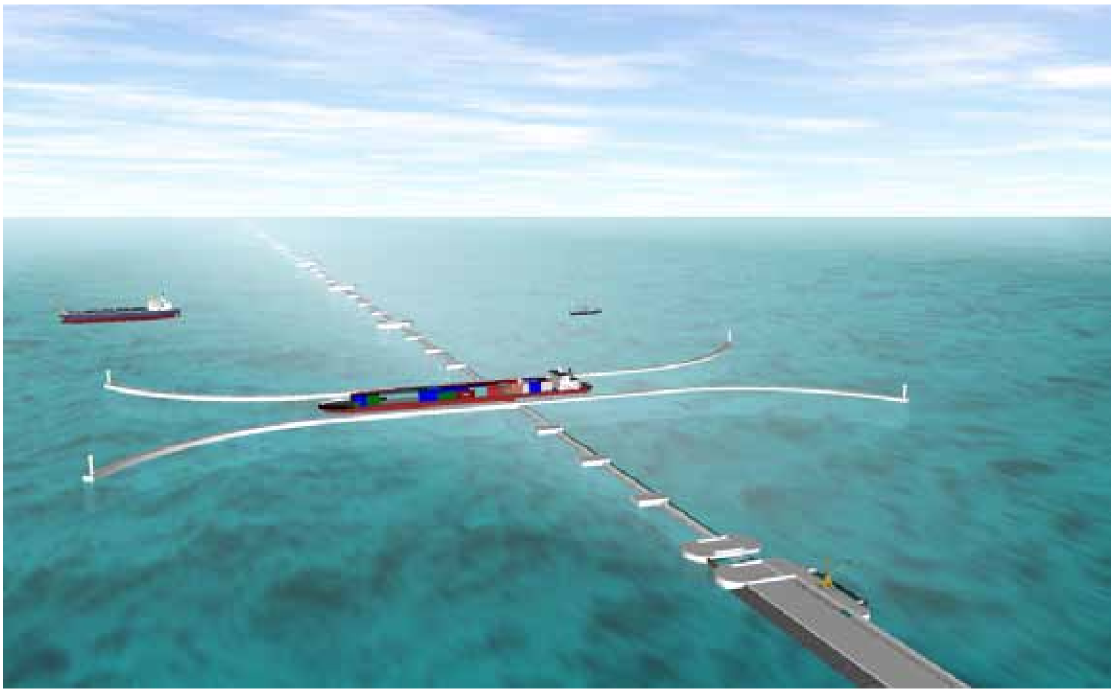
b) ENERGY PROVISION

The output in terms of energy is directly related to the area of estuary enclosed and the change in water level during each tide. The longer you 'hold back' the tide, the greater the instantaneous power output but the greater the difficulty in getting the increased flow of water (because of the delay) away and the greater the damage to the various ecosystems. At the other extreme, a 'Tidal Stream Turbine' operates without any delay but has much lower energy conversion efficiency and so is significantly more expensive. The REEF technology comes between these two extremes. It is a more balanced approach.

The global need to dramatically increase the supply of energy from renewable sources is now unequivocal. It is thought by organisations such as the RSPB that the dangers presented to wildlife by 'climate change' will be far greater than some local habitat modification. It is important to quantify what those local modifications may be.

Integration of large tidal range projects with the National Grid system will be very difficult if the REEF operating system is not used. This is simply because the tides deliver two large peaks in energy production in each 24-hour period and the generation periods advance by about one hour each day so that it will seldom coincide with periods of high electricity demand.

Tidal energy is variable but predictable, so that it is possible to plan years in advance what the input to the Grid Network will be. With the 'active control system' associated with the REEF, it will be possible to enhance the benefits of tidal power generation by 'swinging' the 'generation period' towards periods of high demand. Buffering the inputs from other renewable energy sources including 'off-shore wind', the REEF will help rather than hinder the regulation of the whole Grid Network.



A container ship passing through the low-head structure

c) ENVIRONMENTAL COMPATIBILITY

The Irish Sea has a complex tidal system and any large-scale tidal scheme will have an effect on the tidal behaviour of the whole Irish Sea even if small. Detailed modelling of the dynamic system will help us to understand areas of issue where the design of the REEF can be adjusted to accommodate possible environmental issues.

The coastlines to the West of Minehead and to the West of Aberthaw have special designations and should only be encroached upon if it can be shown that there are significant benefits, and if that were the case, them it would be necessary to minimise the impacts on those coastlines. The main REEF structures do not come closer to the coast than about a mile, and the landfall is in the form of a rock embankment. Modelling could be used to ascertain the best way to form the link between the REEF and the coastline. The goal is to enhance the coastline rather than compromise the existing special designation.

The wading birds that feed on the inter-tidal mudflats of the Severn estuary are protedted on various sites and variousdesignations including “Natura 2000”, so any project has to be exceedingly well thought out in order to minimise any risks to valuable habitats. The estuary is internationally important for its salt marsh communities, for the large numbers of wildfowl that migrate thousands of kilometres to winter in the estuary, for the breeding waders that cling to the surviving tidal marshes and for the migratory fish and Atlantic eels, populations of which have crashed in recent years.’ (extract from environment-agency.gov.uk)

Migratory Fish have to be able to pass safely through the operating turbines of the REEF, and this means that slowly turning blades with outer shrouds and smooth surfaces are necessary to reduce possible injury to a minimum. It is not an unreasonable objective to design a turbine that presents less of a hazard to the passage of fish than a natural river feature (rapids) falling a similar height (two or three metres). The differential operating head of around two metres will not adversely affect fish, which might occur if the head difference was greater. The choice of low specific speed turbines with a small number of blades with wide openings is feasible on this very low head.

Salt marshes would not be threatened because it is possible to maintaining the right condition by allowing some tides to rise to their natural height. Maintaining or enhancing the spring-tide levels is also consistent with the need to maintain navigation depths. If special regimes are required, it should be possible to dovetail these needs in with other requirements or at time that are less critical to the high revenue activities of power generation and shipping.

Several millions tons of fine sediment is moved up and down the estuary on each tide resulting in the characteristic muddy appearance of the estuary waters. This sediment transport is greatest at spring tides when the energy flow is greatest. Much has been said about the increase in biodiversity that would result from installing a barrage, causing much of the silt to settle out and the water to become clearer. The REEF will cause some changes simply because energy is being extracted, but nothing like the changes that are predicted for an ebb only barrage of the type proposed between Cardiff and Weston.

The turbines installed in a barrage type structure between Cardiff and Weston would have to withstand the full effects abrasive silt passing through them at least twice a day and causing wear and the associated maintenance costs. A REEF located between Minehead and Aberthaw would avoid much of the silt as it oscillates up and down the estuary.

Silt will not build up as some fear simply because the inflow of silt from the rivers is so small that even if it was all trapped (which is not credible since millions of tons of water are still passing in and out with each tide) it would take hundreds of years to make any detectable change in depth. Changes to the flow patterns leading to the relocation of sand banks is a more serious issue as it could impact on shipping and the need to change dredging requirements. Adapting the operating procedures for the REEF could well have a controlling influence on silt deposition and needs to be studied.

The Severn Bore is a large surge wave that is one of the biggest bores in the world. The shape of the Severn estuary is such that the water is funnelled into an increasingly narrow channel as the tide rises, thus forming the large wave. The bores usually occur in the spring & autumn & when the tidal surge is big enough, it is a very popular event with surfers. With some coordination with shipping movements the REEF could be adjusted to allow the tidal surge to happen. The times of a large Severn bore can be predicted to within 20 minutes and the coordination of natural conditions to create a decent tidal surge tends to be an annual event. Its financial impact to shipping would therefore be minimal and financial benefit is gained in other areas of industry.

Construction traffic on land would disrupt local communities on both the Welsh and English sides of the estuary, so it is envisaged that the bulk of freight and personnel are moved by sea and railway.

HMS Bulwark passing through the Thames Barrier

d) PORTS & SHIPS

The great value of Bristol docks is its ability to handle large container ships relatively close to large centres of population. The REEF system will minimise the loss of navigation depth and could with sophisticated management, be used to increase the number of valuable high tides by additional pumping during the appropriate part of the tidal cycle. The trade-off between the timing of ship movements, peak power generation and other factors such as flood alleviation is a complex one, but since the tides are predictable it is possible to plan for everything except extreme weather events, many years in advance. Navigating through the REEF should be less hazardous than a conventional barrage located between Cardiff and Weston because the water is deeper and there is more room for ships to manoeuvre in the outer estuary. Once inside the REEF the navigation would be unaltered all the way up river.

Dredging & Quarrying
The construction of the Cardiff-Weston Barrage involves the dredging of a new shipping channel. The 18 million cubic metre requirement would be totally avoided. The main dredging requirement would be to regularise the seabed directly beneath the 'foundation sections. A combination of hard-rock dredging and depression filling would further reduce the need for dredging and the importation of armour-stone. The REEF has a 'lower aspect ratio' (ratio of width to height) and a very low 'solidity' (percentage of open turbine duct to the face area of the impounding structure), so the total amount of material required for its construction is much reduced. The remaining material is largely comprised of reinforced concrete caissons that are to be built away from the construction site under controlled shipyard conditions. Distributing the construction of caissons between several shipyards around the country will cause less disruption to the sensitive local environment and possibly improve employment in locations that do not have the capability to build the large 'big barrage' caissons'.

Delays to ships
It is not commercially acceptable to impose significant delays or hazards to the passage of large container ships operating within an already difficult estuary. A key design criteria for the REEF is that the structure should not impose more than about 10 minutes delay and at 'slack water' ships should be able to pass through unhindered. There are a number of significant design challenges in this area, but none that are much greater than building the Thames Barrier.

REEF related business
Almost all the port facilities along the length of the estuary will be affected by the construction of such a large project. Ports with suitable, or wishing to develop suitable facilities, will be involved in a range of activities from the construction of the caisson and foundation structures, to the provision of offshore services for the numerous contractors. Unlike the construction of the channel tunnel that has only two points of entry, the REEF would have an infinite number of 'entry points' so that services ranging from diving support to tourism could be based in even the smallest harbours.

e) COMMUNITY COMPATIBILITY
Employment prospects during the years of construction will be considerable, and be spread over a wide range of manufacturing and service industries. Locations with specific marine expertise will obviously be in a good position to secure major tenders. Shipyards and marine contractors will be well placed for the construction and later for the maintenance work on the REEF.

The period of disruption for Minehead would mainly be confined to the construction of the rock embankment and causeway connection to Warren Point. The most of the workers could be brought in by train from suitable assembly points so the number of extra cars on the roads in the area should not increase dramatically. There will undoubtedly be an increase in the number of people visiting the area to see the construction. To reduce the impact on local communities during the construction phase by relying on existing rail links, grid infrastructure and remote construction of the concrete caissons.

Flood alleviation
The REEF will not be designed to stop a tidal surge or all flooding, but what it will be able to do is attenuate any extreme weather event by reducing the energy contained within a surge or artificially changing the water levels within the estuary so that high inflows from rivers already swollen by rain do not coincide with high tides causing extreme flooding. The capability of the REEF to modify the natural regime is further enhanced by the 'pumping' capability at both high and low tide. This means that water levels can be raised or lowered artificially to meet a number of objectives including the increase in navigation depths, optimising power generation and flood alleviation. The addition of an inner REEF further upstream on the 'Shoots' alignment would increase the level of control, provide a rail crossing and allow continuous 24-hour generation.

Breaksea point near Aberthaw

Aesthetics & Visual Impact
The REEF is an immense structure that is mainly submerged below sea level. The sections close to shore will be constructed in the form of rock embankments so there is considerable scope for landscaping it to look like a natural extension of the coastline. There will be choices as to whether all structures and buildings are designed for minimal intrusion into the landscape or are of architectural merit like the Thames Barrier. The aesthetics of the estuary and surrounding landscape, while being altered by the REEF project, need not be altered as much as that required by any of the 'big barrage' proposals.

The main structures start more than a mile from shore and will not extend as much above the high tide level as a conventional barrage. The reason for this is that there is no requirement for a continuous powerhouse on top of the impounding structure to containing lifting equipment and other services. The electrical power generation equipment is contained within piers located along the REEF at intervals, and serviced by tunnels in the foundation structure so there will be no external cabling or pylons.

Leisure & Tourism
Coastal accommodation and tourist activities should be unaffected along almost the entire coastline, with the modification of the tidal regime being undetectable by most visitors. For those who will actually be able to see the REEF structure from a distance, it would only appear as a low dark line running across the estuary that would be almost submerged at high tide. For those immediately adjacent to the landfall I see no obvious conflicts. In Somerset the landfall would be adjacent to the holiday camp, so with suitable landscaping it could form an attraction in its own right, being similar to a seaside pier that could be accessed by a tramway or on foot. The Aberthaw rock embankment is adjacent to an industrial area occupied by the power station and railway yard.

Visitors to see the REEF construction, construction personnel and subsequent visitors to see the REEF would be of real positive benefit to the local economy. The transport of materials and personnel during the construction would be mainly by sea and rail, so there should be only minor disruption on local roads.

f) FLEXIBLE APPROACH
The 'Tidal Reef' is an 'Active System', in other words the operating system can be altered from tide to tide to take into account the height of the expected tide, wind conditions and the competing demands of power generation, navigation and wildlife. At certain times, the flow will need to be stopped or to run freely, not generating or offering little resistance to the flow, a feature that is critical to the 'active control' of the REEF. This system allows the characteristics of the whole project to be altered from tide to tide, giving preference to generation, navigation, the environment and even the Severn Bore, at the most appropriate times.

Future proofing
Conventional accounting procedures put a finite life on a particular asset whereas I would argue that the earning power of the asset now and in the future is a more accurate benchmark. The railway system for example, is worth whatever it is capable of earning and has little relationship to what it cost to drive the tunnels and lay the tracks in 1850. The railways have not changed in concept for over 150 years but the track and train technology has developed progressively. In the same way I expect the REEF to evolve rather than depreciate.

Unlike all the other proposed systems, the REEF can be modified to take account of unexpected or planned changes in the future. It is not a monolithic structure that is almost impossible to modify. It is comprised of removable caissons that can be towed to a dry-dock for maintenance work or replaced or updated as the need arises. It is only the mass concrete foundations and civil engineering works that will continue in their basic form virtually indefinitely, making the project 'future proof'.

Financing the REEF can be split into components that link together like building blocks. These component parts can be funded individually or globally by an appropriate network of companies and institutions. The underlying objectives are to reduce risk and increasing the range of equipment and suppliers that can be employed.

Splitting the project (even if they are ultimately financed by the same sources) into the 'Foundation' (infrastructure) and the power generation modules, will give opportunities (Like the Wave Hub) for third-party generators to lease space on the REEF foundation. This reduces their total investment and offers 'The REEF Consortium' guaranteed revenue. A very significant proportion of the project has to be based on pre-fabrication remote from the project site so that the actual on-site build time by lots of contractors is very short (3 to 4 years as opposed to the 10 to 15 years previously envisaged), this will additionally improve the cash flow.

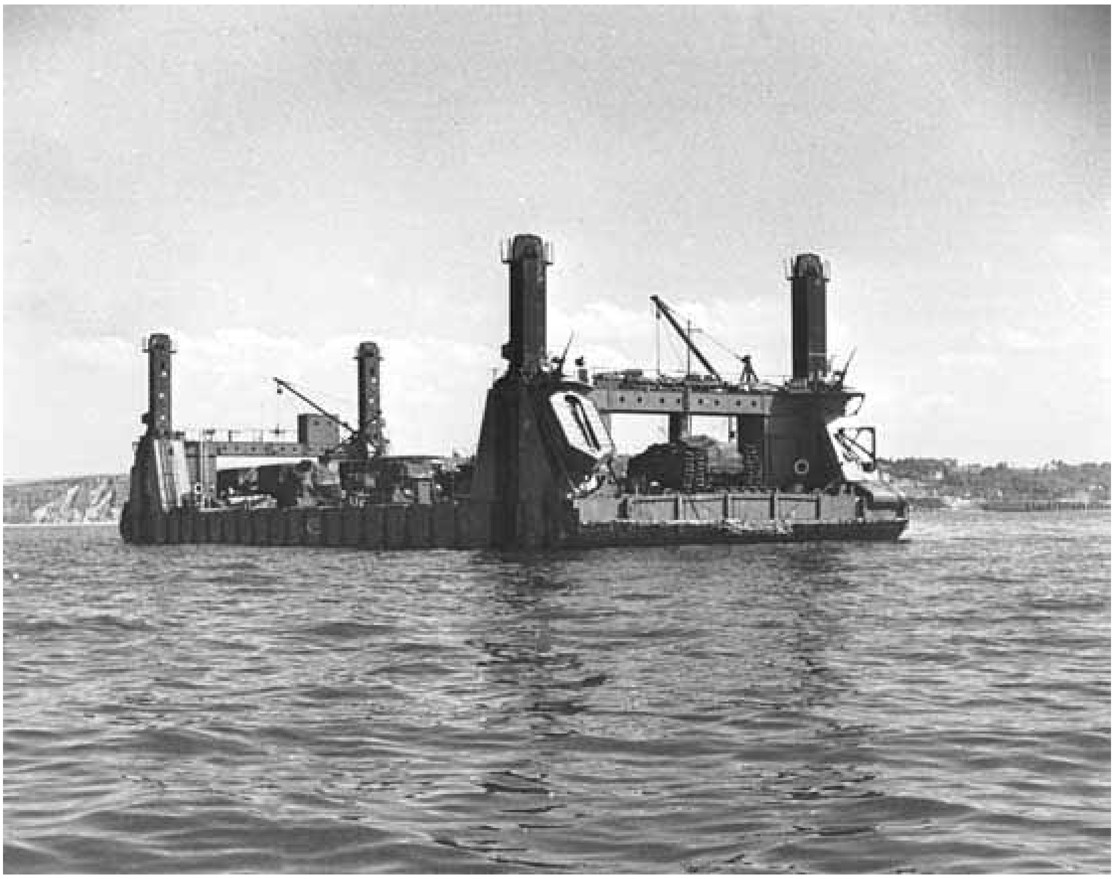
The modular structure of the REEF would allow generation to start before the whole structure was completed, thus producing an early revenue stream. The turbine caissons might be installed prior to the completion of the internal turbine components, should a supply problem develop. These caissons will be designed to be installed and removed in a short time like docking a ship, so when the turbine components become available, the caissons will be exchanged for operational ones.

g) ENGINEERING
Civil engineering structures
Building the impounding structure as far west as possible increases the electricity generation, makes navigation easier and reduce the impact on local communities and wildlife. Limiting the head across the impounding structure minimises environmental impact caused by major modification to the natural tidal regime and currents within the estuary. Reducing the quantities of material required to build the REEF because of the low aspect ratio and the low 'solidity' will in turn reduce the requirement on land for quarried aggregates. Reducing the amount of offshore work by prefabrication in shipyards will shorten the 'off-shore construction period and reduce costs.

Example of a rock embankment under construction

Rock armoured embankments will lead from the shoreline out to about 2 km in length and broadened to accommodate the railway sidings for transferring armour stone aggregate and other supplies to a tramway, road vehicles and barges for transport on to the areas of construction. After construction, this area may be landscaped for environmental and/ or leisure areas. The embankment itself would be comprised of an outer armour stone facing and an inner core of selected landfill such as demolition rubble. Having rail connections, the material could economically be collected from a considerable area of the country as an alternative to paying landfill tax. A conventional reinforced concrete seawall would protect the seaward side of the crest out to the small craft lock and barge quay. It is proposed that these parts of the ‘Reef’ could be completed well in advance of the main project and before the final decisions on construction were made because the materials would comprise rock and land fill, and the end result if the project did not go ahead would simply be a promontory extending into the estuary.

The ‘Causeway’ foundation, over which the **‘turbine power modules’** are installed, would be constructed like a conventional ‘Jack-up’ barge but made of concrete. The causeway sections, measuring approximately 100 metres in length, 25 metres in width and 5 metres in depth, would weigh around 5000 tons each. Transported to site straddling two barges the legs would be lowered to the seabed so that the barges could be removed. When jacked up, a string of these structures would form an access bridge to the working area and present less resistance to the tidal current and wave action than a solid structure. Upon completion of a string of about 10 sections an island would be created using a large pre-cast caisson weighing in excess of 15000 tons. These ‘Service Islands’ would have docking facilities for barges and lifting facilities in the form of a gantry or straddle carrier. They would also contain an electrical sub-station and lift access to the service tunnels that would be created once the ‘Causeway’ units were lowered to the seabed and grouted together.



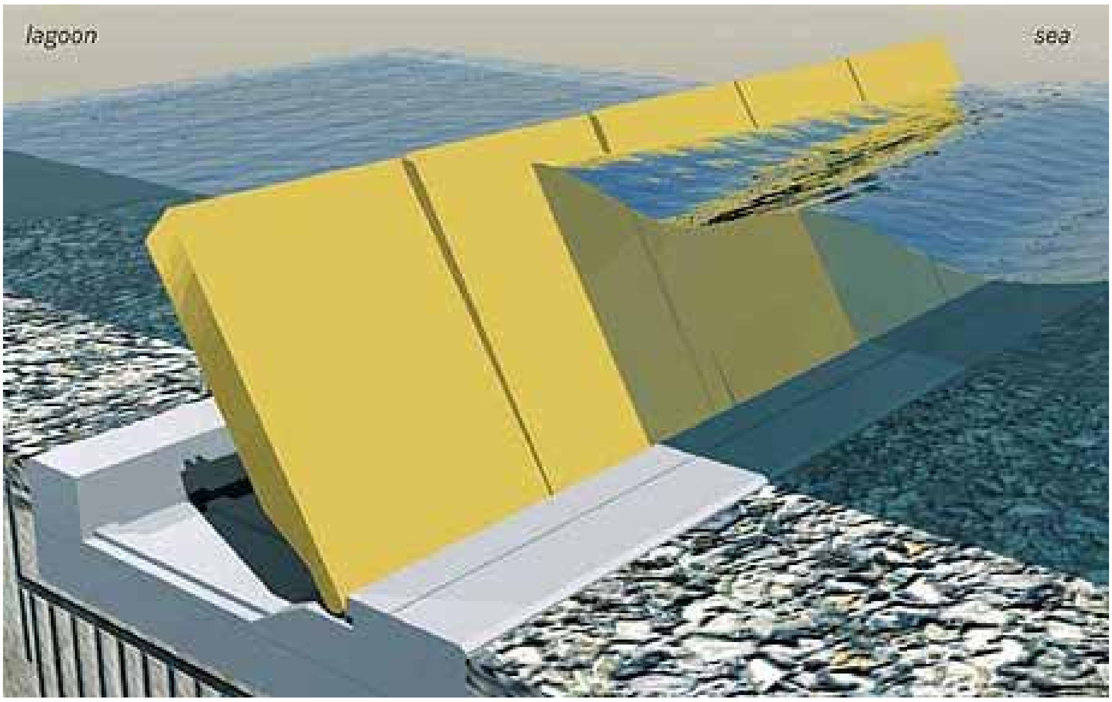
A 'whale' pierhead as used at Mulberry Harbour

The process of lowering the 'Causeway' units is standard practice in the marine construction industry. Additional pre-cast components will be added during this phase to form the intermediate piers that surround the main jack-up legs, vertical cable and service shafts and any mooring points that may be required to locate the turbine 'Carriers. The completed structure would look similar to the Thames Flood Barrier. The voids in the 'Causeway' units and to the irregular seabed and in the islands and piers would be filled with dredged material, aggregates and concrete as appropriate. This method of construction is a variation of standard marine techniques, some of which have been carried out in the Severn Estuary in the past and would form the basis for an accurate design and costing exercise. This method of construction lends itself to a multi-contractor multi-location build. In turn this will help to keep costs lower and reduce the build time.

A system for constructing/placing caisson structures

Flexibility in the work programme to accommodate unforeseen engineering difficulties is possible. The pre-cast 'foundation units' (the causeway) have access tunnels and service ducts cast into their structure, these will subsequently be made water tight and used as cable and access routes to service islands located every 500 metres or so along the REEF. Should wind turbines be considered as part of the project, then generation could begin soon after the first 'Service Islands' are completed and the electrical connections made. Early trials for the 'foundation' building system would be carried out to the seaward end of the 'Embankment' section. In this way, any failures of difficulties, would be buried and form part of the final structure. Real working conditions on the actual site would thus the used to prove the process.

The power generation modules are similar in concept to some of the large low-head hydroelectric plants built on the Mississippi that were floated into place, but this is the first time that is proposed that all major maintenance work is carried out by re-floating the modules and towing them to a dry-dock. Building and operating the infrastructure necessary to do the maintenance at sea would be very expensive. The simple fixed flow turbines proposed, will produce a lower power output but for a much longer period during each tidal cycle. The turbines and civil structures do not have to be designed to meet the higher stresses resulting from the higher heads used by conventional designs. In addition the turbines, though large, can be manufactured by hundreds of relatively low-tech shipyards around Europe, rather than the handful of high precision non-UK based hydroelectric turbine builders.



Schematic illustration of 'Moses' project to protect Venice

The navigation structures associated with the REEF only have to accommodate a small head differential so the gates only need to withstand about one third of the hydrostatic pressure of those proposed for the 'Cardiff-Weston Barrage', they are therefore cheaper to build and ships may pass through quicker. At 'Slack Water' vessels may pass through unhindered and there are possible solutions that would allow ships to pass through at any state of the tide without stopping.

Grid connection may be achieved in a number of ways. Aberthaw power station on the Welsh side is already connected to the grid with a 400,000-volt line. This power station is scheduled for closure in about 15 years time. An underground connection would be possible on the Minehead side, running for part of its route along the West Somerset Railway before being connected into an upgraded but existing overhead line near Wiverliscombe.

Thames Barrier

SECTION 2 – The Design

a) MODELLING

Scaled down physical models and CAD modelling can be used to test and fine tune the design prior to construction. The models can be used to analyse and access many aspects of the requirements that the design needs to meet. This will result in a better understanding of the capability and the REEF and will be valuable in achieving the full potential the REEF is able to give. Modelling will inform

1. How changes to currents and silting in the estuary and Irish Sea will be adjusted by the REEF structures and operation.
2. The fine tuning of turbine design to enable safe passage of marine mammals, eels and fish.
3. How water levels can be adjusted to alleviate potential flooding at high spring tides or during exceptional weather conditions.
4. An analysis of how the structure of the REEF will meet the coastline to facilitate its construction and bring advantage to the coastline rather than environmental impact.
5. An analysis of how the navigation lock will work in an efficient manner to facilitate rapid ship movements,
6. How the Severn bore can still be maintained.

b) ENGINEERING

The REEF would run from Warren Point just east of Minehead in Somerset This route can take advantage of an excellent rail link to Aberthaw, existing industrial and National Grid facilities at the old power station and existing cement works. On the Somerset side, the West Somerset Railway passes within a mile of the landfall and has recently been engaged in transporting large quantities of armour stone from Merehead Quarry for sea defence work at Minehead. Whilst disruption in the immediate area of the landfall would be inevitable, the town of Minehead itself would be bypassed by all construction traffic, and could benefit from the project because of extra visitors. A route further west between Nash point and Hurlstone Point would be slightly shorter and enclose a further 120 km2 but the depth is greater and the access is more difficult put it should be considered in outline.

Landfall embankments will run for 1000 metres from the shoreline out to a point where the smallest diameter of turbines can be installed. Each embankment is comprised of a rock-armour face and a rubble fill. On both sides of the estuary a railway siding will be constructed along the top to bring in material for the construction of the embankment and latterly to transport material to the 'transfer dock' at the seaward end. The railway siding will also adjoin a 'transfer siding' connecting with access tunnels running through the foundation structures of the REEF itself. The embankments will be of sufficient width to accommodate the construction site and storage areas. It is envisaged that most of this area will be landscaped and made into a 'marine park' after construction is completed. A study would be carried out to see if a permanent beach can be maintained without the present need for 'replenishment' with sand dredged from the estuary

Remote construction depots would be required to receive materials and construction personnel, and trains would run to a forward depot located at the seaward end of a rock causeway about a mile offshore. The Minehead rail connection would be made from a point near Dunster station and cross the low-lying land to the coast just east of Warren Point. A rock armoured peninsular would stretch about a mile out to sea and carry the standard gauge line to transfer sidings and a dock on the lagoon side of the peninsular.

Early-stage marine contracts will be to regularise the seabed to accommodate the foundation structures. The seabed at this point is hard rock generally swept clean by the high velocity of the tidal currents. A combination of hard rock cutting and void filling will produce a level shelf of broken aggregate and cut rock surface. In the channels the depth of water at low spring tide is as deep as 23 metres, which is deep for this type of work. The 'foundation

A gantry crane of the type that would be used for light maintenance

structures' in the form of pre-cast concrete frames weighing in excess of two thousand tons each, will be transported from remote construction yards and located at the correct level on jack-up piles before anchoring with rock-armour and grout. Much of the in-shore construction can be achieved using land based construction machinery such as tracked cranes and 'jack-up' barges as opposed to floating crane barges that are considerably more expensive to operate.

The dock would be for the transfer of heavy materials including rock armour stone to barges for placing offshore. The transfer area would allow materials including the long lengths of insulated high-voltage cable to be lifted onto special narrow gauge wagons for transport down into the sub-sea cable tunnel, a process almost identical to that used during the construction of the Dinorwig pump-storage scheme in North Wales. A travelling gantry would also be used to lift heavy items such as transformers from low-loading railway wagons. This peninsular could later be reclaimed and established as a marine park or leisure facility, allowing visitors to walk, cycle or travel by tram, out to the start of the REEF.

Service islands will be built at intervals of 500 metres along the REEF **i**n the form of piers that rise above the high water level by some 20 metres. Contained within these islands are the sub-stations and access down to the service and cable tunnels running beneath the foundations. These islands also provide unloading points for smaller items of freight and alternative access points for maintenance personnel not using the access tunnel. A large gantry crane is also stationed at each island, and able to traverse the top of the 'turbine power modules' to carry out routine maintenance in good weather.

Turbine power modules will be floated into place astride the 'foundation structure' by a combination of internal buoyancy chambers and additional support from pontoons. The process is not only to make the final assembly process a rapid one, but to allow the 'turbine power modules' to be removed to a dry dock for periodic 'heavy maintenance', for upgrading or disposal in the event of decommissioning. The ' turbine power modules' will be of several types according to their function and water depth.

The modules will have a turbine with a fixed alignment that is able to operate in either ebb or flow mode, or the turbine may rotate within the module to face the correct way for the most efficient operation. The turbines will vary in size according to the depth of water in the particular part of the channel, the modules may also be optimised for both generation and pumping operations. The modules may contain more than one turbine and may rotate about a vertical pile. An major feature is that many different types of turbine module and competing consortia will be able to make use of a common infrastructure in a similar way that rail companies make use of the rail network.

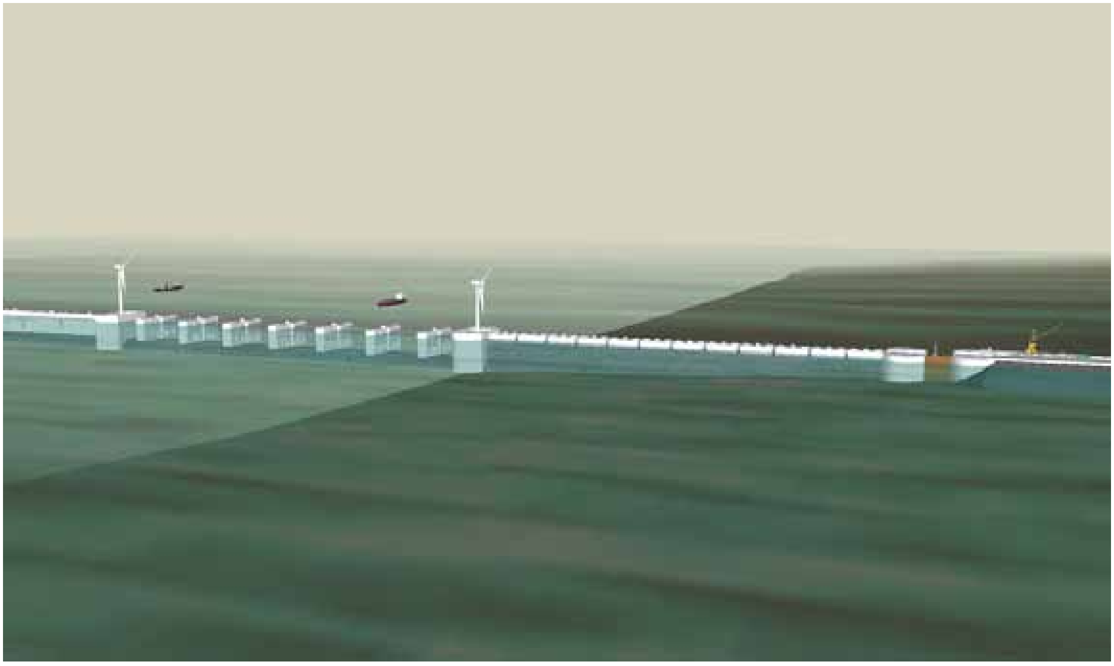
An alternative system would use conventional high-head water turbines in conjunction with water pumps driven directly by the very slow running low-head turbines.
The advantages are that:

- It keeps the electrical side away from the worst of the water.
- It allows variable speed operation at virtually no extra cost.
- It allows the low head turbines to run.
- It can buffer surges caused by sea swell reaching the structure.

Maintenance of the turbines would be relatively straight forward, since all the lighter components could be lifted vertically by means of a mobile gantry crane and transported to the nearest service island. For major refurbishment, the entire **'turbine power module'** would be replaced between tides and towed to dry dock.

The navigation structures will also share some of their footprint with the 'foundation structure' so that the cable and access tunnels run uninterrupted across the full width of the estuary. A lock would be provided on both sides of the estuary for pleasure craft wishing to pass through the REEF, though at slack water all craft will be able to pass freely through the structure without the need to stop.

The grid connection at Aberthaw would be made to the 400,000volt super-grid already in place to the power station, which will be nearing the end of its life by the timethe 'Reef' would be completed. The closest point of the super-grid on the south side is at Hinkley Point, but because of environmental considerations it may be more realistic to consider extending the large high voltage underground cables that will be routed under the 'Reef'. These cables would continue in a duct alongside the West Somerset Railway before branching off to the sub-station at Washford. From here the existing overhead high voltage grid (132,000 volt) would have to be upgraded to Norton Fitzwarren where it would connect to the Super-Grid.



c) SYSTEMS

Operation

The longer generation period means that the probability of being able to synchronise generation with peak demand are much greater. Furthermore, a relatively small increase of head of around half a metre over the nominal operating head of 2 metres, will enable the scheme to operate at an overload capacity to meet peaks for short periods without causing environmental problems.

The Simple fixed-flow, turbines can be built by many more sub-contractors around the country, so the price per kW will probably be the same or even lower than the large turbines that can only be built by a handful of international companies. By limiting the operating head of the turbines to less than two metres, the differential pressure exerted on the structure in much lower than for a barrage, making the construction easier and less sophisticated. The extensive use of concrete and 'resin bonded aggregates' is feasible because the water velocities are very low.

Control Systems

The controls are complicated because they involve several highly complex and interrelated systems. There is the system for controlling the REEF so that it meets the environmental and shipping requirements. There is the system that integrates the 'Reef' operation with the National Grid and finally the system that controls the generating equipment in relation to the tidal level (and sea conditions).

Eastern Scheldt

SECTION 3 – The Conclusions

The technical feasibility of a 'Tidal Power REEF System' is outlined in a report by W.S.Atkins (consulting engineers) commissioned by the UK 'Department of Energy and Climate Change' (DECC) and published February 2010**.** An earlier report, also by Atkins and commissioned by the R.S.P.B. and published in 2009 received a favourable responses from a wide range of environmental groups.

MAIN CONCLUSIONS

1. That a REEF type structure installed between Minehead and Aberthaw could have a total peak power output of 10,000MW and a total annual energy yield of 30.4 Twh.
2. That a REEF type structure installed between Minehead and Aberthaw substantially reduces the loss of inter-tidal habitat relative to the Cardiff-Weston Barrage (ebb-only generation)
3. That a REEF type structure installed between Minehead and Aberthaw can theoretically offer significantly improved fish mortality rates when compared with existing bulb turbine designs.
4. That a REEF type structure installed between Minehead and Aberthaw should be less disruptive to shipping than an ebb-only barrage.

OTHER CONCLUSIONS

1. That a REEF type system would require reduced grid reinforcement due to the flatter generation curve.
2. That a REEF type system would be more likely to retain the natural flow patterns of the estuary.

It would appear that all the initial objectives of the REEF proposal are achievable according to W S Atkins.

THE LEGACY

This is our generation's opportunity to build an 'iconic green energy project'. This is not just a wind-farm or power station, It would be the 'Greatest Machine on Earth' and visible from outer space with the naked eye. It would be our generation's 'Hoover Dam' or 'Great Wall of China' and it would 'say' that we care enough about future generations to invest in them rather than leave a legacy of a resource depleted planet and a stockpile of spent nuclear waste.

Public investment in the form of a 'green bond' is vital, and would mean that thousands or millions of ordinary people could own what is a part of our natural heritage, as opposed to selling off the rights to a multi-national power company. UK Plc would lead this technology sector instead of lagging behind or buying it in from abroad as has happened in the wind industry.

APPENDIX ‘A’

Arguments why we need the ‘Tidal Power REEF System’ as opposed to any other of the proposed tidal systems for the Severn estuary.

Water levels and habitat
It would be legally impossible to employ a conventional fixed barrage across the estuary that causes significant damage to the inter-tidal and salt-marsh habitat.

Safe passage of fish and sea mammals
It is unacceptable to kill any significant percentage of migrating fish species, causing their numbers to decline in the rivers upstream of a barrage.

No barrier to shipping
A fixed barrage across the Severn would cause significant problems for Bristol docks and endanger several thousand jobs and the viability of the new container terminal.

Smoother electricity generation
Generating a lot of electricity for short periods during the day causes major problems for the grid; whereas the REEF systems will act as a ‘buffer’ to the National Grid.

Less changes to morphology
A barrage that releases an enormous amount of stored water over a short period will cause major changes to the morphology. The REEF maintains the natural tidal regime.

Less silting
The estuary will not become silted up as the inflow from the rivers is minute compared to the mass-flow caused by the tide and the small variations caused by the REEF.

Flexible operation
All large civil engineering projects have unforeseen problems. The REEF project is the only one where the operation can be altered significantly to take account of any unforeseen changes.

Scale of project
Small projects can take as long to execute as larger ones and have disproportionate costs associated with planning, so if we are serious about tidal power we should go for the largest feasible project so there is enough capacity to allow for environmental mitigation measures.

Local disruption
All big projects cause some local disruption. The choice of Minehead to Aberthaw with its rail connections allows the construction facilities to be located back from the coast along the railway or out to sea on the approach embankment and away from the town.

Flood alleviation
Placing any form of resistance to the incoming tide can increase the danger of flooding. The REEF is an ‘Active Structure’ like the ‘Thames Barrier’ and located to the west, so it can be used dynamically to attenuate ‘storm surges’ and artificially reduce estuary levels to help reduce river flooding.

Practicality
The REEF uses many established offshore engineering techniques and turbine designs, but they are put together in a novel and flexible way that is well within the knowledge and capability of present day engineering.

Local employment
A conventional barrage design would require large conventional turbines. Since only a handful of international companies can build these turbines, there would be a significant ‘supply chain problem’. The REEF is designed with a larger number of ‘shipyard built components’, as opposed to precision-engineered components, such items can be supplied by the many smaller West Country and UK Firms.

Cost & value
There is much less financial risk with building the REEF because there can be many different contractors and technical avenues, so even if one part experiences difficulties, it will not jeopardize or delay the whole project.

APPENDIX ‘B’
Arguments around the relative cost of the Severn Tidal Power REEF to other systems proposed for the Severn estuary.

1. That the REEF requires less material to build than an ebb-only barrage on account of its large ‘open area (approximately 50%). The amount of concrete may be greater but the total amount of aggregate required will also be less because the REEF has a ‘lower aspect ratio’ (tall rather than wide)
2. There are many more firms that can be part of the supply chain because the turbines are relatively ‘low-tech’ shipbuilding technology, as opposed to large-scale precision engineering.
3. The REEF will offer considerable advantages to the National Grid in terms of energy regulation and this has both capital and on-going revenue implications.
4. The REEF is a ‘modular’ construction, giving greater flexibility in the supply chain, the investment profile and reducing the risks during construction.
5. The REEF give the prospect of generation prior to the structures being totally completed.

Phoenix Caissons at Aromache