ENERGY FROM TIDAL BARRAGES

TECHNOLOGY DESCRIPTION

Tidal barrage energy exploits the natural rise and fall of tidal waters caused by the gravitational fields of the sun and moon. In the open ocean, tidal ranges are small, typically having an amplitude of 1m or less. However, these ranges increase towards coasts, and particularly in estuaries, because of the shelving of the seabed, the funnelling of water and, in some cases, resonance effects.

Most tidal barrage schemes have generally been built in – or considered for – estuary locations. They involve constructing a barrage across an estuary, allowing tidal waters to fill the estuary through sluice gates and then emptying the water back into the sea via turbines.

The barrage itself is likely to consist of steel or concrete caissons manufactured at suitable sites, towed to the estuary and sunk into position. Where it is necessary to maintain navigation to the upper part of the estuary, a ship-lock may be required. An alternative approach is to create a tidal pool by building across only part of the estuary, using a rubble mound wall.

Ebb generation is the simplest mode of operation for a tidal barrage scheme. The operating cycle consists of four steps:

1. Letting water in through the sluice gates during the flood tide, thereby filling the basin.

2. Holding the impounded water until the ebb tide creates a suitable “head” or fall.

3. Letting the water empty from the basin to the sea through a turbine. This takes place during the ebb tide and continues until the tide turns and the rising water reduces the head to the minimum operating point.

4. Holding the water again until the tide rises sufficiently to repeat Step 1.

Ebb generation with flood pumping is a modification of this mode that is favoured by potential UK developers because of the ability to alter the timing of the energy output. By using the turbines in reverse, as pumps, the level of water in the basin, and hence the generating head, can be raised, allowing the barrage to be used as a slow-release pumped storage scheme. UK studies on a number of potential tidal energy schemes indicate that energy storage through pumping could provide between 3% and 13% of the total electricity generated.

Other modes of operation, including flood generation and two-way generation, have been considered but are not generally favoured because they either yield less energy or require more complex plant and machinery. In addition, their reduced water levels may be less acceptable to shipping.

Electricity is generated using large axial flow turbines with diameters of up to 9m. Because of the continuously varying head of water that drives them, variable control of both distributor

blades and turbine runner (ie double regulation) may be necessary for maximum efficiency. Double regulation is also required if the turbine is to be used in both directions for generation, or in reverse for pumping.

Two principal types of turbine generator have been considered for tidal barrage applications: the conventional "bulb" turbine and the rim-generator turbine. The bulb turbine contains the generator in a pod located in the water passage directly behind the turbine runner. However, for larger machines, a directly driven multi-pole generator in the bulb is preferred. A geared bulb turbine in a pit configuration may be cheaper if lower-rated machines are required. A rim-generator turbine, in which the stator is outside the water passageway and the rotor is fixed to the periphery of the turbine runner, has been successfully tested at Annapolis in Canada. However, large rim-generator turbines are not available with double regulation and they therefore have no proven capability for reverse turbining or pumping. As a result, their use may be restricted to simple ebb generation schemes.

MARKET

The primary market for tidal energy barrages is electricity generation. The size of the larger schemes would necessitate connection directly into the national transmission system (Severn 400kV, Mersey 275kV). Smaller schemes could be connected into local distribution systems.

BENEFITS

Tidal barrage electricity generation would add to the diversity of UK generation and reduce carbon dioxide (CO_2) emissions. As robust civil structures, tidal energy barrages would guarantee secure, predictable and sustainable energy supplies, free of atmospheric emissions, for at least 100 years. The Severn barrage could provide 6% of the UK's electricity requirement, and the Mersey barrage 0.5%. Furthermore, although peak generation times would vary throughout the day with the tidal maxima, this could be accommodated because the times are known in advance, some storage can be incorporated, and barrages at different geographical locations have tidal maxima at different times during any 24-hour period.

Barrages would also offer additional communication links and provide a flood defence against storm surges on high spring tides.

Tidal barrage construction is based on conventional technology that major UK construction companies are well placed to provide. Several UK companies have previously been involved in site-specific feasibility studies; construction consortia and civil engineering consultancies have developed substantial expertise in specialised areas, especially energy modelling; and UK companies have international expertise in hydraulic modelling.

The full-scale development of a UK tidal barrage energy scheme would also provide excellent opportunities for UK-based turbine, electrical generation and control equipment manufacturers. For a project on the scale of the Severn barrage, several suppliers would be needed to meet the time schedules of the project.

Some potential for barrage development also exists along the coasts of France, eastern Canada, the Pacific coast of Russia, Korea, China, Mexico and Chile. Other sites have been identified along the Patagonian coast of Argentina and in Western Australia and western India. Experience gained during the construction and operation of a domestic project would give UK companies a competitive edge when bidding for the construction of tidal energy barrages overseas. Although site-specific conditions would determine design and environmental impact, the ability of companies to demonstrate the concept through all stages of a project, would be a significant advantage.

TECHNOLOGY STATUS

The feasibility of developing tidal energy barrages was first investigated during a DTI R&D Programme between 1979 and 1994. This Programme supported a series of technical and environmental studies that were co-funded by industry, as well as complementary generic R&D. The conclusions drawn by the Programme were as follows:

- Tidal energy is technically feasible even at a large scale.
- The technology is available and proven, although major reductions in capital costs are unlikely.
- There is no apparent economy of scale.
- Variations in predicted economic performance reflect site-specific conditions. The most attractive site in the UK at that time had a predicted cost for the electricity generated of ~8 p/kWh.
- There would be some regional and environmental benefits but these would be difficult to quantify and may not necessarily accrue to the developer.
- No insurmountable environmental barriers to the technology were identified. Detailed site-specific environmental assessment would be required for each barrage scheme to clarify the effects and establish its acceptability.

Current thinking is similar. Most investigations of tidal barrage energy schemes have considered artificial impoundments that can control the natural tidal flow. Furthermore, developers believe that a permeable barrage across an estuary minimises the cost of civil structures for the quantity of energy that can be extracted.

Construction of a barrage across an estuary with a high tidal range would be challenging but technically feasible. Such a scheme would use large turbines and power take-off systems similar to those used in large-scale hydropower systems.

Barrages have been constructed in France and North America, and the technology can be considered to work.

The costs associated with a tidal barrage scheme will depend on the size of the scheme (this ranges over two orders of magnitude in the UK) and its location. Examples of some of the tidal energy schemes proposed for the UK are shown in Table 1: a percentage cost breakdown for a representative scheme (Severn) is shown in Table 2.

Table 1 Characteristics of tidal barrage schemes

Barrage	Capacity (MW)	Build time (years)	Load factor (%)
Severn	8640.0	10	23
Mersey	700.0	5	23
Wyre	63.6	2	24

Table 2 Cost breakdown of the Severn tidal barrage scheme

Item	% of Cost
Civil engineering	59%
Turbines	29%
Electrical system	5%
Other	7%

Other concepts based on secondary artificial storage systems (tidal pool) continue to be promoted. These would enable energy production from water captured and stored within free-standing artificial basins.

TARGETS FOR COMMERCIAL COMPETITIVENESS

The target for commercial competitiveness in the long term is to generate electricity for ~2.5p/kWh (2002 prices). In the medium term the target might be ~6p/kWh.

Unit prices of ~5.5p/kWh (comprising the basic energy price of ~2p/kWh plus 3.1p/kWh from the Renewables Obligation and up to 0.43p/kWh from LECs) might, potentially, be available for project developers. The high level of predictability from barrage schemes over a period of several years could attract favourable prices.

However, for the Severn, there would be a lead-time of at least 14 years before full generation (five years for environmental monitoring plus nine years for construction). The construction of the smaller Mersey project could be achieved in nine years (four years for monitoring and development plus five years for construction). Financial institutions may find the long lead times to completion, combined with the underlying risk of political uncertainty, unattractive from an investment point of view. Both they and the barrage developers would almost certainly seek guarantees from the Government to underwrite the cost of pre-construction development work.

RESEARCH AND DEVELOPMENT ISSUES

For the two largest potential barrage projects, the Severn and the Mersey, significant development work has already been completed (geotechnical investigation, detailed design, costing, construction scheduling and energy modelling). Four other locations were investigated but only to a preliminary feasibility stage. Of particular significance is the development and calibration of site-specific hydraulic modelling. There are no generic technology R&D issues to be resolved, although steel and steel/concrete hybrid designs have not been developed or costed to the equivalent level of conventional concrete designs.

The economic prospects for alternative forms of tidal energy such as tidal pool technology are less certain, largely because of the lack of published data on costs, construction techniques and schedules, or performance. No judgement can be made until further information is available.

NON-TECHNICAL ISSUES

The 1979-1994 UK Programme addressed environmental issues in parallel with its technical investigations into scheme design. Both site-specific and generic environmental studies concluded that there would be modifications to estuarine environments, although none of the predicted changes identified so far would be sufficient to stop development. However, further detailed monitoring would be required before large projects could be given the go-ahead to proceed.

Because a barrage could completely close an estuary and regulate water levels, it could be used as a storm surge barrier to prevent flooding of adjacent low-lying areas. Furthermore, the Severn barrage would be a good site for an alternative road crossing of the estuary. By way of contrast, the proposed Mersey barrage could generate conflicts of interest with shipping and related commercial interests at Ellesmere Port.

UK INDUSTRY STRENGTHS

- UK construction companies are technically very competent in the design and development of civil engineering projects on the scale of a Severn tidal barrage.

- The UK has expertise in environmental assessment, especially hydraulic modelling.

TECHNOLOGY ROUTE MAP FOR THE DTI PROGRAMME

In 2001 the Government began a review of the existing information relating to tidal barrages – in particular the Severn. This was in response to several issues, including the Government's policy of producing a greater proportion of UK energy from renewable resources, the publication of the Royal Commission on Environmental Pollution report on CO_2 reduction, and the new electricity trading arrangements (NETA).

The Government is currently funding a new appraisal of the Severn barrage project. However, before any barrage project can be taken further as an energy supply option, work is needed in several areas:

- The credibility of private sector financing needs to be examined for realistic scenarios, including what might be achievable with the Renewables Order and under NETA.

- The implications of timing, consent procedures and connection into the national transmission network (Severn and Mersey) need to be included as part of a broader investment risk assessment.

- It is essential to reappraise the environmental effects and to implement a detailed monitoring programme that will determine, as accurately as possible, what these effects would be at each site.

- The concept of a small-scale demonstration barrage should be included as a prelude to the development of larger projects.

- The tidal pool concept requires independent evaluation to test the validity of the proposed construction techniques, timing, environmental impact and energy modelling.