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# AN ASSESSMENT OF THE PROGRESS OF TIDAL POWER WITHIN THE UK.

A Thesis Submitted To

THE OPEN UNIVERSITY

for

THE DEGREE OF MASTER OF PHILOSOPHY

by


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# AN ASSESSMENT OF THE PROGRESS OF TIDAL POWER WITHIN THE UK


## Abstract

The exploitation, for useful work, of the energy released by the rise and fall of the tides is not a new phenomenon. History records the existence of tide mills, particularly in England and France, many centuries ago.

The conversion of the diurnal movement of the tides into electrical energy by the construction of barrages is, however, comparatively new, the first hard evidence of the technology appearing in the literature some seventy years ago. England, particularly the west coast of the country, has been identified as having very considerable tidal resources and this thesis reviews in detail the several tidal barrage schemes which have been proposed for a number of estuaries, including the Severn and the Mersey.

The successful construction in the 1960's of the 240MW tidal generation scheme on the Rance River in Northern France could perhaps have been expected to provide the impetus required for a tidal project to be agreed in this country. It remains a fact, however, that despite the information available from the successful implementation of the Rance scheme, the succession of Symposia held on the subject, the conclusions drawn by expert Committees, the research and development undertaken by specialist Companies, together with calls for action, no electricity generating barrage has been constructed, or even authorised, in this country.

This thesis places on record the results of a detailed review of the extensive literature which now exists on the subject of tidal power. While so doing, it also attempts to provide insights into possible reasons why, despite environmental pressure for the control and reduction of emissions

from fossil-fired power stations and public aversion to nuclear generated electricity, this country's significant tidal resource of renewable green energy has not so far been tapped for electricity generation purposes.

Acknowledgements

I wish to place on record my thanks to my Supervisors Dr. D.A. Elliott of the Open University - Faculty of Technology, Technology Policy Group and to Professor C. McVeigh of Glasgow College for their valuable advice and helpful discussions during the progress of this project.

My sincere thanks are also extended to Margaret Barnes for typing this thesis.

I also wish to place on record the publication of my own additional work on the subject of Tidal Power, viz:-

'A Paper Barrage?' - Renew 74, NATTA, Milton Keynes, Nov/Dec 1991 p20/21.

'Tidal Power Politics: A Comparison of Political Responses to Large Energy Projects in the UK' - International Journal of Ambient Energy, Vol 13 No 3 July 1992 p145-154.

# An Assessment of the Progress of Tidal Power Within the UK

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FIGURES



Tables

**Table 1**

**Summary of Severn Barrage Proposals**

**(See Fig 1).**

| Date | Comments |
|---|---|
| 1920 | First Tidal Barrage Proposal. No copy of original Report prepared by Civil Engineering Dept. of the Ministry of Transport now available. Certain details contained in 'Studies in Tidal Power' by N. Davey p138-149.<br>'English Stones' the recommended site; Ebb generation with Pumped Storage reservoir at Trelleck Grange. Estimated annual output from DC machines 1.36TWh. |
| 1933 | First major Report. Committee chaired by J.T.C. Moore-Brabazon. 'English Stones' the recommended site, with Pumped Storage at Trelleck Grange as 1920 proposal. Estimated annual output from AC machines 2.25TWh. |
| 1945 | Second major Report. Committee, chaired by A.C. Vaughan-Lee. 'English Stones' again the recommended site for a barrage. Considered unnecessary to develop any Pumped Storage facility in view of newly constructed 'Grid' transmission system. Estimated annual output 2.365TWh. |
| 1981 | Third major Report. Committee, chaired by Sir Hermann Bondi, reviewed whole of Severn estuary and concluded that a barrage from Lavernock Pt. to Brean Down (Cardiff-Weston) was the most favoured. The ebb generation scheme anticipated to produce 12.9 TWh annually. |
| 1985 | Fourth major Report. Produced on this occasion by STPG - concluded that Bondi barrage line should be adjusted to eliminate 'dog-legs'. Output coincidentally increased to 14.4TWh by introduction of flood pumping. |
| 1989 | Fifth major Report. Second report by STPG. Barrage line re-adjusted as a result of geological survey and hydrodynamic studies. Annual output increased to 17TWh* by optimising generating capacity of the ebb generation flood pumping scheme. |
| Nov 1991 | Representatives of STPG summoned to appear before the Select Committee on (Renewable) Energy. |

* 17TWh of tidal generation reduces $CO_2$ emissions by approximately 17M-18M tonnes if coal-fired generating plant is displaced.

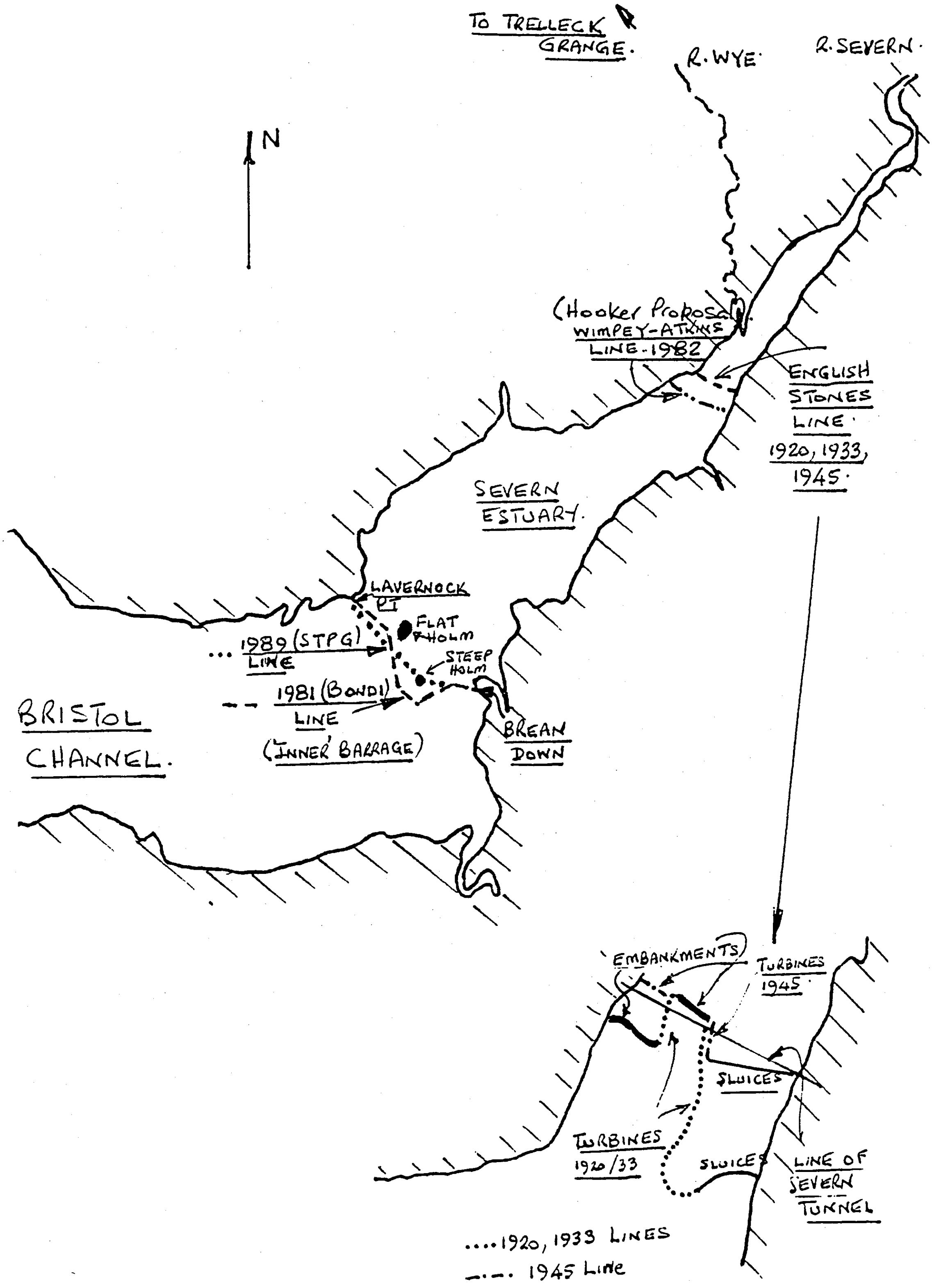
**Table 2**

**Summary of Severn Barrage Details**

| DATE | GENERATION DETAILS | CAPITAL COST £M | CONST$^{N}$. TIME YRS | UNIT COST p/kWh | COAL SAVED (annually M tonnes |
|---|---|---|---|---|---|
| 1920 | 400 Kaplan turbines 3m runner diam. 1300kW DC machines. 520MW | 28 | 'Several' | 0.21 (6% interest rate) | 1 |
| 1933 | 72 Kaplan turbines. 6m runner diam. 12.7MW AC machines. 914MW (of which 850MW would be available at any one time) | 38 | 15 | 0.075 (4% interest rate) | 1.8 |
| 1945 | 32 Kaplan turbines. 6m runner diam. 25MW alternators 800MW | 47 | 8 | 0.083 (3% interest rate) | 1 |
| 1981 | 160 Bulb turbines 9m runner diam. 45MW alternators 7200MW | 5660 | 12 | 3.1 (5% discount rate) | 6 |
| 1985 | 192 Bulb turbines 8.2m runner diam. 37.5MW alternators 7200MW | 5543 | 9 | 3.0 (5% discount rate) | 6 |
| 1989 | 216 Bulb turbines 9m runner diam. 40MW alternators 8640MW | 8280 | 9 | 34 (5% discount rate) | 8* |

* Equivalent to approximately 18M tonnes of $CO_2$ emissions annually.

FIG 1




LOCATION OF VARIOUS SEVERN SCHEMES

**Table 3**

**Summary of Mersey Barrage Proposals**

**(See Fig 2)**

| Date | Comments |
|---|---|
| 1983 | Pre-feasibility studies undertaken on behalf of Merseyside County Council. Three barrage lines (Lines 1,2 and 3) identified - Line 2 quickly rejected. Barrages at Lines 1 and 3 anticipated to produce 1.2TWh and 0.965TWh respectively using Straflo machines. Construction period approximately 6 years. |
| 1986 | Mersey Barrage Company formed. Line 1 adjusted to provide better arrangement for shipping interests - designated Line 1A. Outputs reconsidered with bulb turbines and flood pumping. Line 1A-1.33 TWh with pumping (1.27TWh without); Line 3 - 106TWh with pumping (1.02TWh without). |
| Undated MBC handout - probably 1988-9. | Line 3 revised to new favoured site 600m upstream of original line. Line 1A abandoned. |
| Stage II Studies 1990 | Line 3 now expected to produce 1.5TWh* with flood pumping. Construction time 5 years, Revised Cost £880m. (Line designated 3B). |
| Stage III studies 1991. | 250 page Report submitted to D of E on environmental matters. More details requested. |
| Nov 1991 | Representatives of MBC summoned to appear before the Select Committee on (Renewable) Energy. |

* 1.5TWh of tidal generation reduces $CO_2$ emissions by approximately 1.7M tonnes if coal-fired generating plant is displaced.

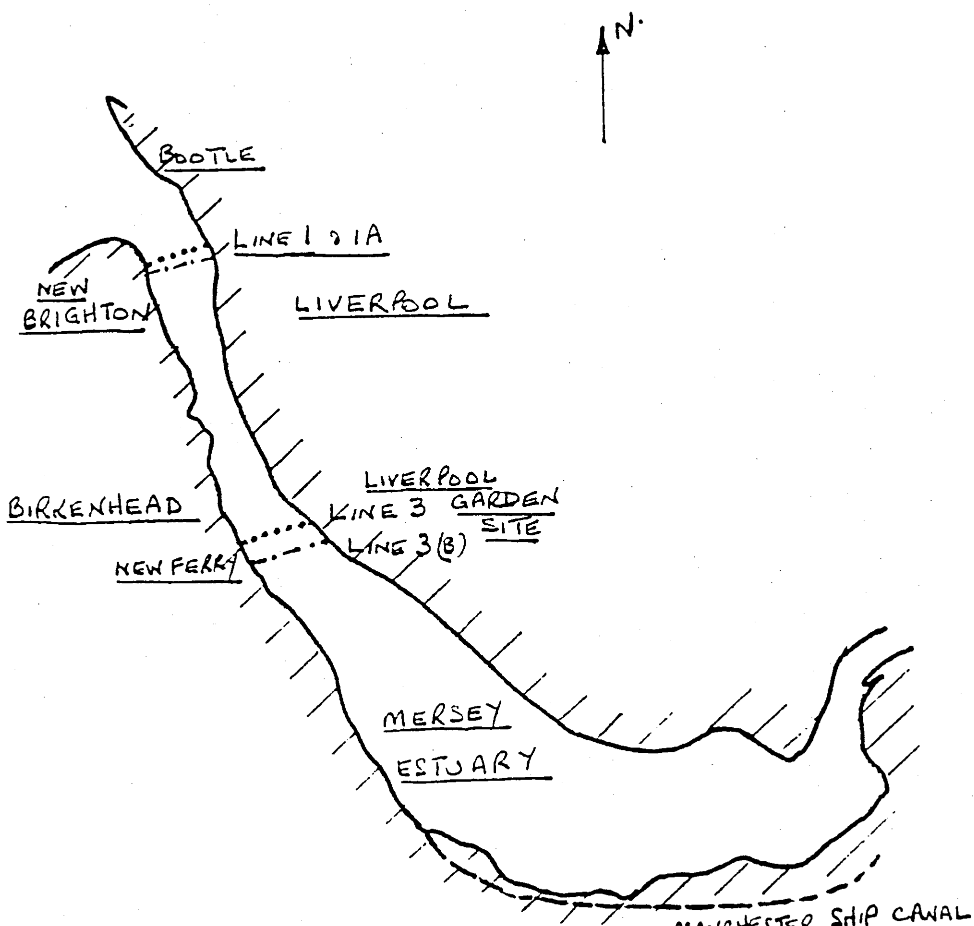
**Table 4**

**Summary of Mersey Barrage Details**

| DATE | GENERATION DETAILS | CAPITAL | CONST$^{N}$ TIME YEARS | UNIT COST p/KWh | COAL SAVED (annually) M Tonnes |
|---|---|---|---|---|---|
| 1983 | Straflo turbines driving<br>Line 1 - 27 x 23MW<br>Line 3 - 21 x 23MW<br>alternators:- 621MW (1)<br>483MW(3) | 522<br>395 | ~ 6 years | 2.89<br>2.71 | -<br>- |
| 1986 | Bulb Turbines - 7.6m runner diam. 25MW alternators.<br>Line 1A (27) 675MW<br>Line 3 (21) 525MW | ← | a s | above | → |
| 1989 | Bulb Turbines - 8m runner diam.<br>Line 3A 26 x 25MW | - | - | - | - |
| 1990 | Line 3B. 28 x 25MW bulb turbine alternators 700MW | 880 | 5 | 5.65 | 0.7* |

* Equivalent to approximately 1.5M tonnes of $CO_2$ emissions annually.

FIG. 2




LOCATION OF DIFFERENT MERSEY SCHEMES.

# 'An assessment of the progress of Tidal Power within the UK'

## Introduction

The demand for energy and particularly for its electrical form continues to increase world-wide. Many would argue that a halt, or at least a reduction in the rate of increase of this commodity, is a major priority if global environmental catastrophe is to be averted.

In this country at least, the seven per cent annual increase in electricity demand, identified following nationalisation in the late 1940s has, over succeeding years, been drastically reduced, the average anticipated annual growth in electricity requirements for the 1990s now being predicted at around one per cent.

During the period of nationalisation, the generation interests of the electrical supply industry followed a generally identifiable course. The planning processes incorporated the advantages of economy of scale, with larger and larger output machines being connected to the busbars, with a loose strategy of fuel mix and including an element of nuclear generation. Indigenous coal resources, however, remained the dominant primary fuel throughout the period, with large scale burning of natural gas for electricity generation being effectively banned by Government legislation.

The generation planning scenario summarised above has been completely overturned by the privatisation of the electricity supply industry, the emission requirements of the EC large combustion plant directive (LCPD), the freeing of natural gas reserves as a power station fuel and a general relaxation of generation planning restraints allowing new generating interests to enter the field in the early 1990's.

The combined cycle gas turbine (CCGT) generating station, with its short construction phase and comparatively low capital cost per installed kW has become very popular. On the basis of present trends, it is anticipated that some 7000-10,000MW of such plant will have been commissioned by the middle 1990's. The owners of this generation will, with the approval of government and the Regulator (OFFER) mainly be the present Distribution Electricity Companies (DECs) in association with private investors.

The seven year statement recently published by the National Grid Company (NGC) suggests that, including CCGT capacity, the uprating of the Scotland/England interconnector and the commissioning of Sizewell 'B', more than 22GW of new generation will become available to the electricity supply network before the end of the century. The NGC statement also indicates that, taking account of the programmed decommissioning of the older, mainly coal-fired, stations, (although some nuclear stations are likely also to be involved) generating capacity of 82GW will remain available, to be set against a predicted demand of somewhat less than 53GW.

Such over-capacity developments run counter to the commercial environment envisaged as a result of privatisation, a reduction in capacity margin being predicted at that time. There are already suggestions that the gas-burn proposed must be limited in view of the finite indigenous reserves available; also that the rate of decommissioning of the older fossil-fuelled plant will be required to accelerate to meet commercial and environmental pressures. But it is evident, in view of the long term (fifteen years plus) gas contracts which have been successfully negotiated together with their matching electricity supply agreements, that all presently identified base load requirements of the country will be satisfied, well into the 2000's, by the modern base load plant already connected in conjunction with CCGT.

Demands for greater energy conservation, for more stringent control of greenhouse gases, for the possible introduction by the EC of a carbon tax continue to grow, any of which may have some small influence on present UK attitudes to energy conversion processes. But it is apparent that, unless pressures other than technical or commercial are applied, the utilisation of environmentally friendly renewable energy on any significant scale or in any form is unlikely in this country for the foreseeable future. The non-fossil fuel obligation (NFFO) has been of some assistance to the small scale wind generation systems but, as presently conceived, cannot be brought to bear on the huge costs associated with large scale tidal power and electricity producing schemes such as the Severn and Mersey Barrages.

It is against this backdrop that the thesis reviews the early history of tidal power and identifies its progress in this country over the twentieth century.

## Chapter 1

## The Early History of Tidal Power

According to Charlier (1), Bernard Forest de Bélidor (2) is the individual to be credited with drawing the attention of the technical experts, in 1737, to the latent power of the tides although Wickert (3) is of the opinion that the oldest treatise on tide utilisation, that due to Mariano, predates the Bélidor work by some three hundred years. Davey (4) lists some one hundred and fifty patents taken out in England alone over the period 1856-1920 dealing with the subject of tidal power development.

An examination of this literature confirms that the ideas associated with all such proposals fall into one of four categories in their attempts to produce mechanical/rotational output from the rise and fall of the tides. The first category, utilising one of the most common principles and incorporated in a number of the early patents, could be called the 'float system'. The first of the many patents associated with the principle was taken out in France by Chauvet in 1837 (5). Basically simple in concept (any complication being introduced by the aspiring patentee), the system consisted merely of a weight or float initially raised by the rising tide, being caused to do work, via systems of links and levers, racks and pinions, as it fell with the receding tide. The gearing was eliminated, in certain of the patents, by attaching the float to a hydraulic accumulator and directing the output to a Pelton wheel. A simple analysis of the float arrangement confirms the very low mechanical output achievable by designs using this principle, even for considerable tidal ranges. The rotational motion imparted by a falling tide to a generator shaft would have been insufficient, certainly in the era under discussion, to achieve any significant usable electrical output.

The second system, favoured by a number of early patentees, the so called 'tide mill', utilised physical water movement, the 'tidal stream', induced during ebb/flow of the tides, to provide motive power for the rotational operation of the water wheel immersed in the stream. There is considerable evidence in the literature that the tides have been harnessed in this manner for several centuries on a number of English (and other) rivers to provide energy for corn grinding and irrigation purposes. Tide mills are in fact conventional water mills which utilise the tidal current as their source of power. Some of them included a refinement of a retaining basin or pond to impound some of the incoming sea for subsequent extension of the operating period of the mill. Their power output obviously depended upon physical size and tidal range; slack water at full and low tide required the basin refinement remarked upon earlier if the period of utilisation was an important factor in its operation.

The third system, the compressed air arrangement, was also a popular topic for inventors during the latter half of the nineteenth century, the French in particular leading the way in this method of tide energy utilisation. In 1845 Havard and Lavalette acquired patents for arrangements of this type while Seiler took out an English patent (No:- 2244) in 1860 utilising the principle; that of compression of the air within an enclosed chamber by the rising tide. Nine of the fifty patents taken out over the period up to 1885 were associated with this method of tidal utilisation. Like other schemes, this method of power generation has a low efficiency due to the inevitably low expansion ratio; indeed, as Davey remarks (6), 'the system might possibly be used for the direct compression of air for sirens ....'.

The fourth method of extracting energy from tidal range involves the impounding of a quantity of water behind a suitably raised dam, the basin being filled by the rising tide. The filling or subsequent release of the impounded volume of water via suitably designed and mounted turbines allows electrical power to be generated by means of machines connected to the turbines. This so called 'basin system' was identified as a suitable method of harnessing tidal power as early as 1839 - a French patent taken out by Lucas-Richardière confirming an understanding of a double basin inflow/outflow system. The first, provisional, patent was taken out in this country by Davies (No 518) in 1862, with numerous applicants for similar tidal cycle patents appearing thereafter. It is apparent from the number of patent applications, however, the French were extremely active in this field of tidal power throughout the period. Davey was of the opinion that the French had identified the first real understanding of the full tidal process, although William Murdoch was known to be working on ways to harness the tides at the time of this death in 1839. (310).

Although the French were responsible for much of the early analysis of tidal energy retrieval by the basin system, they were by no means the only country active in the field. Apart from the UK, the Germans had in 1912 identified a suitable location for a tidal basin or 'barrage' at Busum, Schleswig-Holstein, a plant being constructed at the site only to be dismantled at the outbreak of the first World War. Although no details of energy output or the machines are now available for Busum, the speed with which the construction was completed and subsequently dismantled suggests that it must have been a very small scheme.

Both Canada and America have examined possible sites around the Bay of Fundy - a remote region with some of the world's highest tidal ranges - with a view to extracting tidal power by the basin system. Schemes have been examined over many years, particularly with respect to Passamaquoddy Bay; in 1935 Roosevelt commissioned the US Corps of Engineers to undertake the construction of a power producing barrage there but this was never completed.

It is perhaps of interest at this point, (if not chronoligically correct to do so) to identify that a 20MW tidal plant has been constructed, over the period 1980-6, at Hog's Island, close to the town of Annapolis Royal-Nova Scotia, on the east coast of the Bay of Fundy. It is equally interesting to note that the power station was located at an already existing flood control barrier (7)(8).

The (then) Soviet Union also had expressed interest in tidal generation projects, identifying in 1923, possible regions for further study, particularly in the region of the White Sea and the specific location of the Gulf of Mezen (9). (A small, 400kW, tidal plant was in fact constructed and commissioned near Mezen in 1969).

Summarising this short review of the early interest in tidal power, it can be seen that much of the early effort was concentrated in obtaining some mechanical output, associated with tidal rise and fall, to assist with the manual work undertaken at sites local to a tidal river or estuary. Achievement of system high efficiency or continuous operation would not have been of overriding importance to the process which was basically to support the application of low cost readily available manual labour to a particular task. In any event, machines capable of converting any source of mechanical input into electricity and vice versa did not become available until the middle of the nineteenth century and following, after considerable delay, Michael Faraday's discovery of electromagnetic induction in 1831. (10). It is of interest to record that there had, however, been considerable improvement in the energy conversion efficiency of water wheels around this period, with Benist Fourneyron's outward flow turbine of 1827, by Ionvial's axial flow turbine of 1843 (which was more versatile because it was of the low head design) and by James Thomson's vortex wheel of 1852. (11).

It will also be apparent that, of the four systems initially associated with tidal power retrieval, only the basin or barrage arrangement is capable of achieving a power output on a large scale and this arrangement will be further examined in the next chapter.

## Chapter 2

## The Electricity Producing Tidal Barrage

The literature on this aspect of Tidal Power is extensive. Many learned books and treatises have been written, particularly since 1920, examining the background to and the aspects peculiar to the tidal barrage production of electricity. Robert Gibrat, considered by many associated with the subject to be the 'father of tidal power utilisation' , has produced many papers, culminating in 1966 with a searching and comprehensive analysis of the subject (12). Clive Baker (13) has more recently completed an authorative and 'most readable account' (14) of his extensive experience and knowledge of the subject, particularly relating to but not exclusively dealing with Severn Barrage developments. Roger Charlier's book (15) also provides an absorbing if at times untidy account of 'Tidal Energy'. But the earliest, possibly the most celebrated, certainly at the time the most vilified of the English language tidal power dissertations is that due to Norman Davey (4) and published in 1923.

It is an interesting point at this juncture to note that one of the most vociferous antagonists of Davey's views on tidal power was Sir Eric Geddes (16). A member of the department of the Civil Service which had previously produced a poorly argued but nevertheless supportive report for a barrage across the Severn estuary at English Stones (17), Sir Eric reversed his attitude to tidal power when, as the Minister of Transport, he became responsible for the affairs of that department. 'Essentially uneconomic' became his view of barrage produced electricity (18).

Despite the attitudes of engineering 'specialists', as typified by Geddes, to question the possibilities for tidal power, various interests have continued to the present day to examine the potential of different sites and to consider methods of harnessing the energy of the tides in an efficient and economical manner, for electricity generation purposes.

Any tidal power barrage consists essentially of a basin (or basins) suitably enclosed to allow the sea to enter and to leave via a combination of turbines and gates (sluices). The variation in water level between the sea and the mass of water contained in the basin(s) provides the necessary head to drive the turbines and thereby the generators. It will be apparent that the potential energy available at any time within a basin is proportional to the mass of water it contains and to the difference in water levels between basin and sea. It follows also that the maximum energy available is proportional to the difference in 'height' squared, i.e. to tidal range (R) squared, (See Appendix B(d)).

Although it is not the intention of this dissertation to examine in detail the highly complex variations which take place in respect of tidal range (which are dealt with elsewhere in the literature (20)(21)(22), it is necessary for the better understanding of the energy available from a tidal barrage to summarise those aspects which are particularly relevant to this subject. As identified in the above Appendix, it is due principally to the forces induced by the positions of the moon and the sun relative to themselves and to the earth that variations in the height of the tide at a point on the earth's surface not only takes place roughly in a sinusoidal fashion and approximately twice per day (semi diurnal variation) but also with a period of some fourteen days. These forces produce tides above the mean value, the so-called 'spring' tides for approximately seven days, followed by tides below the mean value, the 'neap tides', also of seven days duration. For the purpose of estimating energy output from a particular tidal barrage over a significant period, it is necessary to base the evaluation on the parameter of ‘mean tidal range’. Modification of the theoretical tidal range will also take place due to the Coriolis force, induced by the effect of the earth's rotation. This results, from a UK point of view, in the tidal ranges on the east side of the Irish sea being higher than those on the west and those on the south coast of England being lower than those on the north/west coasts of France. Furthermore, as an incoming tide reaches a region of diminishing depth of water, such as the continental shelf or the shallows of an estuary, the increased frictional forces reduce the speed of approach of the tidal wave thereby increasing the tidal range. This effect can be further exacerbated if the estuary is funnel shaped while, dependent upon the physical dimensions involved, the water in the estuary may be caused to resonate with the incoming tide, thereby to induce a further increase in tidal range (23)(24). The range associated with the Severn estuary is the result of the effect of these various factors. The Admiralty tide tables (19) provide an extensive list of such information and confirm that the highest UK tidal ranges occur along the west coast of England.

It is mainly as a result of the foregoing that the Severn estuary has received such a great deal of attention over the previous seventy years although there has been concentration on other sites, particularly the Mersey and estuaries associated with potentially large basin areas and significant mean tidal range such as Morecambe Bay, the Wash, the Solway Firth and the Humber. However, smaller sites of interest to tidal barrier electricity generation have been identified and it is of interest to note that some of them, originally pin-pointed by Davey, have more recently received revived interest. As Davey pointed out in his treatise, while the huge costs associated with major civil works demanded by large barrage construction could perhaps not be sustained by either the public or private purse, smaller barrage schemes could be more successfully supported by either/both. It has to be remembered that, in Davey's times, there was no grid system to allow electrical power to be distributed and utilised other than locally, and while the competition was provided by steam (coal fired) stations of comparatively low thermal efficiency, his view, and that of others, was that tidal barrages and proposed pumped storage facilities went hand in hand, this basic requirement being reflected in high capital costs.

Davey identified a total of sixty nine sites on the mainland of the United Kingdom which he considered to have worthwhile tidal generation potential. In surveying these possibilities, he set a minimum mean tidal range requirement of ten feet (a little over three metres), continuous output potential of not less than 1000HP (750kW) and a coastline which permitted realistic basin/barrage construction, i.e. estuaries, inlets and small bays. The Thames and Tyne/Tees estuaries were omitted for shipping reasons. Of the sixty nine sites identified under these conditions no less than forty nine were distributed around the English and Welsh coasts, the remaining ones being mainly on the west coast of Scotland. Thirty three of the forty nine sites were on the west coast, the rest being evenly divided between the south and east coasts of the country. Davey indicated that the water areas and range values used by him were taken from the Admiralty charts and tide tables and that the areas assessed from these data, particularly those pertaining to low water spring tides, were only 'approximate and sometimes indefinite'. He was also of the opinion that 'not all of the stations listed are probable or even possible' due to 'geological factors, great depth of channel and shipping interference'. Bearing in mind the above observations and considering that Davey's evaluations were undertaken in the early 1920's and without the benefits of modern computational assistance, hydrographical surveys and the like, it is remarkable that his results, associated with twenty nine sites similarly located (but differently named) sites identified by Binnie and Partners (25) are in very good agreement with their findings, particularly in annual energy values. (There may, of course, be other reasons for this similarity!) It is no less interesting that two locations identified by Davey as 'Millom' and 'Fleetwood' (26) should, as 'Duddon' and 'Wyre' respectively have only recently been recognised by the Department of Energy as sites worthy of preliminary study to confirm their suitability for tidal barrage construction (27).

As stated above, the Severn estuary has, over many years, attracted interest in its possible utilisation for tidal power generation in view of the considerable tidal range enjoyed by the region - the highest in Europe and the second highest world-wide. It is of concern therefore to undertake a review of the various schemes which have been proposed by the different investigational bodies involved and to comment on their conclusions.

## Chapter 3

## The Severn Barrage Reports 1920 - 1950

### 3.1 The First Proposal; 1920

In November 1920, a proposal to construct an electricity generating barrage across the River Severn was put forward by the Civil Engineering department of the Ministry of Transport, that Ministry being at that time responsible, under the recently promoted Sir Eric Geddes, for electricity matters. Although copies of the actual report are no longer available for scrutiny, Davey's 1923 text (28) contains many of the pertinent aspects of the proposal. From Chapter XIII, it is gleaned that the original report recommended the construction of an impounding dam at the site on the Severn estuary known as 'English Stones' and almost directly above the GWR Severn rail tunnel; the capital cost being estimated at £25-30M and with a construction time of 'several' years. A road and rail crossing, together with lock facilities, were included in the civil works. It is possible, indeed it is probable, in view of the subsequently identified ill considered nature of the electrical aspects, that the barrage scheme was induced as the result of a proposition, put forward earlier in 1920 by the Great Western Railway (GWR) to the Ministry of Transport, to construct over a period of five years and at an estimated capital cost of £5m a high level bridge at Beachley to ease the rail traffic congestion at other Severn rail crossings. The steep gradients of approaches to the proposed bridge at Beachley had previously been identified and it was considered that not only would a barrage at the location alleviate this problem but would also provide facilities for a road, thereby shortening crossing of the Severn by some fifty miles.

The electrical aspects of the scheme proposed that the 18000ft (5500m) barrage should provide for 400 (3m runner) turbines, each geared to DC generators of approximately 1300kW average output, together with some

6000ft of sluice length. (Davey considered unsound the proposed positioning of the sluices and thereby the subsequent area of openings available to be inadequate and argued that, unless additional inflow gates were provided at the turbines, the proposal's estimate of electrical output of the scheme would not be achieved).

Rotary convertors were to be provided to produce alternating current at 330 volts, this to be transformed to 60kV for onward transmission.

In addition to the power generating barrage, the scheme envisaged a high level storage reservoir, situated off the River Wyre and ten miles from the main barrage, fed by a pumping station at Tintern which was in turn supplied with power from the barrage. The Tintern machines were to be designed as pump-alternators, capable of an output of around 750MW.

The contemplated Trelleck Grange reservoir was of considerable capacity, $55 \times 10^6$ $m^3$ , and it was anticipated that the water to and from this storage would pass along a tunnel forty feet (twelve metres) in diameter.

The electrical output from the barrage/reservoir complex was intended to be absorbed by the industrial area of South Wales 'lying within a radius of fifty miles' (eighty kilometres) of the barrage, 'the Midlands and London and the Thames Valley'. In order to distribute power to the latter area, however, a transmission line operating at 120kV and capacity of 500MW was proposed. The cost of the line (it is not identified whether the design was single or double circuit) was estimated at £1.25m.

An examination of the identified costs of the various items making up the scheme indicates that a specific total figure of £28m was applicable. Of this amount, some £2.3m was set aside for road and rail facilities, a figure which should be compared with the £5m estimated by the GWR for its own rail bridge scheme. The 1920 sum estimated for the reservoir and Tintern civil works, viz

£2.5m, in today's terms perhaps £100m, appears relatively conservative in view of the magnitude of the scheme. It is, however, a fact that the capital costs of large civil schemes have, throughout the century, regularly been under estimated as those associated, for example, with the Channel Tunnel will confirm (29).

It was estimated that the annual output of the barrage, operating as an ebb system variable head working arrangement was electrically equivalent to 1.36TWh (Terrawatt hours). Davey, although he obviously doubted the truth of this figure, nevertheless evaluated that, on this basis, the cost of a kWh to a consumer would lie between 0.6 and 1.08 penny, with 'perhaps an additional 0.2 penny per unit' applicable to London customers due to transmission costs. He also pointed out that, since the rail and road authorities were expected to bear a proportion of the costs appropriate to the road and rail bridges, with the Post Office and shipping interests also benefiting from the work, a unit cost, at the barrage, 'of around 0.5 penny' might be applicable assuming the originally estimated outputs and efficiencies. The Civil Engineering proposal pointed that that power from the barrage would be available, at short notice, as a result from its considerable storage capacity, ' to absorb existing peak loads in industrial areas, working in conjunction existing steam power stations.'

It is doubtful, with hindsight, whether the technical expertise necessary to construct such a complex civil /electrical engineering project existed at the time of the proposal. In addition, it will be appreciated that no electricity 'grid' existed at that time to transmit large scale power into the industrial regions of the country. Despite the pumped storage facility, to attempt to absorb the output locally would create its own problems and inevitably affect the efficient utilisation of the barrage itself.

In any event, the project had no chance of survival due to the scepticism of the technical experts of the day including, as identified earlier, Sir Eric Geddes - who must have been a member of the team at least initially responsible for the drafting of the proposal. The learned Institutions also had little faith in the contents of the report, while the shipping and dock interests of the Severn were vehemently opposed to the scheme. The anti-barrage attitudes of the Welsh mining community and their MPs were voiced strongly as were the fears of the representatives of the local authorities, whose responsibilities included the inter-tidal zones above the site of the barrage, that severe flooding of their territories could take pace should construction go ahead.

In any event, the 1920 proposals were shelved indefinitely. It is extremely doubtful, in view of the lack of any data from any official source, that the scheme was even recognised by the government.

3.2 The Report of the 1933 Severn Barrage Committee

In 1925, the Conservative Prime Minister of the day, Stanley Baldwin, took the decision, through the Economic Advisory Council, to have the possibility for a barrage across the Severn estuary ‘examined’; (perhaps ‘re-examined’ would have been more correct). The precise reasons for his decision at this point in time remain unclear from the literature, but it was known that the Prime Minister had grasped the 'political and economic importance of electricity' (30). The inefficiency of the coal fired plant in commission in the industry and the labour problems with the mining community may also have influenced his decision.

Whatever the reason(s), however, Baldwin could not have expressed any urgency in completing the investigation since it was to be 1933 before the final official report was presented by the Committee’s Chairman, J.T.C. Moore-Brabazon, to the then Prime Minister, Ramsay MacDonald of the National

Party. The introduction to the official Report of the Committee (31) does confirm, however, that they had been actively engaged, behind the scenes, the first tentative interim report having assessed, in December of 1925, that a prima facie case had been established for the further expenditure of public money in the prosecution of the inquiry. A hydrographic survey of the English Stones site had been carried out by the Admiralty at the request of the Committee and, in addition, Professor A.H. Gibson, of the University of Manchester and a member of the Committee had been asked to construct a model of the estuary in the English Stones region - 'the point of the River Severn which appeared to offer the best site for a barrage' - and to conduct a series of experimental investigations. In July 1929 the results of both Professor Gibson's work and the Admiralty survey were presented as a second interim report; together with the conclusions that the practicality of building a barrage across the Severn estuary had been confirmed. The contours of the estuary as established by the Admiralty hydrographical investigations were found to be in very good agreement with those used by Professor Gibson (who had utilised 1849 data for his model). A further three years were to elapse before the final report, including the conclusions of detailed investigations undertaken by a sub-committee of experts under the chairmanship of Sir John Snell, the Chairman of the Electricity Commission and the Chief Advisor to Sir Eric Geddes, was submitted.

The results of the technical studies, annexed as an 84 page Appendix to the main report, provided an analysis of certain physiographical problems including an assessment of the geographical and geological features of the bed and banks of the estuary and surrounding district, the effect of a barrage on the regulation of water in the estuary and associated feeding streams and waterways, and included also an estimate of the possible interference with normal estuarine currents due to scouring and siltation.

In addition, the Appendix focussed attention on the problems associated with the intermittent and variable output of energy from a barrage, the question of storage to provide a more continuous output and the effects of the operational cycle on the turbines themselves. The requirements of maintenance and repair of plant, particularly those items operating under immersed or partially immersed conditions, were addressed. The transmission of the generated power to other parts of the country was also addressed. (It will be appreciated that the 132kV 'Grid' system was under active design and construction at this time - the regions of the south west of the country and South Wales were interconnected toward the end of the projected construction period 1927-1933). The possible effects of a barrage on navigation on the Severn were also examined, as were public health related interests associated with the modified water regime which would be induced by the construction of a barrage. Salmon fisheries of the Wye received some preliminary assessment, as did the Severn navigation canals and associated docks themselves.

The interim report produced by the sub-committee in 1929 included the submission that three sites had been examined prior to the conclusion that the English Stones would provide the most suitable one for a barrage. In fact, on examination of the details, it is apparent that all three sites lay in close alignment one to another, suggesting that the particular region around English Stones had already been accepted as most suitable for a barrage.

Professor Gibson's experiments confirmed that the tide levels would be modified by the operation of a barrage, the exact amount being dependent upon the mode of operation of the turbines. Using an operational scheme which 'in our view gives the best all round results' (the exact scheme appears not to have been identified nor the term 'best' defined), the lengthening of the flood tide and subsequent shortening of the ebb was assessed as was the degree of tidal interference induced by the turbines. It was estimated that a reduction of approximately 50% of the amount of tidal water flow into the Bristol Channel would be achieved, while the reduction in tidal range at a number of points on the Severn as a result of the barrage was remarked upon. At Beachley, for example, the spring tidal range was expected to reduce from 41 feet to a little over 14 feet, i.e. by some 65%.

Fears of possible siltation of navigable channels caused by the imposition of dams for hydro power development had earlier (1921) been remarked upon by the Water Power Resources Committee - chaired by Sir John Snell (32). This problem was examined, together with the associated one of power basin siltation, by the experiments of Professor Gibson. His conclusions, contained in an appendix to the Committee Report (31), were that an increase in siltation of the impounded basin of '800,000 cubic yards per annum during the first twenty years of operation would occur' but that following this period, the rate of deposition 'would considerably reduce'. In addition, he concluded 'much of the siltation would take place remote from the navigable channels'. Dredging during the twenty year period to remove some 600,000 cubic yards per annum 'would enable the navigable channel to be maintained at its existing level'.

The model investigations also confirmed that, without any dredging, the depth of the Avonmouth navigable channel would be somewhat greater with the barrage than without it. The model was used also to confirm that flooding of the regions above the barrage was unlikely with flood discharges of up to 18000 cu secs (about four times the mean river flow), the high water level at spring tides being lower with than without barrage construction. In any event, the Report went on, ‘in times of heavy flood or exceptionally high tides, the water height above the barrage could readily be controlled by use of the barrage sluices or turbine gate openings'.

In reaching the conclusions in respect of siltation and the possible effects of a barrage operation on the configuration of the bed of the estuary, Professor Gibson had undertaken the series of experiments utilising 'an appreciably greater sluice area than that on which the original tests were carried out'. It is pertinent to remark at this juncture that, in his assessment of the 1920 scheme, Norman Davey had expressed the view that 'it is not clear whether or not inflow gates were also placed in the turbine dams, or if tide flaps were to be placed on the rock and clay core dam. Without some addition, the gate area provided ... hardly seems adequate'.

It is apparent from the tables included in the Report that a variable head ebb system of working was the favoured scheme, with a minimum head of 5 feet. Advantage had been taken of the effects of turbine development over the period since the early 1920's to recommend that seventy two Kaplan type turbines, each of twenty feet (6m) runner diameter, single regulation and coupled to 62.5 r.p.m. alternators of 12.7MW output, should be installed in the 4550 feet turbine dam associated with a total barrage length of 15,375 feet (4660 metre). It was anticipated that sixty seven machines 'would always be available for use', resulting in a working installed capacity of 850MW and, on the basis of seven hundred and six tides per annum, a total potential annual output from the barrage of 2.25TWh. Allowing an approximate two per cent usage for barrage operation, some 2.2TWh would therefore become available for delivery to the 'grid' - 'the national system now in process of being constructed by the Central Electricity Board'.

The consulting engineers were of the opinion that execution of the scheme would take approximately fifteen years and, in addition to providing the tidal

generating station, would cater fully for rail and road cross river traffic, while satisfying the navigational requirements identified by other authorities.
The costs associated with the scheme were, as explained in the Report, to some extent speculative in view of the uncertainty with regard to interest rates. It was anticipated that a long term loan could be raised under government guarantee at approximately $3^1/_2$ per cent per annum but, in view of the identified starting date of 1937 and the projected period to completion by 1952, an estimate of cost based on an interest rate of 4 per cent was considered more prudent.
On this basis, the total cost of the scheme, utilising 4 per cent cumulative, approximated to £37.8m, of which £8.4m was due to interest charges over the fifteen years. The capital cost of the barrage generation project itself, i.e. omitting road, rail and harbour costs, was estimated at £20.3m; (£25.5m including interest charges). While the estimates included a contingency allowance of $12^1/_2$ per cent, no provision was included for the acquisition of any land required for construction and other purposes, nor for any Parliamentary expenses likely to be incurred during the passage of the necessary Bills.
Based on the figures above, it was estimated that the cost of energy at the generator transformer terminals or, as expressed in the Report 'sent out to transmission lines', would be 'about 0.18 penny/kWh', (including an element for annual maintenance and operational charges).
At this point, the Report refers to the varying and intermittent amount of energy derivable from the barrage, dependent upon the time and state of the tide and the necessity 'for some secondary storage scheme', as, without such a scheme, it would not be possible to reduce the size and number of coal-fired stations already providing energy to the grid and including the necessary provision of standby plant. A comparison of the cost of barrage produced

electricity with that of the firm supply from a coal-fired station could therefore be made only on the basis of the cost of fuel saved by operation the barrage. Assuming the annual generation from the barrage to be 2.2TWh, the cost of coal of around £0.75/ton (the precise cost depended upon the region of the UK to which the fuel was delivered) and the efficiency of generation, estimated for the 1930's to be approximately 1.65lb/kWh (the Report uses the figure 1.75lb/kWh), it follows from the foregoing that an estimated 1,650,000 tons of coal, of a value £1.24m, would be saved for other purposes by operation of the barrage. As the above makes apparent and as the Report itself comments 'it is clear that unless suitable means can be devised by which a secondary storage system may be added ..... the scheme is not economically practicable'.

Two storage schemes received consideration; the first provided for pumped storage facilities, the second identified the conversion of some sixty per cent of barrage energy into some form of thermal storage and its subsequent utilisation in steam turbines. The latter proposal was deemed impractical and attention was turned to the water storage scheme included with the 1920 Ministry of Transport proposals for the Severn Barrage, i.e. the use of Trelleck Grange for the purpose of storing 'surplus' energy over the lunar cycle.

As with the 1920 scheme, it was envisaged that the barrage electrical output would be divided; part of it would pass directly to the grid system for national transmission and the rest would be utilised for pumping purposes at Trelleck Grange. By a process of iteration, and bearing in mind the expected efficiencies of pumping and generating plant, it was anticipated that the total annual output from the combined barrage/storage facility would be 1.64TWh, i.e. approximately 75% of the barrage only output figure. As a result of this expected reduced output, the cost/kWh was increased from 0.18 of a penny to approximately 0.24d.

There follows in the Report (33) an assessment of the cost of generation 'from good coal-fired stations' which, at face value at least, suggests a difference in cost/kWh of around 0.14 of a penny in favour of the barrage/storage combination and indicating that the generation of 1.64TWh using fossil-fuel facilities would result in approximately £1m higher costs than if the barrage/storage was utilised. Since the capital costs of providing the water storage, pumps and pipework at Trelleck Grange were, according to the Report, estimated at £10.26m and which, including the cost of the transmission line between barrage and Trelleck Grange and annual compound interest of four per cent over the seven year construction period amounted to a total of not less than £13m, (i.e. a sum total for barrage and storage of some £50m) the conclusion drawn in favour of the barrage appears, at first sight, not a little surprising. However, the Report itself provides some insight into what could perhaps be called an element of 'creative accounting'. From the identified relevant paragraph (34), it can be noted that while it takes into account the variation in load factor to estimate the annual cost of output from the coal-fired plant, this factor is completely ignored in the case of the barrage/storage combination. When the effect of this omission is taken into account, the cost/kWh of the tidal plant becomes 0.37 of a penny, i.e. 0.07 of a penny or 18.9 per cent higher than that identified in the Report as the probable cost of a unit produced by modern coal-fired plant of the period. Paradoxically, paragraph forty three of the Report states that the 'assumption (of the cost of a coal fired unit) does not err in generosity to the barrage'.

One of the principal conclusions reached by the Committee was that the best site for a barrage on the River Severn would be 'at the point known as English Stones'. It also concluded that, in view of the intermittent and varying nature of supply from the barrage, there could be no reduction in the number and size of coal-fired plants feeding the National grid system; moreover the cost of energy generated by the barrage would not be competitive with that produced by modern 'selected' (i.e. Central Electricity Board - CEB) grid-connected coal-fired stations. However, (and despite the comments included in the foregoing paragraph) the Report asserts the view that in conjunction with a secondary storage system, the scheme would in total produce 'an economically attractive project which could, when completed in 1941, provide around one thirteenth of the anticipated annual supply requirements of the country'. It is of worthwhile, if minor, interest, to note that the total GWh figure used by the Committee to make their latter assessment was exceeded by some 6GWh, or approximately thirty per cent, in 1941 (35).

The capital cost of the proposed scheme, including provision for road, rail and harbour facilities and also compound interest, estimated at approximately £50m has already been remarked upon. The electricity generating aspects of the construction were estimated at £38m.

The eighty four page Appendix included with the main Report is a model example of the literary art of the expert sub-committee, full of their views of many of the facets of the combined barrage and storage schemes. In absorbing the contents of what is an excellent but highly complex engineering document, with its great wealth and depth of detail, the impression is gained that, between the lines, caution is being urged in approaching 'a scheme of such magnitude'. Possible problems with the turbines, despite the fact that the sub-committee itself was recommending their installation, were identified, while a number of further investigations were proposed particularly in respect of the pump turbines, where siltation problems were envisaged. Concern is also apparent in respect of the storage reservoir, its disposition, and that of the pumping/generation plant and associated pipelines. Such aspects must, in truth, have been particularly worrying to the committee since the very viability of the scheme, even as evaluated within the Report, depended upon the construction of the Trelleck Grange reservoir and its engineering facilities. Small wonder, in fact, that the final comment of the Moore-Brabazon Committee included a significant note of caution and delaying any decision whether or not to proceed with the scheme. 'In coming to a decision', the Report concluded, '....., many considerations, not of a technical character, such as social, economic and industrial ..... must necessarily arise, but important though they may be, they are outside our terms of reference and do not concern us'.

There may be some significance in the fact that the type print used for the 'Conclusions' is of different face from that of the rest of the Report, suggesting late modifications. So far as can be ascertained from the records, no official immediate action was taken by any Parliamentary Committee to examine the proposals put forward by the 1933 Severn Barrage Committee although, according to Hannah (36) some 'serious consideration' was given to them - by whom is not clear since no one, other than the Committee members themselves, is identified. The costs of construction were considered to be such as to 'effectively rule it out at a time of increased stringency in government expenditure'.

3.3 The 1945 Report on the Severn Barrage Scheme

It becomes apparent, from an examination of the terms of reference provided, on this occasion, by the Minister of Fuel and Power of the period, Major Gwilym Lloyd George, to the Panel of Engineers associated with the 1945 investigation of a possible Severn barrage that, behind the scenes at least, the conclusions of the 1933 Report had received some consideration. The Chairman of the Panel, A.G. Vaughan-Lee, in his introduction to his Report, confirmed that the panel was appointed in November 1943 'to review the conclusions of the Severn Barrage Committee of 1933'. (37). He went on to enlarge the requirements by adding 'in the light of later engineering experience and practice and of other developments and to suggest what modification, if any, should be made in the proposed scheme, in the programme for its execution and in the estimates of its costs'.

Appendix 1 of the Report includes a Letter of Instructions suggesting that a more detailed identification of the Ministry's requirements had been sought and obtained. An examination of the contents of this Letter confirms that practically all aspects of the 1933 conclusions were to be scrutinised, including the barrage site, the necessity or otherwise for storage facilities, the prime revised costs of the scheme and the related economic value of energy produced. The extent to which the grid system would be associated with barrage production of electricity was to be examined, bearing in mind probable load growth and costs of transmission. 'The probable minimum time of construction, consistent with economy' was to be assessed.

No less importantly, the possible effect of the barrage on shipping interests was to be considered, with estimates of costs to include provisions to enable shipping to continue to use the docks situated above the site of the barrage. The technical feasibility of providing for road and rail crossings of the Severn via the barrage was to be examined, as were the possible costs of such provisions. In other words, the possibility of an energy producing barrage over the Severn was to be re-examined from a new beginning.

It will have been noted, from the opening words of this Chapter, that the level of political seniority for possible barrage development had been diminished; it was now associated with the office of the Ministry of Fuel and Power and not with that of the Prime Minister directly.

A major decision of the Panel, taken early in their Inquiry, was that 'it would be best to treat the Severn barrage on the basis of a power generation scheme only in the first instance'. Aspects such as road and rail crossings, and development of dock area and navigation would be dealt with separately .
In considering the conclusions of the 1933 Committee's Report, the Panel were able to agree to that Committee's findings in respect to the disposition of the barrage site, describing it as 'the best, particularly from the point of view of construction' and that variable head ebb generation was definitely the more advantageous' under the Severn tidal conditions. The 1933 estimates of available power and energy at the English Stones site were also confirmed, as were the views, based on Professor Gibson's previous experiments, that navigation on the Severn 'would be in no way prejudiced by construction of the barrage at that site'.
Three major changes to the conditions which had applied at the time of the earlier Report were, however, considerably to influence the conclusions which would be reached by the 1945 Committee. The design and output of turbine and associated alternator equipment had dramatically increased over the years with much larger and therefore fewer machines being required to deal with the identified power available at the English Stones. In turn, these changes impinged upon the hydraulic conditions likely to be required at the barrage, thereby modifying the dimensions of sluice gates, turbine intakes and outlets and thus the disposition of the sluice, turbine and embankment dams themselves. Secondly, 'the price of coal delivered to generating stations had increased significantly'. Whether this aspect of the investigation was, in fact, of material importance is, in retrospect, doubtful. Coal, a competitor for direct heating and for providing motive power for the private generation of electricity and for mechanical handling equipment had, as identified by Lingard and

England (38) lost its favourable economic position post 1935. Interconnection of generating stations by the transmission grid, the improvement of boiler combustion and turbine efficiency, together with higher system load factors over the period in question had, in all probability, offset the effects of the doubling of coal costs to a station. In any event, only seven or eight per cent of coal mined was utilised by the electricity generation industry at that time which, as identified in the Economist, was providing its product at a lower price than burning the primary fuel, coal, in an open grate (39).

The third condition, very closely related to the second as the above observations confirm and possibly the most important of the changed criteria identified by the Panel, was that due to the 'great expansion in the supply and control of electricity and the development of the grid interlinking the major power stations'. It is as a result of the effects of this last aspect that the 1945 Report departs so fundamentally from the conclusions of the 1933 document.

It will be recalled that one of the conclusions of the previous Reports required the construction of a suitable dam, reservoir and pumping facilities at Trelleck Grange to provide a reservoir of sufficient capacity to smooth out the variable and intermittent nature of the generated supply from the tidal barrage over the lunar period in order to provide one based on the more socially adaptable solar cycle. It will also be recalled that the expert sub-committee of 1933 had voiced some concern over the Trelleck Grange site, the effect of pumping on the River Wye, and other related matters.

As a result of such reservations, the 1945 Panel undertook a comprehensive study of pumped storage facilities throughout Wales, twelve sites being investigated. In their opinion, two of the sites evaluated were 'more economical' than Trelleck Grange. In addition, the Panel concluded (40) that 'pumped storage would increase the capital cost of the Barrage scheme by about forty per cent and reduce the amount of energy available by twenty seven per cent'. The Report went on: 'this has resulted in the cost of Barrage energy with pumped storage being greater than that supplied from coal-fired stations of the same output and saving less coal than by the direct use of the tidal energy. We are led to the conclusion that pumped storage is not an essential nor an economic factor as applied directly to the barrage scheme'.

The Report also referred to an engineering Appendix prepared by one of the members of the Panel which included the results of a detailed assessment of the normal operating regime of a tidal barrage and the possibilities of utilising its varying and intermittent output in the chemical industry or for the purpose of district heating. The parallel operation of tidal plant with conventionally fired and with hydro stations was explored and the conclusion reached, as a result of these studies, that with the transmission system capacity and control capability provided by the now fully operational grid system, there was little if any financial gain in attempting to use the barrage output in other than the 'conventional' way, i.e. as it became available at the generator busbars.

The Appendix also updated the output figure deduced by the 1933 Committee by some five per cent, this being attributed to the higher efficiency expected of the more modern Kaplan turbines; an annual output of 2.36TWh was now anticipated. However, an estimate of the likely summer night demand on the transmission grid network confirmed that the barrage output itself could approach fifty per cent of the system's Southern region requirements at spring tides, as aspect which the C.E.B. viewed with some caution since such reliance on a single source of supply was not considered acceptable. (A figure of not greater than twenty per cent of system load supplied from any one source was favoured by the C.E.B.). Taking this limitation into account, some restriction in barrage output was considered inevitable until the natural growth in system demand eliminated its necessity - this was expected to occur around 1970. The output available at the load centres as a result of barrage operation, taking the above and the effect of transmission losses into consideration, was estimated at 2.1TWh until 1970 and 2.21TWh thereafter.

The scheme put forward by the Panel anticipated that this output would be attained from thirty-two vertical shaft Kaplan type turbines and their directly coupled alternators, each of 25MW capacity, operating on the ebb tide variable head principle of working. The installation of larger machines than those available at the time of the 1933 Report required a major re-assessment of the civil works proposed at that time - one of the changes involved the turbine dam being divided into two parts. That part on the western side of the barrage was to be equipped with additional turbine gates enabling them to be used as sluices in order to enhance the water input to the basin during the rising tide; further confirmation of the accuracy of the forecast by Davey that the sluice gate area which had been put forward previously had been too restrictive.

The basic constructional method proposed was similar to that advocated in the 1933 Report, i.e. the utilisation of temporary cofferdams to provide dry working conditions; the estimated time of construction was eight years.

Although the 1945 proposals included provision for a road and railway across the barrage, with lifting bridges at the locks, these were to be provided only for servicing of the barrage and its plant. As expressed at the outset, the Panel's view was that full road and rail crossings were better treated independently of the barrage scheme, with any attempt at combining the scheme resulting only in delay and with little prospect of economy. The development of a deep water basin above the barrage, as identified in the 1933 Report, was agreed, but it was considered advisable to point out that 'the impounded area would have a tidal variation level of twenty feet, making it virtually a tidal basin and comparing unfavourably, from an operational point of view, with the amenity of the docks in the Bristol Channel itself'.

The capital cost of the barrage and plant was considered difficult to estimate in view of the prevailing wartime conditions and their effect on prices. It was confidently anticipated that the war inflated figures 'would fall substantially when industry reverted to peace time activities'. Costs were therefore based on figures for 1936, inflated by sixty five per cent, with appropriate contingency charges and with interest charges of three per cent compounded annually. A total cost of a little over £40m was estimated for the barrage project, the interest charges attributed to the eight year construction period being £4.2m. The transmission system, inclusive of barrage and other sub-stations, transmission lines and complete with engineering and contingency costs was estimated to cost £6.4m (£6.8m with interest charges), resulting in a cost for the complete scheme of £47m.(41).

The cost of operating the complete barrage scheme, including repair and maintenance of plant, stores, dredging, administration and overhead charges, together with an element for local rates was estimated to lie between £262,000 and £350,000 per annum; i.e. around five per cent of the capital cost of the scheme. The Report points out an interesting aspect of rating a water-operated generating station when confirming that they had had some difficulty in producing a figure for this provision. The basic problem was associated with the practice of valuation and rating based on the net revenue raised or attributed to a business. In the case of a generating station, the costs of the prime fuel and of interest charges were included with other 'deductible' items. Such a method of assessment was obviously very much in favour of coal-fired stations, where fuel was a significant item of cost, in comparison with hydro stations, where the basic cost of fuel was negligible. Some permanent relief in local rates had been proposed in Scotland for their hydro electric plant in view of this anomaly, and the Panel recommended that similar relief should be applied to the Severn barrage station. Their estimates included an annual rate levy of £100,000, a significant reduction in what could have been anticipated as a more usual one of perhaps two or three times that value. The absolute value of the burden was not, however, of material consequence to the running costs of the barrage, which would remain at about five per cent of the capital cost of the scheme.

The estimated costs of a kilowatt hour produced at the barrage were divided on the basis of output restricted (as discussed earlier) and unrestricted (post 1970), the relevant figures being 0.209 and 0.199 of a penny respectively for generator terminal output costs, or 0.275 and 0.262 of a penny at the point of commercial supply. It was further estimated that nine hundred and eighty five thousand tons of coal per annum would be saved over the first fifteen years of barrage operation, but the Report was at pains to indicate that, with regard to subsequent years, increases in the price of coal and in the likely increases in efficiency of the coal-fired stations would inevitably affect the future value of the barrage.

The Report concluded that the Barrage scheme as recommended, i.e. without storage reservoir, was practicable from an engineering point of view and that its construction could be economically justified 'under the conditions identified'. It also went on to state that 'before arriving at a decision to proceed with the construction of a scheme of this magnitude, many considerations other than technical arise which are outside our terms of reference'. None of the considerations were identified in the Report.

Although neither the Government, in the form of its Ministry of Fuel and Power - whom, it will be recalled, commissioned the production of the Report, nor any other government department appear to have commented officially on the conclusions of the Report, it is apparent from the literature that both the C.E.B. and the incoming British Electricity Authority (B.E.A. - the nationalised electricity supply authority) must have had some association with the decision ultimately made. But, as Hannah records 'no action was in fact taken' (42) as a result of their involvement.

Nevertheless, it is of interest to note that, although no action was taken on the 1945 Report's conclusions, engineering interests were intent on examining the possibilities for a barrage across the Severn estuary.

3.4 <u>The Headland Initiative</u>

In June 1949, H. Headland (43) introduced his paper 'Tidal Power and the Severn Estuary' to a specialist gathering at the Institution of Electrical Engineers (IEE) and which, over the following two years, provoked a considerable storm of criticism together, it must be said, with a degree of support in the IEE regions of the UK. Taking the conclusions drawn by the Vaughan-Lee Panel in 1945 as a starting point, Headland provided additional statistics in general support of the scheme, now having capital costs estimated at not less than £50m, emphasising once again that there was 'no technical reason why construction of the barrage should be delayed'. In addition, he argued that the basic criterion on which the value of tidal energy was assessed depended essentially on the fixed charges of the scheme and demanded that the 'capital cost of associated plant, civil works, and transmission equipment should be reduced to a minimum'. In spite of the support for the scheme identified in his Paper, Headland hedged his bets by stating that 'the possibilities of tidal power development appear to justify further investigations of plant and civil engineering design - 'the construction of a pilot plant, with one or two full sized units, would provide valuable operating data on which the Severn barrage design could be based'.

Comments on the Headland paper throughout the IEE regions varied from 'go ahead with such a prestige project for the good of the UK image' to 'an effort made which collapsed under the weight of its own absurdity' .... 'to save face, inquiries and commissions continue and look as though they will continue to do so' (44). The incorporation of gas turbines at the barrage to produce, in conjunction with the tidal output, a degree of firm power, was recommended by another subscriber to these discussions, while Sir John Kennedy, then Chairman of the Electricity Commissioners, supported the proposal for an integration of steam stations on the Welsh coalfields with the barrage (which had already been identified in the 1945 Report). A Mr. Nimmo had the opinion that power from the tides was 'alluring but disappointing' and pointed out that Canadian consulting engineers had estimated that the cost of tidal energy from the Petitcodiac and Memrancook Bay (Bay of Fundy) regions to be 'double the cost of generation from steam power stations', while the cost of production from Passamaquoddy (also Bay of Fundy) had been estimated by the US Federal Power Engineers to be 'three times that from hydro plant on nearby rivers'. Such comments were themselves of little relevance and, without supporting evidence, of no great worth. Professor Gibson's results pertaining to the minimal problems due to siltation, were questioned by doubters, including shipping interests, while others identified possible difficulties with the Kaplan runners as a result of sand and silt impact. UK-wide discussions on the contents of the Headland paper produced widely ranging views. One discerning contributor, A.C. Kay, noting that all economic estimates had been based on the cost of coal, enquired whether conclusions would be modified in the event of the substitution of 'atomic energy for coal' being taken into consideration. A further, and no less discerning comment came from A.P.M. Bennett who enquired whether, 'in view of the enormous capital cost of a Severn barrage scheme and the intermittent nature of the output from it, the expenditure should be devoted to the provision of gas turbine plants sited at or very near the load centres'.

The major figures involved with the discussions on the Headland paper, in the main those having direct and considerable association with conventional electricity generation, system design and consultancy, urged caution in considering the Severn barrage's attributes and apparent advantages, prestige etc., suggesting that such schemes should be 'kept back for a time of depression, when labour and materials could more easily be made available'. Others mentioned, as Headland himself had suggested, the construction of small demonstration designs of a few MW to allow technical and environmental/ecological evaluation to proceed.

As assessment of the many detailed comments recorded on the Headland paper strongly suggests that, although there was considerable interest in the proposals put forward (intimately related, it will be recalled, to those included in the 1945 Severn Barrage Scheme), the real conclusion reached remained one of caution, with the conventional interests in particular leading this point of view.

A companion paper had been produced by B.D. Richards (45) a few months prior to the Headland dissertation, identifying the special characteristics of tidal power and the possible problems which could arise in the period of development and utilisation. The Paper included a comparison of various tidal power projects (including the Severn Barrage) and summarised the conclusions which had been arrived at by the experts who had reported upon them (and as identified previously in this review).

## Chapter 4

### Tidal Power Interest during the period 1950-78

The literature suggests that, during the 1950-60s, much of the UK interest in tidal power, and particularly official government involvement, waned to be replaced by the assessment of wind and wave technology (particularly the latter subject).

G. Wickert (46) produced a short paper in 1956 reviewing man's attempts to harness the powers of the tides which examined the fundamentals of tidal power utilisation. Various types of development, including single and double basin, use of auxiliary basins, single and two way working, Defours three basin system are identified in the paper, which also considers the conditions which must be fulfilled by the designs of tidal turbines and pump turbines.

France, however, retained its interest in Tidal Power. In 1956, Kervran (47) published the results of his interesting study of the possibility of producing tidal power from the Cotentin peninsula, between Lessay and Carentan. With this design, no dam, intakes or gates were necessary, the scheme being based on the construction of a canal to utilise the difference in the times of the tides between the east and west coasts of the peninsula. A virtually continuous supply, of average 50MW, was envisaged from this novel project which was considered to be particularly economic in view of the low capital cost estimated for the construction of the canal. Gibrat (48) continued to present his views on tidal power. In his 'Utilisation Cycles for a Tidal Power Project', he dealt with the most economically attractive methods of filling and emptying tidal basins, especially the 'double effect' (two way) cycle. The role of pumping energy was examined in relation to interconnected operation with fossil-fired and nuclear stations. In a further paper, he examined the operation of a tidal plant from the fuel economy aspect. His previous calculations were updated with regard to the value of incremental units of energy provided on a variable output basis not only as a function of time but also as a function of the total thermal/nuclear power required to be available on the total power network. R. Rath (49) provided an insight into problems with and possible solutions to sea-water corrosion of tidal power station plant. Protection plating and painting, cathodic protection, choice of materials and metals of differing anti-corrosion abilities were identified and a summary of test results obtained was included in his Paper.

In 1963, Sandover (50), identified the Rance tidal scheme and described its design in some detail. So far as can be ascertained, this is the first intimation, in any publically available literature, of the existence of this project although the contents of the papers identified previously (47, 48, 49) confirm that a possible tidal project on the Cotentin peninsula was under examination.

UK interest in tidal power appears to have revived in the middle 1960's, possibly as a direct result of the public identification of the Rance project by Sandover, supported by the interesting studies reported by Hicks (51) and others (52) of tidal power possibilities on the Bay of Fundy.

The economic aspects of a possible barrage across Morecambe Bay were subjected to scrutiny by Pearce (53) while Wilson examined in considerable detail the economics of a Solway Firth barrage (55) and of constructions at Strangford and Carlingford Loughs in Northern Ireland (54), envisaging pumped storage facilities at Rostrevor in common support of both the Strangford and Carlingford schemes. Interestingly Davey (56) had in 1923 considered that the narrowness of the connection between Strangford Lough and the sea greatly impaired its generation possibilities - estimating that no more than ten per cent of the potential energy of the Lough would be available for generation purposes. He did not, however, identify any advantages of pumped storage for that specific site. Wilson considered that recent developments in low head turbine and generator designs, together with the efficiency of newly available reversible pump turbines would bring the cost of tidal energy into direct competition with other more conventional sources of electrical power. In the case of the Solway Firth project, he assessed the technical and economic possibilities of such a scheme, including the estimate of tidal output under various operating regimes. In addition, he examined methods of integrating the output from the barrage with the mixed thermal, hydro and nuclear generation of the Scottish network and recommended a major upgrading of the existing Loch Sloy pumped storage facility to 1200MW in order that the entire project could compete favourably with the conventional energy sources available to the total Scottish system.

Turning his attention to the still moribund Severn barrage, Professor Wilson, a long time advocate of tidal energy schemes around the world (56), proposed the construction of a generating barrage very much larger than had hitherto been contemplated for the Severn, projecting from Lavernock Point in South Wales, via Flatholme (an island in the Bristol Channel) to Brean Down on the English side of the Severn (57). An installed capacity of some 7.26GW was envisaged for the scheme, with an estimated annual output of approximately 13TWh. As he had recommended with the previous Irish and Scottish schemes, a high head pumped storage development of 4GW (at Aberdovey), was also associated with the barrage scheme. Novel turbine/generators of the fixed blade type with the generator rotors mounted at the propeller blade tips and fully immersed ('Straflo' or 'rim generator' design) were also proposed. The proposal identified that the power station would be constructed from concrete caissons which would be floated out and towed to their respective sites before being sunk. The method differed from that used for the La Rance

station which, at the time of the Wilson paper, was being constructed 'in the dry' behind two coffer dams (58), although it was similar in concept to the method employed in the building of the much smaller Kislaya plant (59).
Gibrat (60) in 1966 produced an extensive theoretical treatise on the problems of harnessing tidal energy, including in his treatment further details of the La Rance project and of other proposals in Canada, USSR, UK and elsewhere.
The review and speculation around this period in respect of the construction of barrages across some of the estuaries and bays around the UK induced the water authorities to become interested in their use for water storage and a variety of other purposes. Howell (61) summarised a list of these projects and their proposed uses, noting that 'included in the list is the Severn barrage since it is the only one in this country to have been subjected to a complete engineering investigation and evaluation'. (sic.)
In October 1967, Shaw presented a 'new case' for tidal power and the Severn barrage (62), while in August 1968, Heaps (63) produced a paper 'Estimated Effects of a Barrage on Tides in the Bristol Channel' which drew attention to the importance of evaluating how the introduction of a barrage would affect the overall tidal conditions in the estuary. Using a fairly simple iterative numerical procedure, estimates were made of possible changes which could occur in both tidal elevation and current. Meanwhile Braikevitch (64) produced, in conjunction with Wilson and others, his paper to the World Power Conference which critically examined and exposed the inherent limitations of the pump/turbine concept employed at La Rance before comparing it with the 'more adaptable' tidal power pumped storage method (as identified by Wilson), whereby the low grade energy generated on the ebb tide was stored until required. He suggested that the barrage generating plant was more simple and robust as a result, with better economics.

The straight flow turbine and rim generator design, the 'Straflo', referred to earlier, was also described in some detail as was the method by which the number of turbines and sluices could be selected in order to optimise energy costs. (In passing it is worthy of note that the ‘Straflo' rim generator turbine was patented by Harza in 1919 and that the current patents are held by Sulzer Escher Wyss of Zurich. The design has not only the hydraulic advantages identified by Braikevitch but also the further and highly important 'electrical' advantage of high rotational inertia and thereby better stability in the event of a large disturbance on the electrical network to which it is connected).

In June 1970, Shaw and others (65) identified that, despite the very disappointing economic conclusions which had been reached by earlier Bay of Fundy studies, continuing changes in generation patterns could still produce tidal projects of economic interest, particularly if pumped storage was incorporated with the barrage scheme. In a further paper on the same subject, Shaw (66) used the Severn estuary as a model to expound the economic virtues of combining the storage, by pumping, of large quantities of off-peak energy with a conventional tidal power generation project to produce power as required at a constant rate over a full day-time period. It was the considered view of the paper that coupling energy sources in that way could have many beneficial advantages over their separate development, particularly in terms of efficiency and overall cost.

On a similar theme, Sorenson (67), in his paper to an International Conference on Tidal Power, provided supportive data to Shaw's arguments asserting that, with (underground) pumped storage and nuclear plant generation, large tidal basins could produce electrical energy at high daily load factors and with only minimal variations in daily, monthly and annual capacity. At the same Conference, Wilson (68) examined the features of a single pool, one way scheme and compared them with those of multi basin arrangements, arguing that compensation for tidal output variations would be uneconomic even where it was practical to provide for it. Any solution must be 'a compromise between costs and convenience of operation of the tidal plant and other interconnected generation' he asserted. Suggested solutions included pumped storage and 'tide-boosted' pumped storage.

Other submissions to this International Conference on Tidal Power, which took place at the Nova Scotia Technical College, Halifax over the period 24-29 May, 1970, included papers dealing the the subjects of power units and sluice gate design, connections to electrical supplies, the economics of tidal power generation, the effects of tidal generation on the tides themselves, and on caisson construction and flotation. The contents of these documents (and indeed many of the other papers to the Conference) can be identified as re-iterations, some of them updated, of previously published work.

In 1972 an indication of some German interest in tidal power was identified in an article by Huebner (69) which summarised the potential of tidal power when examining the positions which had been reached in studies in the UK, USA, France and Russia. Experience which had been gained with the La Rance barrage during and subsequent to its construction over the period 1959-67 was the basis for the preparation of a number of articles presented in a special issue of the publication La Houille Blanche in 1973. Faral (70) summarised views on the materials used for the bulb turbine casings (principally 17/10 austenitic steel), with stainless steel and aluminium bronze having been found to be the best combination for the turbine blades. Leborgne (71) identified a list of materials used on the Rance plant, describing their application to and behaviour on the gates, runner blade vanes and associated pipework and providing special emphasis in respect of the effects of corrosion on mundane items such as nuts and bolts and shrink-fit pipe assemblies. Legrand (72) (73) identified the types of cathodic protection methods available and summarised their individual effectiveness, as found after six years of plant operation, when applied to condensers, pumps and lock gates. Gandon and others (74) provided papers dealing with the evaluation of the bulb generator design, including those of up to 40MW in their survey. Civil, mechanical and operational aspects of the Rance project were also included.

Also during 1973, Wilson (75) produced a further article which briefly reviewed the principles of operation of various types of tidal power project, summarising the possible development of suitable sites. The effects of barrage construction on the estuaries themselves were touched upon, together with views concerning the integration of the resultant electrical output from such schemes into existing power networks. The experience gained from six years of operation with the Rance scheme was also discussed while Russian experimental work on the subject of tidal power extraction was described. The paper provided an update of existing technology and discussed modern thinking with respect to sites such as the Severn estuary and the Bay of Fundy. Interestingly, while Wilson was emphasising the tidal power possibilities of sites on the Bay of Fundy, others (76) were examining the power potential of Ungava Bay, a site off the Hudson Strait in Northern Quebec and approximately a thousand miles north of the Bay of Fundy. Although the mean tidal range at this site is considerable at approximately nine metres, Baker (77) suggested that, in view of its extreme remoteness in conjunction with the severity of the climatic conditions, development of the region for tidal generation was unlikely to be considered seriously.

This conclusion was perhaps a little surprising in view of the fact that Bernstein (78) had confirmed continued Russian interest in tidal technology by providing a paper dealing the 1963-1968 Kislaya Bay project, a small scheme successfully installed and operational on the Kislogubsk River, near Murmansk and operating some 10° further north than Ungava Bay. The Kislaya Bay plant, although only of 400kW installed capacity, was interesting to the tidal power experts since it utilised a reversible bulb turbine of the Rance type; moreover the installation involved, for the first time, the use of precast concrete caissons floated into position and submerged on to a prepared bed. The severe arctic conditions had provided considerable constructional and operational problems, many of which were identified by Bernstein. Other aspects of the Kislaya plant are identified by Charlier (79). Despite Bernstein's enthusiasm for the construction of other tidal plants on the White Sea (he visualised, for example, a large plant at Mezen Bay, close by the Kislaya Bay scheme, capable of producing an estimated annual output of 14TWh), no further developments have in fact taken place to date, which may provide additional support for Baker's assertion, referred to previously, that climatic problems and remoteness are factors which are particularly pertinent to the construction of tidal plant.

The June 1974 article by Shaw (80) examined the details of the 1945 Government sponsored study of tidal power from the Severn, English Stones site (referred to in Chapter 3.3) suggesting that an estuary pumped-storage project would, despite the Report's views to the contrary, have offered worthwhile economic and operational advantages over the purely tidal development recommended by the Committee. The Shaw article is unique in that, for the first time in this intensive literature search, the environmental factors associated with a tidal plant situated on the Severn estuary were specifically identified and discussed.

Also in 1974, the French continued to emphasise their interest in tidal generation and in the bay of Mont-Saint-Michel in particular. Deniaux (81) examined the background to the development of tidal power in France, including the Rance construction and identified the special features of the north coast of France which could be exploited by tidal plants. The civil and specific environmental problems related to the construction of the proposed plants were examined. (It is an interesting point and one which is particularly worthy of note in view of the reference in Deniaux's paper to site specific environmental problems that, so far as can be ascertained from the library search, no environmental studies associated with the Rance scheme, prior to the plant's construction, were undertaken. Charlier (82) indicates strongly that none were undertaken). Clare also confirmed that America had not completely lost interest in the topic (83), when reviewing R & D funding levels of renewal energy resources. Estimates of renewable energy costs were compared with those associated with more conventional plant and, as a result, it was concluded that tidal power generation was feasible technically but economically 'uninviting at present'.

Cotillon's (84) view of the service experience gained with the Rance tidal plant was contained in his 1974 paper, in which he confirmed that no major problems had been observed in the six/seven years of plant operation. His breakdown of the costs incurred in constructing the Rance scheme is of interest; in particular, he concludes that the civil works, excluding coffer dams, amounted to somewhat in excess of 299m Fr or twenty eight per cent of the total cost of the project. The use of coffer dams increased the cost of the civil works to some forty one per cent of the total. Such data may be compared with those pertaining to the conclusions of the Severn Tidal Power Group (STPG) reported during discussions in 1986 (83) which suggested that in excess of sixty two per cent of the total costs were attributable to the civil works; this despite the fact that the supposedly more economic caisson method of construction was being proposed.

A paper summarising the attitude of the Central Electricity Generating Board (CEGB) to tidal power projects was presented to a Symposium organised by that body in 1974 (84). The nationalised electricity industry had previously indicated little if any interest in renewable energy projects, their views being associated specifically with the principles of steam produced 'firm power' and by plant representing 'economy of scale'. These attitudes were further reinforced during the Symposium, when a scheme to convert the intermittent output from a barrage on the Severn estuary to a firm supply by means of a combined dam/barrage was discussed.

Interest in tidal power was identified in Korea and in Western Australia during 1975. (85)(86). The Korean paper confirmed the possibilities for the extraction of tidal energy in the south of the country, where mean tidal ranges approaching six metres were applicable. However, as Baker also confirms (88), many of the apparently suitable bays and inlets are shallow at low tide and with intertidal flats which make such sites useless for power generation. According to the Korean paper two sites, one at Garolin Bay, the other on the Gulf of Asam, were considered to be capable of development (and Baker has also confirmed their adequacy for the purpose). In the case of Western Australia, Scott indicated that, unlike the coal rich eastern states, Western Australia is almost totally dependent on oil for its energy requirements. Studies have been made to harness the tidal power at Secure Bay, in the Kimberley region, some two thousand five hundred kilometres north of Perth, which have suggested a firm power capability of one hundred and seventy megawatt when combined with pumped storage. This region had also been reported upon by others (89) when both Secure Bay and Walcott Inlet had been identified as sites useful for tidal generation. Baker's views on both sites (90) confirm that, in the event of agreement to develop them, considerable difficulties would be likely in view of the very fast tidal currents induced by the exceptionally narrow entrances to the areas to be impounded. In addition, both sites are remote from civilisation and their output could not be absorbed locally. Moreover, as Baker remarks, both basins are deep, (Secure Bay being somewhat less so) and would result in difficult constructional problems. In noting the suggestions in respect of pumped storage and identified previously, Baker has commented on the possibility of linking both Walcott Inlet and Secure Bay by means of a connecting channel, and locating the turbines in the channel. He concludes that the combination would not be an economic one.

In continuing his assessment of the potential of the Severn estuary, Shaw (87) put forward his support for as large an impounded area as possible, with generating equipment installed at the estuary's seaward limit; i.e. basically as recommended by Wilson. His views on the environmental effects on the area of such a construction remained cautious, with comments such as 'possibly some improvement in some aspects' and 'suitably sited and operated need not cause further disruption of biological systems' being typical of his approach. These assertions, cautious as they may have been, were however questioned by the Hydraulic's Research Station (91) following their study of both Wilson's single barrage scheme and that of the double basin design which had been proposed by Shaw. The station concluded that the tidal regime would be significantly affected by such schemes, despite previous conclusions to the contrary, with possible problems with flooding and land drainage on and around the estuary and with considerable sediment re-distribution affecting navigation.

There is evidence at this time (92) that UK government sources were not completely inactive with respect to tidal power. This report from the Energy Resources Sub-Committee presented the evidence of the proponents for a Severn barrage, stressing the (technical) feasibility of such schemes in general and bringing together the differing views of the consultant engineers and water authorities associated with evaluating various aspects of the proposals. Central Electricity Generating Board (CEGB) witnesses were also called to provide the investigating sub-committee with their views on interconnecting the project with the electrical transmission system and the possible utilisation of the intermittent supply from the barrage. It is apparent from their replies that significant dissension between the views of these experts on the many aspects of barrage generation on the Severn remained.

This conclusion is further supported by the contents of a paper by Green (93) compiled from hitherto unpublished work of the Geological Science Institute. The paper argues that, contrary to evidence provided to the Select Committee, much of the region of the proposed barrage had bedrock exposed at the seabed and was not covered by drift. The paper went on to propose that a detailed survey of the region should be undertaken.

Shaw, meanwhile, continued to press the case for a barrage on the Severn, reiterating much of the earlier published work in the process (94)(95). In the latter dissertation, he accepted that, although it was agreed that tidal power remained a real alternative to conventional methods of electricity production, 'a number of doubts have been raised regarding its viability'. He nevertheless concluded that a Severn barrage was worth the most serious consideration in the role complementary to thermal sources. On the other hand, the CEGB views, summarised in their Report to UNIPEDE on 'Electricity from Natural Energy Resources', (96) concluded that the identified alternative natural sources of power could not make any large contribution to overall energy requirements by the end of the century. Energy conservation and nuclear power were believed to be the only effective alternatives to the increasing consumption of fossil fuels and the resultant environmental problems associated with their combustion.

The Watt Committee on Energy (97) reached the general conclusion that, in the short to medium term, much of the basic research and some of the development work necessary to provide for the nation's future energy requirements had been completed. Beyond 2000, the committee visualised that the country would again become a nett importer of energy and believed that new energy sources must be developed as identified by many of the individual reports on the subject. The committee's report emphasised the length of time necessary to exploit any energy resource of substance and the considerable expenditure involved in the process.

Yet a further paper from Shaw (98) at this time argued that the tides offered the greatest number of advantages of all forms of energy suited to conversion to electricity and capable of supplying all the needs of the UK via the nation's coastal waters. He also concluded that tidal energy 'compares favourably with other renewable forms of electrical supply from both the environmental and economic points of view'.

Wilson (99) presented a paper to the University of Southampton which traced the history of tidal power for the convenience of the Symposium's delegates and examined construction techniques, turbine/generator designs and possible power outputs for various sites across the world. A comparison of possible costs of tidal generation with those of more conventional methods was included in the paper.

The Select Committee on Science and Technology produced its report concerning the 'Exploitation of Tidal Power in the Severn Estuary' (100) early in 1977 which summarised and reviewed the evidence which had been received on the subject up to the end of 1975 (92). In considering the case for a barrage across the Severn, the various aspects for and against the case, including the views of the CEGB and the Government itself were taken into account. In particular, the Committee regarded the governmental position on tidal power to be 'excessively timid', particularly when compared to the recent interest by the Dept. of Energy (D of E) in wave power, a subject which, unlike tidal power, had 'not been proven on any significant scale and which lacked engineering techniques'. No conclusions were, however, reached in respect of recommendations for the go-ahead for any Severn scheme.

In like manner, the Department of Energy published the results (101) of 'three studies into different aspects of the feasibility of constructing a tidal barrage across the Severn estuary'; the basic conclusion of the work being that any barrage would be 'in the region of Cardiff and Weston-Super-Mare'.

Further criticism of the governmental view on renewable sources of energy were contained in a paper from the Select Committee on Science and Technology in July 1977. (102). Having stated in a previous paper that, in their view, the Government were 'excessively timid' with respect to tidal power, they reinforced their opinion with the view that government spending on renewable sources of energy had been 'grossly inadequate'. Accepting that renewable resources would be likely to provide only modest contributions to total energy supplies before the end of the century, they believed that they should nevertheless be given greater priority by the Department of Energy with R & D investment increased so that 'those which prove technically and economically viable can make a worthwhile contribution to UK energy requirements by 1990 when self-sufficiency in indigenous fossil fuels has passed'.

Wilson also believed that research into tidal power had been neglected by the authorities. In his view (103) this had been caused by the revived interest which had been created by wave power, this being in turn due to the contents of the Rothschild report on 'Energy Conservation' (104) and the Advisory Committee on Research and Development (ACORD) Report on 'Energy R & D in the UK'. (105).

Wilson's paper also welcomed the renewed international interest in tidal power. In this respect, the IEEE PES (the Power Equipment and Systems branch of the American Institute of Electrical and Electronic Engineers) had been active, at their summer meeting of 1977, in pursuing the tidal power possibilities for the Bay of Fundy and Passamaquoddy regions of the USA and Canada (106)(107). The west coast of South Korea was again identified as a possible site for economic tidal power in a paper to the tenth World Energy Conference in Turkey (108). The paper restated the fact that this region has mean tidal ranges of the order of six metres and, with a highly indented coastline, appears to present the capability of tidal power extraction. However, as Baker had previously confirmed (109), many of the bays so formed were very shallow and thereby were of little use for power extraction; in addition, land reclamation projects were being undertaken in the same area.

An intriguing paper by Ryle (110), in discussing the large diurnal, day-to-day and annual fluctuations in heating demand, postulated the construction of low grade heat systems to minimise the necessity to provide electricity generation catering for peak demand. The provision of such storage facilities would obviously be of particular economic benefit to intermittent generation schemes such as tidal power projects. It is of particular interest, therefore, to recall that, during their deliberations into the subject of the Severn Barrage Scheme (111) the 1945 Committee had examined the possibility of utilising the output from the tidal scheme to provide district heating for the surrounding neighbourhood. The Severn Barrage Committee had formed the view, fully supported by Ryle, that the costs of transmitting the electrical energy to storage systems for low grade heat was low in comparison with those associated with pumped storage. However, they had formed the opinion that the facilities for district heating were virtually non existent at the time, that the possible rate of such development would likely to be very slow and that special legislation would in any event be required for such scheme(s) to go ahead. It was considered, as a result, that such projects 'would not be possible for many years to come' and further consideration was abandoned as being outside the committee's terms of reference.

The potential for 'unconventional', i.e. renewable energy sources for the United Kingdom was discussed at some length at the World Energy Conference, Istanbul in September 1977 (112) when Leighton and others reviewed, once again, the 'present state of knowledge' of each potential resource, including its likely magnitude. The conclusions expressed in the paper's review of the different renewable technologies included views on 'their prospects for the next century'. Tidal power was not considered in a particularly favourable light, particularly in comparison with wind power, in terms both of environmental impact and in relation to conventional technology.

In a no less interesting article, Sir Hermann Bondi, the Chief Scientist to the D of E (113) discussed the (then) current proposals for harnessing tidal power. He was of the opinion that, while the unique features of the Severn estuary, 'one of the world's most suitable tidal power sites' could not be ignored, tidal power was 'less promising in the long term than either wave power or solar energy'. To go ahead with even the 'most simple Severn estuary barrage scheme' would, he claimed, 'cost at least £1000m'. (The 1986 estimated cost for a barrage at the English Stones was £1000m, or £1150m with contingencies. (294).

Wicks (114) in his assessment of the power potential of waves, tides, and tidal currents, remained of the view that only the salinity and thermal gradient forms of energy derived from the sea could rival the density of conventional energy sources. His earlier work had led to this conclusion but, as he admitted, schemes involving these processes had not retained the attention of scientists as had tidal, wave and, of course, thermal power. Charlier (115) confirms that the theoretical powers of thermal gradients (OTEC) and salinity gradients are greater, by several orders of magnitude, than that attributed to tidal power. (OTEC - 40,000 x $10^6$ MW; Salinity Gradient - 1400 x $10^6$ MW and tidal power 3 x $10^6$ MW). In a similarly, depressing, report to the American Society of Mechanical Engineers (ASME), Griffin reviewed the feasibility of extracting power from the sea (116) and discussed the technical and environmental acceptability of tidal, wind and thermal gradient for power generation. When comparing the costs of these alternatives with conventional nuclear and coal-fired outputs, he totally rejected tidal power as 'economically uninviting' at least from a USA point of view. (It tends to follow that, on the basis of Griffin's environmental assessment at least, tidal power would also be less than inviting to the UK). Just as importantly, the views of the Central Electricity Generating Board (CEGB) as expressed by Denton (117) were equally discouraging for tidal power, since their assessment of worthwhile renewables did not even include this method of energy extraction. However, possibly of some small comfort, Denton maintained that all the renewables examined were uncompetitive when compared with nuclear power although 'wave power might be worth considering and solar energy might be useful for domestic water heating'.

This view of tidal power (and other renewables) is shared by Madeley (118), who makes no mention of tidal power during his exploration of the different scenarios capable of meeting the UK's future energy requirements. In noting the possible decline in primary energy supplies by the year 2000, he examines the principles of energy conversion through solar, wind, wave, geothermal and waste energy systems, while the possibilities of catering for predicted future requirements by the availability of wind, wave and solar systems are explored. On the other hand, a short dissertation by Beatson (119) suggests that all the different renewable energy sources are viable but depend for their success upon further research and development to be of any practical use. The views expressed by Beatson are perhaps better stated, and certainly are reinforced, by the EPRI (Electrical Power Research Institute) Report (120). Reviewing the features of wind, wave and tidal power, ocean thermal energy and biomass conversion, the conclusion was reached that 'these long shot, indirect solar (sic) technologies have potential and promise but they all have unsolved technical problems'. None could be counted on to provide significant electric power needs by the year 2000.

The June 1978 issue of 'International Water Power and Dam Construction' contained two features on the subject of tidal power. The first, by Shaw (121), reviewed the existing status of the subject and examines once again the Bay of Fundy scheme(s), prospects for the west coast of India, identifying a very large Gulf of Cambay scheme and a smaller possibly less attractive project on the Gulf of Kachehh. The low cost of labour at both these sites and its effect on unit costs are identified by Baker (122). The second article (123) on the subject of tidal power dealt with the experience gained at the La Rance power scheme and included suggestions that the scheme could have achieved better economy by the installation of bulb turbines of larger runner diameter. Further details of the mechanical design and operational characteristics of the La Rance barrage plant were provided (124) in a paper to the Chartered Mechanical Engineer in 1978. This author also briefly explored the characteristics of the prototype Kislogubsk plant before embarking on a detailed historical appraisal of the Severn barrage project.

During the latter part of 1978, the American press showed renewed interest in ocean energy schemes. In one paper (125), the authors provided support for the assessment, also expressed elsewhere (126) that, of the three terrawatt (TW) of power continuously dissipated as a result of tidal motion across the surface of the earth, only a minute fraction could be harnessed for useful power applications. They believed, nevertheless, that this represented up to five per cent of world-wide all source generation and, as a result, supported any action to obtain and to utilise the tidal source of power. The article listed some of the published data re tidal extraction but provided no new thinking on the subject. In the second paper dealing with ocean power technology (127), it is apparent that American thinking remained firmly along the line of ocean thermal energy conversion. Other power conversion schemes, including tidal power, were briefly examined but the main thrust of the paper concerns the technology, equipment, funding and future plans for OTEC. Despite considerable expenditure on the process (some five hundred and twenty million dollars were expended over the period 1978-1986, amounting to about 20% of the total research and development expenditure for renewables) (128), the position presently reached with OTEC appears not dissimilar to other ocean related schemes.

Further thoughts concerning renewable sources of energy and its possible impact on conventional generation were voiced by Glyn England (129), Chief Executive of the CEGB, in an internal paper to members of his staff. In it, England considered the feasibility of off-shore wind generators, wave machines and tidal generation on the Severn. The possible harnessing of geothermal energy by the rock cracking (hot rocks) process, a research project in conjunction with EEC experts, was also examined. The future possibilities for renewables were then discussed against the background of North Sea oil, coal production and nuclear power. (The utilisation of natural gas for generation processes was not mentioned in the paper since the nationalised utilities of the period were excluded from burning this prime fuel). The view of the CEGB to renewable sources of electricity generation, as portrayed by England's comments, obviously remained at best sceptical, believing them to be of little significance in their continuing search for economy of scale and increased generation efficiency.

On the other hand, Civiak (130) indicated that some change in direction for tidal power had perhaps occurred, identifying the fact that both governmental and private interests had now joined forces in certain parts of the world, to study the harnessing of tidal power for electricity generation. His paper also reviewed the technical possibilities of regulating power production and examined methods to minimise the environmental impact of tidal generation on estuaries' ecosystems. His paper also made reference to the high cost of tidal energy as identified from evaluation of earlier studies of Bay of Fundy schemes, but argued that, from a life cycle cost analysis point of view and not the shorter term evaluation favoured by conventional financial techniques, tidal power remained an attractive proposition.

**Chapter 5 - Tidal Power 1979 - to date**

5.1 The Severn Estuary

The criticisms of governmental 'lack of urgency' and 'timid approach' to renewables in general and tidal power in particular, expressed during 1978 by various official committees (ref. 97, 101, 102) together with the large increases in oil prices during the 1970's may well have induced a government re-think on the subject of tidal barrages. No less importantly, the public's growing aversion to nuclear generation may have combined to provide the reasons for Wedgewood Benn, the Secretary of State for Energy in the 1976-9 Labour administration, to call for a re-appraisal of the feasibility and relative merits of a Severn estuary electricity tidal generation scheme. Whatever the real reason(s), a second Severn Barrage Committee (SBC) was appointed for this purpose in late 1978, under the chairmanship of Sir Hermann Bondi, the official report of their findings appearing during March 1981 (132).

5.1(a) The Bondi Inquiry

An internal progress report, produced by the Bondi Committee in 1980, had concluded that although (large scale) tidal power from the Severn estuary was technically feasible, (a conclusion reached by a similarly named committee some thirty five years earlier), it seemed unlikely that its unit cost could compete with that provided by nuclear generation. Nevertheless, it was considered that the output from such a plant might compete with fossil-fuel generation if coal and oil prices continued to rise in real terms. The official report from the SBC, presented to David Howell, the Conservative Secretary of State for Energy, 1979-81, was somewhat less pessimistic in outlook than was apparent from the Committee's earlier comments, although the report still retained the view that any investment in a barrage was unlikely to be as attractive as one involving nuclear plant. A detailed examination of the report confirms that the Committee and its experts had examined no less than six alignments for a barrage constructed to the 'east' of English Stones before concluding that it was technically possible to enclose the estuary by a barrage located 'in any position east of a line drawn from Porlock due north to the Welsh coast'. The economic assessment of various schemes for the estuary resulted in the elimination of all but three of the different possibilities, these being examined in further detail. The first of the schemes examined, the so-called 'Outer Barrage', to be constructed from Minehead to Aberthaw on the Welsh Coast, was considered to be able to account more or less for the whole energy potential of the estuary. Estimated to cost almost nine billion pounds at 1980 prices, not including interest and other charges, the single basin ebb generation scheme was expected to produce around 20TWh annually, or about ten per cent of the electricity requirements of England and Wales, from an installed capacity of 12GW. The second of the initially preferred schemes, the 'Inner Barrage', required an impounded basin to be created by a barrage constructed from Brean Down, a promontory close by Western-Super-Mare, to Lavernock Point on the Welsh Coast and a few miles south of Cardiff. This ebb generation scheme was estimated to produce about 13TWh annually from the single basin, and installed capacity of 7.2GW and to require a capital expenditure, on the same basis as the larger scheme, of £5,600m. The third of the initially preferred schemes, the 'staged scheme', envisaged an extension to the 'inner' barrage by enclosing Bridgewater Bay as a second basin. The committee considered that this scheme would produce as much energy as the outer barrage itself and with a similar economic performance while, if the second basin was to be operated in a 'flood' regime, electricity production could take place for over twenty hours each day. After reviewing their provisional conclusions on the merits/demerits of the three alternative projects, the committee formed their opinion that the staged scheme could be deferred to some future date without affecting the attractiveness of the inner barrage. Moreover, it was their view that the engineering complexities associated with the construction of an outer barrage, together with its possible environmental problems, were such as to impose considerable risks to the project as a whole. The inner barrage scheme was ultimately recommended by the committee.

In assessing the economic viability of the project, the committee concluded that about six million tonnes of coal equivalent would be saved each year although, as a result of the intermittent operation associated with barrage generation, the necessity for future power station capacity would not be reduced by 'more than about one Gigawatt'. The unit cost of the barrage produced generation was estimated, on the basis of five per cent discount rate, to be within the range of future costs of generation by conventional coal and nuclear plant; a figure of 3.1p/kWh was identified. The possibility of part generating', as barrage construction progressed, by the inclusion of non equipped generator caissons in the early construction 'float-out' phases, was also explored, leading to the view that 'the first electricity may be generated within nine years of commencement of construction and not the originally envisaged sixteen years'.

The Report emphasised the critical importance to the viability of a barrage scheme of increases in fossil-fuel prices and of discount rate, making the point that with 'unexpectedly' high energy costs, a barrage would be of great advantage. It also explained the reason for its higher level of optimism than had been previously expressed. The change was due, the Committee stated, to later estimates of energy possible from the barrage amounting to perhaps forty per cent higher than the original figures employed, for the same capital costs.

The possible impact on the environment and its ecological systems of the barrage had been given consideration in the report which, however, emphasised that while a number of preliminary judgements could be made, 'much work remains to be done' in order to study 'all the possible effects on man and the environment'. In particular, important subjects such as the effects on ports and navigation of the estuary and upon the social effects of employment (it was envisaged that the project would provide about 21,000 new jobs for periods of up to ten years) were identified as requiring further assessment before any definite decisions could be made. The rate of manufacture of the one hundred and sixty turbo generators and associated ancillary equipment required for the barrage could , the Committee believed, 'strain UK industrial capacity'.

The possible effects on the upstream (of the barrage) water levels were noted and the necessity to introduce additional treatment plants, at a cost of £120-130m and with annual running costs of perhaps ten per cent of the capital outlay, reported upon. The Report commented that the need to maintain any specific aspect of tidal water quality in its existing state would demand a 'policy decision'. (In view of the number of different authorities having interests on the estuary, its banks and inter-tidal zones, the provision of a single policy acceptable to all would obviously present a formidable task). In assessing the effects of a barrage on land drainage, sea defences, birds, fish and of its use and application to water based recreation, the Committee concluded that it was evident that its environmental, social and industrial acceptability had not been established and that these aspects must be major objectives to be addressed in any future work.

The Committee therefore recommended that a further phase of work be undertaken forthwith, this to be concentrated on the region of the 'inner barrage'. It expressed its great concern of 'the yet imperfectly understood impacts of a barrage and recommended the early setting in train of deeper studies to establish the acceptability of a barrage', the aim being to put Government 'as soon as possible in a position where it could responsibly decide whether to authorise the construction of a barrage'. The Committee believed that a combined acceptability and preliminary design study' should not take more than four years or cost more than £20m; although a decision would also be needed, part way through the study to decide whether to proceed, at a further cost of £25m, with handling and foundation trials of a prototype caisson in the estuary. Since the civil plans of the proposed scheme and the 'early generation' aspects of the project necessitated the use of caisson construction, towing to site and setting-in position, it is difficult to understand why the Committee had decided that the vitally important trials were not to be included, from the outset, as an integral part of the envisaged acceptability and design study at a total cost of £45m.

It is worthy of note that, despite studying a different barrage line, the second SBC was able to confirm in its Report, in similar vein to its 1933 forebear that, in the view of the Committee, a barrage (on a line from Cardiff to Weston-Super-Mare) would be both economically and technically feasible. Sacks (147) believed the Committee's conclusion to be 'yes - but ...' while an article in Water Power Dam Construction (148) considered the verdict 'favourable'.

5.1(b) <u>Formation of the Severn Tidal Power Group (STPG).</u>

Soon after the publication of the SBC Report in March 1981, an industrial consortium comprising Sir Robert McAlpine, Taylor Woodrow Construction, Balfour Beatty, GEC Turbine Generators and Northern Engineering Industries, (to be joined in early 1985 by Wimpey Major Projects -see also p103), was formed as the Severn Tidal Power Group (STPG), which announced their joint investigation of a £5000m private sector scheme for the Severn. Members of the group had individually been active in the Bondi assessments, providing confidential and other information to the SBC. (133)(134). The group proposed to the Secretary of State for Energy that they should now undertake an interim series of studies aimed at reducing many of the uncertainties identified by the SBC Report and, with part funding provided by the Department of Energy, this work was undertaken during the period 1983-85. At a symposium organised by the Institution of Civil Engineers during 1986 Clare (135) summarised many of the results of various investigations undertaken, noting that 'within the limited funds available it was not possible to commission new field work of a technical nature, studies being limited to those which might result in major savings in cost and time or increase the confidence in the different estimates included in the SBC Report'. As a result of such work, it was proposed that the alignment of the barrage as recommended by SBC should be revised to eliminate a 'dog leg' around Steep Holm (an island in the estuary), providing better turbine intake characteristics, a shortening of the barrage by around one and a half kilometres and 'incidentally an increase in the impounded basin area by a small amount'. Moreover, the STPG were of the opinion that the necessity for the preparation of a prototype to assess the performance of the 45MW nine metre runner design of bulb turbine, as proposed by SBC, could be avoided by what was considered to be 'an acceptable extrapolation of the service performance and experience' of bulb generators already in service. As a result, the installation of one hundred and ninety two bulb turbines of 8.2m runner diameter, each with a nominal output of 37.5MW, was proposed for the modified alignment. A further modification to the original SBC proposals concerned the scheme for connecting the tidal generation into the main transmission network. As discussed in detail in the paper by Barr (136), it was believed that, by taking account of the power loading cycle associated with tidal generation together with the fact that expansion of the barrage substation would not be required, a more economic ('mesh') layout of substation could be designed and constructed while still retaining the required electrical security. Moreover, the total barrage output could be cabled to the English side of the estuary, and not to both English and Welsh shores as envisaged by the SBC, a further significant saving in capital costs. STPG also proposed to construct 'embankment' sections (basically dam structures comprised of rock or plain caissons), simultaneously with the installation of those caissons intended to incorporate generators and sluices. This change of construction was estimated to shorten the total construction programme by two years and to provide full electrical output within nine years.

The funding levels agreed with the Department of Energy at the outset of the STPG assessment were considered insufficient to undertake any major new environmental studies. However, papers by Shaw (137)(138) to the Symposium held at the Institution of Civil Engineers, based mainly on an analysis of experts' views to the SBC and other organisations' studies, must have presented a very useful insight to STPG on possible ecological and social impacts of the proposed barrage.

Interestingly, and despite the low level of funding available to them, 'interim studies' were undertaken by STPG during 1985/6 to re-examine English Stones as a possible region for a tidal barrage. The main objective of the study undertaken by Binnie and Roe, (139) was to evaluate the commercial viability of a privately owned and operated barrage selling electricity into the (then) nationalised electricity network. (see also Section 5.1j). As others had concluded previously, the authors reported their view that construction of an electricity generating barrage at the English Stones was technically feasible.

They argued, however, that despite the earlier work at Manchester University by Professor A.H. Gibson, a siltation problem could well exist at the region chosen for the barrage, some two kilometres downstream from the earlier English Stones site.

The problem of siltation was considered in some detail by Kirby (140). This investigator prefaced his evaluation of the region with the comment that the level of knowledge of sedimentary movement in the English Stones vicinity was less advanced than at other sites on the estuary due to a lack of study of the region and of detailed information pertaining to barrage design. Nevertheless, he identified English Stones as having one of the highest tidal ranges and strongest tidal currents in the estuary, noting, as other investigators before him had done, the proximity and the effect of the Shoots - a narrow deep channel truncating the English Stones site. Referring to the very high level of fine suspended solids in this region of the estuary and to the movement of several million tonnes of such sediment per tide, Kirby was of the view that much of this efficiently mixed, high concentration of suspended solids would pass through turbines and sluices to be deposited, at slack water, behind the barrage, remaining there and ultimately reducing the volume of water in the impounded basin. Suggesting that 'further work was necessary' to confirm his assessment of the situation likely to result from a barrage at the English Stones site, Kirby predicted that the life span of the basin would, as a result of siltation, lie between forty and eighty years. Such a period would be sufficiently short to seriously affect the economic viability of a generating barrage at the site and was obviously at variance with the conclusion reached some fifty years previously by Professor Gibson, who had voiced the opinion to the 1933 Committee that siltation would be unlikely to pose any problem to barrage operation. It is significant, however, that although Gibson had deliberately neglected any significant input of sediment from the seaward side of the barrage, arguing that river borne sources were the major infeed of sediment to the basin, Kirby's studies had, on the other hand, supported the view that the main sediment input to the scheme would be from the seaward side. This complete change of emphasis was estimated by Kirby to result in an order of magnitude greater deposition rate than had originally been estimated by Gibson. It is no less obvious from the discussion on Kirby's paper (308) that Dr. Kirby's own views concerning sediment mobility (which had incidentally resulted in his suggestions for modifications to the SBC Cardiff-Weston line) were also open to considerable scrutiny, confirming that author's comments that much careful additional consideration would be needed in any future studies of a tidal barrage on the Severn.

Although at the time of the initial involvement of STPG with Severn barrage generation, no fully identified proposal for the privatisation of the Electricity Supply Industry had been tabled, the necessary scenario for such action had been well publicised in 1982 by the new Tory Administration. Furthermore, the sceptical views of the public generators and distribution boards to expenditure relating to 'environmentally friendly' but infirm sources of power and their own support for economy of scale were no less well known. As a result and unlike the SBC whose remit had included the re-appraisal of the technical, social and environmental problems likely to be faced by the construction of a barrage at various locations on the Severn estuary, the STPG were required, as part of their study, to assess the prospects for attracting private capital to fund the construction of a barrage drawn on the Cardiff-Weston line and also at English Stones. The financial problems involved were summarised in an extremely interesting and detailed paper to the ICE Symposium held in 1986; 'The economics and possible financing of two barrage schemes' by Dr. J.G. Carr (141).

5.1(c) An Economic Assessment

In discussing the difficulties and possibilities of privately financing generating stations, the outputs of which were to be sold to a public body, Dr. Carr chose two parameters to evaluate the economics of the two plants; as a result, their real pre-tax rate of return and the cost of a unit based on a discount rate of five per cent were subjected to close examination. It was mainly supposed that the output of each station would be purchased, at the time required by the CEGB and in accordance with their published bulk supply tariff (BST), although the effects of other purchasing scenarios, used by the CEGB in support of their Sizewell B nuclear station submission, were also examined.

The paper concluded that neither project was economically - more correctly commercially - viable within the terms appropriate to private sector funding, due basically to the fact that the barrage output, and thereby the economic return from the privately financed constructions, would effectively be controlled by the public sector method of evaluation. In addition, the remote possibility of finding equity funding for the preconstruction phase, when the very costly risks of cancellation of the project, or of unforseen difficulties to be overcome, was emphasised.

During discussion of the paper, Grubb (142) identified his view that, in terms of national economic benefit, cash flow should be assessed at a rate which reflected the mean social rate of time preference (SRTP) across the population, a representative figure for SRTP at that period being in the range 2-5%. In an ideal free market economy, this figure, increased by a factor representative of the entrepreneurial risk involved and an allowance for any corporation tax, would therefore be expected to apply to financial returns associated with the private sector. It has to be stated that the private market rate for equity in this country in particular is very high, major financial support for any large project being available mainly from Company pension funds who, together with the banks, demand a high return for their investors. Few companies or funds 'will invest at a level where their capital yields less than the current interest rate'. In this respect, 'it is interesting to note that the average annual rate of return on investments over the period 1977-88 in this country was no less than 24.8% while in the USA, West Germany and Japan the figures applicable were 15.6%, 14.3% and 7.6% respectively' (143).

David Hunt, the Parliamentary Undersecretary of State for the D of E (1984-87), reviewing the discussion of tidal energy assessment summarised at the ICE 1986 Symposium, considered that progress had been achieved in improving knowledge on tidal power 'during the last few years' and remarked on 'the commitment of the Government to tidal energy'. He went on to indicate that the 'next phase of work' presented an exciting opportunity to all in the field' to prove that tidal energy projects in the UK could be built to time and cost', 'to be environmentally acceptable' and 'economically viable'. He referred to the tidal projects at La Rance and at Annapolis and expressed the view that the success of 'these schemes showed that well planned tidal projects could be of significant benefit to the UK's energy economy'. 'The next two or three years will be a vital and challenging period to both the private and the public sectors in establishing the case for tidal energy in the UK' he asserted.

Other commentators took heart from Hunt's comments, in conjunction with the SBC and the initial STPG assessments, believing that tidal power was no longer in the doldrums in UK Government thinking and could come to fruition in the Severn estuary. Ruffard (159) was of the opinion that this country 'still retained an interest in tidal schemes' which, in his view, bore technical and economic comparison with the more conventional methods of generation. This attitude was strongly supported by Moore (160) and by others (157)(158).

5.1(d) The STPG Report and Companion Energy Paper 57.

In July 1986, the STPG published their long awaited report of the interim studies made on the estuary (161). The views of the group included the conclusion that the English Stones site might be more liable to progressive siltation than the Cardiff-Weston line which had in 1981 gained the support of the SBC. In confirming that a barrage on the Cardiff-Weston line was their preferred scheme, however, STPG stated that the rate of return available from the project was likely to be insufficient to attract private funding bearing the full risk of the project particularly when the power system into which the generating barrage would transfer its output was a publically funded body. Nevertheless, their view remained that, since the project would bring regional and non energy benefits in addition to the advantage of diversification of energy resources, further detailed work should be undertaken into barrage design and construction, possible environmental effects, regional aspects, and include a re-assessment of the economic viability of the project. Consideration would require to be given, the STPG Report went on, to a range of legal aspects, by the collection and collation of relevant data and, finally, the study would be expected to define what further assessments would be required in order to decide whether or not a barrage should be built. The Report also noted that 'due to the effects of the proposed privatisation of the Electricity Supply Industry, it was not considered appropriate to proceed with studies of the organisational and financial aspects at that time'.

The proposed 'further study' programme drawn up by the STPG was included in a Consultation Document which was issued for public assessment and comment in February 1987, the replies obtained to be used to review and to revise the programme of work. A further two year period of study and investigation ensued prior to the publication by the D of E of Energy Paper No 57 the 'Severn Barrage General Report' (162) which was in turn followed, during April 1990, by the five volume Detailed Report dealing with the subjects of Energy Capture and Plant Engineering, Physical Environmental Effects, Site Investigations and Civil Engineering, and with Nature Conservation Aspects and Regional Development Effects.

The executive summary of the General Report identified that the sixteen kilometre barrage would comprise a number of concrete caissons floated to site, after construction in local yards, and sunk into position. Alternative construction methods had also been studied, including the use of steel caissons and in situ construction. A dual carriageway would be provided across the barrage linking with the main road system on both English and Welsh shores. The power output from the sixteen kilometre barrage, generated by two hundred and sixteen, 40MW 9m runner diameter turbines and providing an annual energy output of some 17TWh, would be transformed and transmitted, via 400kV cables, from the barrage to two substations, one on each shore, and thence into the national grid system. The necessity for certain system reinforcement, at both 275 and 400kV, was also identified to cater for the very large but intermittent supply from the barrage. Locks capable of accepting the passage, at most states of the tide, of the largest ships trading into the ports enclosed within the basin were included in the scheme as were smaller locks suitable for the movement of inshore vessels. A barrage design life of 120 years had been assumed but it was accepted that, with adequate maintenance and plant replacement procedures, this life could be substantially extended. The construction programme envisaged a production and installation range of forty four turbine generators of bulb design per annum, with seven years to

closure of the barrage and first commercial electricity production from the 144 turbines then installed, with two further years to completion and full output. It is to be noted that included within the detail of the operational mode of the barrage, ebb generation with flood pumping was the preferred method.
The capital cost of the project, including the additional feasibility and environmental studies proposed, but not including the costs associated with the road across the barrage, was estimated at £8,280m. An additional £850m was also identified for the off-barrage connections and system reinforcement required (somewhat higher than this figure should additional undergrounding of connections be necessary - a further £380m was set aside for this purpose). The cross barrage road was estimated to cost upward of £200m. The annual costs associated with the operation of the barrage were estimated at £70m. The cost of electricity at the barrage boundary was assessed at 3.4p/kWh at 5% discount rate. It will have been noted that the estimated capital cost of the project had escalated from £5000m, as determined by the SBC and using 1980 prices, to £8280m in 1988 money terms. The effects of inflation on the project, together with the addition of larger ship locks than hitherto envisaged were identified as the main causes for the increase in costs. The report also drew attention to the revised generating capacity (from 7200MW to 8640MW) and the increased annual output (from 14TWh to 17TWh). On the basis that inflation over the period would account for an increase of around 20%, the cost of generation had increased only slightly over the period from around £938/kW to £958/kW installed, figures which compare not unfavourably, but purely in terms of £/kW installed, with the cost of nuclear generation. Accepting that the firm power delivered by the barrage would not be more than about 1000MW (163) this comparison is interesting but of little practical relevance.

The possible environmental effects of the proposed barrage were dealt with in some considerable detail, although the report prefaced its review by stating that 'the study was never intended to provide a complete environmental assessment' although 'the scope of work was probably as wide as any carried out on an estuary in Britain'. The report went on 'the work has reduced uncertainties but further assessment studies would be required'. The modelling undertaken had predicted that mean spring tide levels within the basin would be reduced by around half a metre, depending upon the degree of flood pumping required for generation purposes; while low tide levels would fall to about present mean sea level. Tidal currents within the basin area were expected to fall drastically as a result of the barrage but less significantly on the seaward side of the barrage. The sum total of the hydrodynamic changes would, it was believed, result in a major change in the transportation rate of sediment in the estuary, substantially reducing the level of sediment held in suspension and, as a result, reducing the turbidity in the region.

While the increase in water clarity due to the reduction in turbidity 'should lead to an increase in primary biological production in the estuary and thereby an increase in food supplies for the birds and fish', the Report believed that 'further studies, particularly of specific areas', were required to reduce uncertainties. Damage caused to fish and other species as a result of their passage through the turbines also remained an uncertain aspect which would require further assessment. The possibility of developing fish ladders or their equivalent to minimise fish damage was identified.

The work involved in rectifying any difficulties to land drainage created by changes in the water levels caused by the barrage was considered to be of a local nature and of minor cost. No less importantly the effect of a barrage on the sea defences of the region bounding the basin area was not considered to be of any significance and the measures necessary to deal with local problems were not anticipated to require other than minor additional expenditure.

The Report also commented that, in producing the anticipated output of 17TWh, annual fossil-fuel burn would be reduced by the equivalent of eight million tonnes, thereby reducing carbon dioxide emissions by some seventeen million tonnes annually. Barrage generation would not of itself create acid rain.

As previous reports dealing with the subject of a Severn barrage had done, the STPG document emphasised that the construction would create many jobs, both temporary and permanent and provide a major boost to the economy. It also affirmed that, in addition to certain other studies, mainly environmental and already outlined, possible options available for promotion and financing of the barrage would need to be addressed. It was accepted that this aspect could not be proceeded with until the results of the privatisation of the Electricity Supply Industry had been assessed.

5.1(e) The Assessment of Public Responses to Energy Paper 57

The publication of the Severn Barrage General Report and its five detailed volumes was followed by subsequent public debate and presentations to interested groups, local authorities and other private and public bodies in order that a period of consultation could take place as had previously been invited by John Wakeham, the 1989-92 Secretary of State for Energy. The detailed results of the consultation process were included in the Report (164) produced by the STPG in 1991 under contract as part of the D of E's Renewable Energy Research and Development programme and managed by the Energy Technology Support Unit (ETSU). More than three hundred responses were subsequently analysed, by the same body, the conclusions reached also being embodied in an ETSU Report (165).

The difficulties associated with any attempt to summarise, in as concise, objective and unbiased manner as possible, the mass of data included within the correspondence from subscribers to the Secretary of State's invitation to comment on the Report and its Appendices must be freely acknowledged. The problem is further exacerbated when the organisation responsible for the analysis is the one responsible for the initial data. Nevertheless, it is difficult to reconcile the many opinions and reservations on record with the simple conclusion reached by the STPG Report that 'on balance comments on the Reports are generally in favour of the project'. (207). For this reason, an individual assessment has been made of the many replies included in Ref 164; the results are included in the following paragraphs.

Major reservations were expressed by the Statutory National Public Authorities, with the Nature Conservancy Council (NCC) in particular being highly critical of the reports although it did welcome 'the intended continuation of ecological studies during the next stage of the environmental implications of the proposed barrage scheme'. (166). The NCC was concerned at apparent inconsistencies between sections of the general report (162) and the detailed report on the Implications for Nature Conservation (Volume IV). NCC believed that a misleading representation of the detailed findings were included in the general report, with 'examples of perceived benefits of the barrage scheme' being included 'while mentioning disadvantages only in the context of further work required'. In particular, it took to task the STPG view that 'the work to date has not identified environmental changes ..... which could not be countered by various means'. The NCC view was that the Severn estuary 'was of particular conservation importance because of its hypertidal character and the associated unusual flora and fauna ..... . If a barrage were to be built the loss of this attribute could not be countered by any conceivable engineering means'. The NCC considered that it was 'perhaps not surprising' that the 'report makes no attempt at explaining how this major effect would be ameliorated'. The Council were equally concerned with the problem of protecting fish and carideans during their passage through the barrage and which, they believed, the Report had dealt with in a superficial manner. Obviously the 'slant' of the detailed Report of Environmental and Regional effects of the Barrage also annoyed the NCC. Taking as an example the second paragraph of the Introduction of this document which begins 'The Severn estuary, with its very large tidal range, is a severe example of this characteristically stressed system', they had the opinion that, perhaps not deliberately but certainly by implication, the report had set out to suggest that any change reducing the 'stress' was of positive advantage to the region and to nature conservation itself. In contradiction of that view, the NCC believed that the large tidal range was 'a prime feature of nature conservation importance and responsible for the unique ecosystem of the estuary'. Further, examples of the report's 'slant' were identified. 'The work on environmental issues ..... has resulted in the identification of some positive benefits' according to the Report - the 'disbenefits should also have been equally positively recorded' according to NCC. No less importantly, the Report states that 'future work for the benefit of the project .....' but, as noted by the NCC 'future work may NOT be for the ultimate benefit .....'. It could therefore be construed, said NCC, that any future work intended by the STPG could be designed specifically to ensure that 'only the benefits are identified'.

The NCC also believed that the reduction of the large tidal range of the Severn imposed by a barrage should have been particularly emphasised in the STPG Report, suggesting that a paragraph identifying that 'the loss of the largest tidal range in Britain and the second largest in the world (sic) must be seen as a significant reduction of the nature conservation resource of Great Britain'. 'Before the construction of a barrage is firmly promoted and approved, proper consideration must be given to this particular change to the present environment'. The loss of the Severn 'bore', which would result from any barrage across the Severn, appears not to have been considered by NCC.

The environmental and ecological groups were, perhaps understandably, and with the exception of the Severnside Green Party, universally critical of the STPG's proposals. The detail of the criticisms, however, varied widely. For example, the Bristol Ornithological Club, via their Chairman, expressed their view of 'the difficulties caused by the short deadline for comment and the apparent reluctance of the Energy department, ETSU and STPG to provide (additional) copies to interested parties. 'A project of this magnitude' their letter asserted, 'surely required more open-handed communication with as many parties as possible than it has received so far'. (In fact, as stated earlier; apart from the invitation from John Wakeham to the general public that they examine and, if possible, comment on the STPG proposals, presentations were also made at a number of schools and libraries, while the attention of some four hundred companies, organisations and individuals whose interests lay on or around the Severn estuary was drawn, by letter, to the existence of the STPG Report. Although no reply to the summary sheets was specifically requested, more than three hundred replies were received).

Like other bodies critical of the barrage proposals, the Bristol Ornithological Club stressed 'the overriding impact of the barrage scheme on the estuary and the effect on the unique bird populations of the area'. The barrage would 'irretrievably alter the nature of the estuary - a wetland which this government has commendably pledged the UK to maintain in its present entirety under the RAMSAR Convention'.*

The Councils for the Protection of Rural England and Rural Wales cojoined (168) in producing their comments on the STPG Report, believing that development pressures on their regions, caused by the existence of a barrage, 'would be equal to or even exceed those associated with construction of the barrage itself'. They were of the opinion that the proposed dual carriageway, to be built across the barrage, would induce 'greater regional development pressures' due to development along the road network. It is also apparent from the contents of their letter, that not only were the Councils concerned with possible commercial pressures induced by the barrage and its carriageway, but also by the possibility of encroachment 'along the banks of the Severn and generally' of tourism and leisure development, 'all of which will have a considerable potential impact on the surrounding countryside' - whether for the good or otherwise is not made clear although the implications are there.

The response to the Report, provided by the Friends of the Earth (FoE), although critical in general terms (169) was, perhaps surprisingly, low-key, and welcoming 'the research which had so far been undertaken' and applauding the further investigations proposed. They were nevertheless anxious to see other studies undertaken, such as the 'quantification of pathogens, persistent chemicals and radionuclides, the effect of sediment contamination on species composition, on the food chain and bio-accumulation', and also a detailed study

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* A convention on the subject of 'The Wetlands of International Importance especially as Wildfowl Habitats' was held at RAMSAR in Iran in 1971, which designated sites coming under the definition. Hence 'RAMSAR' site. A further 'International Conference on the Conservation of Wetlands and Waterfowl was held at Heilingenhafen in Germany in 1974 which set down criteria for sites of international importance. For example, a site which supports more than 20,000 waders is an internationally important one.

of sediment movement and changes in Bridgewater Bay. FoE endorsed the recommendations for additional work to be undertaken on fish migration, commenting that the 'Severn has a higher diversity of migratory fish than any other British estuary'. 'Studies of migration routes and numbers, the qualitative and quantitive effects of hydrodynamics, water quality (including algal blooms), salinity and sediment changes .....' were also proposed, adding that the normal minimum period for such studies would be five years' (sic). FoE concurred with the views previously identified (166) of the NCC in requesting an investigation into fish damage due to turbine passage and argued for studies to be undertaken on 'all the Severn's migratory fish species, nursery fish and invertebrates to determine what damage, if any, is caused by generating, sluicing and pumping'. No time scale was included for these studies! In its conclusions, the letter from the FoE argued that 'the estuary as it is has an intrinsic value and a right to exist'. Construction of a barrage would destroy the unique character of the estuary 'which would be an absolute loss'. In its single technical comment, FoE believed that the energy cost of construction of a Severn barrage should be evaluated; energy conservation being the main thrust of their engineering opposition. This aspect was also identified in the submission of the Royal Society for the Protection of Birds (RSPB) to STPG (169) who believed there to be 'a distinct lack of any national overview or rationale to national energy policy'. The development of a national strategy was, in their view, vital in allowing 'individual energy projects to be placed in context and their relative environmental impacts properly weighed' before reaching a decision. The body responsible for such analysis, the weighting processes to be applied and the myriad of other points of assessment which would need to be undertaken were not identified. In concluding their detailed comments on the contents of Energy Paper 57 (162), RSPB underlined their view that they remained 'fundamentally opposed to the concept of the Severn barrage and its consequent impact on an estuary of international value'. They believed that the work which had been undertaken 'failed to predict adequately the quality of the post-barrage environment' and that should the 'ill-judged' proposal be proceeded with, 'much further work' would be required.

The Severn Estuary Conservation Group (SECG) (170) was no less anxious to present its credentials - 'formed in 1976 from sixteen national and local organisations with the object of the conservation of the Severn estuary and its flora and fauna for the advancement of science and for the education and benefit of the public' in arguing against many of the views recorded in the STPG Report. Its overall attitude to the report was very much in line with that of other similarly minded bodies, i.e. that the over simplification of approach to environmental aspects used in the report led to optimistic solutions to the problems identified. The SECG also identified their attitude to the assumption of continued escalation in energy demand and of the necessity to cater for it which, they believed, should be dealt with by 'taking an end-use approach to energy management', and devoting the same degree of commitment and finance to energy conservation as 'to novel methods of generation and to expanding energy production', which 'inevitably is at the expense of the natural environment'.

The submission of the Severnside Green Party (SGP - a consortium formed from twenty local Green parties in Gloucestershire, Avon and Somerset) to STPG in July 1990 (171) was in itself a document of considerable size and technical complexity, giving consideration to the present electrical generation resources, present and future anticipated demand for electricity and the impact of renewables on scenarios based on zero and on a little over two per cent annual growth. SGP believed that green environmentally friendly policies should wherever possible, be based upon the principle that 'small is beautiful' and keeping 'a community (sic) self-sufficient in its needs including the need for energy', both principles of course being breached by the construction and operation of a Severn barrage and by its own submission. Nevertheless, SGP concluded that a barrage should be constructed, but not until more experience had been gained by building and commissioning the Mersey barrage (sic). [In passing, it is of concern to note that other commentators, of greater experience and understanding than Dummett (the author of the Severnside paper), including Headland and contributors to his IEE paper (43), had also suggested that small barrages could be constructed as models for larger schemes. Indeed, the La Rance project was, in all probability, constructed as a model for the much larger Chansey Islands scheme (172). Shaw (173) had, however, concluded that 'the environment of each estuary is unique'. 'Whereas the results from both (La Rance and Annapolis schemes) are instructive as to the changes which can occur' he said, 'there is no case for anticipating that either is likely to be more than broadly indicative of the consequences of a barrage in the Severn or in any other estuary'. 'In fact, the Rance barrage could give a particularly misleading impression of the environmental effects of this type of project'.

The SGP Report includes the conclusion that the financial incentive to build (a barrage) 'should reflect the true cost of saving fuel' and that 'the price of coal, oil and natural gas should be progressively raised through the tax system'. Whether this conclusion was expressed with a view to increasing the cost of electricity generated by fossil-fired stations or to reducing the fuel burn at such stations is not clear; in any event, the relationship of nuclear produced electricity to the Severnside argument is not identified.

Both the Somerset Trust for Nature Conservation (STNC) (175) and the Wild Fowl and Wetlands Trust (WFWT) (176) emphasised in particular the loss of intertidal mudflats and saltmarsh in the event of a barrage being constructed. In their submission the WFWT argued, as had others, that the Severn was a unique natural system and because it would interfere with the tidal process, a barrage would inevitably destroy that system. The suggestion that the 'barrage could enhance some aspects of interest for nature conservationists was no compensation for loss of others'. The requirements of the Ramsar Convention would be breached by construction of the barrage since the 'ecological character' of the estuary would be destroyed, this being 'unprecedented in the history of the convention'. The STNC were more pragmatic in their approach to the contents of the STPG Report, despite identifying 'impact', 'irresponsibility' and 'intrusion' in the proposals, while proposing additional topics for further research (in particular pertaining to the road crossing of the barrage).

The attitude expressed by the Country Landowners Association (CLA) (177) was more pecuniary in its response to the STPG approach. While noting that, both during and after barrage construction, the movement of migratory fish would be affected, the CLA 'would be looking for compensation for any damage to fisheries especially upstream of the barrage'. Moreover, the Association urged that 'realistic financial provision be made for any pumping, dredging or other costs to safeguard landowners' and farmers' interests both during and subsequent to barrage construction'. Any proposals (for compensation) 'must be fair and equitable to both freeholder and leaseholder'. Their only 'environmental' comment included was that 'sufficient consideration must be given to the effect which construction of the barrage will have on agricultural land'.

The Salmon and Trout Association (STA) 178 were no less pedantic in defending their particular interests - 'wish to lodge a formal objection to the Barrage proposals, purely on fishery grounds ...'. 'It would appear that the proposals have not taken (into account) not only the financial value but also the employment and sporting/leisure value'. Greater investigation into the effects of the barrage on salmon species was required ..... 'to prevent them coming into contact with the turbines'.

The necessity for a comprehensive environmental study of the Severn estuary and its surrounding wetlands was recognised by the South Western Council for Sport and Recreation (SWCSR) (178), while the impact of all types of recreational activity within the region was an aspect which needed to be taken into account also. A plea for a detailed plan, integrating the planning, design and management aspects for the area to minimise the possibility of conflict between environmental and recreational interests was lodged.

The South West Region Sports Council (SWRSC) (179) believed that it was misleading to add any discussion of possible tourism impact on the area to that of recreational considerations, since the region of the barrage zone was already - without a barrage - well established as a considerable recreation resource. High and sustained water quality was considered to be an important requirement, not only as an environmental necessity, but also as a result of its direct bearing on the popularity of the area as a recreational resource. The SWRSC letter took the opportunity to endorse the views of others concerning possible difficulties with fisheries and on migratory fish stocks.

The Sports Council for Wales (SCW) (180) welcomed the STPG report, at least in principle, believing that the barrage would 'create a vast inland lake to provide new opportunities for sport and physical recreation which have hitherto been unavailable owing to the tidal regime and inaccessible environment'.

'Twenty three million people will live within three hours' driving' of the region. The lack of definition of the terms 'leisure', 'tourism', 'recreation' and 'sport' was remarked upon, each term relating to different types of people and forms of activity. Again, the necessity for high water quality in respect to fishing and to any recreational activity was stressed and the necessity for early stage management planning of opportunities for motorised activities such as water skiing and power boating emphasised. It was also accepted as inevitable that residents already local to the proposed barrage and its basin, and presumably enjoying the present state of the estuary and its environment, could well object to the STPG proposals in view of the greater influx of tourists, and others seeking to participate in the new leisure and recreational facilities.
The Welsh Tourist Board (WTB) (181) felt that the development of the Barrage project warranted further study, while the Welsh Federation of Coarse Anglers (WFCA) (182) fully supported its construction, its only reservation being possible damage to fish passing 'in both directions through the turbines...'. An interesting and obviously controversial comment from this Federation argued that 'the objection ... by the enthusiasts of ... bird watching is based on deeply-flawed information'. Their letter considered that 'There should be a complete re-appraisal of shoreline bird species' populations and distribution, using an impartial research team'. '.... the source of information of the original study is wholly unreliable'. An equally controversial topic was included in the recommendations put forward by this body. Under item 7.5 of their letter, 'justification of the recreational pastime of shooting wild birds .... by a few score of individuals .... many acres of foreshore per person in a conurbation around the Severn estuary of one million people has to be proved'. The letter from Associated British Ports (ABP) (183) expressed its concern that emphasis of the STPG Report centred, obviously too strongly for the liking

of the Ports Authority, on 'the ecological impact (of the barrage) with less attention paid to the effect on ports and their operations'. The letter pointed out that 'a high cost dredging regime can render a port unviable and hence ABP must reserve proper comments until extensive research has been undertaken'. The submission by the Severn Estuary Ports (SEP) (184) confirmed their view that the work undertaken and reported upon by STPG was unlikely to lead to an early decision on the building of the barrage. 'The atmosphere of uncertainty will persist', the Ports believed, and a 'pronouncement from the Minister responsible', John Wakeham, was urgently required to remove marketing difficulties being experienced by the ports as a result of possible barrage construction. The question of 'who pays for movement of vessels through the barrage' was, in the Ports' view, included in the barrage running costs. On the other hand the Detailed Report (Volume 5) dealing with this aspect had included the suggestion that 'it would not be unreasonable for shipping to make a contribution in recognition of the improved tidal regime'. The shipping community regarded <u>any</u> possibility of a transit payment as 'adding insult to injury' since the presence of a lock between sea and berth was itself a 'major encumbrance'. The Ports authority considered that the ownership of the barrage and the responsibility for controlling development of the impounded basin area posed fundamental questions which required answers; they were equally adamant that such aspects 'should not fall under the control of a third party independent of port operations'.

Welsh Water (WW) (185) 'welcomed this exciting initiative to generate non-fossil fuel energy ..... bringing the prospect of overall growth to the Region'. Nevertheless, they emphasised that the costs associated with interference to their own responsibilities, such as additional treatment plant and pumping costs, would 'need to be borne by the promoters of the barrage'. They identified, for example, the proximity of a recently constructed outfall to Lavernock Point which could require relocation thereby drawing 'substantial one-off and recurring costs to the promoters'.

Wessex Water (WXW) (186) were no less supportive of the project but believed that the effects of the barrage 'on discharges and sewage effluent made by Wessex Water into the Severn estuary had not been adequately addressed'. They were also very anxious to ensure that their customers did not 'bear any unnecessary increases in water charges' caused by any barrage development.

Companies with interests bordering on the Severn estuary broadly accepted the STPG barrage proposals, the majority commenting on the necessity to take account of environmental issues. Typical of the views expressed were 'would support the concept, as developed so far, since it would appear to produce a major asset by the creation of a unique water amenity' (ASW) (187) and 'a significant, welcome and desirable boost to the economy of South Wales and the English side of the estuary' according to Burley House (BH) (188). The Bristol Initiative (BI) (189) saw the 'vital and imaginative proposals not only as a highly visible contribution to future energy problems' (sic) but also as a 'golden opportunity to enhance the whole environment of the Severn estuary'. The BH Group (188) were 'positively delighted' by the possibility of better road facilities offered by the barrage construction. Road building across the Cardiff-Weston line was, however, viewed with some caution by Brain and Co (B) (190) who believed that the additional road links necessary could have a damaging effect on the Penarth, Sully and Barry regions which could be avoided by the construction of a shorter barrage and road link nearer to the present Severn road bridge. Chem Bank (CB) (191) reinforced the necessity for additional communications, in the form of a second crossing between Wales and England, believing that a great deal of business had already been lost to Wales due to problems caused by the present Severn bridge. It was only 'unfortunate that it (a new crossing) is going to take fourteen years to happen....'. The CBI (192), while supporting the project in principle in view of its 'probable considerable economic benefits for the regions', were concerned by 'the absence of financial information', 'a detailed business plan' and a firm indication that the 'power generated would be taken up at a fair market price'. The Dale Owen Consultancy (DOC) confirmed its enthusiasm for the project (193), believing that the economic benefits which would accrue to Wales and the South West of England could help to offset the 'tilt which 1992 and the Channel Tunnel would inevitably bring to the South East'. Urgency in completing all additional studies was requested; in addition, the raising of the barrage link road to full motorway standard was considered 'essential to ensure maximum economic and commercial benefit'.

While the Cardiff Chamber of Commerce (CCC) commented on the 'staggering proposed cost' and 'the necessity to check the arithmetic very carefully' (194), the Newport and Gwent Chamber of Commerce (NGCC) (195) considered the 'costs as portrayed were reasonable' particularly 'when taken against the cost of Nuclear Power Stations, with the extended expenditure on close down after the short life span of 20/25 years'. The Wales TUC (196) declared its whole support of the project, believing that it would 'considerably benefit the economy of South Wales'. The South West Regional Council of the TUC (SWRTUC) also welcomed and supported the main conclusions of the STPG Report (197). They were anxious 'that further work should be encouraged', accepting that there was a need 'to complete studies leading up to an environmental statement ...'. Moreover, the body believed that 'an arrangement should be established' to bring together all those with a particular interest in the project to 'share information and to discuss potential future developments'. Study of the impact of the construction and operation of a barrage on the economy of industrial South Wales and on the rest of Wales was urged by the Welsh Committee for Economic and Industrial Affairs (WCEIA) (198), who declared that 'no doubt others will be pressing the need for an environmental impact study and similar work'.

In this latter respect, perhaps the most comprehensive review of the Report and its Appendices was made by the National Rivers Authority (NRA) (199). In it, the NRA 'broadly welcomed' the results of the research reported, commenting that the Severn estuary was now 'probably the best studied estuary in the UK'. It also 'broadly accepted' the conclusions which had been reached by the STPG. However, from a detailed analysis of the views put forward by the NRA, it becomes apparent that their recognition of 'broad' acceptance was in fact strictly limited, with much additional information, on many aspects, being required 'in order that (the NRA) may be satisfied that the construction and operation of the barrage will have no unacceptable adverse effects on any of its statutory responsibilities'. The NRA admitted that many of the necessary investigations 'will be difficult to undertake and may be innovative at the threshold of intellectual and technical capability .... with a significant input of resources to provide the necessary information'. 'Any remedial works consequent upon a decision to proceed (with barrage construction) were to be borne by the promoters of the barrage'. If this financial arrangement was not agreed the NRA would 'have no option but to oppose' the development. Further, unless the impacts of the barrage on migratory and estuarine fish stocks and fisheries and on the ecosystem of the hypertidal estuary were resolved, 'the NRA would oppose the barrage proposals'. It was again pointed out that the intertidal area of the estuary was designated an SSSI (of special scenic and scientific interest) and that the entire estuary had been proposed as a Ramsar site. A particular NRA concern was the possible damage to fish during their passage through turbines. Observations at the La Rance project had suggested that such problems had a low order of probability but the Authority 'believed that the data should be treated cautiously'. The NRA considered that there was a need to complement experimental studies 'with field experiments at La Rance, under differing operating conditions and using the fish species relevant to the Severn, particularly salmon and shad'. 'The apparently high risk of damage ..... when turbines are sluicing and pumping remains a substantial obstacle to NRA acceptance ..... and must be resolved'. Numerous additional proposals for further work were identified by the NRA as a result of the deficiencies which, they believed, arose from the STPG proposed programme of future work. For example, NRA considered it essential to review many of the areas impinging on water quality such as hydrodynamics and sedimentology, the effect of reduced tidal levels on farm drainage and water disposal schemes and the implication on effluent disposal in Swansea Bay of circulation patterns which might evolve as a result of the barrage. NRA believed that the sediment issue, already identified as a problem area by other investigators, required to be examined in further detail, particularly in respect of the changed capacity of sediments to absorb contaminants and the subsequent effect on possible public health and ecological patterns. The redistribution of sediments subsequent to barrage construction was considered to require additional studies in respect of possible effects on outfall performance, on fisheries' interests and on present and future recreational sites. Better information on the survival times of bacteria and viruses following barrage construction was considered to be essential, with a prediction of probably microbiological quality at existing and new recreational sites requiring to be undertaken. The public health aspects of water quality changes caused, for example, by discharges known to contain contaminants and, by saline intrusion needed to be assessed. NRA believed that 'major programmes of work remained to deal with the problem of water quality'; these could 'be resolved provided that adequate resources were made available'. Despite the fact that the STPG Report had identified no problems with ground water rise due to barrage construction, the NRA considered that flood defence issues needed to be addressed, listing a number of investigations which were necessary to satisfy the Authority. It considered that the effects of global warming, although not specifically dealt with by the Report, were 'likely to affect regions of concern to the NRA no less than the barrage construction itself'.

Previous paragraphs have considered the plethora of views received by STPG from the numerous organisations which had requested a sight of the Report and its Appendices. Although, as would be anticipated, (and has been noted here), many of the comments received were biased, almost inevitably, toward their specific speciality, by the bodies concerned, and by NIMBY attitudes, it is apparent from the depth and detail of the majority of replies that the D of E documents had received very fair consideration. In marked contrast to this appreciation, what can only be described as a paltry, even derisory, response was made by the South Wales Institute of Engineers (SWIE) (200) following the presentation by Dr. Tom Shaw of the contents of the Severn barrage Report. Thus, (reported their Secretary), the 'Council of the Institute on 11 April decided to address to you a written response to Energy Paper No. 57 to the effect that it offers general support for a tidal power project in the Severn estuary'. The guarded reply received from the then South Western Electricity Board (SWEB) confirmed its 'broad' welcome for the Severn barrage but believed that the 'scope, cost and potential benefits are so great that the impetus to make the scheme a reality could only come from national or supra-national agencies' (201).

Despite, or perhaps because of, copious reports produced as part of the reply by the Standing Conference of Severnside Local Authorities (SCOSLA) (202), it is difficult to draw an absolute conclusion in respect of their views concerning the Severn barrage. A consensus view could be drawn that the project was welcomed, in spite of many identified reservations, by all but one of the authorities represented. Stroud Council (SC), the single objector, 'did not support the principle' of a barrage, especially in view of the 'potential disadvantages to the District and estuary upstream of the barrage'. The Council also believed that 'energy conservation .... far outweighed the benefits of an electricity generating barrage' and at 'far less cost than the £8000m cost of the barrage'. (203). (It is of interest to note from Page 3 of the relevant minutes of SCOSLA that the contents of the Stroud letter were merely to 'be noted and referred back for discussion pending further information'.!)

The financial and legal implications of the construction were of particular concern to the cities of Cardiff (204) and Bristol (205) and to the County of Avon (206) which, they believed, should be better identified and with the 'clear establishment that no financial burden, either direct or indirect, would fall upon local authorities as a result of the barrage'. The possible effects of the barrage on the working of their respective ports was also an obvious issue of prime importance to these Authorities. Bristol, however, considered that the main problem 'overshadowing all others' was the 'spectre of uncertainty'. Referring initially to the Bondi Report of 1981, in which 'a working barrage was seen as fifteen years ahead', the City complained that 'it is still no nearer'. The effect of such uncertainty was imposing 'a constraint on the ports and on future planning in the broadest sense'. Delays were seen as tending 'to invalidate the results of previous investigations' and it was 'therefore imperative that the Government should now be invited to move the project forward with momentum or not at all'.

5.1(f) Conclusions Drawn From The Public Responses.

A survey of the comments summarised in earlier paragraphs indicates that one submission only, that of the Bristol Initiative (a business leadership established under the auspices of the CBI) supports unequivocally the barrage project proposed in Energy Paper 57. 'We would urge the Government to do everything in its power to enable early achievement of the development', it states. Environmental bodies, perhaps with the surprising exception of the Severnside Green Party, were generally critical of the proposals, as were those other organisations who saw their responsibilities for flora and fauna under threat as a result of barrage construction and operation.

The majority of the remaining authorities, i.e. those with local or national statutory responsibilities or with industrial, commercial and labour interests, even those concerned with leisure activities in the area likely to be affected by the barrage in the short and longer term merely expressed 'support in principle', 'welcomed the progress', 'noted the preliminary results', 'looked forward to new information' and to 'further open discussion'. This cautious 'support' was supplemented by additional provisions and requirements sufficient to make, in many cases, even their meagre acceptance meaningless. The response of the National Rivers Authority is a case in point. On the surface, its 'broad' acceptance of the conclusions reached by the Report is stated but beneath that assertion lies a plethora of research demands which the NRA itself accepted 'will be difficult to undertake and may be innovative and at the thresholds of intellectual and technical ability'. 'Major and lengthy' programmes of investigation 'thought to be capable of resolution' and 'provided (that) adequate resources are made available, are identified for water quality assessment, while 'very significant problems' require resolution in respect of fish and fisheries. The NRA were especially 'keen to ensure that the D of E and STPG did not underestimate the complexity of the mathematical modelling required to adequately forecast the physio-chemical and biological effects of the barrage'. The many man-years of study necessary to satisfy such demands must be obvious - many of the investigations could themselves bring forward other interesting and time absorbing fields of research and examination. Overhanging the evaluation of these many issues lay the implied 'threat' that, should the matters not be resolved to the satisfaction of the NRA, that body would have 'no option but to oppose the (barrage) development'.

One senses, from many of the heavily qualified replies, a desire to 'sit round the table', to 'keep a finger in the pie', to 'defend their own corner' and to maintain at least some involvement, perhaps as a right, to keep a watching brief on the progress of a very large and costly project. But certainly not to have any responsibility for carrying it out or to become financially involved in any way. Perhaps the most important response came from the City of Bristol who, as quoted earlier, insisted that 'it was imperative that the Government .... move the project forward with momentum or not at all'. The French had displayed similar feelings of frustration in the very early days of Channel Tunnel negotiations - 'Cesson d'écrire des articles ..... creusons le sol avec des machines puissantes - AGISSONS!' ('Stop writing - start digging - ACTION!') (207).

5.1(g) Comparison of Conclusion Drawn with STPG views.

The detailed assessment of the replies received during the consultation process associated with Energy Paper 57 strongly suggests that the main conclusion drawn by the STPG - 'on balance, comments were in favour of the project' was more than a little too optimistic and, not unnaturally, biased in favour of their own project. It is acknowledged that the STPG may have had access to information not contained in Ref (164); nevertheless, it must be the conclusion of this dissertation that the best that can be drawn from the available data is that in practical terms, an outright 'NO' to the project came from those bodies expected to veto the construction of a barrage, i.e. the environmental groups. Or, perhaps a little more graciously, the conclusion which had been reached, some years previously, by Sacks (147) in respect of the SBC 1981 Report 'yes BUT ...!' could still apply.

5.1(h) The Third ICE Conference on Tidal Power -1989.

Clare, opening the Third Conference on Tidal Power at the Institution of Civil Engineers in 1989 (209) confirmed that, as a result of the public consultation process, adjustments had been made to the original STPG programme of future work and that additional ecological studies had already been commissioned. He referred particularly to the findings of the earlier geological survey and to their influence on barrage alignment - an aspect reviewed in one of the numerous Department of Energy bulletins issued on the Severn barrage project (210) and discussed in much greater detail by Kerr et al (211) (212).

Of possibly greater interest than Clare's technical appraisal of the future for a Severn barrage is a comparison of the conclusions drawn by him in his 1986 paper with those included in his 1989 assessment of the position. Gone is the positive, optimistic, 1986 view that the 'STPG remain convinced that in the Severn Estuary there is a major source of renewable energy that should be developed to the benefit of UK Ltd. ...' (213); the 1989 summary merely reiterates the (old) fact that 'The barrage is technically feasible, would produce 7% of the present electricity consumption of England and Wales ....'. (214). In their Paper to the 1989 ICE Symposium, Petty and MacDonald (215) examined whether Kapeller (adjustable runner - single regulated) or Kaplan (adjustable runner and guide vanes - double regulated) turbines should be installed in the Severn barrage, based on the fact that they would be required to operate over a variety of tidal ranges from neap to spring and over a single tide. On the basis of maximum energy recovery, it had been evaluated that no less than 86% of the annual energy would be generated over the 4-8 metre range of tide which, 'on present day technology and economics' determines that turbines should be single regulated direct driven bulb machines'. The design details associated with the bulb generator identify modifications which would be necessary to increase its known low inertia constant (a factor reflecting the ability of a generator to maintain synchronism following a severe power system fault) of a conventional bulb machine (around 1MW.sec/MVA) to one more appropriate to its connection to the barrage transmission system. More significantly, the report confirmed that, '.... as it may be several years before the final design phase, the (final) choice should be re-evaluated at that time'. The report, surprisingly perhaps, makes no mention of the use of the turbine for flood pumping, although mention is made of the fact that the Kaplan double regulated machine 'recovers some $2^1/_2$% more energy that the Kapeller machine' when operated in a total '216 machine scheme with ebb generation and flood pumping'. The paper by Goldwag and Potts (216) to the same conference supports the application of the Kapeller machine to the Severn barrage on the basis that the extra two and a half per cent more energy obtained from the Kaplan design is more than offset by its cost. In confirming its preferred operating regime for the Severn machines, i.e. ebb generation and flood pumping, the paper recalls that, although the La Rance double regulation bulb sets were intended for all four modes of operation, only ebb generation and flood pumping are now used. The benefit of flood pumping was variously assessed, using different models, to lie between 3.7% and 11.2% with 216 machines being brought on stream sequentially, prior to equalisation of water levels at the barrage. The report also indicates, surprisingly, that the 216 machines envisaged for the barrage would utilise only some 54% of the energy potential of the impounded basin. In order to achieve a higher percentage retrieval, the installed capacity would have to be substantially increased; moreover , it would be necessary 'to limit generation to a short period of time around low tide when available heads would be at their highest'.

In an interesting paper to the ICE Conference, Kirby (217) considered one of the most important aspects identified during the consultation process; that of sediment regimes and associated ecosystems and the extent to which physical processes (waves and currents) control them. He argued that, as a result of its hypertidal (mean tidal range greater than six metres) range, the Severn will exhibit quite different problems from those likely to occur from barrage construction on either the Mersey or the Humber (both macrotidal - i.e. less than six metres). In particular, he identified (as he had done in his 1986 paper) (140) the instability of the Severn's sediment and the fact that the extremely high suspended load it sustains are in marked contrast to other estuaries. Kirby was of the opinion that construction of a barrage may cause changes in the sedimentary regime, particularly in the medium or longer term, which would in turn have radical effects on land drainage, coastal defences and other man made structures. In emphasising the possibility of such changes, he argued the necessity for special and accurate modelling techniques, together with an adequate understanding of sediment strengths and their erosion potential. Shaw identified and discussed the results of the numerous environmental studies made of the Severn estuary during the 1987-9 period (218). He emphasised the necessity to continue to study the estuary by both modelling its principal features and also by studying 'other similar estuarine systems'. Many of his comments regarding sediment regimes, including turbidity, movement and erosion were in close accord with those due to Kirby. He argued for the incorporation, in any barrage, of suitable fish pass facilities since a review of the provisions made of low head hydro schemes 'had not clarified fundamental questions regarding the actual risk to fish, according to species and size, of passage through the turbines. It was believed that the effects of a barrage on the environment need not necessarily be damaging although some change would be inevitable'. A list of further studies was included but Shaw concluded that 'this short list of priority studies must not be taken to suggest that causes for environmental concern are now regarded as minimal' '.... recent ... studies appear to have given confidence in the likely outcome of further priority work'.

A further paper to the ICE symposium by Moon (219) provides a new and interesting local authorities' view of the Severn barrage. For example, it confirmed that the Standing Conference of Severnside Local Authorities (SCOSLA) 'was formed to bring pressure to bear on the government to make a decision on the recommendations of the Bondi Committee'. Their co-operation with the Department of Energy and the STPG through the years was recorded in the Report but it was also to be noted that, despite their continuing interest, 'the local authorities in SCOSLA have never at any time committed themselves to unequivocal support of the barrage project'. Nevertheless, SCOSLA had 'demonstrated enthusiasm for the completion of all the necessary studies so that Government and others can take a decision on whether a barrage should be constructed'. Moon identified many legal and other issues of concern to the local authorities, accepting that 'it has not been appropriate to discuss these issues so far but they are matters which will require thought and discussion before any legislation is introduced in Parliament'. He also believed that public participation in any barrage decisions was important, arguing that 'the situation which prevailed in the last century when an extensive rail network was constructed throughout the country relying simply on private act powers is not seen as appropriate to the present day'. Moreover, he visualised that 'people in all parts of the country ........ will be interested in the barrage ... should have an opportunity of expressing their point of view'. A local paper had spearheaded the campaign for more consultation (220) claiming that 'a major public inquiry .... would be a great thing to have on a scheme of this size'. 'It's really the only time that a whole mass of detail could be brought together and a proper judgement made'. (sic). On the other hand, the STPG had previously argued (161) that, if the scheme was to attract private funding, there could be no question of a full scale Public Inquiry since that 'could introduce even more delay and increase the financial burden even further'. STPG had therefore proposed that the 'well proven procedure of a Private Bill' be adopted. To date, however, there has been no official public assessment of the STPG barrage proposals other than the (public) consultation process previously referred to. As noted later in this dissertation, there has, however, been significant discussion with the House of Commons Select Committee on (Renewable) Energy.

5.1(j) A Comment On The Hooker Proposals

It will have been noted that, despite the concentration of activity at the Cardiff-Weston line, the literature continued to include reference to work undertaken in the region of English Stones. The Autumn 1990 edition of NATTA (Network for Alternative Technology and Technology Assessment) (221) contained a short note concerning studies, ongoing under the auspices of Wimpey Atkins, at English Stones, which indicated that 'more recent studies have suggested that siltation could be cut by up to seventy five per cent if water intake is via high level sluices'. 'Further studies are underway'.

In examining the background to this continuing interest in English Stones, an interesting insight into a possible reason for the inclusion, in early 1985, of Wimpey Major Projects in the STPG Consortium has been obtained, which is worthy of inclusion here.

During 1970, A.V. Hooker of W.S. Atkins and Partners, introduced his views of 'Severnside of the Future' (307), including a barrage/road crossing of the Severn. The scheme, based on English Stones, re-emerged in 1977 and was assessed, with others, by the Bondi Committee who decided in favour of the Cardiff-Weston line. Hooker persisted with his scheme, describing it at a Weston Conference on Tidal Power in 1982 (273), emphasising its better chance of obtaining private capital and in particular the provision of a road of motorway standard across the Severn (at a cost of £50m) which he considered to be of greater interest than the power output. In November 1983 the project was taken up by a Consortium comprising Wimpey Major Projects, W.S. Atkins and Partners and Westminster Bank, which applied for 'Prefeasibility Studies to be undertaken for the alternative, less ambitious, tidal barrage scheme to be located a few miles downstream of the existing

Severn Bridge'. No further action appears to have been taken on the proposal, but, in early 1985, Wimpey Major Projects, representing the Consortium, joined STPG.

5.1(k) The Attitude of The (Renewable) Energy Select Committee to STPG Proposals.

It is interesting to study the exchanges between members of the all-party Select Committee on Energy (Renewable Energy) and STPG which was reported in November 91. (222). A memorandum from STPG to the Committee dated 29 August 91, which formed the basis of discussion, confirmed that since the publication of EP57 (162) 'additional small parcels of priority work' had been put in hand. It noted also that Government funding for the project had, to date, totalled £6.48m. The memorandum went on, 'the STPG had reported that the project cannot be funded in the private sector without some Government support' and pointing out that 'the substantial non-energy national and regional benefits would not accrue to the private developers of the barrage'. Moreover, the memorandum asserted, the considerable up-front pre-construction and legal costs, in excess of £200m would, without commitment by Government 'to act as guarantor of last resort', be regarded as 'too high a risk to be funded in the private sector'. In his response to the request from Dr. Michael Clark, the Committee Chairman's request that the barrage capital and annual running costs be updated, Clare, Chairman of the STPG Management Board, indicated that the best estimates at September 91 were £10.2 billion and £86m respectively, an increase of some 24% over the 1988 figures. Mr. Lofthouse, a member of the Select Committee exploded 'you are telling us about these studies, studies, studies; you must have shoals and shoals of paper. When are we going to get some movement?' (incidentally supporting the view held by the writer (223)). 'What do you foresee the time period to be before the studies stop and we start getting some action ....' questioned Lofthouse. Based on the present method of economic analysis 'this scheme will not go ahead', retorted Clare; hence the requirement 'for some Government backing'. Referring to the fact that no government funding had been made available to the Channel Tunnel consortium, the Chairman asked whether any willingness for the Government to 'give any finances' had been detected by the STPG. The answer was 'NO'. But, as Mr. Rost quickly asserted, STPG had not put to Government a costed proposal, identifying the minimum support necessary either in cash terms or guaranteed loans - 'you have got to put down a firm proposal to the Government, surely?' 'You cannot be surprised if the Government does not lie down and offer you what you want'. Mr. Clare admitted that he did not have an answer to how the scheme would be funded. A risk-free return of 20% and full repayment over eight years were the private sector requirements for a 'risky and pioneering manufacturing project' according to Mr. McAllion of the Committee. Mr. Clare believed that a Government commitment 'in the region of two billion to three billion pounds' would be necessary to create private sector interest in the scheme. (Whether such sums were in addition to NFFO support was not established during discussion but the present NFFO deadline of 1998 would have passed long before any generation had been achieved at the barrage). The necessity to develop such a large barrage was questioned by the Committee - 'why have you not gone for the River Parrett instead of the River Severn and got on with it, it is a small project, you could cope with that one?' 'Why not concentrate on something that is more realistic?'

On the question of the number of environmental studies already undertaken and others yet to be completed, Mr. Clare confirmed that, in the case of the La Rance barrage, 'an environmental assessment of the pre-barrage conditions was not done, "they" just went in and built it'. No 'before' and 'after' comparison was therefore available, 'which was unfortunate'. In answer to the question of what further studies were to be undertaken with 'this £4-5m', Mr. Clare declared 'The key to the whole thing .... is the movement of fine sediment, that is the key to everything. We are beginning to understand that movement, we have got to make sure that we totally understand it ....'. These studies continue.

5.2 The Mersey Estuary

Although the Mersey estuary, with a mean spring tidal range of eight metres had been identified by Davey in his 1920's studies as a promising site for tidal generation (144), no further consideration of the region for such a development can be identified from the literature until 1981, when a short paper by Paynting (145) re-opened the subject. More importantly perhaps, also in 1981, the Merseyside Enterprise Forum, a body comprising a number of Merseyside businessmen and public figures, examined in detail the concept of a barrage, apparently 'first mooted by Mr. James Fitzpatrick' - Chief Executive of the Mersey Docks and Harbour Board (224). The Forum recognised that many non-energy benefits would accrue to the region by the construction of a barrage impounding the 'largest lake in England' providing opportunities for both recreation and tourism. A project of 'the magnitude envisaged' would, it believed, 'do much to improve Merseyside's tarnished image'.

5.2(a) Pre-feasibility Study 1

As a result of the Forum's enthusiasm, the Merseyside County Council (MCC) were encouraged to undertake pre-feasibility studies of a barrage scheme and the Northern Universities' based Marinetech consultancy was retained for this purpose. The consultancy's report identified three possible sites, designated 'Lines 1, 2 and 3 for the barrage (146) (225), with Line 2 the least favoured of the three. Annual outputs of 1.2TWh and 0.965TWh were identified for Lines 1 and 3 with energy costs of around 2.8p/kWh at 5% discount rate. However, as with so many previous barrage reports, the 1983 Marinetech document 'merely' concluded that while the project was a 'developable project' and, based on construction technology similar to that proposed for the Severn estuary 'technically feasible', the internal rate of return of less than five per cent made the project 'unattractive'.

5.2(b) Pre-feasibility Study II

In view of, or perhaps despite the as yet unquantified non-energy benefits which had previously been identified by the Forum, the MCC in 1985 commissioned a further pre-feasibility study, using funding provided by the Council, the European Commission (EC) the Science and Engineering Research Council (SERC) and the Department of Energy. Line 2 was excluded from this study in view of the earlier findings. The likely barrage construction costs were, on this occasion, assessed by Marinetech in conjunction with consulting engineers Rendel-Parkman. It was concluded that the costs of building the barrage could be drastically reduced by the use of the sunken hulls of scrap very large crude carriers (VLCCs) in conjunction with the construction of a series of diaphragm walls providing cells for the turbines and sluices. 'An excellent piece of lateral thinking' remarked Mr. D. Kerr of Sir Robert McAlpine's (226) during subsequent discussion, who wondered whether due consideration had been given to the necessity to create an even bed and to prevent scouring beneath the tankers and whether the forces acting on their hulls during placement had been considered.

The reduction in costs achieved by the use of this novel form of construction, in excess of 38% of the original assessment, resulted in a return on capital employed somewhat greater than eight per cent which, although 'not sufficient to ensure commercial success, caused considerable excitement because of other benefits the barrage might bring'. Hayward (156) believed that tidal power was poised for take-off in the Mersey!

5.2(c) Formation of the Mersey Barrage Company (MBC).

On the basis of this more optimistic report, the soon to be abolished MCC encouraged the formation of a private company to further the project. By mid 1986, the Merseyside Barrage Company (MBC), a consortia of twenty four companies and associations - including the University of Liverpool and the Merseyside and North Wales Electricity Board (MANWEB) had been formed, (the D of E offering strong support and funding to the tune of £400K), 'to investigate, design, build and operate a tidal power generating barrage on the Mersey'. The Board of the MBC included shipping, financial and parliamentary interests, selected to ensure that any future approach to the EC would receive a sympathetic hearing. From an early stage, the Board's attitude to the barrage was that 'it would remain a private sector operation'; moreover that any barrage scheme would stand or fall on its 'commercial viability'. Notwithstanding these views, it is interesting to note that the embryo company had received 'a grant towards half the study costs' from the D of E. (227). The D of E also commissioned a series of studies covering a variety of engineering and environmental interests which had a direct bearing on the possibilities for a Mersey barrage.

5.2(d) MBC Stage 1 Studies

Under the new management, Stage 1 of the feasibility studies commenced in October 1986. The studies were undertaken to identify whether any fundamental impediments to the barrage existed in respect of the modified tidal regime, water levels, sedimentation; also upon the ecology of the estuary and its water quality. A further financial appraisal was undertaken. The effects of barrage site on shipping were examined, while the changes likely in social and industrial patterns were identified. As explained earlier, two possible barrage sites, designated Lines 1 & 3, had previously been identified and, although it had been anticipated that one or the other of these locations would become the preferred site, as a result of the studies, no primary contender had emerged from them. However, as Davey had noted so many years previously, a barrage at the mouth of the estuary posed significant problems for shipping and for navigation generally. In an attempt to reduce the possible impact of a barrage in this region, the Line 1 alignment was moved upstream by a few hundred metres - a re-alignment of relatively minor importance for study purposes (228); the new barrage line was identified as Line 1A. Line 3, some seven kilometres upstream was also retained in the study.

The detailed results of the Stage 1 studies are contained in the 1988 D of E Report 'Tidal Power from the Mersey Estuary ETSU TID4047 (225) which concluded that the studies had 'highlighted a number of problems' ... 'none are considered to be overriding impediments that preclude further feasibility studies'. It was pointed out in the environmental assessment chapter of the report that the Mersey estuary met the criteria for designation as a wetland area under the Ramsar Convention and that 'a modified design and operational regime of the barrage .... could reduce the impact on ornithologically important components of the ecosystem'. The status quo of the estuary was to be maintained to the 'greatest extent possible'; an aspect which needed to be 'given considerable emphasis in the next stage ..... the need for interfacing between engineering and environmental studies'. The studies had confirmed that 'on balance Line 3 was ... marginally preferable to Line 1(A)'. The Navigation and Lock study concluded that 'the findings indicated no clear overall location preference (for the barrage) as a result of the 'diversity of interests and the way that they are affected'. Significantly, 'most maritime interests stated a clear preference for a barrage not to be built' (sic). All these bodies were concerned about 'aspects such as local currents, local siltation, lock security and charges', which the study had not previously addressed. The energy yields for the two sites had been assessed on the basis of ebb generation, with and without flood pumping; Line 1(A) being estimated to produce 1.33TWh with flood pumping and 1.27TWh without pumping from its twenty seven 7.6m runner diameter 25MW turbines, with Line 3 producing 1.06TWh and 1.02TWh respectively from its twenty one machines. Studies involving an increased number of turbines for both Lines were also undertaken which confirmed that an increase in net yield would be 'probable' and that 'substantial environmental and sedimentation benefits could be introduced' as a result of the increase.

In its own, undated, handout (229), but obviously produced subsequent to the 1988 ETSU Report, MBC indicated that the Mersey Barrage Project would be a 'unique opportunity to create a 'truly alternative energy source', a 'catalyst for regeneration within the North West' and 'for future barrages'. The studies 'carried out by the Company' had 'again concluded that there were no overriding problems' and that the barrage 'will' create both direct and indirect employment, with over five thousand jobs created during construction'. The barrage 'could be a significant factor in the economic generation of the Liverpool area'. MBC went on to state that 'well tried engineering solutions were available to overcome and/or offset any adverse effects' created by the barrage on shipping interests, navigation and locks.

Not everyone was happy with the idea of a barrage across the River Mersey. Professor Minford of Liverpool University (the University was identified as an investor in the scheme) claimed that it was 'likely to be uneconomic', to interfere with shipping, 'irrelevant' and 'potentially damaging to the estuary, its business and its ecology' (240).

On the other hand Professor McDowell in his letter to the Times (241) argued that, in common with many other estuaries, the Mersey in its present form was 'man-made' - 'not just locally but on a massive scale which has affected their whole hydraulic and sedimentary behaviour'.

'The preliminary results of the Stage 1 studies encouraged the Company with continued support and financial assistance from the D of E to embark upon the Stage II studies' stated the MBC handout. In a most important departure from the main conclusions of its Contractor Report (225), the MBC note included the comment, under Section 6 'Barrage Location':-

'The Stage 1 studies were unable to state a clear preference for the location of the Barrage ..... The Company has now stated its preferred line as being a revised Line 3 - some six hundred metres upstream of the original Line 3'.

'The barrage .... will comprise twenty-eight generators .... giving a rated capacity of approximately 700MW and a net power output of 1.5TWh'. (sic).

The revised cost of the barrage, to be constructed over a period of five years, was put at £880m at 1989 prices, with an operating cost of £10.5m per annum.

The precise reasoning behind this somewhat abrupt decision by the MBC to prefer Line 3 (modified) is not made clear in its Report. A later D of E Project Summary (231) indicates that the decision was made on the basis that, 'on balance (the new site) would yield electricity at the most economic cost'. Line 1A was rejected in view of 'the significantly greater capital costs'.

It is of particular relevance to examine these latest views of the location and generated output of a Mersey barrage with those put forward by Davey (230). Davey's views took into account interference with shipping interests which he accepted 'was a very vexed question' and that such interests would be 'adversely affected' where the barrage lay downstream of ports. Nevertheless, he accepted that the advantages of a greater depth of water at these ports as a direct result of the barrage could be an advantage to them. His preferred site for a barrage on the Mersey lay 'above Liverpool' and a comparison of the map associated with this location (Ref 230 - Chart 38 Page 229) with that proposed by MBC very strongly suggests that the two locations are identical. Moreover, the annual energy generated by Davey's two thousand metre long barrage assessed, using his 'horsepower' data, to be 1.5TWh per annum, is identical to the figure quoted by the MBC. Even more intriguing is the fact, included in the 1990 D of E Project Summary (231) that the Mersey barrage now proposed would be 'approximately two kilometres long' i.e. also identical to Davey's proposal. The anticipated annual output for the revised Mersey barrage was also identified (in Ref 231) at 1.5TWh, with flood pumping (1.3TWh without such assistance), a factor overlooked in the MBC report itself. The capital cost of the project, without interest charges, was assessed at £880m; the unit cost at 5.65p. It is also relevant to note that the use of 'scrap LCCTs' had been discarded in favour of concrete caisson construction although the D of E report hedged its bets by the inclusion of the view that 'other construction methods-specifically the use of steel caissons and in-situ diaphragm walls ... could be incorporated if appropriate' to do so.

5.2(e) Stage II Studies

Both the MBC and the D of E reports refer to the 'Stage II studies', the cost of which had been assessed earlier at £1.74m, to be shared equally by the Company and the D of E. The studies were expected to be completed within 'four years'; the D of E report also comments that 'work on Stage II is due for completion towards the end of 1990', confirming that initial reviews in respect of engineering, barrage construction and costs had already been undertaken.

The additional work associated with the Stage II studies involved a more precise determination of the line of the barrage (the presence of 'recent' glacial deposits of the proposed Line 3(A) was expected to require the use of load bearing piles to support the civil works) confirming that the 'final location of the structure will not be determined until further site investigations have been completed'.

The monitoring of environmental conditions in the estuary, already taking place, were to be supplemented by additional studies, 'particularly those pertaining to the roosting and feeding patterns of wading birds and wild fowl', declared the Stage II proposals. Further, a 'long term' review of the possible impact of the barrage was to be set in motion and, in addition, an appraisal of the possible non-energy benefits and development opportunities likely to emerge to the economy of Merseyside as a result of the barrage was to be undertaken.

The MBC report included, as part of their Stage II scenario, the creation of a funding/finance plan for the detailed design of the project, its Parliamentary approval and for the construction and operation of the barrage. Also included in these proposals was an anticipated timetable for the barrage to its completion 'in late 1998', together with the statement that 'in order to raise the funds for the Development and Parliamentary stages and to enable the MBC to commence the Parliamentary process in November 1991, the barrage MUST be included within the initial tranche of the Non-Fossil Fuel Obligation (NFFO)'. It has to be stated that the barrage was not included in the 1990 NFFO, nor was it accepted as part of the 1991 NFFO.

The decision by the 'government', (presumably referring to the D of E), to help fund the detailed studies of the Mersey barrage was criticised by the Royal Society for the Protection of Birds (RSPB) in a short article under the heading of 'Barrage Protest' (232). The Society claimed that 'a tidal barrage across the Mersey estuary', making it the largest single source of renewable energy in Britain' would 'put at risk mud flats that are internationally important feeding grounds for 20,000 waders'. However, in late 1990, Mr. Baldry the Parliamentary Under Secretary for the Dept. of Environment compounded the felony by confirming, during his meeting with the MBC that, 'my department will continue to fund the feasibility studies required for the next (Stage III) of the Mersey barrage project' (233). Moreover, he asserted, 'Consultation with interested parties will continue'.

New objections to the project emerged, in early 1991, when a report, prepared by the Port Advisory Services, commissioned by the Mersey Docks and Harbour Company (whose 1981 Chief Executive - Mr. James Fitzpatrick, it will be recalled, had claimed the credit for the original idea of a Mersey barrage), in conjunction with the Manchester Ship Canal Company and Shell Oil, predicted 'increased risks to shipping due to floating construction plant and cross-currents on the approach to locks' (234). The Report, which was supported in its views by Delft University and the Hydraulic Laboratory of Delft, envisaged queues of up to a hundred vessels long due to the cross-currents problem.

A more important problem on the minds of the MBC was identified in an article 'Mersey barrage scheme in peril' printed in the Sunday Times in June 1991. (235). The article maintained that the MBC 'may be forced to wind itself up', having concluded that the government would 'fail to provide £8m of public money to match pledged private investment for the next stage of the project, which needs £16m to proceed'. 'The existing credit lines will allow the completion and reporting of Stage III investigations' according to James McCormack - a director and general manager of the Company - claimed the Sunday Times report, which went on to indicate that the private sector backers had stated that they would not commit more money 'until the government gives the official go-ahead'.

5.2(f) Stage III Studies

A two hundred and fifty page report from the MBC, summarising the results of the Stage III studies, had resulted in the D of E requesting more details on the effect of the barrage 'on shipping and navigation', plus an 'environmental analysis'.

The report stirred the government 'to provide a further £1.2m to extend the existing feasibility studies' according to Electrical Review (of 6/19 September 1991), although 'the Consortium behind the scheme had hoped for an £8m injection to take the project to the next stage'. Issues 'which will be studied over the next fifteen months ..... will allow the D of E to look more closely at the prospects for tidal power in general and the Mersey scheme in particular'. The Electrical Review, went on, McCormack, the MBC's general manager says 'the Government's decision could result in parliamentary approval for the scheme being delayed by a year from its target date of November 1992'.

A request from the Government for a twelve month standstill for the project was feared by the Company which, according to McCormack, would result in the private backers 'walking away'.

The financial problems being faced by the MBC had perhaps been 'predicted' (a better term would be re-iterated') in September 1990 at the World Renewables Conference in Reading, when a report by the Watt Committee on Renewable Energy Sources (236) was introduced by the Chairman of that Committee, Professor Michael Laughton. 'The long term pay-back period associated with large scale renewable energy projects such as major tidal projects made them unsuitable for solely private sector funding', asserted Professor Laughton, referring specifically to the proposals pertaining to the

Severn and the Mersey tidal barrages. His working party 'urged a measure of public sector funding for all such major projects' with 'continuing government support for research and development across all the renewable energy technologies. A 'rough ride' was also predicted for renewable energy projects 'in the new era of privatisation', Professor Laughton emphasising that 'new institutional and financial factors would seem positively to harm the prospects .... of electricity supply by renewable sources'. A plea was entered that large renewable systems such as tidal barrage generation should be funded by the State using public sector rates of return in recognition of their potential national importance in the longer term.

5.2(g) The Attitude of the (Renewable) Energy Select Committee to MBC Proposals.

In November 1991, representatives of MBC were summoned before the House of Commons Select Committee on Energy in support of that Committee's inquiry 'into the prospects for the commercial implementation of renewable energy technologies and the role of Government, in the context of energy and environmental policy, in promoting the development, implementation and export potential of these technologies in the UK'.

A lengthy and detailed memorandum had previously been submitted by MBC to the Select Committee in reply to certain questions raised by the latter and in defence of the request for the continuation of funding for the Mersey barrage. The advantages of the barrage were identified in the summary to the memorandum which included the warning that 'unless action is taken to ensure the development of renewables, the private sector will look for other investment opportunities'. A likely project budget of £966m (£1337m including interest and inflation) based on January 1991 prices was now envisaged, the power and energy data remaining as included in the Stage II assessment.

The memorandum also confirmed that the Stage III studies had been completed, with an 'interim' report submitted to the D of E. The studies had determined that the barrage should be located 'slightly upstream' of the earlier Line 3(A) position 'to found the barrage on better ground conditions' (it will be recalled that 'recent' glacial deposits had been found at the Line 3, (3A) sites which necessitated piling). In addition, the Stage III investigations had confirmed that the 'remaining concerns of the shipping interests could be overcome or accommodated by on-going engineering development and refinement'. Moreover, the report went on; 'with continued sympathetic consideration, creative conservation and careful habitat management, the environmental impact (of the barrage) would be minimised and any adverse effects could be managed' (237). The conclusions of the Stage III report led the MBC to recommend to the D of E that the project should proceed immediately to Stage IV of the development in order to 'answer or crystalise outstanding problems and ensure that the necessary and extensive consultation took place' prior to any decision to proceed to the Parliamentary stage and secure the necessary project approvals'. The vital part of the MBC submission then followed.

'In proceeding to Stage IV, the MBC statement asserted, it was necessary for the D of E to confirm that a long term NFFO contract would be available and that the 1998 cut-off date imposed by Brussels would be removed for non-nuclear renewables'. Private sector funds of £8m (i.e. half the expenditure associated with the Stage IV investigations) 'were or would be made available assuming a clear D of E statement on the issue'. It was noted that the D of E had <u>not</u> endorsed the MBC views relating to the remaining work to be undertaken but had agreed to continue with the environmental and other studies essential to any continuance of the project. The MBC stated finally that 'unless the D of E provides clearance to proceed to Stage IV and secures long-term levy contracts, the MBC will not be able to agree to a further piecemeal extension and the 'support within the MBC ..... will be lost, possibly for ever, as supporters turn to other investment opportunities'.

The MBC memorandum referred to the Government's acceptance of the Large Combustion Plant Directive (LCPD) with its attendant requirement to reduce $SO_2$ emissions which, together with their target also to reduce $CO_2$ discharges, strongly implied a reducing role for fossil-fired generating stations in the future. The memorandum also took the opportunity to compare what it called the 'transitional technology' of combined cycle gas turbines (CCGTs), emphasising their short life cycle of ten to fifteen years and the uncertain future envisaged for nuclear generation, with the long life (one hundred and twenty years plus), and environmentally friendly aspects of a tidal barrage providing low marginal cost energy.

Inevitably, the questioning of the MBC delegates by members of the Select Committee centred on the novel method of financing the barrage proposed by the Company. In simple terms, the plan put forward proposed an extended (twenty five year) NFFO contract, with advances of the levy being made during the five year construction period totalling £829m. 'But', said a member of the Committee, 'it looks as if you are asking £829m in advance out of a total capital project of £966m; it sounds to me as if you are expecting the whole thing to be financed by the purchasers?' 'No' said Mr. J. McCormack, the leader of the MBC delegation, '£966m is the cost in January 1991 terms - if one puts in interest ... inflation during construction, the overall figure one is looking for over the five-year construction period is of the order of £1.4 billion ... just over half by way of advances'.

In answer to further questioning on this subject, the MBC leader confirmed that he faced 'a simple situation, which all renewables do: my electricity is not immediately competitive with the traditional fossil fuel. All I need is a framework which the Government has already devised, the NFFO and I need a long take-off contract'. 'You would like the NFFO to be extended beyond 1998' queried the Chairman Dr. Michael Clark; 'Yes' retorted MBC, 'it is essential, otherwise we will not continue beyond this year'. 'We wish you every success with your project' was the Select Committee's final comment. The back page of the Financial Times of July 21 1992 contained an article (238) entitled 'Setback for £1bn Mersey Barrage scheme' which stated that the project had failed to win government backing. The barrage, it said 'would not qualify for public funds (presumably a reference to the NFFO) to subsidise the cost of its electricity'. It was anticipated that shareholders of MBC would meet to decide 'whether to keep the ten year old project alive and team together with an injection of £14m. While supporters of the scheme were of the opinion that the decision 'raised questions about the government's commitment to environmentally friendly power generation', others pointed to the 'high energy costs' and the opposition of 'shippers who use the three Mersey ports of Liverpool, Garston and the Manchester Ship Canal'. The article also referred to the 'mixed feelings' of the environmentalists, who, while 'favouring renewable sources of energy are worried about the impact of such big schemes'. According to the latest information (September 92) from ETSU, Mr. Michael Heseltine - Secretary of State for Trade and Industry (now responsible for Energy matters) had confirmed his rejection of the MBC proposals. Moreover, ETSU understood that 'the Company were considering their next move' and that 'a further approach to Government was possible'. No public declaration on future plans has since been made by the MBC.

## 5.3 Other Barrages

### 5.3(a) General

Articles dealing with the subject of tidal power have continued to appear in the technical press, much of the subject matter being a re-iteration of earlier work. The tidal scene was again reviewed by Wilson (149) while further experience with the La Rance project, after fifteen years of operation, was assessed by Banai and Bichon (150). The success achieved by the Annapolis single machine barrage was considered by Whitaker (151) to point the way forward for the development of other schemes on the Bay of Fundy, although Daborn (152) cautioned against any moves in this direction in his review of the possible environmental effects on the region. China (153), who had for many years utilised existing dams and dykes to develop small electrical generation schemes, indicated their continuing interest in the development of their huge tidal resources, equivalent, according to Charlier (154), to some 90 TWh annually. Bernstein re-affirmed his country's interest in tidal technology (155).

Meanwhile, in this country, the on-paper potentials of tidal schemes other than those of the Severn and the Mersey were being considered or re-assessed. The possibilities for tidal generation from barrages constructed on the Solway Firth and Morecambe Bay were actively assessed (278) (279) and this section examines some of the others in greater detail.

### 5.3(b) A Comparison of Davey's Tidal Sites with those of Recent Identification.

As has occurred several times in this dissertation, it is appropriate to commence this review with specific reference to Davey's seminal text on the subject. In Chapter VI of his thesis (239) Davey undertook a Tidal Power Survey of the British Isles. In making this survey, he was of the opinion that locations having mean tidal range of less than ten feet (three metres), as assessed from the Admiralty Tide Tables, would be unsuitable for exploitation. Further, he considered that it was necessary to fix a lower limit for the possible generated output - in his case he took an equivalent continuous power output of one thousand horsepower (750kW) as that value. The third factor in his assessment was the necessary configuration of the coastline to achieve the economic enclosure of the maximum water area with a minimum of barrage construction, thereby limiting the search to suitable estuaries, inlets and small bays.

Neglecting, for reasons not stated (but obviously associated with shipping interests), the estuaries of the Thames, Tyne and Tees, Davey identified a total of sixty nine sites, forty nine in England and twenty in Scotland which he adjudged to be suitable for further consideration and possible exploitation. He acknowledged in the text that his list of sites was not exhaustive and, moreover, recorded that his technical assessment were necessarily tentative in view of shifting sand banks and indefinite low water levels. He emphasised also that whether or not a barrage 'station' was practical would depend upon 'detailed geological studies of the chosen site'.

In the 1980's, studies had taken place to assess or to re-assess the tidal generating potential of the Dee and Conwy estuaries, the Solway Firth, Morecambe Bay, The Humber and the Thames (243) (244) (245) while the smaller locations of Langstone Harbour (246), Padstow and Hamford Water have also received their share of attention. (247).

More recently still, a survey of possible tidal generation sites 'from small estuaries' has been completed, the results being reported by the D of E. (242). During the study, a total of one hundred and eighteen estuaries and embayments, located in the west and south west coasts of England was examined; the coasts of eastern England and of Scotland were not considered in view of the fact that 'they had much smaller tidal ranges'. In much the same manner as outlined by Davey, Admiralty charts and tide tables were perused for the required information by Binnie and Partners; some sites, obviously unsuitable for water turbines in view of their minimum submergence requirements, were included in view of the future possibility that 'air turbines could be used instead'.

A comparison of the conclusions reached by Davey with those of the more recent studies reveals, perhaps not surprisingly, a strong degree of similarity in many of the locations chosen for tidal power development. Also unsurprisingly, since the basic calculations are relatively elementary and the sources of information the same, the potential energy assessed by the different investigators for each site are not greatly different, particularly if the details of the precise location of each barrage site are allowed for.

The degree of correlation becomes even more evident if the selected barrage locations are appraised on the basis of possible capital cost of each scheme and the unit cost of the electricity produced by it. Although the parametric method of costing utilised for this assessment, developed by Baker (248), was obviously not available to Davey, a majority of his sites are nevertheless included in the list of Binnie's most economic locations (Table 4.1, 4.2, 4.3 of Ref 242). An indication, perhaps, of Davey's ability as a pragmatic and discerning engineer. Certainly the results engender a considerable degree of confidence in accepting for any future use his energy estimates for locations which have not otherwise received corroborative assessment from other investigations; e.g. those on eastern England and the coasts and lochs of Scotland.

In further support of Davey's views, it is relevant to note that a location for a barrage on the estuary of the River Loughor, Llanelli, identified by Binnie & Partners as a 'potentially interesting tidal site in earlier studies (242), although not included in Davey's list of possible locations, was subsequently subjected to an extremely detailed re-assessment. (249). The latter Report concluded, perhaps inevitably, that 'the construction of a tidal power barrage at the Loughor narrows .... is technically feasible'. It went on to state, however, that the construction 'could not be justified at the estimated basic unit cost of 6.7p/kWh unless other benefits can be ascribed to the development'.

A pre-feasibility study to examine the technical, economic and environmental aspects of a combined energy barrage and road crossing of the River Duddon, Askam-in-Furness, was announced by the D of E on 22 January 1992. (250). The proposal for the study emanated from a consortium comprising McAlpine and Sons and Balfour Beatty with additional support from a number of local and regional authorities and also by NORWEB plc and Shawater Ltd. The D of E supported the study 'as part of its on-going research programme on renewable energy', contributing approximately £100k towards the anticipated costs. Colin Moynihan, the Parliamentary Under Secretary of State, Dept. of Energy (1990-92), when announcing the Duddon project commented 'Tidal Energy is a very promising renewable energy. This study ..... is part of my Department's renewable energy research and development programme and follows on from work which identified the most promising tidal schemes around the UK'. (242). The study was expected to take twelve months and, as part of the environmental assessment, consultations would take place 'with relevant interest groups'. It is worthwhile pointing out that the potential of the Duddon estuary had first been identified by Davey (251), his estimate of the Duddon's capability bearing close comparison with the assessment of 255GWh annually, made by the D of E (242 - Site 20a).

Also on 22 January 92, the D of E released the results of the preliminary feasibility study into the possibility for a power barrage across the Wyre estuary (252). This study, undertaken by a group headed by Trafalgar House Technology (THT) and supported by Lancashire County Council in association with NORWEB, the NRA and a contribution from the D of E of around £130k, confirmed (253) that the estuary was 'well suited for a tidal energy scheme and, subject to further studies, a barrage is unlikely to have serious adverse effects on present developments or current users'. Moreover, the report went on, 'a road crossing could be incorporated into the barrage' (at an additional cost of £7m) and concluded that the maximum benefit to the region 'would be obtained from a combination of road bridge and barrage'. The ability of the barrage to control flood water from storm surges was emphasised; it was also noted that the 'use of pumped drainage would be required to keep ground water in areas surrounding the barrage to existing levels'. The £90m scheme was anticipated to have a capability of 131GWh/annum, the electricity being produced at a barrage cost of 6.5p/kWh (1991 prices - 8% discount rate), and would reduce annual $CO_2$ emission by 'up to 136,000 tonnes'.

In his 1923 text, Davey (254) had also made an assessment of the Wyre's annual tidal generation capability; he estimated that a barrage at the point more or less as identified by the above THT report and which he called 'Fleetwood-North', would have a capability of 126GWh annually.

As a final comment to this Chapter, it is interesting to compare the high note of optimism in Moynihan's comments when discussing his department's involvement with the Duddon investigation with the more reserved attitude taken by the 1991 Select Committee on Renewables (255) (256). While that

Committee viewed, with varying degrees of enthusiasm, the future for wind, solar power and wave power, they saw Tidal power as unlikely to prosper, given its very high initial capital costs, unless state financial support was made available to the projects. Moreover, the Committee argued, 'a single huge project such as the Severn barrage made it difficult to justify smaller, more adaptable schemes'. They considered that 'tidal power was likely to be reliable and eventually cheap - smaller barrages than the Severn might exemplify these virtues'. The death knell, perhaps, for the Severn but not for the Mersey? Or merely hope, in the longer term, for much smaller multi-purpose projects such as the Duddon and the Wyre?

# Chapter 6 - Analysis

## 6.1 General

As stated earlier, the literature pertaining to the utilisation of the tides for man's purposes is huge; moreover, it continues to grow year by year. This dissertation has identified and discussed the contents of many treatises dealing specifically with the use of tidal power for electricity generation; inevitably many more have been omitted from the survey.

It is now some seventy years since the first objective assessment of the potential of the tide's power and the feasibility of utilising this power for electrical purposes was put forward; even longer if the Decoeur studies of 1910 are included.

Although it must be doubtful that the technology necessary to construct an electricity generating barrage existed in those early days, the fact remains that such ideas did exist, it being necessary 'only' to convert them into practical reality.

Since that time, the required civil, mechanical and electrical engineering expertise to bring a tidal generation construction to a successful technical conclusion has been attained. As confirmation of this attainment, a barrage of significant size and complexity has been constructed on the estuary of the River Rance where, according to EdF, (the French electricity authority and owner of the barrage), the plant has delivered electrical energy, both economically and without long term damage to the environment, to their distribution network for the past twenty five years.

And yet, despite the considerable tidal ranges to which the British Isles, particularly its west coast, is subjected, together with the millions of words, both written and spoken, reviewing the progress (or otherwise) made to harness this undoubted and continuing source of green energy, not a single barrage, large or small, has been constructed in the UK. It could be argued, in fact, that the country appears, in practice, to be no nearer a 'real' barrage than it was in the 1920's.

It is the purpose of the remaining paragraphs of this thesis to identify possible reasons for this state of affairs.

Consideration of the contents of the many articles which have been perused leads to the conclusion that, perhaps unwittingly, there have been certain discrete and identifiable stages in the 'progress' of tidal power in this country. The initial period of assessment was perceived to be mainly one of civil and electrical engineering importance. Later on, appraisal of the economics of tidal produced electrical energy became of major consideration while, latterly, solutions to the intractable environmental and ecological problems have become the overriding influence. Throughout the period, however, political factors, in combination with vested interests, have maintained a most significant control over the future for tidal generation. It is with this latter aspect that this discussion must commence.

6.2 Political attitude to Tidal Power

The British political mind, whether local or national and of whatever persuasion has never been one to take risks. History confirms that anyone rash enough to introduce a politically unsound policy is quickly out of office. Technological issues in particular have always proved problem areas to the politician, very few of whom have at any time received any technical training. Electricity matters have been plagued with political interference and indecision; as early as the Electricity Lighting Act of 1882, entrepreneurs believed that parliamentary interference had 'stifled the electricity industry at birth' (257). For any political debate to take place on a technical topic, the subject must first of all be assessed and simplified to make it understandable to the lay mind.

This process is undertaken by technical staff working in the 'second and third divisions' of the Civil Service and their conclusions are in turn used by Wilson's 'first division' (258) to provide the necessary briefs for their Minister. Inevitably, debates based on such processes are largely misunderstood, with the outcome depending more upon the politics of the argument that its technicalities. These procedures also lend themselves to 'lobbying' by other, vested, interests, thereby leading to possible distortion of the basic technical content in order to achieve the desired result.

Avoidance of political risk also produces a reticence to support a cause which may be open to doubt and delay becomes the best attitude to take. There are, daily, examples of such procrastination not only in Parliament but also in local government and in the public services - 'why should we stick our necks out' is the feeble phrase used for doing nothing.

Moreover, political expediency and delay are not only the prerogatives of the state mind; there are many similar examples to be found within the scientific and engineering communities. The thickness of moon dust likely to be encountered by Neil Armstrong was a good example of scientific dissension, the science of cosmology itself an even better one. There are many items of scientific disagreement to be found on the topic of Tidal barrages, as already evidenced. Such disagreement, particularly if identified during public Conferences or Symposia discussions, is 'grist to the mill' to politicians who discern in this lack of unanimity perfectly adequate reasons to reserve their own opinions and continue the process of delay. Perhaps the comment attributed to Trollope applies also to the political mind - 'to practical Englishmen, most of these international Congresses seem to arrive at nothing'.

It is worthy of reiterating, in this assessment of political attitudes to tidal power, that the technical advisers to both the pre-1920 and the 1933 studies included Sir Eric Geddes and Sir John Snell; Snell being the Chief Adviser to Geddes on electrical matters. Geddes had drive, expertise and an identified ability to 'cut through red tape'. His technocratic views on public ownership were well known to his parliamentary colleagues, as were his views on Ministers themselves - 'Ninety per cent of Ministers accept the theory but are reluctant to put it into practice', he wrote to Prime Minister Lloyd George (259).

Little wonder, taking all things political into consideration, that the 1920 and 1933 Barrage reports were left to accumulate dust.

On the other hand, Lord Weir was able to ensure the Royal Assent for his Bill to construct the 132kV Grid (iron) system by his understanding and manipulation of the Parliamentary process. While previous engineering reports to Parliament on the necessity for interconnecting generating stations in order to save coal had fallen on barren minds, Weir reduced the Reports' own arguments 'to substantial and attractive gains readily understandable to Ministers'. 'Scrupulosity was perhaps reserved for the general direction of the truth rather than its precise quantification' (262). While Weir could stand accused of being economical with the (technical) truth, the point can also be made that the earlier, mainly complex and engineering oriented, reports were less than persuasive in their ability to communicate in a language best understood by their non-expert political readers. This vital aspect of communication was not lost on Cairncross who was able to secure, by means of a severely worded but simply stated Report - á la Weir -, Parliamentary approval for the go-ahead of the Channel Tunnel, a feat which had been found impossible by many expert led Committees before his own (261).

The analyses of the Severn Barrage reports, particularly those written since 1945, strongly suggest that the 'Weir' principle of report writing for Parliamentary purposes had not been applied. But perhaps Weir himself may not have found it possible to produce an easily read, unambiguous, Report in favour of the construction of a Severn or Mersey barrage which would have been acceptable to today's Parliamentarians.

6.3 Institutional Barriers ('Vested Interests')

Experience strongly supports the view that the attitude taken by 'vested interests' to any change in the status quo is one of disapproval unless some tangible evidence of 'profit' - however defined - can be detected. In the early days of empire, the United Kingdom, with its vast investments in the slave trade and dramatically increasing textile business with the colonies, constructed port and shipping facilities on a number of river estuaries to cater for these activities. In particular, the Rivers Mersey and Severn became two of the vital arteries for international business and both Liverpool and Bristol became major cities as a result. Although patterns of trade have altered, both ports retain significant business interests on their respective estuaries which are of great importance to the financial wellbeing of the surrounding regions.

It is inevitable from the foregoing that any suggestion to effect the (partial) closure of their waterways by means of a barrage must result in a vociferous defence of the right to free passage, without hindrance or cost, for the shipping associated with the business of the ports both above and below any barrage.

Proposals to incorporate locks of the size and ability to cater for identified vessel maxima with minimum but inevitable delay have not silenced these arguments. The inescapable reduction of high water levels upstream of a barrage, the possible/probable movement of sediment and resultant siltation of navigable channels and basins remain problems which the port and shipping authorities consider they could well do without. There are few if any real benefits to compensate for the disturbance to the well known and used regime of river passage; in fact, additional costs could be incurred as a result of lock delays.

For these reasons, the Severn authorities associated with the early barrage schemes remained opposed to these projects. More recently, their defence of such rights has perhaps softened somewhat, at least on paper. The current view of the Port of Bristol merely states that 'if the Severn Barrage is built neither the Port nor shipping visiting the Port should suffer consequential detriment'. 'This applies equally to the physical provisions made for shipping to pass through the barrage and to the costs faced by the Port and shipping attributable to the Barrage'. Associated British Ports held the view that the introduction by the barrage of a second locking system will be to the detriment of the interests of the ports - while the 'loss of peak high water would not be compensated by an increase in the length of stand'. The shipping interests on the Mersey have become equally vociferous.

The mining interests of the South Wales coalfields were no less firmly opposed to the early proposals put forward for a Severn barrage. Whether any logically reasoned argument was ever put forward in support of their opposition is not clear from the literature; the estimated displacement of around one million tons of coal per annum, as a result of barrage operation, must have been of only minor concern compared with the two hundred million tons produced annually by the industry at that period. Possibly it required no more than a suggestion of job loss, or of opposition, to ensure that the strength of the mining community, well represented in Parliament, restrained any further consideration of a barrage.

More recently identified barrage schemes have not resulted in open opposition from the mining community; certainly no resistance can be detected, for example, to the Bondi or the STPG proposals of the 1980's. Yet coal as a major fuel for electricity generating purposes was stoutly defended by the NUM and the Coalfields Community Campaign during the Hinkley Inquiry of 1989/90 (263). Perhaps their fierce opposition to nuclear generation but not to a barrage was based on the supposition that renewables schemes were unlikely to make any major impact on electricity generation and on coal production in particular?

Local authorities' concern in respect of the 1920's barrage proposals were limited to the 'possibility of severe flooding' of regions for which they had responsibility. The submissions made to the STPG were, as has already been observed, much more detailed, with interests set much wider. While supporting the concept of a barrage, they object to the release of land for development funding purposes, endorsing a requirement that no financial burden would fall upon them as a result of barrage construction and operation. Most importantly, they sought a detailed involvement 'at the earliest possible stage, in any further consultation about legal, financial and administrative aspects of the barrage'.

Opportunities to develop, using private capital, hydro-electric schemes in the north of Scotland were rejected, in the 1930's, by Parliament worried on the one hand about the impact of such projects 'on Scottish miners' jobs' and, on the other, by 'groups anxious to preserve the wilderness of the Highland' (264).

Virtually without exception, the authorities, the 'vested interests', have expressed their concern for the environment and ecology of the Severn estuary (similar comments have been made in relation to the Mersey), seeking assurances for their continued well being in the event of construction and operation of a barrage being agreed.

6.4 <u>The Economics of Tidal Power</u>

The literature survey has confirmed that a decision whether or not to proceed with the construction of a barrage across the River Severn (and more recently the Mersey) depends critically upon the cost comparison of a barrage produced kilowatt-hour ('unit') with one produced by a coal-fired station, or since 1980, by a nuclear one. Thus, the 1933 Severn Report concluded that 'the cost of (barrage) power' (sic) at 0.176 of a penny per unit 'would be only two thirds of the cost generated at an equivalent coal-fired station' (a fundamentally flawed judgement as has been pointed out previously). Although that Report's conclusions make no mention of the cost of money, the body of the document includes the rather involved statement 'in order to put the relative costs on a strictly comparable basis they should be calculated on the assumption that coal-fired stations were able to raise their capital at an average rate of four per cent, the rate we have assumed for the barrage scheme'. The 1945 Severn Report confirmed that 'the interest charged on capital and sinking fund investments was three per cent per annum'. The cost per unit was, in the 1945 case, complicated by the restriction on output for the first fifteen years and referred to earlier; figures of 0.209 of a penny and 0.199 of a penny per kilowatt-hour respectively were considered relevant. (Headland subsequently supported these data). The 1945 Committee considered that the 'prices were lower than those from existing coal fired stations', but expected them to be higher than the prices likely to apply from new, more efficient, stations. They declared that the 'financial value of the barrage scheme will depend upon the price of coal per ton'. The 1981 Bondi Report declared that 'in many scenarios the ... barrage is likely to be an economic investment although not as good ... as nuclear plant'. The unit cost of electricity generated 'might be around 3.1p/kWh at five per cent discount rate' (real or internal rate of return above inflation and the figure previously set by Government for public sector economic performance). The Report went on 'since nuclear fuel is very much cheaper than coal or oil, the size of the nuclear component of the generating station is decisive for the evaluation of the .... barrage'. Statements of this type are merely reporting the obvious, i.e. that in the modern world of electricity supply, the position of a tidal generating plant is any running merit order table would be determined, like any other plant, by its relationship to the economic performance of other generating stations available to the electricity supply network and its controllers. An aspect which obviously could prove to be a great deterrent to the possibility of any privately financed tidal project, since the investor must face the risk of the plant not generating revenue if more economically priced generation is available to the despatchers.

The capital costs of hydro-related generation schemes have historically been significantly higher than those of conventional fossil fired station. For example,the capital cost/kW installed of the 1928 designed Galloway hydro-electric scheme was around £35 (265), approximately double that quoted for the 1930s 'big, new public supply station' (266) and not dissimilar to the figure appropriate to the large coal-fired generating stations of the 1970's. No less importantly, the capital costs associated with nuclear generating stations approximate several hundred pounds/kW installed. The civil engineering costs involved in the construction of hydro and nuclear stations far outweigh those pertaining to conventional plant. In the case of the Galloway scheme referred to above, some two thirds of the total costs related to dam construction and associated works, a figure not greatly at variance with that of the 1945 Severn barrage project.

The fuel costs applicable to fossil-fired and nuclear stations are greatly different; however, they are both affected by world demand and local labour conditions. On the other hand, there are no fuel charges directly applicable to tidal generating stations; in fact, considerable savings of fossil fuels would be achieved by their use.

Moreover, while the economic lives of both coal/oil fired and nuclear generating stations are assessed at thirty years or so (Hunterston 'A' Magnox nuclear station was taken out of service after twenty five years), hydro-powered plant may well have a life of eighty or one hundred years and possibly in excess of such figures. While replanting must occur during such a long time scale, the basic civil works will, with adequate maintenance, remain unimpaired by time. Taking the foregoing into consideration, it is basically unsound to assess the 'present worth' of future generation income from the different schemes by the accounting analysis known as 'discounted cash flow' (DCF). The DCF process bears particularly heavily on the long term worth of electricity produced by any generation method, even when quite moderate discount rates are used. For example, a discount rate of five per cent will result in the worth of the energy (to be) produced in thirty years' time being less than a quarter of its present value while the fifty year 'worth' will be reduced to less than nine per cent of its present value. If the discount rate is increased to eight per cent, (quite insufficient to satisfy today's currency markets) these figures become ten per cent and two per cent respectively while, at a discount rate of twelve per cent, the energy produced in twenty five years' time would be practically worthless in evaluating the present day merits of a scheme. The impact of such accounting procedures on the economic merit of a tidal barrage generating project is obvious. Nevertheless the use of the DCF technique continues to be applied to electricity supply assessments; the advance of the combined cycle gas turbine, with its low initial capital cost, short construction period and even its comparatively short operating life fits perfectly into a DCF structured privatised electricity industry. The destruction of the coal mining industry's future prospects can thereby, at least partially, be traced to the effect of financial policies based on this discounting technique.

The foregoing confirms the fact that the economic judgement of whether or not to go ahead with a project does not depend primarily on the level of capital to be employed, or even the source, (public or private) of that capital. What matters to the financiers is the perceived real rate of return on capital as determined by the application of a technique which, in truth, may or may not be appropriate to the project itself. For example, by the application of single minded financial manipulation, conventional economic policy has enabled a civil engineering project similar in magnitude to that of the Severn barrage to be financed by private capital. The Channel Tunnel, with an anticipated final cost of around £9,000m and a project time scale not dissimilar to that assessed for the Severn barrage has gone ahead, although its true rate of return must remain open to question for years to come.

Recent official reports on the possible development of a Severn or Mersey barrage have shown an increasing concern for the environment and ecology of the estuaries. As stated elsewhere (267) 'modern day environmental quality ratings are much higher than they were twenty or thirty years ago'. Unfortunately, presently accepted accountancy techniques include no factors for allowing comparison of the economic benefits of projects of differing environmental impact, although suggestions to deal with this shortcoming have been made (267).

6.5 Environmental Aspects

'The "existence" value of an environment not necessarily for physical use but merely to be viewed has been found to be a significant reason for its preservation' (268). 'Preservation of the remoteness of the Scottish Highlands' was put forward as one of the reasons for denying the use of the water power of that region for generation purposes (264). In November 1931, a 'Scenery Committee', under the chairmanship of Lord Hamilton, had been commissioned to discuss the implications and to oversee the effects of the imminent construction of the Galloway hydro scheme (268). This Committee was subsequently to 'register its concern' at the 'bare and unsightly collection of apparatus' which constituted the electricity substations at Glenlee and Tongland. Yet the Central Electricity Board (CEB), whose responsibilities included the arrangements of these structures, had previously discussed their proposed designs and constructions with the Association for the Preservation of Rural Scotland (ARPS) and had obtained their complete acceptance. It is perhaps of interest to note that the Tongland 132kV substation, probably as a direct result of the ARPS discussions, became the first Transmission substation in the United Kingdom to be designed and commissioned in the compact, metalclad format (269).

It is also worthy of this period to note that a claim, purporting to come from the promoters of the Galloway scheme that, 'far from impairing the beauty of the area', ... 'the works would improve its amenity', was considered 'untrue' in a report prepared by the newspaper The Scotsman which believed 'the construction' (on this occasion of the dams) to be 'extremely ugly'. (268). Further, the MP Sir Thomas Inskip, arguing this point, asserted that 'no desecration of places of beauty could occur if a Scenery Committee was appointed', a view which was unacceptable to Lord Hamilton. He was anxious to point out that 'whether or not the public advantage of the proposed works outweighed the public loss that may be caused by the spoiling of a beautiful place is never considered under our present system'. (270). Another example of 'beauty being in the eyes of the beholder', again associated with the electricity supply industry and the CEB, concerned the criticism of the 'pylons and overhead connections' of the Grid system in 1931 by groups of environmentalists-'landowners and city nature dwellers'. Herbert Morrison, the Minister of Transport whose ultimate responsibility it was, was able to win them over. 'They (the towers/pylons) have, he said', a sense of majesty of their own and the cables stretching between them over the countryside gives one a sense of power, in the service of the people, marching over many miles of country' (271). Nevertheless, it is recorded in the later 1930's that 'the increasingly stringent environmental requirements affected the planning of suitable sites for power stations' and 'delayed the completion of the plant programmes'. (272).

The willingness of the population to tolerate or accept any visual or other form of degradation of their own environment varies not only from place to place but also in relation to their initial perception of their environment. A coal mining community brought up to identify with pit-head workings and the spoil of coal-getting might be more tolerant of a particular visual intrusion which would be completely unacceptable to a country village. Local resistance to environmental change remains basically a sociological problem although there is, without doubt, a greater reluctance to accept changes when their main benefits are enjoyed elsewhere. It remains a fact, however, that environmental changes and intrusions to the normal course of life are usually acceptable to the population unless personal involvement can be identified. The so-called NIMBY (not-in-my-back-yard) syndrome is the result of such attitudes.

Experience confirms that public opinion, 'that chaos of prejudices' (286), can usually be marshalled to accept or reject a proposal by the publicised views of the recognised 'expert' or celebrity.

And what of the environment which the present generation and its politicians are anxious to preserve. (274). The estuaries of the Severn and the Mersey have been and continue to be used for the construction of shipping and port facilities for the purpose of trade; numerous other rivers were likewise involved in these activities. Many of these industrialised rivers and estuaries are no longer associated with business but still retain the scars of yester-year; evidence remains of redundant boat yards, decaying wharf and dock facilities, overgrown feeder canals and filthy effluent outfalls. It is worthwhile repeating here part of the contents of Professor McDowell's letter to the Times (275) 'In common with many other estuaries, the Mersey in its present form is 'man-made' - not just locally but on a massive scale which has affected their whole hydraulic and sedimentary behaviour'.

A not inconsiderable part of the environment from which the public derives its visual, social and physical enjoyment and which interests, comparatively recently, have set out to protect may well have been man-produced by activities undertaken during the not too distant past.

This is not to suggest that protection of the environment as we now know it is unnecessary and that full analysis, assessment and regard for any human impact upon it need not be undertaken. It is intended merely to draw attention to the fact that environmental and ecological issues are highly subjective ones, equally complex and, in view of their complexity, usually minority led. Nevertheless, some forty eight per cent of the UK population believe that 'environmental protection' is essential, while eleven per cent put 'development' as their priority. European figures support these data (276).

Other statistics (277), based on highly questionable techniques, suggest that no less than two thirds of the UK's electricity customers would pay an additional £7/annum for their supply in order to achieve ten per cent renewable energy by the year 2000, while sixty one per cent believe that renewables should be given the highest priority to combat global warming.

But, as Shaw observes, it must be 'recognised that energy production and preservation of the environment are often in conflict (not only in respect of power generation). The skill is achieving a compromise between the options available and the economic penalties'. 'The challenge of environmental investigations is nowhere more multi-disciplinary than in the case of tidal power stations'. (277).

Although the possible effects on the environment particularly of energy producing or transportation schemes have more recently been publically aired within the corridors of power, the Severn barrage reports of 1933 and 1945 contained little on the subject. The only comment which could perhaps be construed to point in this direction was that included in the 1945 Report' ......, many considerations other than technical arise which are outside our terms of reference'. The literature survey undertaken strongly suggests that the 1974 article by Shaw (280) made the first specific mention of the 'environmental factors' of a proposed tidal energy plant on the Severn estuary. As previously stated, no environmental study was made of the Rance river prior to the construction of the barrage on its estuary. (281).

Both the Severn and the Mersey estuaries have been and are continuing to be the subjects of wide ranging environmental and ecological studies. The Severn can justly claim to be the most widely studied of the estuaries of the UK, and possibly of the world. Working from the assumption that the 'physical aspects of an estuarine regime are the major determinants of its character' (282) Shaw has made an assessment of the possible effects of a barrage at English Stones and also at the Cardiff-Weston site of the Severn estuary on the currents, turbidity, salinity and patterns of sedimentation of the estuary. The varying aspects of water quality were also reviewed and their effects found to be 'important' but 'capable of recognition'.

He retained the view that ecological changes caused by a barrage were 'less amenable to solution', believing that the changed intertidal and subtidal substrates, together with the associated turbidity and salinity regimes, would significantly affect the whole productivity of the estuary, from primary fauna and flora to birds and fish. He also emphasised that, since it was unlikely that the environmental effects of one tidal barrage would have little if any commonality with those associated with another estuary or barrage site, it was necessary 'to consider each tidal barrage on its own merits'; 'the environment of each estuary is unique', he argued. Nevertheless, he concluded that the information available in respect of the Severn did not suggest that a barrage 'would, on balance, necessarily have an adverse influence on the ecology of the area it would affect, though this depends to a large extent on the regularity with which levels in the basin are permitted to vary'. Even with further evidence, Shaw was of the opinion that 'all the evidence will be equally convincing on all topics and to all people'.

Since Shaw's 1986 pronouncements, many other environmental and ecological studies have been completed. The results of investigations by Webb, Tinkler, Little, Mettam and others are detailed in Ref 277, where the subjects of water quality, drainage, biological effects, intertidal, eco-systems, salinity and turbidity are fully assessed. Possibly one of the most practical studies was undertaken by Firth, when 'Pollution' was studied in considerable detail. He concluded that there were no precedents for the effect of a tidal barrage on the degree of pollution in the aquatic environment. Although many investigations had been made of the ecological effects of impounding fresh water behind dams, little had been attempted in respect of two way flows of water of varying salinity via a barrage structure. Firth was particularly concerned with the barrage effect on oxygen levels which had yet to be established in detail, pointing out that estuaries are usually channels for the release of sewage, usually untreated. 'Swift scouring, high tidal range and high oxygen levels were relied upon to deal with this problem'. The presence of heavy metals in solution, adsorbed on the surfaces of sedimentary particles or chemically combined with other material' required further assessment in view of possible barrage effects. This aspect was also emphasised by Towner in respect of the Mersey barrage (283), his Paper pointing out that the 'Mersey estuary presently has poor water quality as a result of the large number of domestic and industrial effluent discharges it receives'. He also identified that 'significantly elevated concentrations of a number of potentially toxic trace metals and organic micro pollutants (exist) in the water column, sediments and biota'; indicating that a barrage would reduce the degree of interchange of water between the estuary and the expanse of Liverpool Bay. The 'flushing time' of the estuary would be significantly increased, he believed, reducing the salinity of the estuary and increasing its toxicity. He concluded that the effect of a barrage on the estuary's environment and ecology would be significant but there would also be 'positive effects' as well as impacting ones. Consideration would need to be given to 'specific conservation measures as part of a management plan, to further reduce impacts'.

Hydraulics Research, a company specialising in barrage and barrage closure issues and with detailed understanding of the many hydraulic factors influencing the type of structure, its mode of operation, tidal flow, sedimentation, water quality and other aspects of tidal station operation have been involved with or been responsible for many of the studies reported previously (284). They continue to be concerned with the on-going studies at both the Severn and the Mersey estuaries; 'much work remains to be done'. When considering the environmental impact of a barrage project, it is necessary to remember that the electrical output will, over its working life, save not only considerable amounts of fossil fuel (equivalent to perhaps 700-800m tonnes of coal over the lives of the Severn and Mersey barrages) but would also eliminate the colossal amounts of gaseous and other pollutants resulting from the combustion. A tidal station produces no toxic emissions or wastes and, importantly in view of earlier comments, is unlikely to have any significant visual impact, particularly if the electrical connections to it are undergrounded.

Apart from possible environmental impacts which have already been identified, the main problem area with a generating barrage concerns the inevitable reduction in tidal range behind the barrage, particularly affecting wading bird life and with the attendant possibility of increased sedimentation difficulties due to reduced current flow. This latter point has been of considerable concern to the ports and the shipping interests as earlier remarks in this work have confirmed. But, as Laughton (285) has affirmed, 'the reduction in tidal range and currents within the enclosed basin are seen as highly beneficial to the development of water-based activities'. In addition, (and as identified by Hooker (273) a road crossing added to the barrage construction, as undertaken on the Rance project, involves comparatively little additional cost but can bring considerable eonomic benefit to the region.* The favourable use of a barrage for flood

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* It is worthy of mention that the construction of a second Severn bridge has recently been authorised at a cost of £300m. Moreover, David Hunt, who, in

control of the upper reaches of an estuary has already been noted. Shaw had a point when he remarked that 'the skill (of obtaining barrage acceptance) is in achieving the compromise between the options available and their economic penalties'. It is surely a case of 'paying your money and taking your choice'. In a previous section, mention was made of the possibility of assessing the environmental costs associated with fossil-fired generation in order better to assess the benefits of tidal (and other) 'environmentally friendly' forms of electricity production; i.e. a form of 'environmental accounting'. The problem of environmental evaluation is, however, a difficult one. For example, how does one assess the cost of miners' lives, the effect of their loss on families, of acid rain damage to buildings, forests; the destruction of the countryside by pit-head workings and spoil-tips? How do or would such costs compare with the damage due to oil exploration and exploitation, oil spills and the inevitable loss of human life? What is the global damage of such activities likely to be, can it be costed and how does one attribute the proportion of 'blame' to individual countries? Obviously very complicated and on-going studies in experimental design would be required, the 'techniques employed would vary in complexity, data are not readily available', while 'considerable bias may be applied both as a result of the method of questioning and by the evaluators of such studies. (287). In confirmation of this latter point and as quoted earlier, a public opinion poll commissioned by Greenpeace has purported to indicate that some two thirds of the UK's electricity customers would pay 'an additional £7/annum on their electricity bills so that renewables would provide ten per cent of electricity needs by the turn of the century'. (sic).

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1986 as the Parliamentary Under-Secretary of State for Energy, opened the ICE Tidal Power Symposium, has already laid the inaugural stone.

The European Commission (EC) has given expression to its general policy towards renewable energy sources in several Regulations and Recommendations - its Communication of February 1990 providing 'further clear encouragement to energy sources which will diversify the Community's energy supplies and contribute to limiting emissions into the atmosphere from fossil fuel combustion'. An additional communication, still under discussion, intended to limit carbon dioxide emissions and to improve energy efficiency was issued in 1991 (288), which proposed strengthening the Community's renewable energy programmes and introducing a combined carbon/energy tax which would encourage switching to renewable sources of energy by exempting them from it. The UK Government's own attitude to renewable energy sources is to 'stimulate their exploitation wherever they have prospects of being economically attractive and environmentally acceptable'. Its view is set out in detail in 'Renewable Energy in the UK - The Way Forward' (296). The UK policies on the subject are also embodied in the Electricity Act of 1989 and the Environmental Protection Act of 1990. The Electricity Act of 1989 empowers the 'Secretary of State to make orders requiring Public Electricity Suppliers to obtain electricity from a specified capacity of generation plant supplied by renewable electricity sources'. This requirement is known as the 'Non-Fossil Fuel Obligation' (NFFO), which, until it runs out in 1998 (as presently proposed) allows premium electricity prices to be paid for energy generated by different technology bands. The price presently paid for Hydro-Electricity (Tidal energy is not so identified) is 6p/kWh. The NFFO obviously goes some way towards offsetting (subsidising) the non-identified environmental costs of fossil-fired generation; its application is necessarily crude and must, in reality, relate to the 'size of the obligation', i.e. the declared net capacity of each technology band and of the total net capacity itself. Nevertheless the NFFO is a step, albeit a small and temporary one in support of renewables. The EC proposal to introduce a carbon-energy tax is, in itself, an admission of the difficulties involved in penalising individual methods of electricity generation for their share of any damage, pollution, present and future, caused to the environment.

The broad proposals being floated at present in respect of an oil related carbon tax include the imposition of three dollars on each barrel of oil imported from 1993, with an additional one dollar increase per annum until the year 2000. This burden has been estimated by the oil industry to equate to an increase in Community revenues of around £45000m/annum. At a recent World Energy Council congress in Madrid, the General Secretary of the Organisation of Petroleum Exporting Countries (OPEC) is reported to have said (289)' .... we suspect that the tax is not for environmental purposes but more for the collection of increased revenues'. He went on, 'OPEC ... welcomes measures taken to secure a cleaner .... environment but we deplore the politicisation of the issue and the imposition of measures based on questionable scientific evidence and prejudicial intentions'. '... Is global warming indeed taking place? And, if so, is it due - in part, in entirety or indeed at all - to fossil fuel burning?' The Chief Executive of British Petroleum endorsed these comments, stating that he was not against taxes as such, 'but I do object when taxation is justified on spurious or dishonest grounds, adding 'how many of the so-called environmental taxes are merely an excuse for raising money ... or for protecting one fuel against another'. He urged the use of 'market-related instruments' and not taxation 'to improve the environmental record of the energy industry'. 'Investment cannot take place', he claimed, 'in industries whose profitability is destroyed by regulation' (sic) 'or by taxation or by consumers whose personal wealth suffers the ravages of taxation or of non-existent economic growth'.

No doubt the hearts of coal-mining and electricity board executives would have warmed to such appeals; possibly consumers themselves would have some sympathy with the views expressed.

It is against the backdrop of the sentiments expressed in this Chapter that the modified environments and ecologies which would be induced by the generating barrages proposed particularly for the Severn and the Mersey continue to be assessed. The impact of such issues on the pseudo-economics used to evaluate the worth of the barrage schemes themselves will be evident.

And finally it has yet again to be re-iterated that the La Rance project was constructed without any prior environmental assessment. 'The new pattern of pool (basin) levels has improved conditions for people living on the shores of the pool as regards flooding, yachting etc. and has effectively turned the estuary into a lake' claims Charlier (281). The method of construction of the Rance project, (by cofferdam), necessitated the temporary closure of the estuary; environmental specialists admit that the 'quality' of the 'new' estuary is not less than that of its predecessor. In this context and as confirmed by Charlier (281) and Shaw, it is nevertheless important to note that the Rance River does not transport significant volumes of sediment; moreover, the river current is small compared with that due to tidal movement. As a result, no basin siltation is likely. Such 'easy' conditions do not of course apply to the Severn estuary; hence the necessity, as many contributors have pointed out, to give adequate consideration to this problem.

## Chapter 7

## Concluding Remarks

This dissertation has distilled the important parts of much of the major literature pertaining to the subject of tidal barrages and their application for electricity generation. Although its basic terms of reference related specifically to the UK, the assessment has strayed occasionally from these shores to ensure that the account is as complete as possible. Inevitably, however, attention has concentrated particularly on the estuaries of the Severn and the Mersey.

It will have been noted, possibly with some surprise, that the dissertation contains little detailed review of what might be termed 'pure engineering' of a barrage. It is, however, a fact that apart from a few publications, identified in the thesis, the general literature is not overendowed with engineering detail. The reader will therefore search in vain for comparisons of cofferdam construction (as employed on the Rance scheme) with steel/concrete caisson flotation and of straflo turbines with the bulb design. These aspects, together with related issues of sluice size and design, turbine runner diameter, submergence and control are all matters of specific engineering judgement, dependant upon barrage location and open to modification or alteration and to personal opinion.

As perusal of the vast literature progressed, it became evident that, from an engineering point of view at least and irrespective of the barrage design or of the installed equipment, the ability within the country to provide a tidal generating barrage across any UK estuary (or elsewhere) was not in doubt. Even the first identified Severn proposal agreed the technical feasibility of the barrage project although this dissertation casts doubt as to the necessary technical expertise and manufacturing capability being available to complete the project successfully. Later investigations of the Severn estuary 'merely' confirmed the engineering practicality of constructing a tidal barrage, a conclusion which has more recently been endorsed as a result of a similar exercise associated with the Mersey estuary.

It is also evident from the detailed analysis of the reports of the various committees, Symposia and like bodies which has been undertaken for the purpose of this thesis that the economists involved were much less convinced of the viability of any barrage generation scheme and, moreover, they have remained so. Politicians have seized upon such doubts to delay any agreement, incidentally making political capital by heeding the entreaties of vested interests. The economic justification for the construction and operation of a tidal barrage has been further eroded as a result of the transfer of the electricity supply industry from the public to the private sector with its demand for increased returns on capital invested.

But it is the more recently confirmed strength of argument which has emerged from the many interests concerned with the environment and the ecology of the estuaries identified with barrage generation projects which has effectively halted any possibility of barrage construction for the forseeable future. Many investigations into related subjects have been identified as necessary, even vital, before any agreement to proceed with a construction on any estuary can be made. As time progresses other, no less important investigations will no doubt be identified and further, if limited, Government money will be injected to keep the projects alive. As Wilson has stated (290) 'Am I being too cynical thinking that after the next three years, there will be another little grant for another three years - just enough to keep the engineers quiet but not so much as to actually get things done?'.

Clare (291) highlighted the time scale likely to be involved when he confirmed the importance of 'solving the environmental issues'. 'Nor must the time scale that is necessary for such work be underestimated', he stated; 'For the Severn scheme a period of six years more will be required to complete the environmental analysis, the planning and the detailed design. Even for a small scheme it is doubted that the period could be sensibly reduced below four years'. Unfortunately, that statement was made in 1986; many more years must now elapse, as a result of recent environmental decisions, before any conclusion as to the future for (Severn) tidal power can be drawn. Moreover, Clare's obvious earlier optimism for the Severn project must have been severely tested as a result of the economic issues highlighted by the privatisation of the electricity supply industry and by the continuing and indeed increasing environmental demands being made on his Group. The sharp comments and criticisms voiced by the Select Committee on Renewable Energy cannot have gone unnoticed by either Clare or McCormack (the MBC Manager).

But any lingering hopes they may have had for the future of their projects must have finally been dashed by the Government's reply to the Report prepared by the Select Committee.

'Tidal Barrages', the Government avers, 'are not currently amongst the most cost effective of renewable technologies when considered in terms of revenue from electricity and it is difficult to see how they could be financed in the near future'. (309).

On such a basis, doubts for their future must be uppermost in the minds even of the promoters of the much smaller Duddon and Wyre tidal schemes.

McLaughlin (292) had a valid point when, at the 1986 ICE Symposium, he speculated that 'if France had a site as favourable for tidal power as the Severn Estuary, it would probably have been completed ten or fifteen years ahead of us. Promoters, contractors, financial institutions, generation boards and the Government should reflect on the truth of this and why it should be'. Or maybe, as the author has suggested (293), 'although many experts have produced literally millions of words reviewing the progress made to harness this undoubted source of green renewable energy', no one of real standing and authority truly wants a tidal generating barrage constructed in this country. But the last words of this dissertation certainly must be those written by Norman Davey, (295) the 1920's proponent of Tidal Power who, some eight years earlier had been vilified for his equally 'contentious' views on the subject of the 'Internal Combustion Turbine'. 'In all places and at all times', he wrote, 'in the precincts of Westminster, in the lanes of the City, from the pulpits of our academies, the eminent, the learned (and the mass of technical opinion) assure me that the gas turbine is necessarily inefficient and that tidal power is uneconomic'. The Davey inspired gas turbine is assuredly successful; in the due course of time it is possible that his views of tide generated power will be equally applauded in this country.

## Chapter 8

## Proposal For Further Work - Possibilities for PhD Study.

As has been identified in this thesis, the intermittent and variable nature of tidal barrage produced electricity has been emphasised by many contributors to the literature. Early barrage projects in this country proposed to minimise this shortcoming by utilising some of the barrage generated power to pump water to an upper storage reservoir, this to be used for generation during periods of low or nil output from the barrage itself, thereby smoothing the electrical output from the overall scheme to a lower but more continuous 'firm' level. The low level of firm power produced by their proposed barrage was remarked upon by the 1981 Bondi Committee, which commented that only 1000MW of the installed 7200MW of generating capacity could be considered firm.

Consideration of the Admiralty Tide Tables confirms, however, that high water occurs at different times around the coast of the UK. For example, high tide occurs in the Solway Firth some two hours after that at London Bridge, while high tide at the Mersey is further delayed. On the other hand, high water at the Severn estuary occurs five/six hours before that at London Bridge. Other regions have different tidal constants.

It follows from the foregoing that, by judicious selection of barrage sites of differing tidal constant, a continuous (firm) source of supply could be obtained from tidal generation stations. It would be the purpose of a further investigation to identify environmentally suitable barrage locations, to evaluate their individual and combined electrical outputs, to determine the methods of interconnection to be used, to assess possible capital costs, together with the effect on revenue of the cost of money, transmission losses and thereby to make an estimate of the firm power likely to become available, together with its unit costs, from an integrated UK wide tidal barrage project.

Appendix A

## Brief Biographical Details of People Mentioned in Thesis

| | |
|---|---|
| BALDRY Hon. A.B. | Parliamentary Under-Secretary, Dept. of Environment since 1990. |
| BENN Rt. Hon. A | MP for Chesterfield since 1984.<br>Minister of Technology 1966-70,<br>Secretary of State for Industry 1974-5<br>Secretary of State for Energy 1975-9. |
| BONDI Sir Hermann | F.R.S. Chief Scientist - Dept. of Energy 1977 - 1980. |
| CHARLIER R.H. | Erstwhile Professor, Northeastern Illinois University. Author of 'Tidal Energy'. |
| CLARE R. | Chairman - STPG Management Board. |
| DAVEY N.<br>1888-1934 | MA Cantab. Author of many travel and fictional books. Author of 'The Gas Turbine' and 'Studies in Tidal Power'. Associated with the Civil/Hydraulics Firm of Hathorn, Davey & Co, Leeds. |
| ENGLAND G (Glyn) | Chairman of SWEB (South Western Electricity Board) 1973-77, Chairman of CEGB 1977-82. |
| FITZPATRICK J.B. | Chief Executive of Mersey Docks and Harbour Board 1977. Chairman, Merseyside Enterprice Forum 1988-9. |
| GEDDES Sir Eric C.<br>1875-1937 | Member of War Cabinet 1919.<br>Minister of Transport 1919-21.<br>President of Federation of British Industries 1923-4. |
| GIBSON Professor A.H.<br>1878-1959 | Lecturer in Engineering and Hydraulics.<br>Emeritus Professor of Engineering - University of Manchester.<br>Member of Board of Trade Commission on Water Power in British Isles. |
| HESELTINE Rt. Hon. M. | MP for Henley since 1974.<br>Secretary of State for Environment 1990-2.<br>President of Board of Trade 1992 - |

| | |
|---|---|
| HOWELL Rt. Hon. D. | MP for Guildford since 1966.<br>Minister of State - Dept. of Energy 1974.<br>Secretary of State for Energy 1979-81. |
| HUNT Rt. Hon. D.J.F. | MP for Wirral since 1983.<br>Parliamentary Under-Secretary of State, Dept. of Energy 1984-7. |
| MOORE-BRABAZON J.T.C.<br>(BRABAZON OF TARA)<br>1884-1964 | MP for Rochester 1918-29. MP for Wallasey 1931-42.<br>Parliamentary Private Secretary to Minister of Transport 1923-24, 1924-27.<br>Minister of Aircraft Production 1941-2.<br>Member of Lord Weir's Advisory Committee 1923. |
| MOYNIHAN Hon. C.B. | MP for Lewisham East until 1992.<br>Parliamentary Under Secretary of State, Dept. of Energy 1990-92. |
| SNELL Sir. J.<br>1869-1938 | Chairman of Electricity Commissioners 1919.<br>Member of Advisory Council for Scientific and Industrial Research. President of IEE 1914-15.<br>Chairman of Water Power Resources Committee of Board of Trade 1921. |
| VAUGHAN-LEE A.G.<br>1862-1933. | Engineer and Professional Soldier. |
| WAKEHAM Rt. Hon. J. | MP Colchester South since 1983.<br>Secretary of State for Energy 1989-92. |
| WEIR Viscount W.D.<br>1877-1942 | President G & J Weir Ltd.<br>Scottish Director of Munitions 1915-16.<br>Member of Air Board 1917-18.<br>Director General of Aircraft Production 1918.<br>Director General of Explosives - Ministry of Supply 1939. |
| BAKER A.C.<br>(Dr.) SHAW T.L.<br>(Professor) WILSON E.M. | 'Workers'/Authors in the Field of Tidal Power over many years. |

## Appendix B

### The Generation of Electricity From The Tides

In its most simple form, a tidal generating barrage consists essentially of a dam (or 'barrage') constructed across a sea-connected inlet in which one or a number of turbines are installed. These can be operated to provide electricity as a result of the difference in head between the water above and below the barrage.

Like any hydro-electric project, the volume of water passing through the turbines per second is a valuable indication of the energy output of the scheme, while its economic viability depends greatly upon the capital employed in its construction and upon its method of financing.

It follows that, in practice, a tidal project has the greatest likelihood of being an economic proposition if (a) the mean tidal range R available is large and (b) the area A of the impounded basin is great per unit length of barrage construction. These various aspects are examined in further detail below.

(a) The Tide - Assessment of Mean Tidal Range (See Fig 3).

The theory of the tides is complex. Many learned treatises have been written on the subject (1) (298). This Appendix is merely intended to discuss the subject sufficiently to provide information relevant to the use of the tides for barrage generation purposes.

The tidal phenomenon is the periodic movement of the sea (known as the 'astronomic tide'), induced mainly as a result of the effect on the earth's surface of the gravitational forces due to the sun and the moon. As may be deduced by the application of Newton's Law of Gravitation, it is primarily the moon which is the source of our tides; nevertheless, the force due to the sun is considerable, producing approximately fifty per cent of that attributable to the moon.

Since, as a result of their respective orbits, the earth, moon and sun do not remain in the same relative positions one to another, it follows that the gravitational forces operating on the earth's surface vary periodically. When the sun, moon and earth 'line-up' (or are 'in-phase') as at new or full moon, the total gravitational pull is at its greatest and the highest or spring tides occur. When the sun and moon are at right angles (or in quadrature) relative to the earth, as at first and last moon quarters, their combined pull is at a minimum and the lowest or neap tides occur.

It will be evident that the height between successive high and low water levels, known as the tidal range, will vary throughout the lunar month, during which two spring and two neap tides will occur. A similar variation will also occur as the seasons advance; the highest spring tides take place in the equinoxes of March and September, when the moon is closest to the earth, while the lowest neap tides occur in June and December when the moon is furthest from the earth.

The tidal range in mid ocean (the 'equilibrium tide') is the result of the various forces identified; a range of approximately 0.5m has been estimated to apply (298). The actual tidal range occurring at a particular locality, however, depends upon the coastal configuration, the rate of reduction of the depth of the sea in the region and upon the occurrence or otherwise of a phenomenon known as 'resonance'. This latter aspect is caused by the natural frequency of the water column in an estuary or bay being similar to, or a close multiple of, the frequency of propagation of the incoming tide. The phenomenon, which is analogous to that of the voltage increase effect in an AC series connected LC circuit, can create a much increased tidal range than would otherwise be anticipated. The Bay of Fundy experiences this effect while, in this country, the Severn estuary, with a mean tidal range exceeding nine metres, is a classic example of tidal range resonance enhancement.

(The mean tidal range, the arithmetic mean of the spring and neap ranges for each lunar cycle, is used for the assessment of the tidal energy available).

It will be evident that the Mersey estuary, with its mean tidal range of seven metres, also exhibits a significant level of resonance enhancement; other estuaries on the West Coast are also affected to a lesser degree.

(b) Area of Basin - Barrage Length

Both the estuaries of the Severn and the Mersey lend themselves to the reasonably efficient enclosure of a large area of water per unit length of barrage. Other, smaller estuaries suitable for the purpose have been identified elsewhere in this thesis.

It is evident, however, that the 'specified' requirements for economic barrage produced electricity generation, as identified previously, are likely to be best complied with on the estuaries such as the Severn and the Mersey.

(c) Operation of a Tidal Barrage

It is possible to operate the turbines of a tidal barrage in either the ebb mode, the flood mode or, depending on the design of turbine, in both modes.

(i) With the ebb method of generation (See Fig 4) the barrage gates or sluices are opened to allow the basin to fill during the incoming tide. At high tide, the sluices are closed and, after a suitable time interval to provide sufficient head for efficient turbine operation, the impounded water is discharged via the turbines into the sea. The sluices are then re-opened, the basin refilled and the cycle repeated. Two periods of generation are obtained per day as indicated in Fig 4.

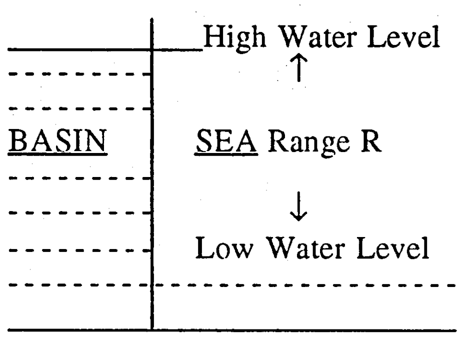
(ii) With the flood method of generation (See Fig 5) the barrage remains closed until a suitable head between the sea and the water in the basin has been achieved to provide efficient operations of the turbines which are operated until the effective head between sea and basin level has become too small for generation efficiency. The sluices are then opened to complete the emptying of the basin and the cycle repeated. Again, two periods of generation per day are achieved.

(iii) Two-way generation (See Fig 6) combines ebb and flood utilisation as part of a two way generation cycle; an arrangement which is included in the operation of the La Rance barrage. The scheme requires the use of reversible turbines which in turn involves a loss in overall efficiency of the machine/water passage design. While two way working may produce more net energy from the barrage than a simple ebb generation arrangement, the more expensive reversible turbines result in an increase in kWh costs of about ten per cent compared with the simple ebb generation scheme (132). The four pulses of power output per day will be noted.

(iv) The process known as flood pumping (See Fig 4), used with ebb generation, has comparatively recently been suggested for incorporation in the Severn and Mersey barrage projects. This concept requires the reverse-pumping-operation of turbines at or soon after high tide (when the sluices have been closed) in order to 'top-up' the water level in the impounded basin and thereby increase the resultant head available for ebb generation purposes. The use and efficiency of flood pumping is essentially one of overall scheme economics and depends upon the attractiveness of the supply tariff and thereby the cost of electricity required for the pumping operation. 'Off-peak' electricity supply would not, as a result of the lunar controlled, variable and intermittent nature of tidal generation, necessarily be available for pumping purposes.

In spite of economic shortcomings, there may be benefits which are not directly related to energy production and efficiency. The increase in water levels at docking facilities within the basin area as a result of flood pumping may well have been one reason for both the Severn and the Mersey barrage schemes to include this technique in their proposals. The La Rance barrage is equipped with flood pumping facilities.

(d) <u>The Energy stored in a Tidal Barrage Scheme</u>



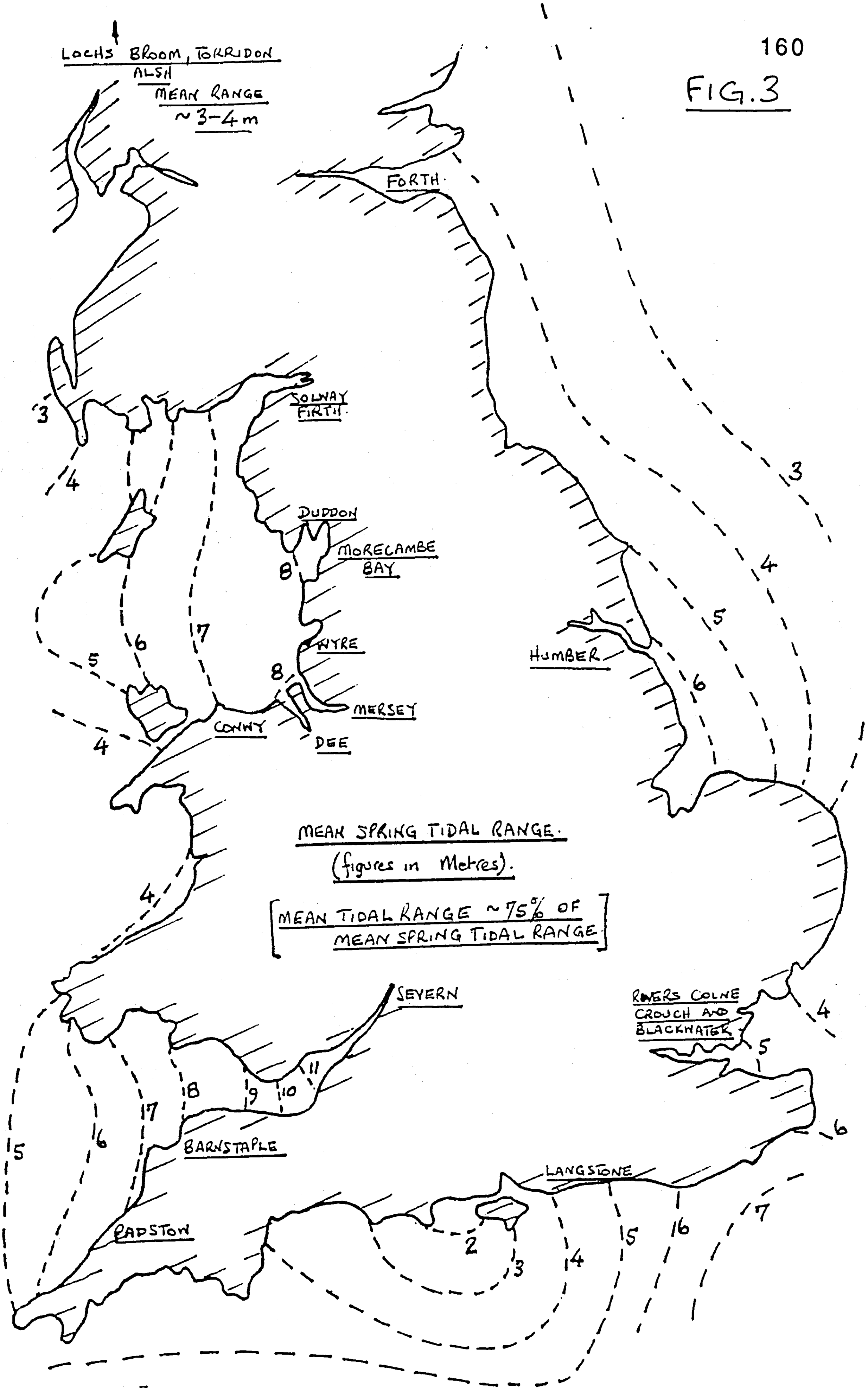

Suppose the surface area of the BASIN to be A and assume that it remains constant throughout its depth.
Then Mass of water in Basin
= ARS where S is specific weight.
Centre of Gravity of mass of water= $R/2$
Then Potential Energy in Basin

$$= \frac{ARSR}{2}$$

$$= \frac{S}{2} AR^2$$

i.e. The basin energy is proportional to its <u>Area</u> and to <u>Range</u>$^2$

FIG. 3




CO-TIDAL LINES AROUND THE UK.

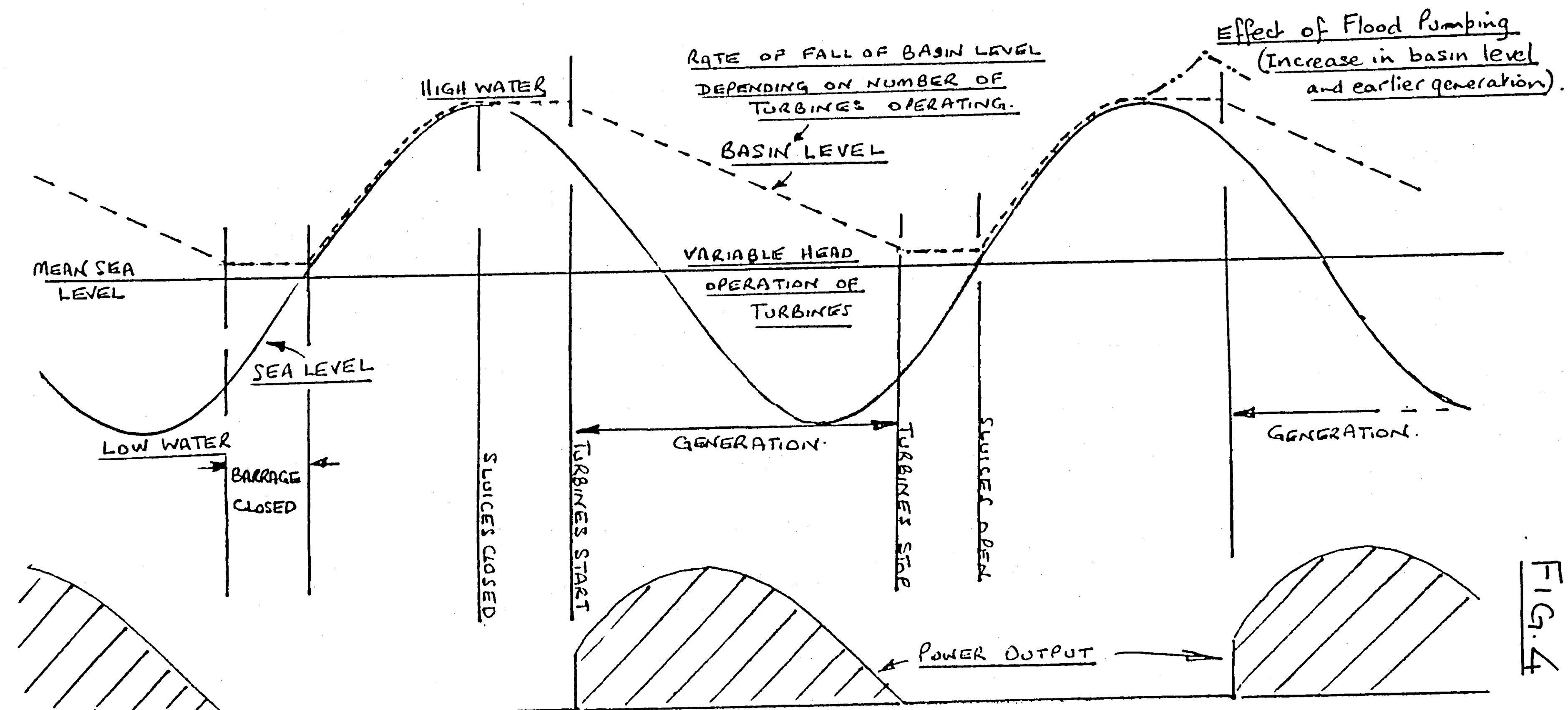
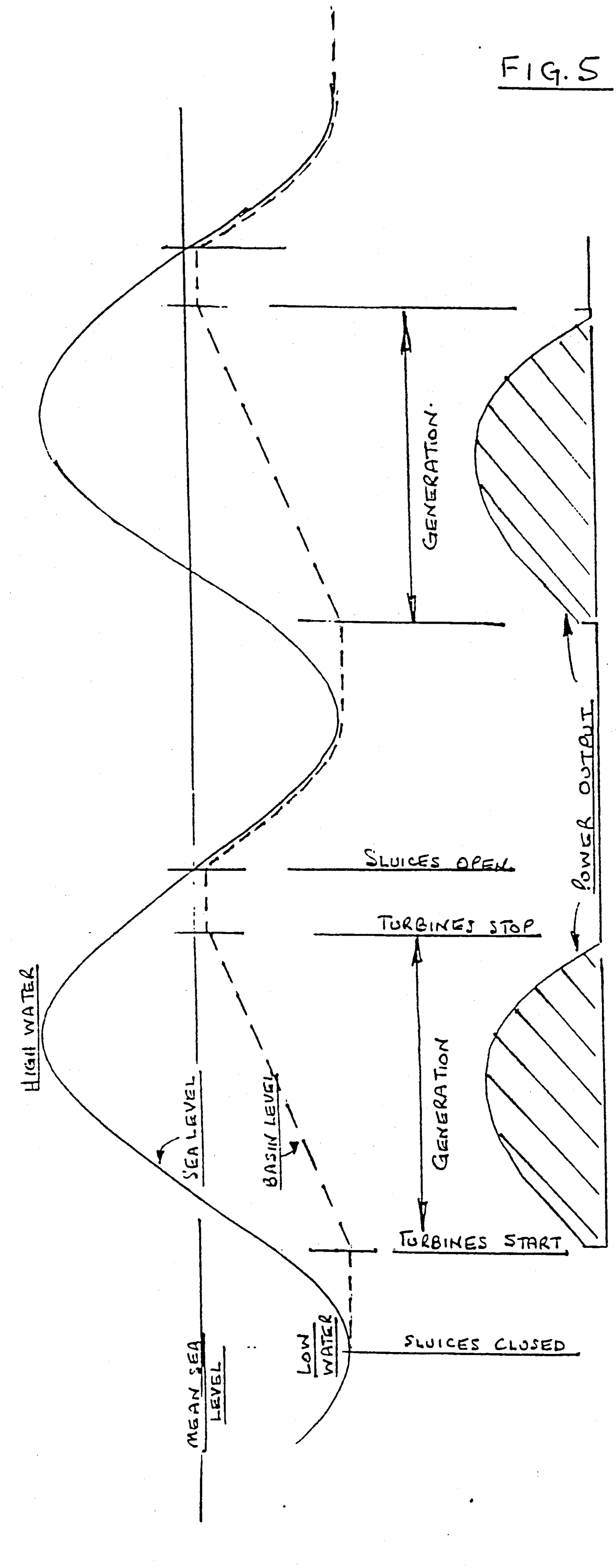



FIG. 4

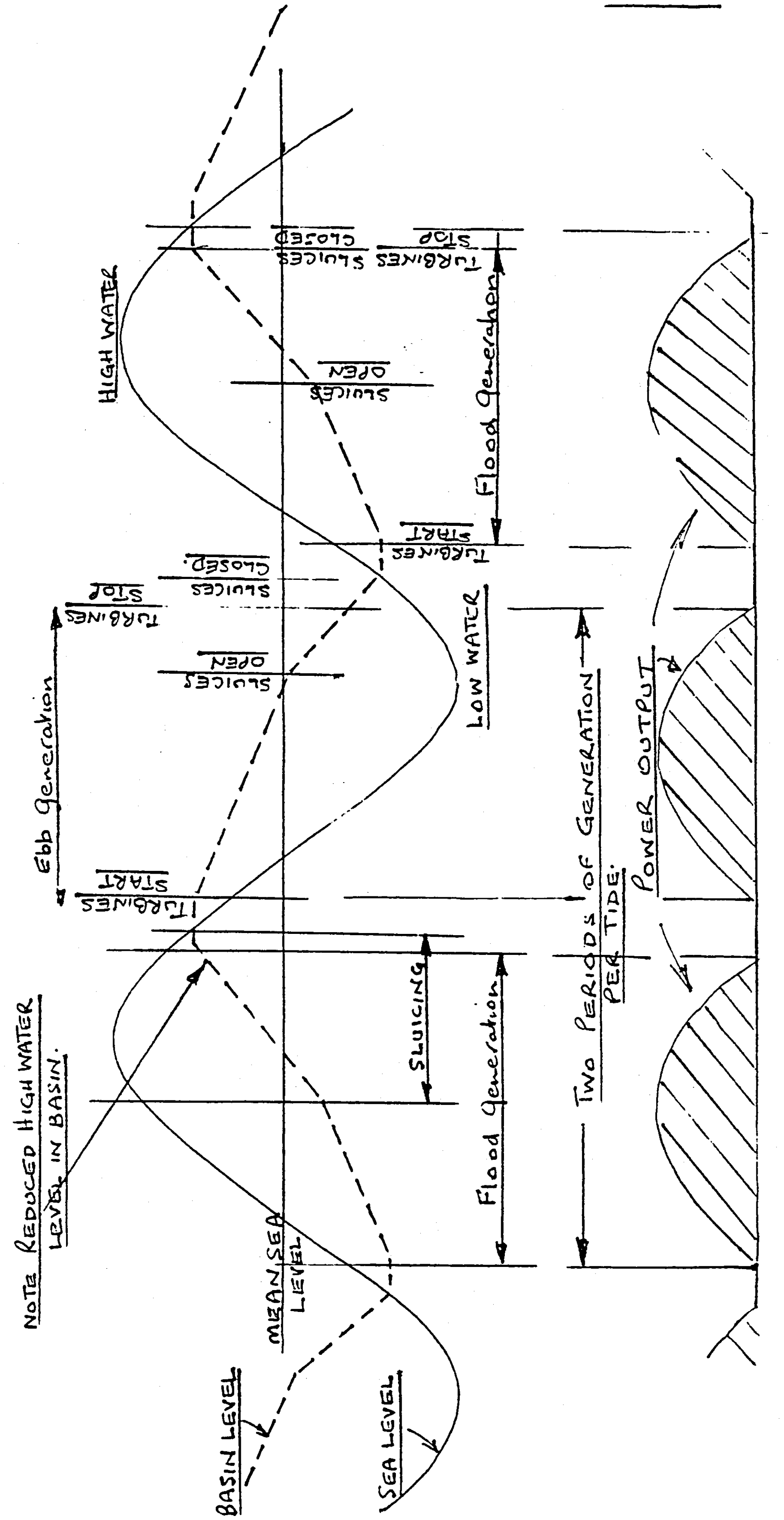
CHARACTERISTICS OF EBB GENERATION

FIG. 5




CHARACTERISTICS OF FLOOD GENERATION.

FIG. 6




CHARACTERISTICS OF TWO-WAY GENERATION.

**Appendix C**

## The Relationship of Tidal Power to other Renewables

The exploitation of renewable sources of energy involves the utilisation of energy flows which occur in the natural environment and which are continually being replaced by natural processes.

The sun provides the natural energy source of hydro power by its evaporation of water, subsequent rainfall and increased river flow. Similarly, by creating thermal gradients, the sun is responsible for wind power and for wave power. It is the obvious source of solar power.

As explained elsewhere in this thesis, tidal power is the result of the interaction between the sun and moon's gravitational forces and the earth's rotation. Geothermal energy exploits the increase in temperature which occurs as a result of the progression from the earth's surface toward its core.

Biofuels such as firewood, straw, domestic and industrial waste and specially grown 'energy crops' are also, but less directly recognised, solar provided sources of energy. They are not, however, 'renewables' in the strict sense of the term since their fuel is destroyed by burning, either for direct use or by suitable conversion, to produce motive power and/or electricity. Land fill gas, largely methane, is the result of the fermentation of waste products at refuse sites or farm septic tanks, which can be burned directly or used to fuel gas engines to provide electricity.

Like tidal power, most renewable sources are of low density and capable only of intermittent outputs. Some, like wind power, are also unpredictable in the amount of power they can produce at any time; i.e. their 'firm powers' are very low. As a result it is necessary, for the foreseeable future, that the firm power of a conventional electricity supply system, with its interconnected "Grid' capacity, is retained to compensate for the varying and intermittent electricity supply which may be obtained from 'renewable' generation. As stated elsewhere in this dissertation, the controllers of the UK Grid system have agreed that a renewable generation capacity of 10GW or thereabouts (some 20% of the present firm capacity connected to the national busbar at any one time) can be absorbed without undue concern for the system's overall stability. The potential for renewable energy in this country at the present time is summarised below.

| Technology | Estimated Energy Potential TWh/annum | Power Potential GW |
|---|---|---|
| Wind power - on shore | 45 | |
| Wind power - off shore | 140 | |
| Tidal Power | 54 | 24 |
| Wave Power | 50 | |
| Additional Hydro | 2 | |
| Solar | 14 | |
| Biofuel. Waste Products | 44 | |
| Energy Crops | 40 | |
| Geothermal | 210 | |

Data taken from 'Renewable Energy in the UK'. ISBN 0 85296 527 3
Institution of Electrical Engineers - March 1992

It should be noted that the present level of electricity consumption in the UK approximates 250TWh/annum, with a winter peak demand of 50GW.

Charlier indicates that, in world terms, the possible power levels available from the sea are enormous, with tidal and wave sources appearing low down on the overall list of estimated power outputs.

| Resource | Estimated Power Availability $10^6$MW (TW) |
|---|---|
| Thermal Gradients (OTEC) | 40,000 |
| Salinity Gradients | 1,400 |
| Marine Bio Conversion | 10 |
| Tidal | 5 |
| Ocean Waves | 3 |
| Off-shore Winds | > 20 |

Data taken from Tidal Energy - R.J. Charlier P7

Notes:-

The solar energy absorbed by the oceans is immense; estimates suggest that as much as 80 billion MWh may be absorbed on a daily basis.

OTEC

The Ocean Thermal Energy Converter (OTEC) is simply a turbine plant suspended in the sea and designed to utilise the temperature difference between the ocean surface and its depths to boil a fluid such as propane to operate a vapour turbine. The OTEC process was considered in detail by the French who in 1952 constructed a plant at Abidjan (Republic of Ivory Coast). Major mechanical problems were encountered as a result of wave action on the huge suspended vessel and its adduction (cold water) pipe. Charlier asserts that the plant 'went out of business due to the above plus the fact that conventional generation produced cheaper electricity .....'.

Salinity Gradients

Using as a source of energy the salinity gradient between fresh and sea water, small batteries have been manufactured which, when immersed in the sea, provide low level power for emergency situations. Wicks and others (303) have examined the possibilities for large scale generating plants based on the principle. Problems have occurred at the permeable membrane separating the fresh and 'salt' water, due to concentration polarisation and bio-fouling which, together with the cost of the membrane itself and the expected damage to aquatic life, have cast doubts as to the ultimate success of this type of plant. Proponents of such schemes are, according to Charlier, 'confident of their (eventual) implementation'. (304).

Marine Bio-conversion

Some of the enormous solar energy impinging on the surface of the oceans can be retrieved, as identified by the American Gas Association and others (305) (306), by the harvesting of 'kelp' (brown algae) and its subsequent conversion into methane and other useful residues. As with many other forms of renewable energy, large scale biomass production at sea appears to face major problems in respect of required capital and in operating the extensive kelp farms (several thousand hectares in area) necessary to make the method a feasible economic proposition.

Tidal Currents

A considerable literature exists on the subject of tidal currents. There are suggestions that tidal current technology and exploitation may be far less expensive than tidal barrage generation. (299). The French in particular have given much consideration to this method of sea power extraction (300) (301). Musgrove has indicated (299) that the annual average power released by the currents through the North Channel of the Irish Sea is equivalent to 3.6GW; 6.1GW is the estimated power of the tidal current through the Pentland Firth. The 'most straightforward' system of power extraction would be the underwater equivalent of the windmill, with vertical axis rotor. With a rotor in excess of one hundred metres diameter, blades fifty metres long and a tidal current of four knots, an output of ten megawatt could be expected. 'Farms' of several rotors feeding a central servicing facility have been proposed. (302).

**APPENDIX D**

## Comparison of the Various Severn Schemes

## (Planned Capacity/Construction)

| Date of Scheme | Planned Capacity | Construction Period | |
|---|---|---|---|
| | GW | Years | GW/annum |
| 1920 ) | 0.52 | Several | - |
| 1933 ) English | 0.914 | 15 | 0.06 |
| 1945 ) Stones | 0.80 | 8 | 0.1 |
| 1981 ) | 7.2 | 12 | 0.6 |
| 1985 ) Cardiff - | 7.2 | 9 | 0.8 |
| 1989 ) Weston | 8.64 | 9 | 0.96 |

Appendix E

## A Comparison of Quoted and Anticipated Capital Costs and Unit Charges Associated with Severn Barrage Proposals.

Applying information assessed from:- 'What Did It Cost The Day Before Yesterday'.

- Dr. Harold Priestley.

| | INCREASES | |
|---|---|---|
| | 1915-1945 | 1945-1990 |
| Wages and Salaries | Marginal | x 16 |
| RPI less Wages and Salaries | x 1.68 | x 14 |
| Fuel and Lighting | x 1.1 | x 11 |

it is possible to make some comparison of the capital costs and kWh charges quoted by the different Severn Barrage committees with those which would be anticipated on the basis of changes which have taken place to the RPI over the years. The following table summarises the comparisons.

| Year | Capital Costs £m. | | kWh Charges | |
|---|---|---|---|---|
| | Quoted | Anticipated | Quoted | Anticipated |
| 1920 (datum) | 28 | - | 0.5d | - |
| 1933 | 38 | 37 | 0.15d | 0.69d |
| 1945 | 47 | 47 | 0.20d | 0.88d |
| 1980 | 885* | 850-900 | 3.1p* | 3.15p |

(*Hooker figure 1982) (*Bondi figure 1980)

Although the quoted capital costs are in generally good agreement with those expected as a result of RPI changes, it is apparent that the unit costs quoted for 1933 and 1945 are very much lower than anticipated. The precise reason for this divergence is not evident from the literature, but Hannah (311,) confirms that, by 1947, electricity tariffs and prices were now out of line not only with competing fuels but also with the cost structure of the industry at post war price levels.

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