MERSEY TIDAL POWER

FEASIBILITY STUDY: STAGE 3

Civil Engineering (Power) Report

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Report prepared by:

URS Scott Wilson

Project Sponsors:

PEEL ENERGY

Northwest REGIONAL DEVELOPMENT AGENCY

WORKING TOGETHER FOR englandsnorthwest

www.merseytidalpower.co.uk

Prepared by	Reviewed by	Approved by	Verified by MTP Project Director
Nigel Somers Associate	**Chris Grant** Technical Director	**Mary Holt** Director	**Mary Holt** Director

URS Scott Wilson
Brunel House
54 Princess Street
Manchester
M1 6HS

Tel: 0161 907 3500

www.urs-scottwilson.com

Peel Energy Limited
Peel Dome
The Trafford Centre
Manchester M17 8PL

Tel: 0161 629 8200

www.peelenergy.co.uk

Project Background

In the face of current and anticipated issues of security of supply and climate change, the need to find local sources of renewable energy has never been more urgent.

The Mersey Estuary has one of the largest tidal ranges in the UK, making it one of the best locations for a tidal power generation scheme. It has the potential to make a significant contribution to the Government's target to secure 15% of UK energy from renewable sources by 2020.

A large scheme could deliver enough renewable electricity to meet the needs of a significant proportion of the homes within the Liverpool City Region, as well as beyond. Any scheme put forward will need to take into account the ecological diversity of the Estuary, which supports internationally important bird habitats.

Phase 1 Pre-Feasibility Study - 'Power from the Mersey'

Peel, in partnership with the NWDA set out to explore the potential, the impacts and the implications of utilising the Mersey Estuary's renewable energy potential for the benefit of the Northwest region.

The Mersey Basin Campaign gave its full backing to the work and a consortium of consultants led by Buro Happold was commissioned in July 2006 to undertake a 'pre-feasibility' Phase 1 Study.

The primary objective of the Phase 1 Study was to undertake a full and open assessment of the options available for the generation of renewable energy and to undertake a preliminary assessment of viability.

A number of potentially viable schemes were identified. The continued development of marine power technology means that others may also need to be considered as the project moves into the next phase.

Meeting 2020 Renewable Energy Targets

An overall timetable was defined to ensure the project supports the policy objective of contributing to 2020 renewable energy targets. The key milestones of the project include submission of applications for planning or other statutory consents by 2012 and commissioning of the scheme by 2020.

Phase 2 Feasibility Study

Peel Energy and the Northwest Development Agency are progressing the project in line with the principles for sustainable development. A feasibility study has been commissioned to assess the options and identify a preferred scheme to take forward for submission of a planning application.

The feasibility study has been led by URS Scott Wilson, EDF and Drivers Jonas Deloitte, and supported by RSK, APEM, HR Wallingford, Regeneris, Turner and Townsend, University of Liverpool, Proudman and Global Maritime.

The feasibility study has been undertaken in three stages as follows:

- Stage 1: Definition of project strategies, data gathering and gap analysis, and selection of long list of suitable technologies
- Stage 2: Appraisal of the long list of technologies and formulation and appraisal of scheme options to identify a shortlist
- Stage 3: Further refinement and appraisal of the short list of scheme options and selection of the preferred scheme.

The project has been pursued in an open and transparent manner, building on the consultation and stakeholder engagement started in the Phase 1 study. An extensive programme of stakeholder engagement has taken place through project advisory groups, consultation with statutory and non-statutory consultees and public consultation targeted during appropriate stages of the project.

Mersey Tidal Power Scheme Objectives

The objectives of the Mersey Tidal Power scheme are:

(a) To deliver the maximum amount of affordable energy (and maximum contribution to Carbon reduction targets) from the tidal resource in the Mersey Estuary with acceptable impacts on environment, shipping, business and the community either by limiting direct impact in the Mersey Estuary or providing acceptable mitigation and/or compensation;

and in doing so,

(b) To maximise social, economic and environmental benefits from the development and operation of a renewable energy scheme, including where appropriate:

- (i) the development of internationally significant facilities and skills to support the advancement of renewable energy technologies and their supply chains,
- (ii) improvements to local utility and transport infrastructure,
- (iii) improvements to green infrastructure and environmental assets,
- (iv) the development of a leisure opportunity and tourist attraction.

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Note on Terminology

This technical report uses a different naming system to the Stage 3 Feasibility Report to refer to schemes variants, as follows:

- IBv2a = A1.02a;
- IBv2b = A1.02b;
- VLHBv2a = A2.01a; and
- VLHBv3a = A2.02a.

If a lower case letter is not used, this is because the operating regime (as denoted by the lower case letter) is not relevant.

1 Introduction

1.1 Scope

1.1.1 This Stage 3 Civil Engineering (Power) report covers the evolution of design concepts for the various power schemes and locations considered in the Feasibility Study and the progression towards the identification of a preferred scheme. The concept development work undertaken in each of the three Feasibility Study stages was as follows:

Stage 1: Review of all available and emerging marine energy generation technologies and selection of technologies that are suitable for conditions in the Mersey and have the potential to meet project objectives;

Stage 2: The development of initial scheme options comprising combinations of selected technology and location to facilitate an initial appraisal of technical acceptability, consenting risk and financial viability; and

Stage 3: The development of further scheme options selected to address the findings of Stage 2 and present a basis for moving towards the preferred option.

1.1.2 This Stage 3 report summarises the work undertaken at Stage 1 and Stage 2 of the study and covers the options considered at Stage 3. A range of locations, layouts, technologies, and operating strategies has been developed in response to the constraints of navigation interests, ecological requirements and planning issues, and the requirement for a significant and viable source of renewable energy.

1.2 Stage 1 Studies

1.2.1 Stage 1 of the study was undertaken in October and November 2009. A wide ranging review of conventional and embryonic power generation technologies was undertaken and the technologies listed in Table 1.1 were identified for appraisal.

Table 1.1: Stage 1 Technology Options

<table>
<tr><th>Principle of Operation</th><th>Option</th><th>Concept</th><th>Description</th></tr>
<tr><td rowspan="2">Impounding of reservoir to develop maximum available head difference for power generation</td><td>Tidal barrage</td><td>Reservoir created by barrage across the estuary</td><td>Ebb generation, with or without pumping, or ebb and flood generation possible. Power generation using conventional horizontal axis plant.</td></tr>
<tr><td>Tidal lagoon</td><td>Reservoir independent from the estuary</td><td>Isolated or land connected reservoir. Possible multi basin configuration. Power generation using conventional horizontal axis plant. Ebb generation, with or without pumping, or ebb and flood generation possible.</td></tr>
<tr><td rowspan="3">Very low head barrage to develop limited head difference for power generation</td><td>Tidal power gate</td><td>Moveable gates fitted with a matrix of small axial flow turbines</td><td>Hydromatrix™ or StrafloMatrix™ system suitable for shallow water conditions. Gates can be lifted to provide free opening on the flood tide.</td></tr>
<tr><td>Tidal reef</td><td>New concept of low head barrage</td><td>Vertical axis turbines operating at a constant head difference of 2 m housed in caissons that would rotate if turbines are unidirectional.</td></tr>
<tr><td>Very low head turbine</td><td>New design of turbines enclosed in a partial barrage</td><td>New concept of very low head turbine that can be rotated to provide two way generation. Concept is intended to operate at a low head difference.</td></tr>
<tr><td rowspan="4">Open stream device operating in natural flow velocity conditions without impacting the tidal range</td><td>Ducted horizontal axis</td><td>Array of turbines placed where natural velocity is sufficient</td><td>Bi directional horizontal axis turbine in duct to reduce runner size, mostly with direct drive variable speed permanent magnet generator.</td></tr>
<tr><td>Unducted horizontal axis</td><td>Array of turbines placed where natural velocity is sufficient</td><td>Large diameter open stream turbine in natural velocity field. Bi directional operation can be provided symmetrical blade geometry or by rotating blades through 180 deg.</td></tr>
<tr><td>Vertical axis</td><td>Array of turbines placed where natural velocity is sufficient</td><td>Vertical axis open stream cross flow turbines. Bi-directional and provides opportunity for generator to be located above water surface.</td></tr>
<tr><td>Oscillating</td><td>Array of turbines placed where natural velocity is sufficient</td><td>Oscillating devices based on a reciprocating action induced by natural stream flow over a foil.</td></tr>
</table>

Principle of Operation	Option	Concept	Description
Tidal fence to command increased velocity resulting from constraining the tidal flow	Tidal fence	Line of tidal stream devices housed in a structure that extends across the estuary	Tidal stream technology can be either horizontal or vertical axis plant. Vertical axis plant is well adapted to this arrangement.
	Rotating blade vertical axis turbine	Alternative vertical axis turbine design for a tidal fence	Concept comprises vertical stream lined blades that rotate to reduce drag force.
	Vortex turbine	New concept of ducted tidal stream device	Entrance guide vanes cause flow to create vortex which accelerates and is reinforced. Turbine comprises tubes that capture vortex and rotate.
	Spectral Marine Energy Converter	Fence of tubes from which water is drawn by Venturi effect	Low pressure induced in vertical venturi columns causes flow to be drawn from a horizontal connecting manifold that drives a conventional turbine.
	Waterwheel	Large diameter undershot water wheel	Suitable for shallower water conditions. Traditional undershot technology and located in concrete channels to constrain and concentrate the flow. Suitable for ebb & flood generation.

1.2.2 The power generation technologies listed in Table 1.1 were assessed against five basic criteria to assess their suitability for conditions in the Estuary and the requirements of the project. These criteria were:

1. ***Estuary water depth & width:*** Can the technology be implemented given the width of the Mersey Estuary and the water depth whilst achieving acceptable impacts, if necessary by adjusting the size of the scheme or modifying the operating conditions?

2. ***Water velocity:*** Will the technology be capable of generating a commercial quantity of energy from the natural tidal current velocities in the Estuary?

3. ***Performance parameters:*** Has the performance of the technology been sufficiently studied to enable its energy output to be assessed?

4. ***Technology maturity:*** Will a prototype of the technology have been sufficiently tested (or will there be the technical and financial capability to undertake such tests) in representative conditions including adequate flow magnitude, physical scale and marine conditions, in time for the technology to be adopted as the basis of a commercial scheme in a planning application in late 2011?

5. ***Delivery:*** Will the technology have the support of a company with sufficient technical capability and financial security to enable it to be adopted as the basis of a commercial scheme in a planning application in late 2011?

1.2.3 Based on assessment against these criteria the technologies selected for incorporation into project options to be studied at Stage 2 were as presented in Table 1.2. Full details of the selection process were published in the Stage 1 Options Report[1] and the selection matrix is in Annex A of this report.

Table 1.2: Stage 1 Selected Technologies

Principle of Operation	Power Generation Technology	Application
Impounding of reservoir	Horizontal axis bulb or Straflo™ turbines	Conventional barrage impounding the tidal range of the Mersey to obtain the maximum energy yield. Most economic solution provided by large diameter plant requiring deep water conditions. Concept could be further developed to command a reduced water level difference if required to limit impact on the estuary.
Very low head barrage	Tidal gate comprising Hydromatrix™ or Straflo™ matrix turbines	Barrage operating at a low head difference, below the operating range of conventional horizontal axis plant. Tidal gate solution employs small diameter units mounted in vertical lift gates suitable for a shallow water application. Concept formulated in earlier studies[2].
Tidal Fence	Vertical axis cross flow machines or horizontal axis ducted stream flow machines	Partial or continuous barrier across the estuary constraining the tidal flow and increasing the velocity locally to drive stream flow generating plant.
	Spectral Marine Energy Converter	Innovative tidal fence concept developed by VerdErg Ltd. based on the Venturi effect, suitable for low flow velocity conditions. Potentially requires deep water conditions depending on final configuration of generating plant.

[1] Mersey Tidal Power. Feasibility Study: Stage 1. Options Report February 2010. Scott Wilson & EdF
[2] Mersey Tidal Power Study. Buro Happold, Strategic Planning Advice, The University of Edinburgh & The RSK Group. September 2007

1.3 Stage 2 Studies

1.3.1 The objective of Stage 2 was to develop the technologies identified at Stage 1 into a range of sample schemes in sufficient detail to permit an initial assessment of their performance against key technical, consenting and financial criteria using a defined decision making framework.

1.3.2 The Mersey Estuary is one of the largest in the UK and comprises two distinct geographic and bathymetric zones. There is a narrower and deeper section towards the mouth of the Estuary and a much wider and shallower section further upstream. A simplified plan is shown in Figure 1.1.

1.3.3 At Stage 2 three broad location bands were identified in the Estuary to represent the typical geographic and bathymetric characteristics that are likely to be of relevance to a tidal power development. Within these bands notional lines for power schemes were adopted to permit the Stage 2 studies to be undertaken. The location of the bands are shown on Figure 1.1 and their typical characteristics are as follows:

- ***Band A –*** The Estuary is approximately 1.8 km wide at this location and the maximum water depth is 11m at low Spring tide. Approximately 80% of tidal flow passes this alignment. Commercial shipping passing this location heads to Eastham Locks, Garston Docks and the Mersey Wharf at Bromborough. There is very little inter-tidal exposure and Band A is towards the downstream limit of most of the internationally designated nature conservation areas in the Estuary.

- ***Band B –*** The width of Band B is typically 4 km. There is extensive inter-tidal exposure with water depths of only 2 m in some locations at low Spring tide. The abutments of Band B are upstream of Eastham Locks and Garston Docks and therefore impact on commercial shipping is avoided. Band B is entirely within internationally designated nature conservation areas. Approximately 50% of tidal flow passes this location.

- ***Band C –*** Band C is located at the entrance of the Estuary and is therefore the location with the greatest energy potential. The estuary is deep and narrow. All commercial shipping entering the Estuary must pass this location.

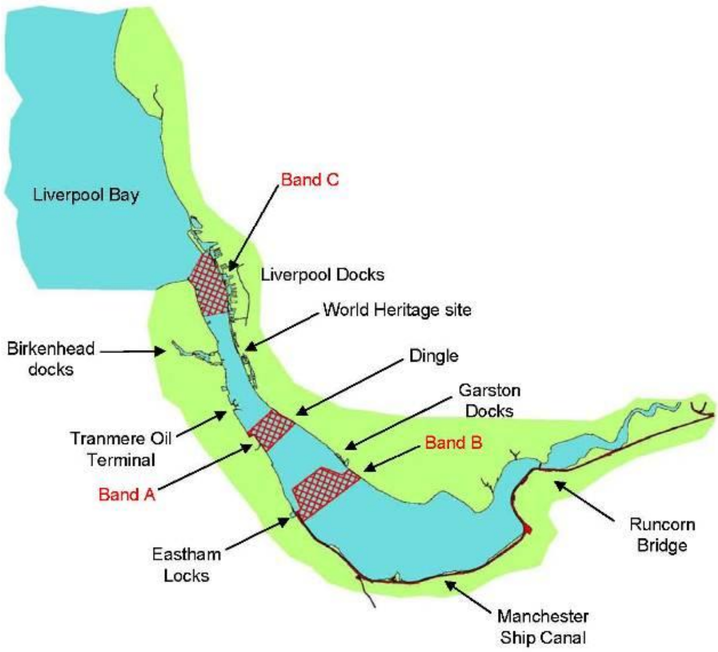


Figure 1.1: Stage 2 Location Bands

1.3.4 Five initial project options were selected with the intention of examining the range of technologies identified in Stage 1 in conjunction with appropriate locations in the Estuary. These are listed in Table 1.3.

1.3.5 No initial options were selected in Band C since physical conditions are similar to those in Band A and it was considered preferable to await the outcome of the initial Band A studies to avoid abortive work. Band A was selected in preference to Band C because of the reduced navigational and planning constraints.

1.3.6 Early in the Stage 2 studies it was determined that the tidal gate concept selected in Stage 1 presented considerable constraints and a revised approach was required that separated the turbines from the gates. This provided operational freedom throughout the tidal cycle and avoided the requirement to raise and lower the generating plant several times per day. An initial assessment of flows to be conveyed on each generating cycle also indicated that the Hydromatrix^{TM} system did not provide adequately sized turbines and the larger Ecobulb^{TM} technology, also supplied by Andritz Hydro, was required.

1.3.7 An alternative arrangement was therefore developed using Ecobulb^{TM} technology mounted externally on a fixed barrage structure extending across the Estuary with the gates confined to specific locations.

Table 1.3: Stage 2 Initial Project Options

Option	Technology	Principle of Operation
A1.01	Bulb turbines in a barrage equipped with sluice gates	Impound all ebb tide for generation and convey flood tide through sluice gates and turbines in orifice mode
A3.01	Open stream turbines in a fence	Passive operation on ebb and flood tides
A4.01	SMEC venturi system promoted by VerdErg Ltd	Passive operation on ebb and flood tides
B2.01	Ecobulb^{TM} turbines mounted externally on a simplified barrage equipped with sluice gates	Impose level control to achieve low head operation on the ebb tide and convey flood tide through sluice gates and turbines in orifice mode
B3.01	Open stream turbines in a fence	Passive operation on ebb and flood tides

1.3.8 Outline descriptions for each option are given in the following sections and selected drawings are in Annex B.

Option A1.01

1.3.9 The details are shown on Drawings PD0330-11-2014, 2015, 2016 and 2020 in Annex B.

1.3.10 The scheme comprises two ship locks. The Wirral abutment accommodates the Eastham Channel ship lock whilst taking account of the potential impacts on the New Ferry SPA downriver and the Port Sunlight and Mersey Wharf navigation interests upriver. Landside facilities including a workshop, GIS sub station and visitors centre would also be accommodated on this abutment.

1.3.11 The Liverpool abutment accommodates the Garston Channel ship lock whilst taking into account the location of Devil's Bank and the implications of abutting the Garden Festival site.

1.3.12 A straight alignment has been adopted for the barrage structure and the orientation has been adjusted to align with the main channel at this location.

1.3.13 28 No. 25 MW bulb turbine units are accommodated in 7 No. turbine-generator caissons located on the Wirral section of the barrage where the depth to rock is a minimum and a foundation system can be engineered that avoids differential settlement.

1.3.14 18 No. vertical lift gates in 5 No. caissons are located in the central channel. Blank caissons make up the remaining sections of the barrage where no discharge in either direction is required. These blank caissons accommodate a small boat lock for leisure craft and provide the opportunity for the installation of additional sluice gates if required. Blank caissons could also be used for other functions such as accommodating a test facility for new tidal power devices. The blank and gate caissons would be left open during barrage construction to provide unobstructed flow paths for the Estuary.

1.3.15 Option A1.01 is an ebb tide only generation scheme. The flood tide would be admitted to the basin through the sluice gates and the turbines running in orifice mode. Power generation would cease at approximately mean tide level permitting the turbine centre line to be placed at -6 m CD.

Option A3.01

1.3.16 The details are shown on Drawings PD0330-11-2018, 2019 and 2021 in Annex B.

1.3.17 The basic abutment arrangement and alignment of Option A3.01 is dictated by the same considerations as for Option A1.01. The arrangement comprises an embankment (Drg. 2019) or light caisson barrier (Drg. 2021) across most of the Estuary leaving an opening for the tidal fence (Drg. 2018) aligned at a central location approximately mid way between the Wirral abutment and Devil’s Bank. At this location the fence mono-piles can be driven into the thick glacial strata in the centre of the Estuary. The width of the fence opening has been selected to constrain the Estuary and generate flow velocities suitable for open stream devices under a range of tidal conditions. The generating plant comprises 34 No. 500 kW horizontal axis 5 m diameter open stream turbines in a continuous horizontal band formed by 8 m square inlet and outlet cowls.

1.3.18 The target flow velocity range is 2 to 5 m/s. The plot in Figure 1.2 shows the open stream velocity over a single tidal cycle using data from the MIKE 21 baseline model developed for the project. The natural mid stream velocity for a Spring tide is shown by the green line. It will be noted that the lower bound target value of 2 m/s is not reached at any time during a Spring tide so that the channel must be constricted to achieve this minimum flow velocity.

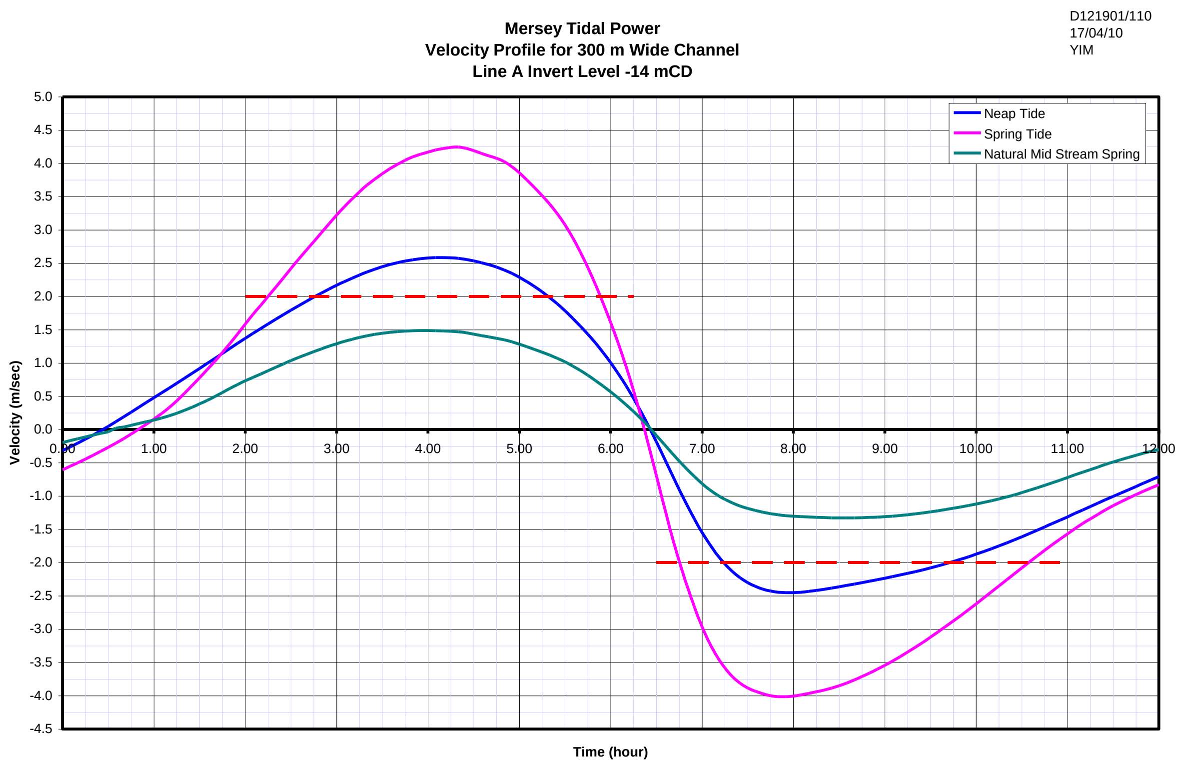


Figure 1.2: Open Stream Velocities at Band A

1.3.19 As a first approximation for sizing the constrained channel it was assumed that the water depths and flux values in the base line model remain unchanged. If the channel width is reduced to 300 m and channel invert is uniform at -14 m CD then the Spring and Neap tide velocity profiles become as shown in Figure 1.2. Velocities remain above the lower target value of 2 m/s for approximately 6 hours on the Neap tide and 8 hours on the Spring tide. The upper bound velocity of 5 m/s is not exceeded.

Option A4.01

1.3.20 Selected details of the Spectral Marine Energy Converter (SMEC) system are presented in Annex B. The basic SMEC technology and the specific application to the Mersey on Line A have been proposed by VerdErg Ltd, the promoters of this system. The details have not been verified by the project team.

1.3.21 The location and abutment layout is based on the same considerations that apply to Option A1.01. The power scheme caissons are located at the Wirral end of the barrage where the shallow depth to rock provides more favourable foundation conditions. No gate caissons are currently envisaged as part of this scheme and the entire ebb and flood tidal flow is intended to be directed through the SMEC units. However dam safety considerations and requirements for unit maintenance may require the incorporation of sluice gates if this option were to be considered further. There is ample opportunity to introduce sluice gates into the layout.

1.3.22 The venturi plant comprises 8 No. 50 m long SMEC units with alternate 10 m wide turbine caissons. Two turbine generator units per SMEC unit would be provided resulting in a total of 16 No. 15.625 MW vertical axis turbine and generator units.

Option B2.01

1.3.23 The details are shown on Drawing PD0330-11-2023 in Annex B. The selected line is upstream of the entrance to the Manchester Ship Canal and the Garston docks at a location where there are areas of open ground on both abutments. Access to the Wirral abutment would require the construction of a bascule or swing bridge over the Manchester Ship Canal.

1.3.24 The basic objective of this location is to avoid impact on commercial shipping. A small boat lock would be provided near the Liverpool abutment for leisure craft.

1.3.25 In this section of the estuary there is substantial inter tidal exposure and open water is reduced to discrete channels at low tide. No geological information is available at this location but the depth of alluvium is expected to be in the range 10 to 15m. According to the Port of Liverpool Charts, water depths and the position of the sand bars at this location are subject to frequent change. This is a significant consideration in the planning of a water power scheme.

1.3.26 The initial plant selection for this location comprises 640 No. 400 kW, 1.45 m diameter Ecobulb^{TM} turbines suitable for the shallow water depths and low head operating conditions. Almost the entire length of the barrage is required to accommodate these units.

1.3.27 12 No. vertical lift sluice gates are accommodated in 3 No. caissons on the Wirral abutment at the head of the Eastham Channel and a further 12 No. sluice gates in 3 No. caissons are accommodated on the Liverpool abutment at the head of the Garston Channel.

1.3.28 Option B2.01 is an ebb tide only generating scheme. The flood tide would be admitted to the basin through the sluice gates and the turbines running in orifice mode. The sluice gates would additionally be required to operate on the Mean and Spring ebb tides to control basin water levels. Trial analysis with larger diameter generating plant marginally reduced the requirement for ebb tide gate operation but relatively little additional energy was captured.

1.3.29 The arrangement represents a flexible solution where blocks of turbines could be shut down at different water levels in response to progressive exposure of mud flat areas as the water level drops. Sediment management would be a significant consideration for this scheme.

Option B3.01

1.3.30 The design concept would be the same as that proposed for the tidal fence (A3.01) on Line A and the basic alignment would be the same as that proposed for Option B2.01.

1.3.31 As with Option A3.01 the width of the fence opening would be selected to constrain the width of the Estuary and generate flow velocities suitable for open stream devices under a range of tidal conditions. The Band B flow velocity plots are shown in Figure 1.3. The target flow velocity range is 2 to 5 m/s.

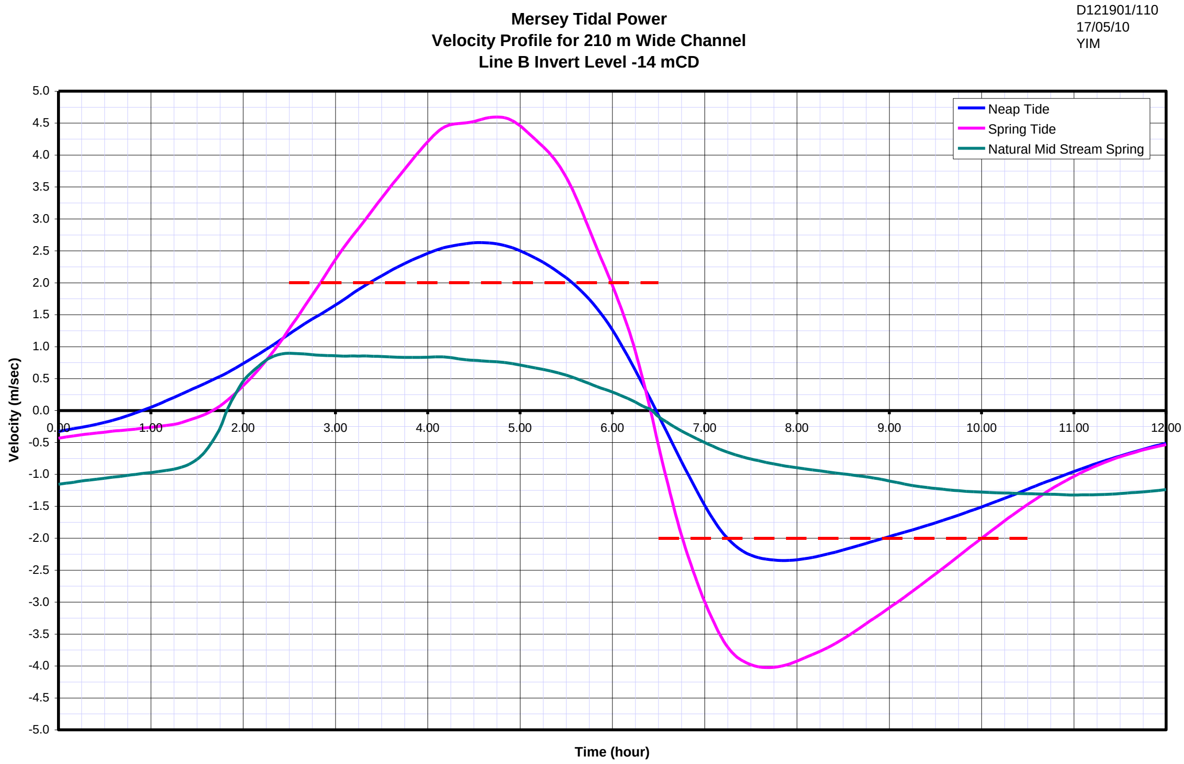


Figure 1.3: Open Stream Velocities at Band B

1.3.32 The natural mid-stream velocity for a Spring tide is highly asymmetric and falls well below the minimum target value. Reducing the open channel width to 210 m results in velocities that remain above 2 m/s for approximately 4 hours on the Neap tide and 6 hours on the Spring tide. The upper bound velocity of 5 m/s is not exceeded.

1.3.33 The generating plant comprises 24 No. 600 kW horizontal axis 5 m diameter open stream turbines in a continuous horizontal band formed by 8 m square inlet and outlet cowls.

Energy Results

1.3.34 The energy results obtained for the initial Stage 2 options are listed in Table 1.4.

Table 1.4: Stage 2 Energy Results

Option	Technology	Mode of Operation	Installed Capacity (MW)	Annual Energy (GWh)
A1.01a	Bulb turbines in a barrage	Ebb tide generation	700	900
A3.01	Open stream turbines in a fence	Bi directional	17	27
A4.01	SMEC (VerdErg Ltd)	Bi directional	250*	639*
B2.01a	Ecobulb™ turbines in a barrage	Ebb tide generation	256	400
B3.01	Open stream turbines in a fence	Bi directional	14	17

* Data provided by VerdErg Ltd and not confirmed by SW/EdF

Stage 2 Conclusions

1.3.35 The energy results for the tidal fence options are extremely low and grossly under utilise the resource of the Mersey Estuary. A full assessment is presented in the Stage 2 Options Report[3]. This assessment showed an overall negative carbon balance for the tidal fence options and no commercial viability. Although improvements could be obtained through revised arrangements there is no prospect of such arrangements becoming comparable in performance with the barrage options. Tidal fence options were therefore not taken forward to Stage 3.

1.3.36 Further study of the SMEC technology was placed on hold until such time as further information becomes available based on full scale prototype trials in a representative environment.

1.3.37 Navigation and planning constraints at Band C were assessed and considered to make a tidal power development at this location unfeasible.

1.3.38 On the basis of these considerations barrage options at Bands A and B were selected for further study at Stage 3. However the findings of the Stage 2 Options Report indicated that mitigation measures such as low head operation, ebb & flood generation, low tide sluicing and high tide pumping should be considered in Stage 3.

[3] Mersey Tidal Power. Feasibility Study: Stage 2 Options Report. November 2010. Scott Wilson.

2 Stage 3 Options

2.1 Band B

2.1.1 At the commencement of Stage 3 consideration was given to possible changes that could be made to the design of Option B2.01 to overcome the key technical and commercial issues identified at Stage 2. These issues were:

- The cost of energy was 1.85 times greater than the cost of energy delivered by Option A1.01.
- Approximately only 5/8th of the water passing Band A in each tidal cycle passes Band B thereby imposing a corresponding reduction on the maximum energy potential at Band B.
- The width of the Estuary at Band B is considerably greater than Band A, largely offsetting the cost savings associated with avoiding navigation structures.
- Shallow water conditions require a more costly configuration for the generating plant.
- Long structures comprising a large number of small diameter turbines present a considerable barrier to fish passage.
- Shallow water depths prevent larger generating heads being developed.
- There is more uncertainty regarding geotechnical conditions and the depth of alluvium is typically much greater on Band B.
- Band B is characterised by considerable mudflat exposure under low tide conditions making power generation at lower tide levels very difficult.
- The large mobile sand banks and inter-tidal channels at Band B present a considerable construction and operational risk requiring major dredging in zones of potentially contaminated sediments.

2.1.2 Consideration was given to increasing the diameter of the generating plant in Option B2.01 and to an alternative scheme layout with fewer, larger units in the deeper channels of Band B. Both were found to be potentially more costly arrangements without any significant improvement in energy yield and reduction in the sediment management risks associated with Band B.

2.1.3 The planning advantages previously envisaged for a scheme at Band B location were judged not to be compelling and the ecological advantage over Band A was found to be limited. A large proportion of the SSSI/SPA/Ramsar protected areas are upriver of Band B and studies at Stage 2 showed that there would also be some impact on the areas downriver of Band B.

2.1.4 A key feature of adopting a scheme at Band B would be that impact on commercial navigation is avoided. However an acceptable navigation solution at Band A is possible. The issue is the capital and operational costs of providing this solution.

2.1.5 On the basis of these considerations it was decided not to undertake a full assessment of a scheme on Band B in Stage 3. A short paper outlining the main considerations is included as Annex C.

2.2 Generating Plant at Band A

Turbine Type

2.2.1 The key considerations for selecting generating plant for a barrage at Line A include:

- Large diameter units with high volumetric flow capacity will permit the adoption of a fewer number of units with a corresponding reduction in the capital cost of the generating plant and associated civil structures.
- Plant that can operate at low gross head differences across the barrage will permit basin water levels to be maintained closer to the natural tide level and improve the time and extent of mud flat exposure.
- Plant that can operate at higher gross head differences across the barrage will permit higher energy extraction from each tidal cycle and make best use of the renewable energy resource of the Estuary.
- Simple and robust technology will improve plant availability and reduce O&M costs.
- Proven technology will be associated with lower delivery and performance risk and facilitate the provision of warranties by the supplier.
- Plant that can operate in direct or reverse turbine mode, and additionally function as a pump, will provide the greatest operational flexibility for the barrage.

2.2.2 A review of turbine technologies undertaken in Stage 2 examined a number of existing and embryonic alternatives that might be considered for a tidal power scheme. These technologies comprised:

- Conventional direct and reversible bulb units manufactured by several major plant suppliers;
- ECOBulb™ direct compact bulb units manufactured by VA TECH / Andritz Hydro;
- Hydromatrix™ compact units designed to be incorporated as multiple units in a gate, manufactured by VA TECH / Andritz Hydro;

- The Rolls Royce very low head dual generation turbine proposed as a concept under the Severn Embryonic Technologies Scheme;
- The Very Low Head turbine manufactured by MJ2 Technologies S.A.R.L. from Millau, France; and
- Open stream turbines manufactured by several suppliers in a range of sizes and configurations.

2.2.3 In each case a review of the technology was undertaken to establish its current market position, operational characteristics, civil works requirements and additional properties such as compliance with the Idaho National Engineering and Environmental Laboratory criteria for fish friendly turbines.

2.2.4 Stage 2 studies had concluded that a tidal fence comprising open stream turbines is not a viable proposition as a main energy delivery solution. However this technology might still be considered as a secondary source in conjunction with a different development. A possible example would be a fence commanding the sluice gate outflow from a tidal barrage.

2.2.5 The ECOBulb™, Hydromatrix™ and MJ2 VLH turbine are not adequately sized for the energy potential and width of the Mersey Estuary at Band A.

2.2.6 The Rolls Royce unit has been specifically conceived for a tidal power application unlike the other units which were developed for run of river use in the hydropower industry. The concept offers a bi-directional unit with uniformly high efficiency in either direction and designed to operate at a gross head difference of approximately 3m and lower. The turbine comprises low speed contra rotating runners with variable pitch blades. The design is configured to maximise fish survival. Civil costs are reduced by a requirement for modest cavitation submergence and correspondingly higher centre line setting levels. In addition low exit velocities avoid the requirement for long diffuser sections. Conversely very large diameter units are required and the relationship between diameter, discharge and power output will require a larger number of units than the equivalent bulb turbine configuration. The concept is at an early stage and it is currently unlikely that the technology will be available at an industrial scale within the project programme. This position could however change at some stage in the future.

2.2.7 Based on these considerations, large diameter bulb turbines remain the best choice for a major tidal power development on the Mersey at Band A and have been proposed for all options to be studied at Stage 3.

Number of Turbines

2.2.8 Studies undertaken by the Mersey Barrage Company in the early 1990's[4] determined that the optimum plant configuration for an ebb only scheme in Band A comprised 28 No. 25 MW units. No optimisation analyses will be undertaken in this current study until the later

[4] Tidal Power from the River Mersey. Feasibility Study Stage III. Mersey Barrage Company 1993.

stages and therefore the findings of the 1993 study have been adopted as a starting point. This current study has indicated a live Estuary basin volume that is lower than the 1993 study and re-optimisation may therefore result in a lower number of units. It is also important to note that the 28 unit configuration is associated with high gross head operation on the Spring tides and a larger number of turbines is required if the Spring tides are to be turbined at lower gross heads for ecological reasons.

2.2.9 Layout studies on Line A indicated that there is sufficient space available to accommodate 56 turbines and 18 sluice gates. Initial 0D modelling was undertaken using 56 units on the basis that this maximum number of units would most effectively limit the gross head difference across the barrage. Head control trials were undertaken where turbines were progressively brought into service as the gross head increased across the barrage. The objective was to limit the head across the barrage to generally less than 3 m.

2.2.10 These studies indicated that there were very few instances throughout the year when all 56 units were required and this level of investment in generating plant was not justified. A summary table of results is shown in Annex D.

2.2.11 Further studies showed that a 44 unit scheme with an operating rule that had all units in operation at a gross head of 2.5 m would provide sufficient flow capacity to limit the head difference across the barrage to less than 3 m for all but a few extreme Spring tides each year.

2.3 Selected Stage 3 Options

2.3.1 The development process undertaken in Stages 1 and 2 resulted in the conclusion that only barrage schemes at Band A and Band B should be considered in Stage 3. Further consideration of Band B design issues resulted in a decision that the Stage 3 studies should be confined to barrage schemes at Band A. A review of potential power generation technologies has concluded that conventional bulb turbines currently provide the best solution for a barrage scheme at Band A on the Mersey.

2.3.2 Based on these considerations, the design options listed in Table 2.1 were selected for full assessment in Stage 3 to cover a suitable range of possible operational requirements. Option A1.02, with 28 units designed for ebb only generation, was selected as having the potential to deliver the highest energy output whilst being able to adopt different operating strategies when required to do so for ecological reasons. Option A2.01 with 44 units was selected to examine the cost and energy implications of adopting a scheme with a larger number of units that would permit the ebb tide to be turbined at a lower gross head across the barrage. Option A2.02 was selected to examine the implications of an ebb and flood scheme operating at a limited gross head as a comparison with Option A2.01.

2.3.3 Bulb turbine barrage schemes are inherently flexible in terms of operation and a wide range of energy and ecological impact outcomes can be achieved from a particular scheme design. The 3 options listed in Table 2.1 were selected for the development of outline designs, cost estimates, assessment of commercial viability and ecological acceptability. A wider range of operational strategies was then tested to determine the impact on energy output.

Table 2.1: Stage 3 Tidal Power Scheme Options

Option	Type	Operating capability	Installed capacity (MW)
A1.02	Impounding barrage equipped with 28 No. turbine-generators, 18 No. sluice gates, double navigation lock on the Wirral shore, 3 No. fish passage routes and blanked-off water passageways for potential future use	Ebb tide generation only, without limiting the gross head across barrage but limited to ceasing generation at Mean Tide level	700
A2.01	Impounding barrage equipped with 44 No. turbine-generators, 18 No. sluice gates, double navigation lock on the Wirral shore, 4 No. fish passage routes and blanked-off water passageways for potential future use	Ebb tide generation only with lower turbine centreline setting to permit operation at lower tide levels resulting from limiting the gross head across barrage to generally less than 3m	660
A2.02	Impounding barrage equipped with 44 No. reversible turbine-generators, 18 No. sluice gates, double navigation lock on the Wirral shore, 4 No. fish passage routes and blanked-off water passageways for potential future use	Ebb and flood tide generation with lower turbine centreline setting to permit operation at lower tide levels resulting from limiting the gross head across barrage to generally less than 3m	660

3 Band A Barrage Options

3.1 Location & Layout

3.1.1 The alignment of the barrage options in Band A is based on a location sufficiently far upriver to provide manoeuvring space for super tankers arriving at Shell's Tranmere Oil Jetty whilst avoiding increased barrage length as the Estuary widens upriver. At this location it is necessary to provide for shipping transit of the barrage to the Eastham Locks, Mersey Wharf and to Garston Dock. The chosen alignment is also expected to have the better geological conditions for the barrage than other locations and has been previously investigated[4]. The selected line for the barrage is shown in Figure 3.1.

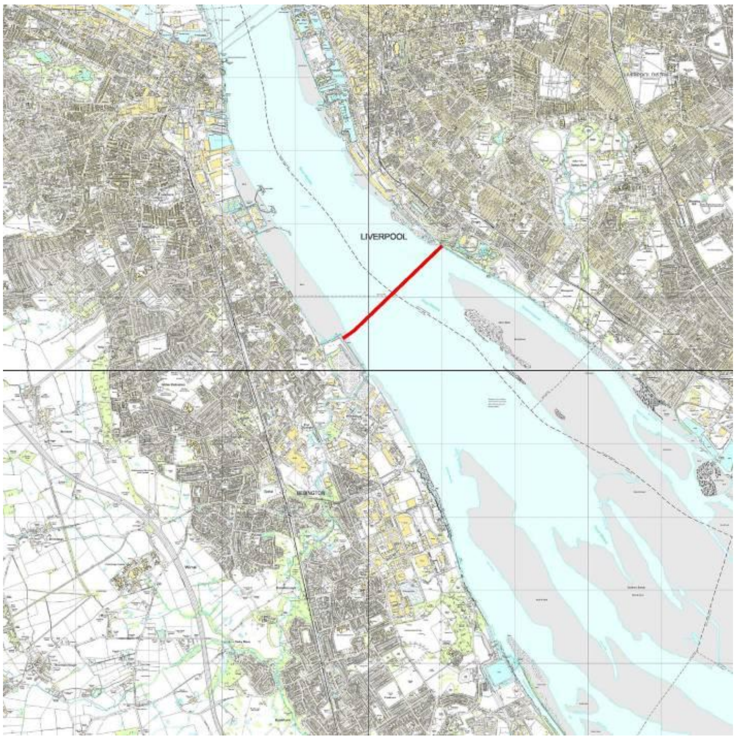


Figure 3.1: Proposed Barrage Line

3.1.2 The main geological feature along the barrage alignment is a buried river valley which has been in-filled by glacial and recent alluvial deposits. The rock-head is much higher at the left (Wirral) bank than in the centre of the river. This makes it advantageous to place the heavier structures (locks and turbine-generator caissons) on the left bank. Within the buried valley floor area there are zones of deep erosion forming hollows which may have been caused by glacial plucking.

3.2 Option A1.02

3.2.1 This option is shown on drawings PD-0330-11-3000 to 3005 in Annex E. The layout comprises a double lock structure on the Wirral bank, turbine-generators in the left river channel and sluice gates in the centre river channel. The generating plant comprises:

Number of turbines:	28 in 7 caissons
Unit capacity:	25 MW
Unit centre line:	-5.7 m CD
Runner diameter:	8 m
Configuration:	ebb only generation (flood tide admitted in orifice mode)

3.2.2 The sluice gates are designed to operate in either direction. For this reason vertical lift gates were selected. The sluices will operate with a free water surface to avoid flow transitions and limit the foundation depth of the structure. The gate details are as follows:

Number of gates:	18 in 5 caissons
Gate type:	Wheeled vertical lift, free water surface
Size:	12 m x 12 m
Setting:	Top of gate at HAT (10.5 m CD), sill level at -1.5 m CD

3.2.3 The remaining barrage sections between the turbine and gate caissons are made up from seven blank gate caissons partially backfilled with sand. These blank caissons could be equipped with additional sluice gates if required and provide an opportunity to incorporate test facilities for new tidal power technologies. A small boat lock for leisure craft is provided in one of the right channel blank caissons.

3.2.4 Three fish passage routes are provided that will convey a combined total of 2% of the turbine discharge. Acoustic guidance may be considered to deter fish from the turbines on the ebb tide. The fish passages are located at either end of the turbine-generator caissons and between the sluice gate and blank caissons.

3.2.5 The civil engineering structures are founded on sandstone rock at the Wirral (left) bank whilst being generally founded on glacial tills elsewhere. The details are shown on Drawing PD 0330-11-3001. Thus the heavier turbine-generator units are located on the left bank in order to minimise capital costs and avoid the risk of settlement induced by vibration from the generating plant. Elsewhere the structures require piling in order to minimise total and differential settlements under load, which is important for the safe operation of the sluice gates.

3.2.6 The ship lock layout is set by navigation considerations and extends upriver of the barrage axis in order to avoid as far as possible the Special Protection Area of New Ferry Beach. This arrangement is adjacent to the Bromborough Dock infill area, which will provide shoreline access to a great length of the lock. This is important for emergency planning, for example in case of a fire incident on board a vessel in the lock.

3.2.7 The landside facilities are located on the left (Wirral) bank on an area of reclaimed land, using dredged material, between the Bromborough Dock infill and the lock system. A bascule bridge will be provided over the locks to access the barrage and installed generating plant. A tunnel will carry cables below the lock to the shore where they will be ducted to the bulk supply (substation) area on the left bank. Maintenance and workshop facilities will be provided together with office and other support facilities. Visitors will be catered for in separate facilities away from the operational areas on the left bank. Only simple security measures and emergency access are planned for the right bank.

3.3 Option A2.01

3.3.1 This option is shown on drawings PD-0330-11-3050 to 3054 in Annex E. The layout is similar to Option A1.02 but with a total of 44 turbine-generator units, eight of which are located on the right (Liverpool) abutment. The centre line of the generating plant has been placed at a lower setting level to permit power generation to continue at the lower tide levels accessible as a result of generation at lower gross heads across the barrage. The generating plant comprises:

Number of turbines:	36 in 9 caissons on the left (Wirral) bank
	8 in 2 caissons on the right (Liverpool) bank
Unit capacity:	15 MW
Unit centre line:	-8.5 m CD
Runner diameter:	8 m
Configuration:	ebb only generation (flood tide admitted in orifice mode)

3.3.2 The sluice gate provision is unchanged from Option A1.02. Two blank caissons are provided to complete the barrage. One of these blank caissons provides a location for a small boat lock for leisure craft.

3.3.3 Four fish passage routes are provided that will convey a combined total of 2% of the turbine discharge. Acoustic guidance may be considered to deter fish from the turbines on the ebb tide. The fish passages are located at either end of the turbine-generator caissons on the left and right banks.

3.3.4 The turbine-generator structures are founded on sandstone rock at the Wirral (left) bank to the fullest extent possible with a back filled foundation to rock being required for the additional two caissons. The details are shown on Drawing PD 0330-11-3051. The right (Liverpool) bank turbine-generator caissons are located to take advantage of higher rock levels but will also partially require piled foundations.

3.3.5 Stability considerations resulting from the deeper turbine centreline adopted for this option require the base length of the caisson to be extended. This has been achieved by providing a longer inlet section on the basin side.

3.4 Option A2.02

3.4.1 This option is structurally very similar to Option A2.01 except that revised inlet geometry is provided on the seaward side of the structure to provide improved conditions for flood generation. The generating plant will be equipped for ebb and flood tide generation. The extended basin side inlet geometry added to Option A2.01 for stability reasons provides a diffuser section under flood tide generation.

3.4.2 The generating plant comprises:

Number of turbines:	36 in 9 caissons on the left (Wirral) bank
	8 in 2 caissons on the right (Liverpool) bank
Unit capacity:	15 MW
Unit centre line:	-8.5 m CD
Runner diameter:	8 m
Configuration:	ebb and flood generation

3.5 Construction

3.5.1 The proposed construction method will be similar for all options and is shown on Drawing PD 0330-11-3200 in Annex E. The basic method will be to form a dry dock area around the main lock structure and the New Ferry beach area. The New Ferry beach area will be used for sluice and blank caisson construction whilst the area around the in situ lock barrels will allow construction of up to 8 turbine-generator unit housings in situ. The enclosed area will then be used for the production of floating caissons, each holding four turbine-generator units. The sluice caissons will be installed from the right bank towards the centre of the river and can be progressively fitted out and opened to allow river flow through them in order to reduce river flow velocities in the closure gap. The in situ locks and lead-in jetties will be constructed and then opened to river flow and navigation. Finally the turbine-generator caisson units will be installed to close off the river. There may be quality assurance and programme benefits to be gained from pre-installing embedded pipe work and turbine components prior to floating out the caissons. Completion of plant installation, testing and commissioning will then proceed. Units would enter commercial operation sequentially to deliver early revenue prior to project completion.

3.5.2 The general arrangement of the turbine-generator caissons is similar for all options. The caisson layout is arranged to accommodate the generator transformers, unit electrical and mechanical equipment and to provide access in the minimum caisson volume commensurate with stability. The lower section of the caisson comprises four water passageways shaped to reduce hydraulic losses, each containing a turbine and a generator pit. Above this level there is the turbine hall and electrical galleries which are surrounded by chambers for ballast.

3.5.3 On the top deck there are travelling gantry cranes for generating plant maintenance. These cranes will operate in pairs for heavy lifts. Items of equipment recovered from the caissons for maintenance will be transported by road vehicle across the lock bridge to the workshop area on the Wirral shore. The total number of gantry cranes to be provided will most probably be governed by construction programme requirements. A further smaller travelling gantry crane is provided for the sea side outlet stop logs. The top deck also accommodates the access covers for the turbine and generator pits, an access road, stop log storage areas and wave walls.

3.5.4 The sluice caisson comprises four channels divided by piers. Each channel is fitted with a vertical lift gate to command the flow of water to and from the basin. The base of the caisson is a cellular reinforced concrete raft providing buoyancy and resistance to torsion during floatation and installation, and access for foundation grouting. The piers are also cellular. Each gate has a dedicated pair of hoists for operations and a travelling gantry crane is provided for maintenance. A further smaller travelling gantry crane is provided for the basin side stop logs. An access road crosses the caisson at deck level. The access road deck will accommodate power and control cables crossing the barrage.

3.6 Design Methods & Criteria

3.6.1 Having determined a setting for the turbine-generators and confirming the design of the sluice and blank caissons developed at Stage 2, stability analyses were undertaken to assess the loads on the foundations. These loads were used in the geotechnical assessment and, depending on location across the barrage line, piles were introduced to support the caissons.

3.6.2 Preliminary analysis was also undertaken of the floating stability of the heavier turbine-generator caissons.

3.6.3 Pre-cast concrete caissons were taken as the basis of design, since, in general terms these are usually the lowest cost form of construction for floated structures and have been proposed for other barrage designs.

3.6.4 Settlements of structures must be limited to acceptable values taking into account the mechanical operational requirements to avoid excessive distortion of moving parts, particularly those that rotate at speed. Differential settlement across a caisson must be limited and piles are required where structures are founded on glacial and alluvial soils. Similarly, differential settlements between caissons will need to be restricted to allow free movement of travelling gantries, and to avoid damage to cables, which will cross the barrage.

4 Operation and Energy

4.1 Operation & Energy Results

4.1.1 A range of operating modes has been examined for each of the three options using 0D modelling. These are listed in Table 4.1. The energy results have been simulated for the full year 2010 period.

Table 4.1: Energy Results

Option	Mode of Operation	Installed Capacity (MW)	Average Annual Energy (GWh)	Comment
A1.02a	Ebb only generation with optimised starting head for maximum energy	700	1050	Best energy base case (excluding pumping) for comparison with alternative operating strategies.
A1.02b	As A1.02a but with low tide sluicing and a hold period to improve inter-tidal exposure	700	950	Selected for 2D hydrodynamic modelling and ecological assessment
A1.02c	Ebb only generation with the gross head across the barrage limited to generally less than 3m to improve inter-tidal exposure	700	530	Gross head limit is achieved by using the sluice gates to provide additional discharge capacity on the Spring to Mean ebb tides. This option may require a lower turbine setting level (similar to A1.04)
A1.02d	Strategy A1.02a for 8 months of the year and A1.02c for 2 months of the year with 2 months transition	700	920*	Assessed to be ecologically unsatisfactory as a seasonal event but other combinations of time period might be considered (see A1.04b)
A1.02e	As A1.02a with high tide pumping	700	1340	Basin high tide levels are raised during the hold period to approximately 0.5 m higher than the natural peak level of each flood tide

Option	Mode of Operation	Installed Capacity (MW)	Average Annual Energy (GWh)	Comment
A1.03a	Structure and operation as A1.02b but with 24 sluice gates in place of 18	700	1010	Investigated using 2D modelling on the Spring tide only. The addition of 6 gates improves the recovery of high tide levels in the basin following the low tide hold period
A1.04a	Ebb and flood generation without head control. Structure as A1.02 but with A2.02 turbine caissons	700	800	Investigated to establish energy comparison with ebb only generation (A1.02a). Energy result has been increased by maximising ebb production and use of sluice gates at the ends of the generating cycles.
A1.04b	Ebb only generation on the Spring-Intermediate tide range without head control, head controlled ebb generation or ebb & flood generation on the Intermediate-Neap tide range, and ebb only generation on the lower Neap tides	700	Variable**	Considered as a possible strategy to capture the Spring tide energy whilst promoting the inter-tidal habit under other conditions
A1.04c	Ebb and flood generation as A1.04a but with high tide pumping to restore high tide levels	700	930	To examine the potential for high tide pumping to restore high basin levels and improve energy output of ebb & flood operation
A2.01a	Ebb only generation with the gross head across the barrage limited to generally less than 3m to improve inter-tidal exposure	660	560	Gross head limit is achieved by progressively bringing turbines into service such that all 44 units are operating at a gross head of 2.5 m. No ebb tide sluice gate discharges are required. Selected for 2D hydrodynamic modelling and ecological assessment

Option	Mode of Operation	Installed Capacity (MW)	Average Annual Energy (GWh)	Comment
A2.02a	Ebb and flood tide generation with the gross head across the barrage limited to generally less than 3m to improve inter-tidal exposure	660	520	Gross head limit is achieved by progressively bringing turbines into service such that all 44 units are operating at a gross head of 2.5 m. Sluice gate operation is required to partly restore high and low basin levels. Selected for 2D hydrodynamic modelling and ecological assessment

* Derived from A1.02a & A1.02c

** Value depends on combination of operation selected

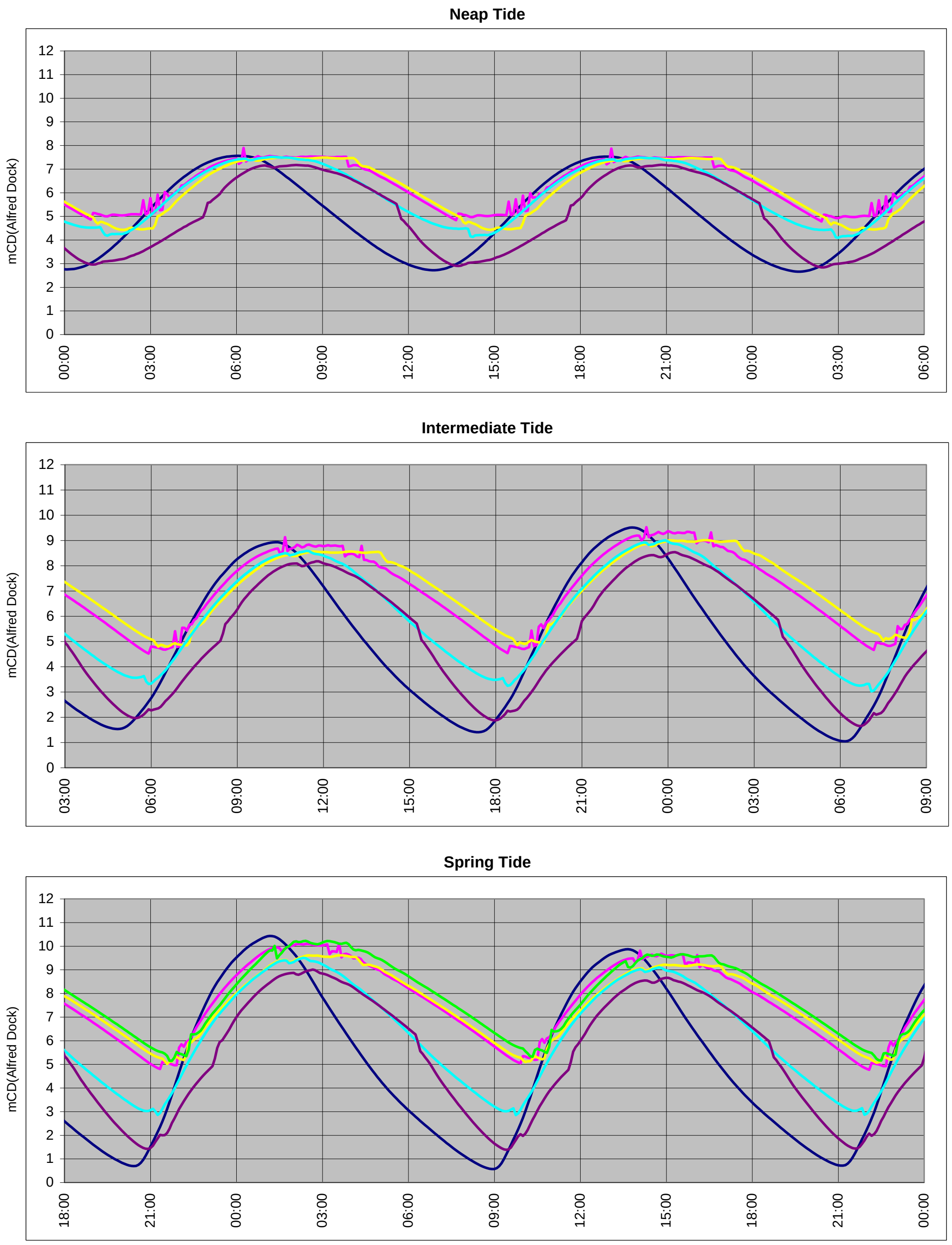
4.1.2 The water levels at the barrage resulting from the options for which 2D hydrodynamic modelling has been undertaken are shown in Figure 4.1.

4.1.3 It will be noted that the ebb only generation schemes without head control, (A1.01a & A1.02b) result in the basin water being restricted to oscillation between high tide and mean tide level resulting in reduced inter-tidal exposure. The average water level in the basin is also raised.

4.1.4 The energy results obtained from the 44 unit (A2.01& A2.02) head controlled schemes are typically some 50% of the results obtained from higher head operation of the 28 unit (A1.02) scheme. Although the increased number of turbines in the 44 unit schemes is passing additional flow through the generating plant this is partly offset by the lower operating efficiency of the units at low heads and the reduction in energy yield is approximately proportional to the reduction in gross head through the generation cycle.

4.1.5 A more commercially efficient method for limiting the gross head across the barrage to enhance inter-tidal exposure is to use the sluice gates to provide additional discharge capacity at peak flow periods. This is demonstrated in Option A1.02c. A change from Option A2.01a to A1.02c avoids the additional investment of 16 generating units and their associated larger structures and achieves a reduction in project cost of approximately 30%. This change results in an energy loss of only 30 GWh per year, approximately 5%, if this operating policy was pursued for an entire year. Optimisation of turbine numbers and capacity is required in future studies but this trend appears to indicate that a scheme with a fewer number of units is likely to provide a better commercial case.

4.1.6 The provision of additional sluice gates requires relatively small additional cost because the structures require no modification. It may be seen from Figure 4.1 that the provision of additional sluice gates assists with the recovery of the high basin water level following the ebb generation cycle. This improves energy yield (see Option A1.03a) and may have ecological advantages. The provision of additional sluice gates will also improve performance of the sluice structures at low tide levels when the depth of water is at a minimum. Under these conditions higher water level differences may induce velocities that mobilise sediment and cause shock waves and flow transitions.



Scheme Descriptions

Baseline

A1.01a: Stage 2 scheme
A1.02b: Modified using OSH, low tide sluicing and LW hold
A1.03a: As A1.02b but with 6 additional sluice gates (spring tide only)
A2.01a: Head controlled to 3m
A2.02a: Head controlled with two way generation and low/high tide sluicing

Figure 4.1: Water Levels at the Line A Barrage

4.1.7 A large proportion of the energy from the Estuary is obtained during the Spring tides. Operational variants such as A1.02d and A1.04b have therefore been introduced to examine the potential benefits of changing the strategy such that operating restrictions for ecological benefit are confined to specific periods or tidal conditions and the overall energy yield of the scheme can remain high. Option A1.02d was formulated on the basis of providing greater habitat exposure during the winter months but a purely seasonal strategy was assessed to be unsatisfactory ecologically. However there may remain an opportunity for a better distributed combination of high and low gross head ebb only operation. Option A1.04b would be a repeatable pattern throughout each Spring-Neap cycle and is intended to maintain high overall energy yield by targeting the Spring to Intermediate range for priority energy production and the Intermediate to Neap range for a strategy that provides basin water levels much closer to natural conditions.

4.2 Value of Energy

4.2.1 Once project commissioning has been completed and basic operational strategies have evolved, the energy output profile from a tidal power scheme on the Mersey can be predicted with a high degree of certainty. However the extent to which it can be controlled is very limited. Depending on the development of the energy market in the UK there may be commercial value in arranging generation patterns such that coincidence with higher system load times of day is increased. A change from ebb only to ebb & flood generation may achieve this under particular conditions. The ability to slightly modify the start and stop times for tidal power generation could also make a contribution.

4.2.2 The energy output of each option has been analysed for 2010 to determine the average power output at each hour of the day for all 365 days of the year. The results are shown in Figures 4.2a, b and c. Option A1.02a is the optimised ebb only generation case. The energy output is delivered in a single block of variable time duration (typically in the range of 3.5 to 4 hours) every 12.4 hour tidal cycle. The timing of this block of energy therefore progressively changes each day.

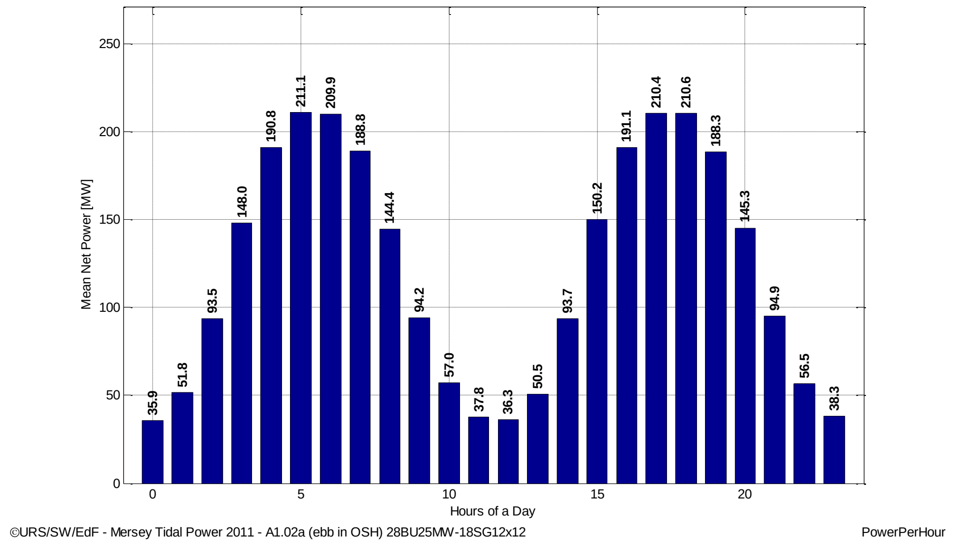


Figure 4.2a: Average Annual Distribution of Hourly Power Output for Ebb Only (A1.02a)

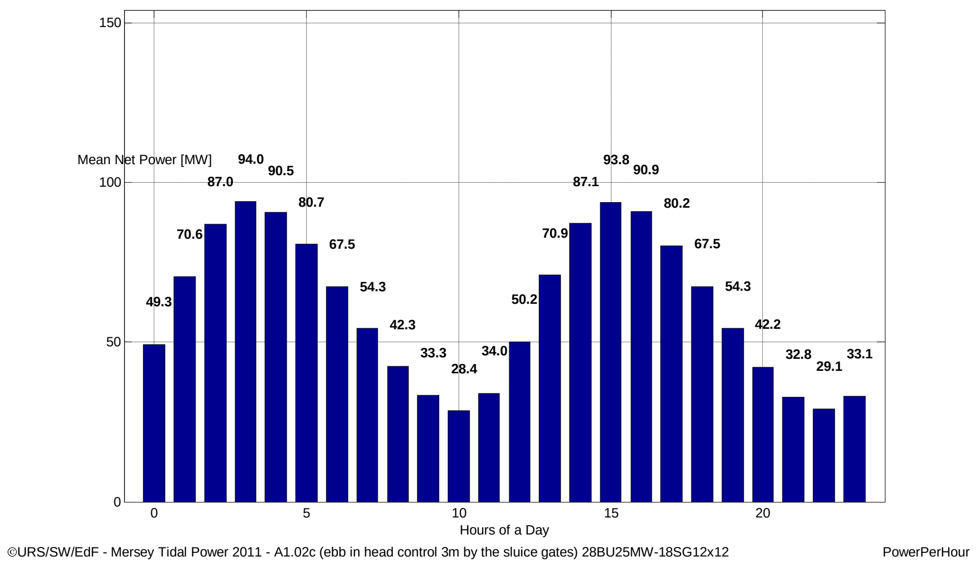


Figure 4.2b: Average Annual Distribution of Hourly Power Output for Ebb Only with Head Control (A1.02c)

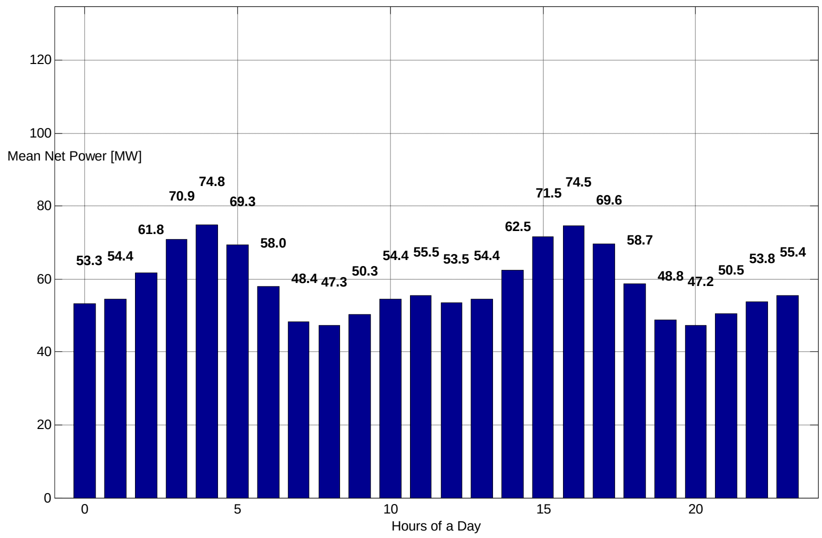


Figure 4.2c: Average Annual Distribution of Hourly Power Output for Ebb & Flood (A2.02a)

4.2.3 Figure 4.2a shows that, on average, most energy is delivered around 6.00 am and 6.00 pm each day. This is a characteristic of the Mersey Estuary and will remain the case for all years. This non uniform but repeated average energy distribution is because most energy is derived from the Spring tides and the Spring tides have a significant solar component that follows a 24 hour cycle and not a lunar cycle.

4.2.4 The period of higher energy demand on the UK grid ramps up from approximately 6.00 to 8.00 am and ramps down from 7.00 to 11.00 pm. There is generally a peak period between 5.00 and 7.00 pm. The average distribution shown in Figure 4.2a provides a very good fit this demand profile. It must be noted however this is an average result derived from a maximum energy ebb only strategy. If head control is applied for ecological reasons, generation starts earlier and the distribution is skewed as shown in Figure 4.2b.

4.2.5 With ebb only operation there will be many times in each lunar cycle when energy is delivered at less favourable times of day. On these occasions an ebb and flood strategy could possibly provide a better fit with market demand. Figure 4.2c shows the average hourly power distribution for Option A2.02a, the 44 unit scheme with ebb & flood operation and head control. The distribution is seen to be more uniform throughout the day than the A1.02a option with more energy delivered at other times of day less frequently covered by an ebb only scheme. However the overall energy output is reduced by this form of operation.

4.2.6 The merits of pursuing a value of energy strategy would depend on many factors, including the nature of the energy market and ecological constraints. This would be a complex subject and would require detailed study and continuous revision. A key requirement to take advantage of any revenue opportunity would however be flexibility of operation. These considerations reinforce the case for adopting a scheme design that can operate under both ebb only and ebb & flood generation.

5 The Preferred Scheme

5.1 Preferred Layout

5.1.1 Optimisation studies are required to determine the final generating plant provision and operating rules to improve the energy delivery, commercial viability and environmental performance of the project. However the work undertaken in Stages 1, 2 and 3 of this Feasibility Study has provided a basis to reach a broad definition of the preferred scheme.

5.1.2 A review of technologies and locations has confirmed that the preferred scheme would comprise conventional bulb turbine generating plant accommodated in a barrage across the Estuary between Dingle and New Ferry. It remains possible that conventional bulb turbine plant could be replaced by a new innovation such as the Rolls Royce Very Low Head Contra Rotating Turbine if sufficient development takes place within the required time scale.

5.1.3 The number, size, centre line level and power rating of the turbine-generator units require optimisation. However results from this study indicate approximately 28 or fewer units with a rating of approximately 25 MW or lower may be appropriate. These will be preferentially located on the left (Wirral) side of the barrage where high rock levels provide better foundation conditions.

5.1.4 Navigation locks, landside facilities and arrangements for power export are also preferentially located on the Wirral abutment.

5.1.5 The number, size and setting of the sluice gates also require optimisation and consideration might be given to an alternative submerged gate design. This study has indicated that 18 gates, 12m square, is probably the minimum provision required and it would be advantageous for a larger number to be provided. These gates would be located in the central or right (Liverpool) sections of the barrage. The final location and distribution of the turbines and gates would be based on further considerations of estuary hydrodynamics and sediment transport.

5.1.6 The maximum energy and lowest capital cost scheme has been found to be an ebb only generation project with the turbine centre line set at a level where power generation below mean tide level is not possible or required. However in order to meet the ecological requirements for lower basin water levels and greater inter-tidal exposure, a lower turbine setting may be necessary.

5.1.7 Consideration has been given to a range of operating strategies including ebb and flood generation. Although energy yield will be reduced by the adoption of ebb and flood generation, due to lower turbine efficiency in both directions, this form of operation may have ecological, sediment management and value of energy benefits. The preferred scheme will therefore be designed for both ebb only, and ebb and flood generation capability.

5.1.8 Limitation of gross generating head across the barrage has been shown to have a significant adverse impact on overall energy production and results in an under utilisation of the renewable energy resource of the Mersey. The preferred scheme must therefore be designed as capable of generating at unconstrained gross heads.

5.1.9 A large proportion of the energy available from the Estuary comes from the Spring tides where the tidal amplitude and potential for high gross generating heads is greatest. For this reason the generating plant for the preferred scheme will be rated with a best efficiency point towards the upper end of the gross head range.

5.1.10 On the basis of these considerations the preferred scheme will comprise the development of the A1.02 concept but with the turbine caissons replaced by the larger and deeper A2.02 units. The generating plant will comprise conventional bulb turbines designed for direct and reversible operation.

5.2 Preferred Operation

5.2.1 Simulations undertaken in Stage 3 of this study have shown that operation of the scheme on ebb only generation with an uncontrolled gross head delivers maximum energy (before incorporation of pumping) but results in the basin level rarely going below mean tide level. This has a significant impact on the ecology of the impounded basin.

5.2.2 Simulations undertaken for schemes that operate with limited gross head across the barrage result in a low energy yield and a non viable project.

5.2.3 The challenge is therefore to formulate a composite operational strategy that combines periods of high energy production with periods of restricted operation for ecological reasons. Option A1.04b would be a repeatable pattern throughout each Spring Neap cycle and is intended to maintain high overall energy yield by targeting the Spring to Intermediate tide range for priority energy production and the Intermediate to Neap tide range for a strategy that provides basin water levels much closer to natural conditions.

5.2.4 The implications of high tide pumping have not been analysed in detail in Stage 3. Options A1.02e and A1.04c have been included to provide an indication of the significant increase in energy output that might be obtained from this strategy. However this approach requires raising the natural high tide levels and this may have ecological, flood risk and ground water implications.

5.2.5 Pumping may be of ecological value to assist with the restoration of high tide levels in the basin to natural levels in order to prevent salt marsh ingress. Normally sluice gate operation should be sufficient to achieve this but the adoption of ebb & flood generation may require intervention by pumping. A net energy gain on the following ebb generation cycle should normally be possible. The overall merits of pumping will require careful consideration since drawing energy from the grid may result in local load flow, tariff and stability issues. Figure 5.1 shows the average hourly distribution of energy demand and output of Option A1.02e over the trial year of 2010.

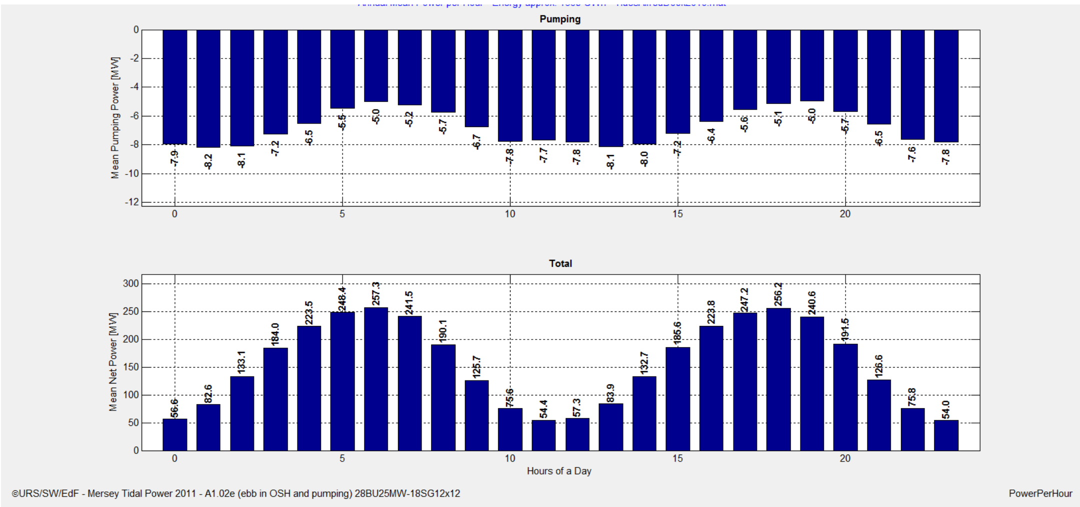


Figure 5.1: Average Hourly Distribution of Energy Demand and Output for Option A1.02e

5.3 Further Studies

5.3.1 In order to develop the details of the preferred option, optimisation studies are required to determine the final layout, plant details and operating strategies. Consideration of the overall scheme masterplan, including associated developments such as the visitors centre, access routes and other issues will also be required. Some of the additional subjects that need to be addressed include:

Site Conditions:

- Ground investigations to confirm foundation and sediment conditions, including pumping tests, UXO survey (unexploded ordnance), contamination survey and risk assessments;
- Identification of groundwater conditions in the area and consequences of barrage operations on outfalls, riparian structures and flood risk;
- Bathymetric and topographic surveys, including along navigation passages through the estuary to ascertain keel under clearance for floated caissons;
- Determination of wave climate and surge effects in the estuary, including site investigation by wave rider buoy;
- River traffic surveys to assess risk of impact with barrage structures and mitigation measures and for queuing studies at locks; and
- Identification of further utilities (and possibly oil pipelines) that may require diversion or protection to suit the barrage arrangement.

Design Development:

- Value engineering studies to identify opportunities for reductions in capital cost including comparison of materials for caissons i.e. steel or concrete or composite;

- Development of electro-mechanical and hydro-mechanical plant to ascertain noise levels, construction and installation requirements, maintenance requirements, spatial requirements within caissons (and landside);
- Development of preferred navigation lead-in to locks, for final barrage layout;
- Development of fish passage route structures and special requirements to direct fish to passages;
- Determination of requirement for small boat lock and layout;
- Sediment modelling to confirm layout of turbine-generators and sluices;
- Seismic risk assessment to confirm design parameters and assess liquefaction susceptibility of foundations;
- Development of steel sheet pile training walls and transitions between locks, turbine-generators, sluices and blank caissons; and
- Development of scour/erosion protection for river bed and abutments together with necessary hydraulic modelling.

Construction Issues:

- Development of construction sequence and location of casting basin for caissons;
- Identification of construction waste management requirements and planning;
- Optimisation of caisson design to minimise weight for float-out and sinking and account for spatial requirements for plant;
- Assessment of towing requirements and caisson towing attachments; and
- Development of access road across barrage to suit deck levels that could vary between caisson/structure types to meet weight and cost requirements.

Annex A: Stage 1 Technology Selection Matrix

ANNEX A: STAGE 1 TECHNOLOGY SELECTION MATRIX

Principle of operation	Name of option	Concept	Description	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Acceptability	Comments
Impounding of reservoir	**Tidal barrage**	Barrage across the estuary to create head difference for power generation	Typically comprising horizontal axis generating plant, sluice gates and ship locks	Green	Not applicable	Green	Green	Green	Green	Exact location to be defined. Ebb generation or ebb & flow, including pumping. Straflo or bulb turbines. Mature technology and construction (La Rance, Annapolis, Sihwa)
	Tidal lagoon	Reservoir independent from the estuary to create head difference for power generation	Same generating plant as barrage but with an embankment to create an isolated or land connected lagoon	Red	Not applicable	Green	Green	Green	Red	Insufficient space / water depth within the estuary. Possible multi basins, land connected configuration, location to be defined (outside the Mersey estuary). Ebb generation or ebb & flow, including pumping. Straflo or bulb turbines. New concept but based on mature technologies and construction.
Very low head barrage	**Tidal power gate**	Moveable barriers fitted with a grid of small diameter axial flow turbines able to provide free opening or a closed barrier	Hydromatrix or StrafloMatrix turbines that operate at heads between 2 and 6 m.	Green	Not applicable	Green	Green	Green	Green	The tidal power gate configuration as defined in the Phase 1 Study could be adapted and integrated in a low head barrage in shallow water with a intermediate head (around 2 m). Mature technology
	Tidal Reef	New concept: causeway + turbines installed in a « carrier structure ».	"Floating" caissons track tide. Turbines would operate on constant 2m head. Rotating carrier if the turbines are unidirectional, otherwise bidirectional turbines are installed.	Data not available	Not applicable	Red	Red	Amber	Red	Very low head turbines (2 - 3 m). Multiple small units to preserve distribution of flow. Reef is a concept.
	Very low head turbine	Tidal stream ducted turbines enclosed within partial barrage	New concept of very low head turbine in rotative structure to allow two way generation. The objective is to keep a constant low difference of water level across the structure.	Data not available	Not applicable	Red	Red	Green	Red	A new design of very low head turbine (2 to 3 m). The study of this turbine design has just started. Concept selected for the SETS. No prototype.

Principle of operation	Name of option	Concept	Description	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Acceptability	Comments
Tidal stream turbine	**Ducted technology**	Units installed in open condition in best places within the estuary	Bi-directional, horizontal axis turbine. Mostly with direct drive, variable speed, permanent magnet generator.	Amber	Red	Green	Green	Green	Red	The position of the tidal stream units in the estuary is driven by technical, navigation and grid connection considerations. The mean maximum velocities in the Mersey estuary generally do not exceed 2m/s.
	Horizontal axis technology	Units installed in open condition in best places within the estuary	Horizontal axis stream turbine.	Amber	Red	Green	Green	Green	Red	The position of the tidal stream units in the estuary is driven by technical, navigation and grid connection considerations. The mean maximum velocities in the Mersey estuary generally do not exceed 2m/s.
	Vertical axis technology	Units installed in open condition in best places within the estuary	Vertical axis stream turbine.	Green	Red	Green	Green	Green	Red	The position of the tidal stream units in the estuary is driven by technical, navigation and grid connection considerations. The mean maximum velocities in the Mersey estuary generally do not exceed 2m/s.
	Oscillating technology	Units installed in open condition in best places within the estuary	Oscillating devices (foil).	Amber	Red	Amber	Amber	Red	Red	The position of the tidal stream units in the estuary is driven by technical, navigation and grid connection considerations. The mean maximum velocities in the Mersey estuary generally do not exceed 2m/s.
Tidal fence	**Tidal fence**	Array of tidal stream devices housed in submerged cells within a structure that stretches across the river.	The tidal stream device technology used could be chosen between those selected in open. Vertical axis machines are specifically well adapted in this configuration	Green	Not applicable	Green	Green	Green	Green	Project not considered as viable in the Phase 1 study but kept for further development in the Severn project. Concept selected for the SETS .Several tidal stream devices technologies could be implemented (mainly vertical axis or ducted)

Principle of operation	Name of option	Concept	Description	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Acceptability	Comments
	Rotating Blade Vertical Axis turbine	Other concept of tidal fence with a new vertical axis turbine design	Vertical axis turbines (housed in a caisson. Blade areas specifically designed to avoid drag force (aerofoil section + independent rotation)	Data not available	Data not available	Red	Red	Amber	Red	Currently only a concept
	Vortex turbine	New concept of tidal ducted stream device based on vortex effect	At the entrance, guide vanes cause the water entering the duct to spin and create a vortex. Due to a pressure gradient, the water accelerates and the vortex is reinforced. The turbine comprises tubes and the water vortex creates its rotating movement	Data not available	Data not available	Red	Red	Amber	Red	Currently only a concept
	VerdErg Spectral Marine Energy Converter	New concept of fence using tubes to make a partial barrier that creates a venturi effect.	Radical new fence design based on venturi effect. A large proportion of tidal flow passes through a fence structure formed of a series of vertical and horizontal tubes. When water passes through the vertical tubes a pressure difference is created causing water to flow at high speed in the horizontal connecting tubes, which then drives turbines	Green	Green	Green	Amber	Amber	Amber	This concept has the advantage to produce energy with very low water velocity (below 1m/s). Only tank tests have been carried out. The design uses a conventional Kaplan turbine for electricity conversion. Concept selected for the SETS.
	Waterwheels	Large diameter wheels with 24 blades with axis above water level	The wheels would be housed in short concrete channels. The piers between the wheels would be wide enough to house a gearbox and the generating equipment.	Green	Not applicable	Amber	Red	Red	Red	Model studies undertaken in Phase 1 Study at the University of Southampton. No prototype is expected before several years .

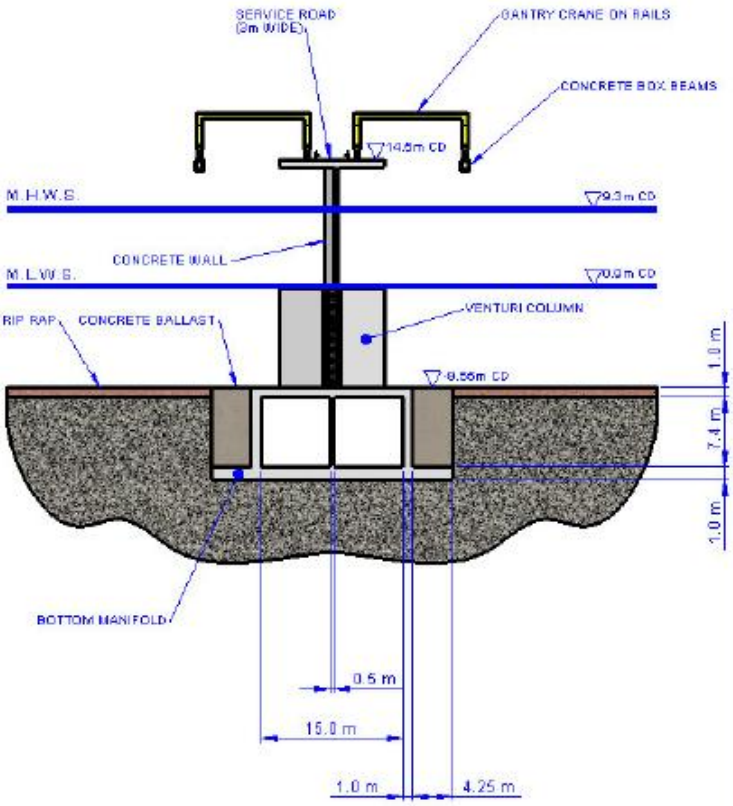
Annex B: Selected Stage 2 Study Drawings

Drawing No	Title
PD0330-11-2014 rev P2	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.01, Sluice Gate Caisson
PD0330-11-2015 rev P2	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.01, Turbine Caisson
PD0330-11-2016 rev P2	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.01, Blank Caisson
PD0330-11-2020 rev P1	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.01, Turbine Caisson, Piled Alternative
PD0330-11-2018 rev P2	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A3.01, Tidal Fence, Details and Sections
PD0330-11-2019 rev P1	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A3.01, Embankment
PD0330-11-2021 rev P1	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A3.01, Alternative Blank Caisson
PD0330-11-2023 rev P1	Civil Engineering (Power), Line B – Garston to Eastham, Option B2.01, Turbine Details

The SMEC venture system promoted by VerdErg Ltd is taken from Document Ref No RD206-500, pages 18 to 21, and is used in Option A4.01.

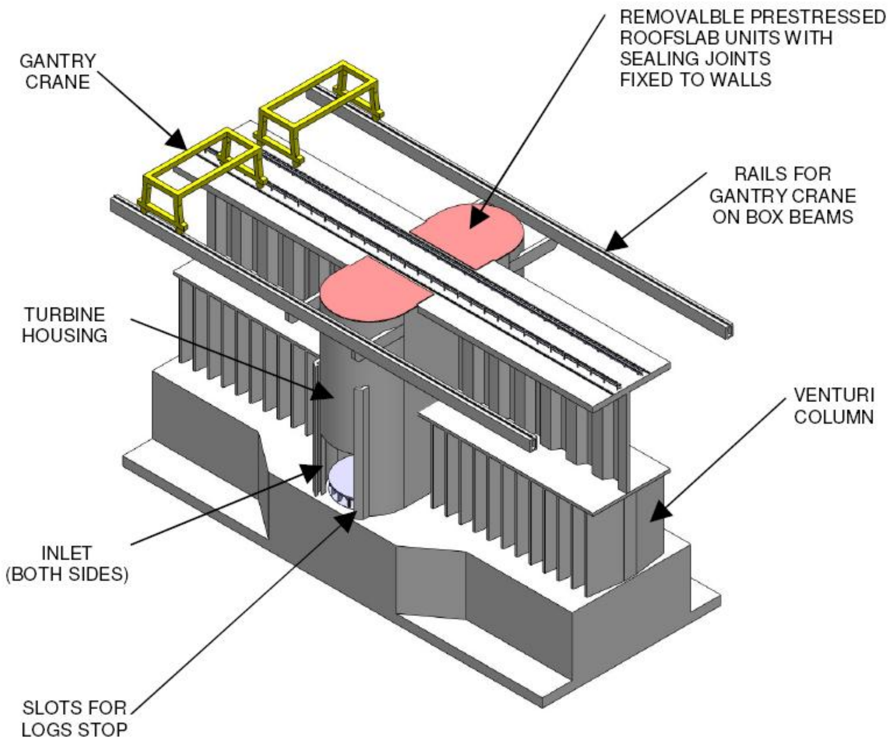
VerdErg Green by Design™	DOCUMENT REF No:RD206-500 Rev. 0
Mersey Estuary-Tidal Energy SMEC	Page 18

Mersey Estuary SMEC
Typical Cross Section



VerdErg Green by Design™	DOCUMENT REF No:RD206-500 Rev. 0
Mersey Estuary-Tidal Energy SMEC	Page 20

Mersey Estuary SMEC
Concrete Gravity Unit (60m Long) – Isometric View



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Annex C: Band B Options

Band B Options

1. Mersey Estuary

The Mersey Estuary is one of the largest in the UK and comprises two distinct geographic and bathymetric zones. There is a narrower, deeper section towards the mouth of the Estuary and a much wider shallower section further upriver. A simplified plan of the Estuary is shown in Figure 1.

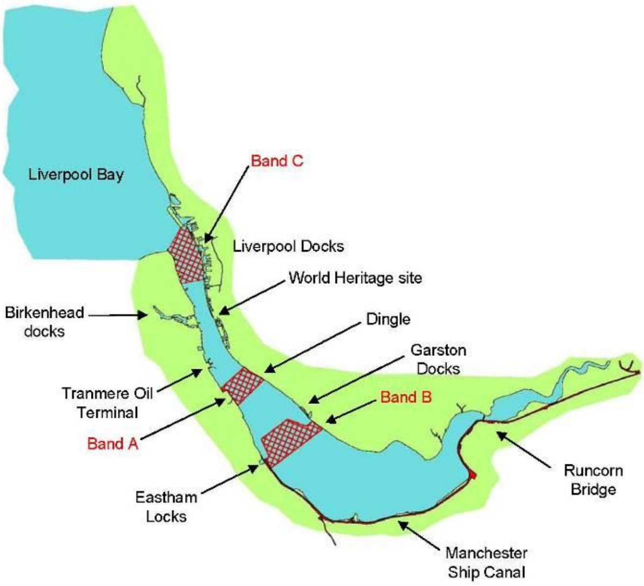


Figure 1: Mersey Estuary

The basic Estuary characteristics are represented by the three broad location bands shown in Figure 1. The key physical features of each band are as follows:

Band A

Band A is located at the upstream end of the narrow section of the Estuary. Approximately 80% of the flow volume at the Estuary mouth passes this location on each tide. The width is approximately 1.8 km and there is very little inter-tidal exposure. The water depth across the Estuary in Band A at low Spring tide varies from 11 m in the Middle Deep to less than 2m nearer the Liverpool shore.

Natural tidal flow velocities vary across the Estuary on Band A but are sufficiently high to prevent accumulation of significant alluvial deposits over most of the width. The geotechnical conditions in this band have been investigated in previous studies including work undertaken by the Mersey Barrage Company in 1990[5]. Suitable rock levels have been identified for power station and navigation lock structure foundations on the Wirral side of the Estuary channel. Lower bearing pressure or piled structures will be required across the remainder of the channel width.

[5] Tidal Power from the River Mersey. Feasibility Study. Stage III Report. 1992

Band B

Band B is located in the wider and shallower section of the upper estuary. The key reason for selecting this location is to be just upriver of Eastham Locks and Garston Docks and therefore avoid any impact on commercial shipping. Approximately 50% of the flow volume at the Estuary mouth passes Band B on each tide.

The width of the Estuary at this location is approximately 4 km. There is considerable inter-tidal exposure and at most low tide conditions the Estuary discharge is confined to isolated channels. At low Spring tide the sand bars across the Estuary rise to more than 5 m above water level. The configuration of sand bars and channels across the Estuary is continuously changing. Under current conditions there is a main channel approximately in the centre of the Estuary and two further channels near the Liverpool and Wirral shores at the heads of the Garston and Eastham channels respectively.

Geotechnical conditions in this band have not been specifically investigated and can only be implied from regional data. The depth of alluvium across Band B will however be considerable and any structure across the Estuary will require piled foundations and major dredging operations for the structures and approach channels.

Band C

Band C is located at the entrance to the Estuary and therefore offers the greatest potential for a tidal power scheme in terms of energy resource. The central channel of the Estuary is typically 18 m deep at low Spring tide and the width varies between 1 and 1.5 km. Geotechnical conditions are known to be more favourable than at Band A.

Power scheme options in Bands A and B were developed and examined in Stage 2 of this study. Options in Band C were initially placed on hold awaiting the outcome of the Band A studies. It was subsequently concluded in Stage 2 that planning and navigational constraints on Band C effectively precluded the development of a tidal power scheme at this location.

This paper considers the technical issues associated with the development of a tidal power scheme at Band B.

2. Phase 1 Study

The Mersey Tidal Power Study, 2007[6] considered a range of existing and emerging marine power technologies to assess the feasibility of generating renewable energy from the Mersey Estuary. The work was undertaken by designating geographic zones in the Estuary and considering the possible types of tidal energy scheme that could be suitable for the conditions in each location.

The extent of Zone 3 adopted in the 2007 Study[6] is shown in Figure 2.

[6] Mersey Tidal Power Study. Buro Happold, Strategic Planning Advice, The University of Edinburgh & the RSK Group. September 2007

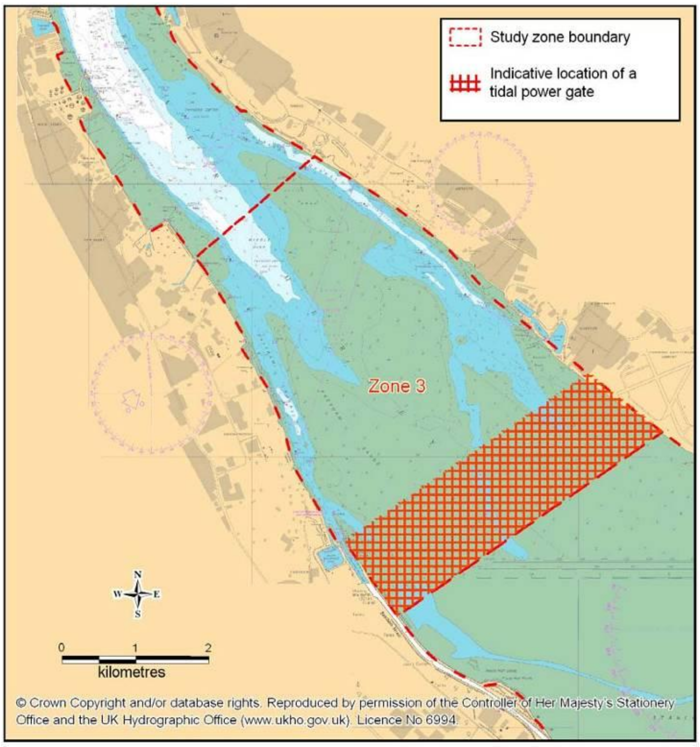


Figure 2: Zone 3 (2007 Study)

The upstream extent of Zone 3 is broadly coincident with Band B adopted in this current study. At this location the 2007 Study[6] considered the possibility of introducing either a Water Wheel or Tidal Gate power scheme. Both these concepts were proposed as possible solutions to the shallow water depths and inter tidal conditions at this location.

3. Power Scheme Options for Band B

Water Wheels

The water wheel technology was examined at Stage 1 of this current study. It was concluded that conditions in Band B could be suitable for a major water wheel development. Water wheels have been used as a source of power for many centuries but currently only very small units are in commercial production and there is no prospect of this technology being sufficiently advanced for a large scale development on the Mersey within the time frame required. This technology was therefore not selected for further study.

Tidal Gate

The tidal gate concept proposed in the 2007 Study[6] was selected for further consideration in this current study but it was recognised at the outset that the proposed arrangement presented considerable operational difficulties and a revised concept was needed that separated the gates from the turbines. An alternative arrangement was therefore developed using the same Hydromatrix™ technology proposed for the tidal gate, but mounted externally on a fixed barrage structure with the gates confined to specific locations. This arrangement was developed as Option B2.01 in Stage 2 of the current study.

Tidal Fence

The possibility of creating a tidal fence scheme on Band B was also examined at Stage 2 of this current study. Natural tidal stream velocities at Band B are too low for commercial operation of open stream devices and an arrangement was therefore examined where the Estuary was constricted with an embankment to a width of just 210 m to create the necessary velocity conditions. This arrangement was found to deliver a very low energy yield that grossly under utilised the tidal resource of the Mersey Estuary. Study of this concept was therefore discontinued.

4. Option B2.01

Design

The concept developed for Option B2.01 in Stage 2 is shown in Figure 3. The turbine generator unit is externally mounted on the basin side of the structure so that it may be recovered for maintenance at deck level. This arrangement is also convenient for the progressive replacement and upgrading of units as advances in technology occur.

The draft tube is embedded in the body of the structure and a control gate is incorporated at exit. The units are unregulated and this control gate will be used for barrage operation. Stop log slots are provided in the pier ends both upriver and downriver so that the passage can be de-watered for maintenance. The hydraulic control systems, electrical panels, transformers and cable ducts are accommodated in cells within the caissons. The remaining cells are ballasted to provide the necessary stability.

A rated head of 3 m was adopted for the turbines to achieve the basic objective of a low head barrage. A 1.45 m diameter compact ECOBulb™ turbine generator unit was selected from the Andritz range. The ECOBulb™ is a development of the smaller units used in the Hydromatrix™ system. Larger diameter turbine generator units from the ECOBulb™ range could be considered in subsequent design iterations of this option but would require deeper submergence and a larger amount of excavation.

The ECOBulb™ unit is a self contained system that permits reduced civil engineering costs because of the low tail water depth required for operation. This characteristic permits the adoption of a higher foundation level for the power caissons and therefore reduced excavation costs on long structures.

Inspection of the available width in the estuary at Line B indicated that 640 turbine units could be accommodated providing a combined discharge capacity at rated head of approximately 7,050 m^3/s. The cumulative length of the turbine structures was approximately 2,925 m. This configuration provides a distributed ebb flow discharge across the width of the Estuary but presents a considerable barrier to fish. Small diameter turbines typically have high rotational speeds that are not fish friendly and a large number of fish by pass routes would be required for a structure of this length.

The sluice gate requirement was assessed to be 24 No. 12 x 12 m vertical lift gates, requiring a combined structure length of 420 m. This requirement was provided in two equal structures on the Wirral and Liverpool banks of the estuary.

The concept requires a large permanently dredged area extending the full length of the barrage. At the turbine caissons the depth of the dredge pocket would need to be up to 12 m in places and to create stable profiles this would require approach slopes extending approximately 100 m on both the sea and basin side of the structure.

Operation

On the flood tide the gates are opened and the turbines are permitted to run in reverse orifice mode. The flood tide is admitted without significant head loss across the barrage and the water level in the basin closely follows the natural tidal shape. There is virtually no attenuation of the high tide level.

Under Neap tide conditions the entire ebb flow can be conveyed through the turbines for power generation whilst maintaining the objective of not exceeding a 3 m differential head across the barrage. However under Mean and Spring tide conditions it was found necessary to augment the turbine discharge capacity by using the sluice gates so that the head across the barrage could be limited to approximately 3 m. The sluice gates were additionally used at the end of each generating cycle to create lower water levels in the basin and promote mud flat exposure.

A key feature of the operation of this scheme is the shallow water depth in the impounded basin. As generation on the ebb tide takes place the depth of approach flow to the barrage reduces and progressively breaks down into divided channels. This condition will be associated with a loss of generating head at some locations, sediment mobilisation and the tendency for flow to run along the face of the barrage. These conditions can not be accepted and power generation must be progressively shut down before this occurs.

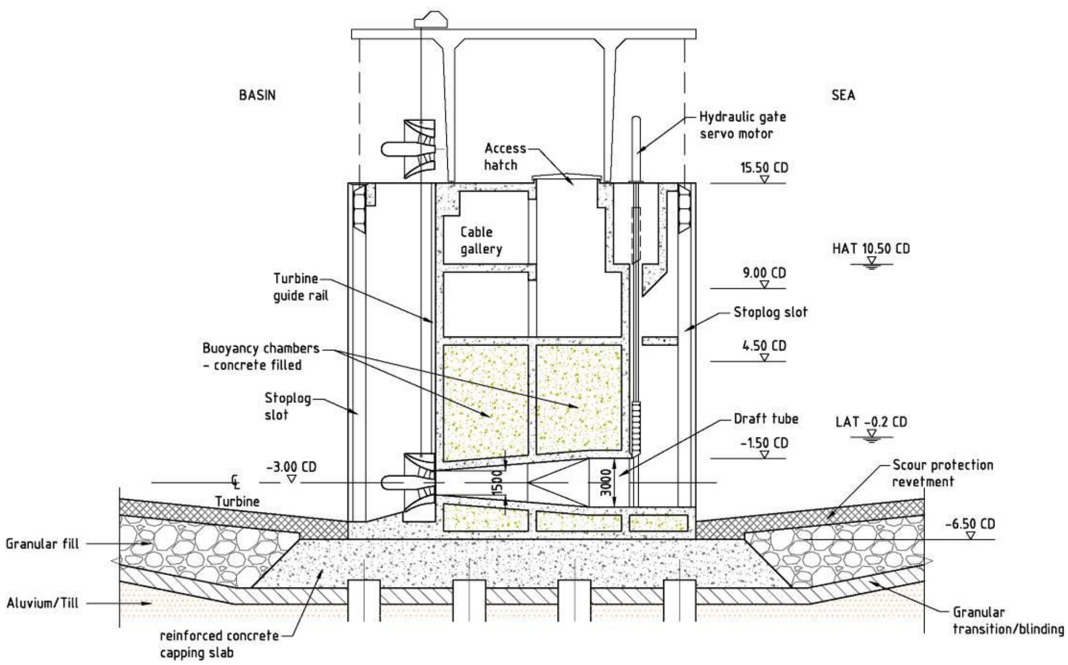


Figure 3: Option B2.01 Arrangement

A similar approach to the arrangement shown in Figure 3 has been adopted for the Ashta 1 and 2 hydropower projects currently under construction on the Drin River in Albania. These two projects are due for completion in 2012. Each project comprises 45 No. externally mounted Hydromatrix™ units with installed capacities of 24 MW for Ashta 1 and 45 MW for Ashta 2.

Sample outputs from the 0D model for the Spring tide are shown in Figure 4.

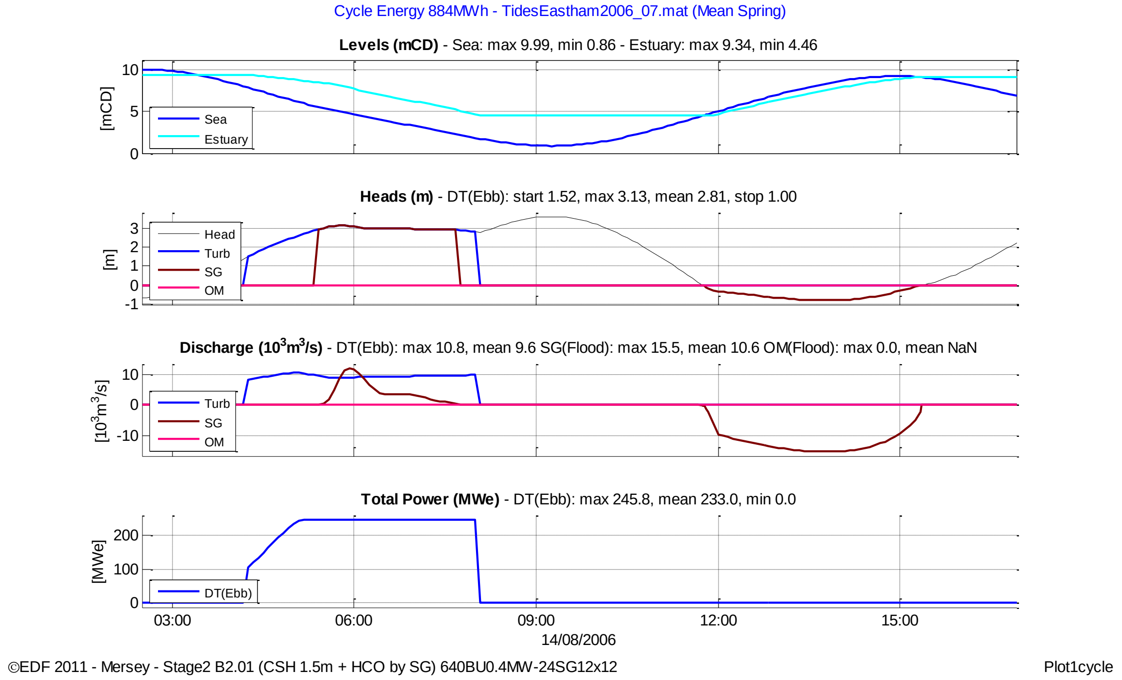


Figure 4: 0D Simulation for the Mean Spring Tide

5. Conclusions for Band B

Preliminary simulations for Option B2.01 undertaken in Stage 2 indicated that an energy yield of some 400 GWh per year could be delivered. With further design and operational refinements this figure could probably be increased. However the overall commercial and renewable energy performance of a scheme at Band B will remain less satisfactory than barrage options that could be developed on Band A. The key technical reasons for this relative performance are:

- Approximately only 5/8th of the water that passes Band A passes Band B, thereby imposing a corresponding reduction on the maximum energy potential at Band B.
- The width of the Estuary is considerably greater, largely offsetting the cost savings associated with avoiding navigation structures.
- Shallow water conditions require a more costly configuration for the generating plant.
- Long structures comprising a large number of small diameter turbines present a considerable barrier to fish passage.
- Shallow water conditions prevent larger generating heads being developed.
- There is more uncertainty regarding geotechnical conditions and the depth of alluvium is typically much greater on Band B.
- Band B is characterised by considerable exposure under low tide conditions making power generation at lower tide levels very difficult.

The large mobile sand banks and inter-tidal channels at Band B present a considerable construction and operational risk to a tidal power scheme at this location. Major dredging operations in potentially contaminated sediments would be required to create and preserve flow approaches to the structures and substantial morphological changes both upstream and downstream of the structure are likely to occur.

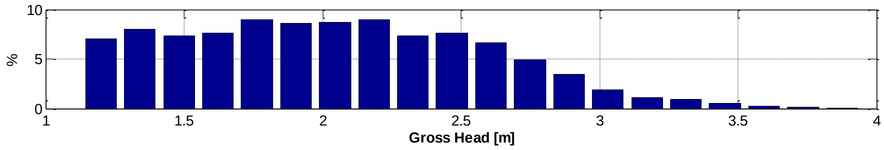
Band B is not a logical location to adopt for a tidal power scheme unless there are compelling ecological, navigational or planning reasons that override the technical and commercial disadvantages.

Annex D: Number of Turbines on Line A

56 units: Head and Energy

```
- Ebb Generation:
Head control choice .................. Nb Units variable
Mean Head ............................ 2.07m
Max  Head ............................ 3.68m
```

Plant Histogram - TidesAlfredDock2010.mat



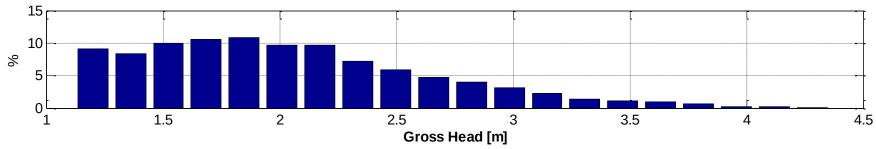

```
+ ------------------------------ +
| Annual Generation : 599.4 GWh  |
+ ------------------------------ +
```

DAG 14/12/2010

44 units, OP Head 2.5: Head and Energy

```
- Ebb Generation:
Head control choice .................. Nb Units variable
Mean Head ............................ 2.12m
Max  Head ............................ 4.28m
```

Plant Histogram - TidesAlfredDock2010.mat




```
+ ------------------------------ +
| Annual Generation : 619.6 GWh  |
+ ------------------------------ +
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DAG 14/12/2010

Summary

Case	Max Estuary Level	Min Estuary Level	Max Estuary Range	Mean Head	Max Head	Annual Generation
	m	m	m	m	m	GWh
HCO 40	10,38	1,24	9,14	2,35	4,69	702,8
HCO 44	10,38	1,17	9,21	2,25	4,39	669,3
HCO 48	10,38	1,16	9,22	2,18	4,12	642,6
HCO 52	10,38	1,16	9,22	2,11	3,88	618,0
HCO 56	10,38	1,15	9,22	2,07	3,68	599,4

Supplement: Sensibility to the Maximum Operating Head, with 44 units

Case	Max Estuary Level	Min Estuary Level	Max Estuary Range	Mean Head	Max Head	Annual Generation	Max Operating Head
	m	m	m	m	m	GWh	m
HCO 44	10,38	1,13	9,25	2,12	4,28	619,6	2,50
HCO 44	10,38	1,17	9,21	2,25	4,39	669,3	3,00
HCO 44	10,38	1,30	9,08	2,39	4,49	715,1	3,50

DAG 14/12/2010

Annex E: Stage 3 Drawings

Drawing No	Title
PD0330-11-3000 rev P6	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.02. General Arrangement
PD0330-11-3001 rev P4	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.02, Longitudinal Section
PD0330-11-3002 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.02, Turbine Caisson Plan
PD0330-11-3003 rev P4	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.02, Turbine Caisson, Section
PD0330-11-3004 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.02, Sluice Gate Caisson
PD0330-11-3005 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A1.02, Blank Caisson
PD0330-11-3050 rev P5	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.01, General Arrangement
PD0330-11-3051 rev P5	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.01, Longitudinal Section
PD0330-11-3052 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.01, Turbine Caisson Plan
PD0330-11-3053 rev P3	Civil Engineering (Power), Line B – Garston to Eastham, Option A2.01, Turbine Caisson Section
PD0330-11-3054 rev P4	Civil Engineering (Power), Line B – Garston to Eastham, Option A2.01, Turbine Caisson Section (Piled Foundation)
PD0330-11-3055 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.01, Sluice Gate Caisson
PD0330-11-3056 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.01, Blank Caisson
PD0330-11-3100 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.02, General Arrangement
PD0330-11-3101 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.02, Longitudinal Section
PD0330-11-3102 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.02, Turbine Caisson Plan
PD0330-11-3103 rev P3	Civil Engineering (Power), Line B – Garston to Eastham, Option A2.02, Turbine Caisson Section
PD0330-11-3104 rev P3	Civil Engineering (Power), Line B – Garston to Eastham, Option A2.02, Turbine Caisson Section (Piled Foundation)
PD0330-11-31015 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.02, Sluice Gate Caisson
PD0330-11-3106 rev P3	Civil Engineering (Power), Line A – New Ferry to Dingle, Option A2.02, Blank Caisson
PD0330-11-3200 rev P1	Civil Engineering (Power), Line B – Garston to Eastham, Left Bank Temporary Casting Basin & Site Establishment

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