8,000MWs of tidal power in the Severn? Finding the energy/cost/environment/economic balance.

C.J.A. BINNIE, Severn Tidal Power Feasibility Study, Minehead, UK
P.M. KYDD, Parsons Brinckerhoff, Bristol, UK

SYNOPSIS. Reducing carbon dioxide emissions to 80% of the 1990 levels by 2050 is a priority for the UK and is likely to require most, if not all, feasible low carbon technologies to achieve this. Following on from the conclusions of the Sustainable Development Commission[i] (SDC) that "there is a strong case to be made for a sustainable Severn barrage", the Government launched a feasibility study[ii] in January 2008 to assess whether it could support a tidal power scheme in the Severn estuary, and if so, on what terms. Several options exist for development of tidal power from the Severn including the previously studied barrage proposed between Cardiff and Weston-super-Mare. These options have the potential to generate up to 5% of the UK's electricity demand and the largest proposal would save over 7 million tonnes of carbon dioxide per year.

INTRODUCTION

In January 2009, the Government launched a public consultation[iii] on the first phase of the Severn Tidal Power Feasibility Study. This summarized the results of work undertaken in 2008 to identify potential options for tidal power in the Severn and to evaluate them to develop a shortlist of options for more detailed study in Phase 2. Phase 1 also included the work necessary to scope the requirements for the Strategic Environmental Assessment (SEA) to be undertaken in Phase 2.

Phase 1 started in January 2008 with the Department of Business, Enterprise and Regulatory Reform (BERR) assembling a cross-Government team to manage and undertake the two year Feasibility Study. In April 2008, following a competitive tendering process, a consortium led by Parsons Brinckerhoff (including Black & Veatch, ABPmer, HR Wallingford, Corderoys, APEM, BTO and others) were appointed by BERR to undertake the main engineering and Strategic Environmental Assessment (SEA) studies for the Feasibility Study. At the same time, PricewaterhouseCoopers (PwC) was appointed by the Government to provide advice on the financing

Managing Dams: Challenges in a Time of Change. Thomas Telford, London, 2010

and ownership issues. An independent Expert Panel was also appointed by BERR with assistance from the Royal Academy of Engineering to act as the peer reviewers for the engineering studies. BERR's lead responsibilities were taken over by the Department of Energy and Climate Change (DECC) on its formation in October 2008. The Government's statutory agencies were used for peer review of the SEA. The SEA was also guided by a Steering Group[iv].

The key deliverables from the consortium in the first phase were published alongside the main consultation documents and are shown in Table 1.

Table 1. Phase 1 Deliverables

Deliverable	**Description**
Call for Evidence	A Call for Proposals of tidal energy schemes to be considered by the study and a Call for Information of relevant technical, environmental and regional data
Interim Options Analysis Report	A report assessing the engineering and cost of different tidal power options for the Severn
Topic Papers	16 topic papers were produced to inform the SEA Scoping Report covering the potential environmental and socio-economic effects
SEA Scoping Report	A consultative report identifying the scope of the SEA studies to be undertaken in Phase 2
Habitats Regulation Assessment	A preliminary screening of the implications of the Habitats Directive

In addition, other reports prepared directly by the DECC study team, PwC and DTZ also supported the main consultation document. The South West Regional Development Agency and Welsh Assembly Government jointly appointed DTZ to advise on regional economic issues for Phase 1. The Expert Panel's remit in Phase 1 was the review of the Interim Options Analysis Report[v]. The constitution of the Expert Panel is set out in Appendix 1.

The following sections of this paper describe the Phase 1 approach and the simultaneous consideration of engineering, cost, environmental and regional issues in the analysis of the various options on the long-list drawn up following the response to the Call for Proposals. It also describes the work being undertaken by Phase 2 although it will not be possible to present any results or conclusions from the Phase 2 work until this work is itself concluded and the reports published as part of the next Government Public Consultation. The latter is expected to take place in 2010.

OPTIONS FOR TIDAL POWER IN THE SEVERN

In addition to the options considered by the SDC's Study, a wide variety of potential options were received both during and after the Call for Proposals in June 2008. The submissions fell into five different categories:

i) Tidal Barrages

ii) Tidal Lagoons – onshore and offshore

iii) Tidal Fences – using tidal stream technologies

iv) Tidal Reef – similar to a barrage but using a low differential head and larger water passages similar to tidal flow schemes.

v) Alternative forms of construction for lagoon basin walls

There were also some illustrative concepts submitted but without any supporting analysis. A long-list of options was developed and these are described below.

Tidal Barrages

The tidal barrage options (prefixed B in Figure 1) ranged from an outer barrage B1 between Minehead and Aberthaw (originally proposed in the 1981 Bondi[vi] studies) to a relatively small barrage upstream of the mouth of the Wye at Beachley (B5). The Cardiff to Weston (B3) and Shoots (B4) Barrages were both carried forward from the SDC Report and a proposal for a modification of the Cardiff-Weston barrage, whereby instead of landing at Weston, the barrage landed at Hinkley Point, was also received (B2). A 1km wide causeway scheme (U1) had also been proposed between Cardiff and Weston, producing energy but also dependent upon other forms of infrastructure revenue.

Tidal Lagoons

Tidal lagoons (prefixed L) were considered as a generic option as there are infinite variations of location, shape and size. Several proposals for lagoons were received but most were conceptual in nature. The most detailed proposal was received from Fleming Energy of Ireland for a land-connected lagoon on the Welsh Grounds (L2). Tidal Electric proposed several indicative locations and energy yields for offshore lagoons. All lagoon proposals other than the detailed Fleming proposal were therefore considered generically and a range of locations and sizes of lagoons – both land connected and offshore – were subsequently analysed (L3a to L3e).

Tidal Fence

A tidal fence comprising a single line of ducted tidal stream turbines set in a submerged concrete structure across the Severn was proposed by the Severn Tidal Fence Consortium. Their proposal assumed that a significant

extrapolation of tidal stream turbine performance could be achieved (from 0.6MW to 5MW per unit) and it was therefore classified as embryonic. However, the tidal fence was modelled using existing tidal stream technologies at two locations – Cardiff Weston (F1a) and Aberthaw to Minehead (F1b).

Tidal Reef

Evans Engineering proposed a new concept for a submerged barrage between Minehead and Aberthaw (R1). The barrage was capped with rotating steel siphons which housed vertical axis turbines and could be rotated to increase water passage through the barrage. The operating concept was for the basin levels to be maintained within 2m of the normal tidal range. Although the peak power output was reduced by comparison with a normal barrage due to the 2m operating head, the reef was able to operate for a longer period of the tidal cycle.

Alternative Forms of Lagoon Basin Wall Construction

Several alternative forms of lagoon wall construction were submitted to the Call for Evidence. These included several modular pre-cast concrete (and other materials) solutions, and sand/silt filled geotubes. The intent of these forms of wall construction was to reduce the unit cost of lagoon wall construction to compensate for the longer lengths involved compared with a barrage. A conventional rockfill form of construction was also assessed. These forms of wall construction were studied for the various lagoon options (prefixed L3).

FAIR BASIS ASSESSMENT

The aim of Phase 1 was to differentiate between options to produce a short-list for more detailed study as part of the SEA. It was recognised that some schemes had benefitted from more intense study than others. A fair basis method of assessment was therefore undertaken to consider all options on the same terms but informed by the previous more detailed studies where this could be applied to all options. This meant that the schemes submitted by proposers were given the benefit of the doubt, particularly where they were proposing more innovative technologies. Where the assumptions underlying innovative approaches were of concern, the agreement was sought from the Proposer to modify the assumptions but Proposers did not agree to these changes in all circumstances. In those cases, the proposers' assumptions were carried forward unless there was a clear evidence base to suggest that they should not be.

The fair basis methodology using new cost build-ups based on the most studied option (the Cardiff Weston Barrage[vii]) and applying them – at principal quantity level – to the other options, reflecting their specific

configuration. For the purposes of differentiating between options, the ebb only mode of generation was applied unless an option used technology which relied significantly on currents rather than tidal range in which case, ebb and flood generation mode was used to capture the optimal currents. Turbine sizes and installations were determined by the original proposer and/or previous studies. For tidal lagoons, proposers' individual assumptions were amended to achieve consistency of installed capacity and basin sizes to enable the merits of different lagoon sites to be compared.

In summary, the fair basis methodology involved preparation of new cost estimates (using a consistent cost database and independently estimated by cost consultants Corderoys) using consistent assumptions relating to programme, mode of operation and the significant compensatory and mitigation requirements (primarily habitats, ports and land drainage).

An assessment framework was developed jointly with DECC to assess the options in both quantitative and qualitative terms. The quantitative elements were input from the fair basis analysis and covered:

- Capital cost
- Levelised cost (discounted capital and operational/maintenance costs and associated energy yields) using a 120 year life and an 8% discount rate
- Total CO_2 emissions saved
- Total energy yield
- Development and construction times
- Cost of compensatory habitat and other significant mitigation costs (e.g. land drainage, continued navigation)

The qualitative elements covered the primary environmental and regional effects including effects on geomorphology, species, marine and terrestrial ecology, water quality, historic environment as well as regional economic impacts such as flood defence, construction impacts, effects on ports, fisheries and aggregates and long term employment.

The qualitative assessments were informed by the work undertaken for the SEA scoping and whilst not definitive, it was generally possible to classify the various effects as largely positive, negative, neutral or unknown. The available information / data and bringing together of technical experts at specific workshops during the SEA scoping phase did highlight certain areas where experts did not agree – for example, water quality and geomorphology, and flood defence benefits / costs. These areas of

uncertainty informed much of the additional research work necessary to inform the SEA. For those options that were not shortlisted (and therefore would not benefit from the additional research carried out for the SEA), a feedback loop was incorporated in the second phase of the study so that the outputs from the more detailed research could be considered in the context of the original long-list of options. This would enable a rejected long-listed option to potentially be re-introduced into the short-list on the basis of emerging data from Phase 2.

Another issue for Phase 1 was how to deal with the embryonic technologies, in particular balancing the claimed benign environmental performance with the uncertainties in terms of development time, cost and energy output. A difficulty is that unlike conventional bulb turbine technology used for barrages and run-of-river hydropower schemes alike, there are very few marine devices in the water, and those that are have costs reflecting their prototype / pilot status. Embryonic options were costed anticipating that prototype costs experienced to date would reduce significantly in future but nevertheless levelised costs in terms of £ per MWh still exceeded the more conventional technologies by some way. This is partly because, to achieve a more benign environmental effect, embryonic technologies are more permeable than a barrage and this leads to a reduced energy yield for a particular location. As a consequence of these results, and in order to study embryonic technologies further, the Government launched the Severn Embryonic Technologies Scheme (SETS). The final reports from the three successful applicants for this fund will be completed by end January 2010 and taken into consideration before the Government's Feasibility Study is concluded.

SHORT LIST OF OPTIONS

The Government published a draft short-list of schemes to be studied in Phase 2 in January 2009 and confirmed these in July 2009[viii] following a public consultation which concluded in April 2009. The short list comprised those options that were considered affordable and feasible on the basis of work undertaken across all workstreams in Phase 1. A threshold figure of £200 per MWh was considered to be the upper feasible limit in terms of levelised energy costs and this was based on providing a relatively generous upper bound above the Government's renewable energy strategy figure of £170 per MWh (the cost to reach the last percentage point of the Government's 2020 renewable energy target). The upper bound figure of £200/MWh was justified on the basis that it would not preclude, on cost grounds alone, options which had the potential to be more environmentally benign.

The shortlisted options are:

- Cardiff to Weston Barrage (from SDC 2007 report)
- Shoots Barrage (from SDC 2007 Report)
- Beachley Barrage (identified as part of the DECC Study)
- Welsh Grounds Lagoon (proposed by Fleming Group)
- Bridgwater Bay Lagoon (identified as part of the DECC Study)

Of these, the Cardiff to Weston barrage (8.6GW) is the largest option costing around £21 billion and saving 7.2Mt of CO_2 per year. Options larger than Cardiff Weston, i.e. B1 barrage Minehead to Aberthaw, were not considered by Government to be affordable, although B1 had similar unit energy cost and impact to B3, Cardiff Weston.

Beachley Barrage (625MW), Shoots Barrage (1.05GW) and the two shortlisted lagoons (both modelled at 1.36GW installed capacity for Phase 1) are appreciably smaller but could potentially be constructed in combination (two lagoons, or one/two lagoon and one upstream barrage). Figure 1 shows the location of the shortlisted options.

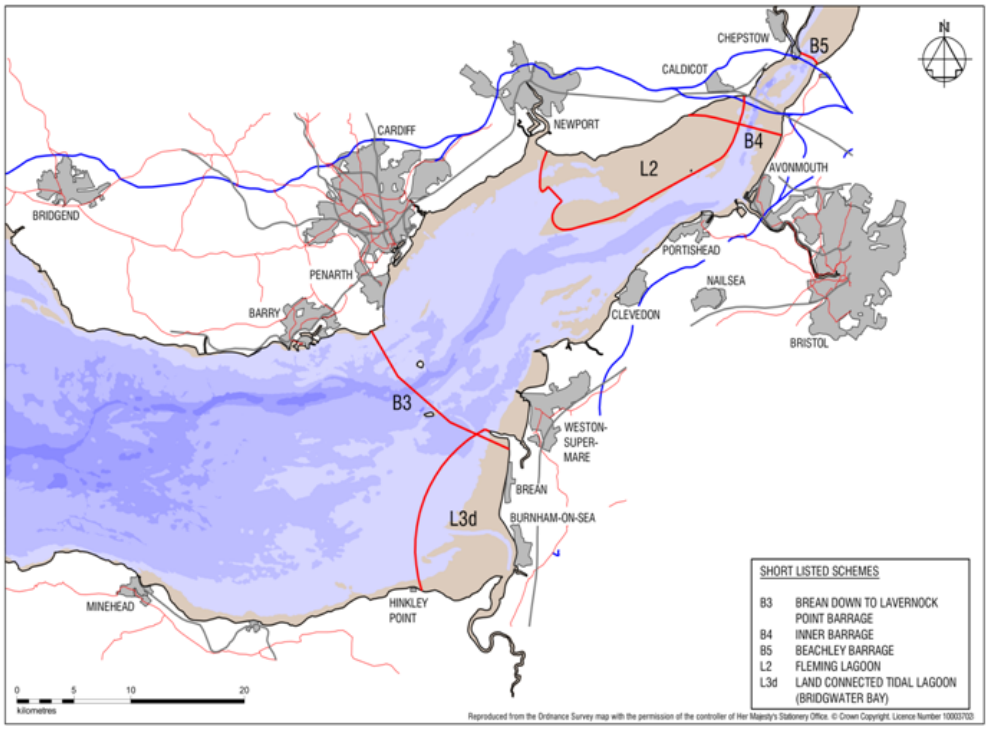

Figure 1. Location of Short-listed Tidal Power Options

ENVIRONMENTAL EFFECTS

The primary environmental effects resulting from a tidal power scheme are generally caused by three main drivers:

- The change in water levels resulting from the operation of a barrage, lagoon or fence (see Fig 2 showing water levels for ebb / ebb and flood operation respectively)
- The volume of water passed through a barrage, lagoon or fence and the associated change in tidal currents
- The ability for aquatic species to navigate through a barrage, lagoon or fence without suffering physical or pressure related damage.

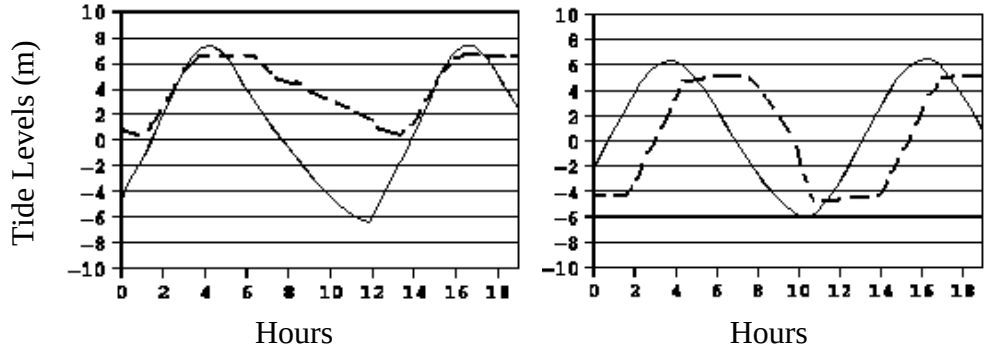

Figure 2. Indicative Upstream (dashed) and Downstream (solid) Water levels for ebb (left) and ebb and flood (right) modes of operation

In the case of the Severn, any option that abstracts energy will have some effect on the environment but the precise nature of the effects will vary on a scheme by scheme basis. A structure or permeable fence constructed across or within the estuary will affect the geomorphology of the estuary, changing sedimentation and erosion patterns. Abstracting energy from the estuary results in a reduced tidal range and, for barrages and lagoons, a longer period at which high water level is held, increasing the risk of erosion at the soil/water interface. Changes in water quality (salinity, turbidity, temperature, nutrients etc) and impacts on species (birds, fish etc) are therefore to be expected as tidal range, currents and erosion/sedimentation occur. The Habitats Directive provides certain safeguards and these are discussed below as are the issues related to fish and associated mitigation.

Habitats Directive

A reduction in tidal range also decreases the area of inter-tidal habitats. This is of major significance on the Severn which is protected as part of the Natura 2000 network under the Habitats Directive. The implications of this are that, providing the project is in the over-riding public interest and that no less-damaging alternatives are available, any habitats lost have to be

replaced to preserve the integrity of the Natura 2000 network. In the UK, planning consents have generally required compensatory habitats to be replaced using a ratio of between 150% and 300% of the" lost" habitat. For the purposes of Phase 1, a ratio of 200% was used with a cost of £65,000 per hectare of replacement habitat. Further work is being undertaken on this during Phase 2 but replacement habitat costs are significant. Changes are already underway in bird populations using the Severn with some species increasing and others decreasing. Construction of a tidal power scheme on the Severn will represent a further change but will be compensated through the application of the Habitats Directive. It should be noted that sea level rise due to climate change will also affect inter-tidal feeding areas and the SDC[i] identified the opportunity provided by Severn Tidal Power for the UK to become a leader in large scale habitat creation to offset such losses.

Fish

Protected fish species include Allis and Twaite Shad, Sea, River and Brook Lamprey, and Atlantic Salmon. These species are classed as diadromous migratory species, i.e. they live in freshwater and marine environments at different stages in their lifecycles.

Key environmental changes resulting from the development of tidal power options in the Severn include:

- Alterations to migratory cues (e.g. changes in salinity etc)
- Disruption to route of passage (e.g. passing through turbines)
- Habitat Changes (reduction in tidal range)
- Water Quality (changes in salinity, sediment, temperature etc)

REGIONAL EFFECTS

Regional effects and their impact on society and economy can be subdivided as follows:

- Effects caused by the changed hydrodynamic regime and associated environmental effects
- Effects caused by construction and operation.

Ports and Navigation

The construction of a barrage and the resulting changed hydrodynamic regime require works to enable the ports in the Severn to keep operational. This includes the construction of new lock facilities through the barrage (itself a significant construction project) and modification works at the existing port facilities to reduce lock sills etc to enable existing vessels to continue to use the ports. These costs were included in the Phase 1

assessment of costs. The principal long term effect is the additional transit time through a new set of locks in the barrage for any ports upstream of the barrage. Lagoons should not directly impede shipping but may have an influence on changed sedimentation patterns and upstream water levels. Compared with the present day, the requirements of the navigation authorities to undertake routine maintenance dredging will continue but higher barrage basin low water levels may provide greater flexibility in transit for vessels once they are in the impounded basin.

Land Drainage and Flood Defence

Raised water levels at low tide upstream of a barrage or lagoon will require modifications to existing tide locked drainage outfalls – most probably through provision of increased storage and/or pumping. Because there will be a stand-time in the barrage or lagoon basin at high water level before generation starts, there is an increased risk of erosion at the soil / water interface. This may affect the stability of existing earth bank tidal defences which may consequently require an increased maintenance budget in future years. On the positive side, barrages and lagoons provide an enhanced level of protection to upstream communities, particularly when considering storm surges and future sea level scenarios.

Construction Impacts

Activities during construction have both positive and negative effects. There will be significant employment opportunities in the region but equally there will also be an influx of workers from other regions. The local service economy will benefit but there will be pressure on accommodation and local services. Construction impacts will include construction of new roads and construction compounds although a significant amount of construction can take place as a marine activity and the construction of the pre-cast concrete caissons will probably take place in specialist sites away from the barrage/lagoon locations.

Longer Term Impacts

The operation of a major power station will provide sustainable employment opportunities both for the management and maintenance staff employed at the station itself and also the contracted maintenance operations (e.g. dredging etc). Other effects on, for example, tourism are likely to have both positive and negative effects and will vary from scheme to scheme.

MITIGATION

Work is currently underway in Phase 2 to explore mitigation options. Identification of mitigation measures is not straightforward due to the often contradictory set of requirements. Taking the above examples of inter-tidal habitats and fish, a preferred option to reduce the loss of inter-tidal habitats

without compromising energy yield is to operate on both ebb and flood tides. This can reduce the loss of inter-tidal habitats by up to 50% when compared with ebb only operation but in terms of fish, there is a risk that fish will pass through turbines twice as frequently in a tidal cycle. Use of pumping to lower the water levels in a barrage/lagoon basin and further reduce inter-tidal habitat loss will also increase the risk to fish. Water levels also have other implications. For example, ebb only operation is more favourable to port operation as the loss of high water level is significantly less than for ebb and flood mode of operation. The larger vessels entering the Severn Ports typically require spring tides so any loss of water level at the top of the tidal cycle should be as small as possible from a navigation perspective to reduce subsequent costs in terms of reducing lock sills and modifying dock handling facilities.

ISSUES FOR PHASE 2

As can be seen from the commentaries above on the environmental and regional effects, this is not a single dimensional issue and even within specialist areas there are both positive and negative aspects. To achieve the primary objective of reducing carbon dioxide emissions involves difficult decisions relating to what is acceptable in terms of environmental and regional effects. The key issue for the work being undertaken in Phase 2 is to study these effects in more detail having refined the shortlisted schemes using parametric studies to achieve further convergence on scheme definition taking account of the engineering, economic and environmental issues. Work undertaken in Phase 2 has included:

- Refining each of the short-listed schemes in terms of installed capacity, mode of operation, location and having regard to the main environmental and regional effects
- The refined options have then been reviewed in terms of engineering design and assessment of energy yields and costs
- The environmental effects have then been assessed by mathematical modelling to assess geomorphological effects, sedimentation, water quality, energy yield etc
- Strategies to prevent and reduce effects (aka mitigation measures)

Finally an Options Definition Report, Environmental Report and Appropriate Assessment are being produced summarising the Engineering analysis and Strategic Environmental Assessment, with these outputs feeding into DECC's Feasibility Study.

The work in Phase 2 is nearing completion and will be published alongside the Feasibility Study conclusions in the next public consultation (the exact

dates are not know at the time of authoring this paper but it is expected to be after the General Election in 2010).

ACKNOWLEDGEMENT

Both authors would like to acknowledge the help and support provided by their colleagues in Parsons Brinckerhoff, Black & Veatch and other members of the consortium and the Expert Panel throughout the study period. Particular thanks are due to the Feasibility Study team at DECC who have assisted in reviewing this paper as well as permitting its publication.

REFERENCES

i. Sustainable Development Commission (2007). *Turning the Tide – Tidal* Power in the UK, October 2007
ii. Department of Energy & Climate Change. Feasibility Study Terms of Reference.
http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/severn_tidal_power/feasibility/feasibility.aspx
iii. DECC Severn Tidal Power Public Consultation web site
http://www.decc.gov.uk/en/content/cms/consultations/stp_phase1/stp_phase1.aspx
iv. SEA Steering Group Minutes http://www.pbworld.co.uk/index.php?doc=630
v. Parsons Brinckerhoff (2008). Consultation Documents – Technical Options Appraisal – Interim Options Analysis Report, DECC Severn Tidal Power Public Consultation web site
http://www.decc.gov.uk/en/content/cms/consultations/stp_phase1/stp_phase1.aspx
vi. HMSO (1981). Tidal power from the Severn Estuary -Volume 1. Energy Paper 46.
vii. HMSO (1989). The Severn Barrage Project: General Report: Energy Paper 57.
viii. DECC (2009) Low Carbon Transition Plan, 15 July 2009
http://www.decc.gov.uk/en/content/cms/publications/lc_trans_plan/lc_trans_plan.aspx