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SUMMARY

The object of this project was to develop a Project Initiation Document (PID) covering the business, technical, environmental cases for the utilisation of low head tidal pools, to produce energy from a sustainable resource that is both predictable and quantifiable. The aim is to produce cost effective energy for national grid consumption while enhancing the local environment for both wildlife and the local community.

The context of the report is site specific, the chosen location of Hayle in Cornwall possesses redundant infrastructure to reduce the investment required in both capital and invested carbon terms. The enhancement of the business case through cost reduction will encourage adoption of the PID into a viable project.

Established and proposed tidal pool developments have been researched, primarily La Rance in Brittany France and the proposed development of the Severn barrage in the UK. A number of other tidal range project proposals have been submitted in the UK over the last century. However the high costs associated with barrage construction have prevented the development proposal being built. Adoption of existing pools would substantially reduce the capital costs.

The UK is committed to delivering its share of the EU target of 20% of energy from renewable sources by 2020. The competition for tidal pool electric engineering within this sector currently stand as onshore and offshore wind, dedicated biomass & Solid Recoverable Fuels(SRF). The business modelling utilises the current cost associated with other renewable technology construction and operation to compete with these more mature generating systems.

Problems were experienced in obtaining data on specific tidal electric generation systems from manufactures. Thus a stated specification of the type of turbine and generating capacity was made rather than a specific manufacture and model. A number of existing developers globally exist and established turbine technology would be selected rather than a concept design.

Comparable renewable energy electrical generation technologies costs have been calculated giving a unit cost per pool generating capacity of between £27 million and £54 million.
The sustainability measured in lifecycle carbon savings are over a generating life of 120 years a saving of 186.9 Kilo tonnes of carbon per pool and an estimated carbon payoff in less than 12 months.

It would be fair to say that this document lacks the detail for commencement of the project however that is not the aim, it is to present facts and stimulate discussion into the further work required for the UK`s first Tidal Range site. In conjunction with the Wave Hub project Hayle harbour could be a site of excellence for Marine renewables.

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Hayle Harbour Power Generation Scheme

Tidal power generation, Hayle Cornwall: Utilising redundant infrastructure to enhance commercial viability

Contents

1. Introduction

1.1 Background to this project

The aim of this project report is to develop a Project Initiation Document (PID), covering the business, technical, environmental cases for the utilisation of low head tidal pools, to produce energy from a sustainable resource that is both predictable and quantifiable. The aim is to produce cost effective energy for national grid consumption while enhancing the local environment for both wildlife and the local community.

As a child I lived and played on an estuarine pool (lagoon) in Hayle in Cornwall and I remember the sluicing operations utilised to keep the navigation channel clear from both the two man made tidal pools Copperhouse and Carnsew with the greater Hayle estuary site (Annex A). The town also possessed a coal fired power station now decommissioned with the associated electrical distribution infrastructure that remains. Further research during my Open University study and further reading into the history of Hayle, provided me with a greater understanding of the opportunity that exists in combining the a given natural resource, modified during the Industrial revolution and the 20th century electrical supply infrastructure

The ability to forecast the time and quantity of the natural resource associated with tidal lagoons, as opposed to wind, wave and solar will enable a stronger business case to be derived.

The project would fit within and answer the requirements of the redevelopment plan for Hayle (www.hayleareaplan.org.uk/documents/06_4160HayleAreaPlan.2o.pdf) and contribute to the area becoming a centre of excellence for Wave and Tidal energy production in conjunction with the RegenSW sponsored Wave Hub project also located at Hayle in Cornwall. The redevelopment plan calls for the recommencement of sluicing to ensure the safety concerns associated with the navigability of the harbour channel.

1.2 Approach

This Project Initiation Document (PID) does not intend to encompass in depth specific detail regarding the business, technical and environmental principles but to give a sufficient detail to allow a developer to make an informed decision to proceed with a consultation phase of planning and development. Secondly it hopes to promote engagement within the field of tidal resource in a lower cost non multi billion pound proposal like the Severn barrage project.

The strategy behind this project is to divide the technical stages of this project and assess them for suitability, however it is understood that design and project do not occur in a linear path and thus iterations to revisit previous stages may occur. Once each technical stage has been reviewed and the preferred decision reached it is to be reviewed against the constraints and criteria of the environmental and business cases. If the chosen technical solution satisfies these constraints and criteria the decision to progress the next stage through the management of the project can be taken.

The project management style utilised to track and manage the project will be of Prince2 methodology. It divides the project into stages sequentially with decision points to proceed at the end of each stage. MS Project has been chosen as a software tool to manage and display the progress of the PID. (Annex E).

1.3 Project aims and objectives

The aims of this project are to quantify the viability of a “small scale low cost” tidal range project as opposed to established larger in commissioned tidal-electric plants such as La Rance in France and the Severn barrage proposal. The aims were constructed and developed through stages of iterative design as research was conducted and ideas were formed assessed and discounted, ideas that lay “out of scope” were noted and recorded primarily the integration into an energy system whether private wire (to service the redevelopment of Hayle by ING Real estate) or in conjunction with another form of energy generation or store to act as a base load generator.

Aims

- To describe tidal phenomenon
- Qualify and quantify market requirement for Tidal Electric energy.
- Establish that proven tidal electric technology exists that could be applied to the chosen site.
- To assesses the business case associated with other renewable energy technologies and utilise this data to analysis the commercial potential of a tidal electric scheme.
- To give an overview of environmental impacts associated with a tidal electric development during construction and operation.

Objectives

- To identify potential energy within both Copperhouse and Carnsew Pools.
- To apply the business case of established renewable technologies to the development.
- To specify an operating system and the associated technological specification.
- To demonstrate integration into local area plan and UK government energy policy
- To assess the sustainability of the project in terms of carbon reduction potential.

1.4 Energy Policy and local area plans

The UK and EU policy towards the adoption of Renewable Energy has clearly defined targets however the mechanisms to support the adoption are constantly evolving the regulations are extensively documented at the Business Enterprise and Regulator Reform website (www.berr.gov.uk/energy/index.html) . The latest UK ministerial statement reported does not include a recognisable increase in funding support, however relaxed the planning conditions attached to the construction of primarily wind farms. The media reported (BBC evening news 26/06/08) that the extra costs associated with renewable energy development will be passed on directly to the consumer from the operator/owner.

The Government is currently undergoing a consultation period with regards to Renewable energy strategy thus further evolution of policy is inevitable.

Funding for capital projects is carried out through regional development agencies as with RegenSW (www.regensw.co.uk/) which is the renewable energy agency for the south west. RegenSW is currently supporting the Wave Hub development in Hayle to the cost of circa £ 24 million.

Support is also given to the production of renewable energy through Renewable Obligation Certificate (ROC) which places incentives on the producer to generate a percentage of its total output from renewable sources.(www.ofgem.gov.uk/Sustainability/Environmnt/RenewablObl/Pages/RenewablObl.aspx).

A Tidal Range development at Hayle fits with and enhances the local area plan (www.hayleareaplan.org.uk/documents/06_4160HayleAreaPlan.2o.pdf) It directly addresses within Section 5 Project 7 “A water based sustainable energies development strategies”(Page 17) and will have a positive influence on projects detailed as 6,8,9,10.

1.5 Alternative Renewable Energy costs

The first area to investigate in line with T307 study was the availability of a market in a consumer orientated context; the project requires a market pull as a driver not a technological push. Yes! Almost everyone consumes electrical energy in the UK and through societal marketing there is a rise in ethical orientated power provides, from small specialist providers as in Good Energy to major generators offering green tariffs such as Npower renewables. Governmental targets of 15% of all UK energy needs (electricity, heat, transport) most recently documented in a written government statement dated 26/06/08 www.berr.gov.uk/files/file46800.pdf demonstrates the awareness of climate change and the need to derive energy from a non fossil fuel source.

With an expanding viable market, support by legalisation available, the focused turned to research into a technical solution for the chosen aim.

Research into established technology with the field of renewable energy in particularly existing tidal range and hydro electric power technologies, but also investigation to the installation costs associated with other established renewable technologies.

Utilising a report into the 2020 vision - how the UK can meet its target of 15% renewable energy from the UK government Business Enterprise and Regulatory Reform department . The estimated capital expenditure (Capex) required for the following renewable technologies to achieve 2020 targets are.

Onshore wind

13,000 MW required at £13bn Indicative capex = £1 million per MW

Offshore wind

18,000 MW required at £36bn Indicative capex = £ 2million per MW

Dedicated biomass & Solid Recoverable Fuels

4,000 MW required at £6bn Indicative capex - £ 1.5 million per MW

Therefore the project based purely on commercial terms would at first have to compete in the range of £1 to £2 million per installed MW; however the operating efficiencies of wind turbines are around 30% (www.bwea.com/ref/faq.html#cost)

Thus a cost in the range between £3 and £6 million per installed MW should be thought of as required for an installed base load generator.

2. Tidal Theory and Site Overview

2.1 Tidal Phenomenon

Coastal areas throughout the world experience a twice within a 24 hour period a rise and fall in sea level. This is quantifiable in terms in change in level and the time of day that the high and low points occur during the day as the advance by circa 50 minutes a day. The prime driver for tidal phenomenon is the action of the Moons upward gravitational force on the Earths surface, during the orbit of the Moon the water level will experience a high water and low water mark, the difference between the two is known as the Tidal Range. The Sun also exerts a gravitational force on the tidal variation, but due to its distance from the Earth the effect is about 45% of the Moons, the conjunction and opposition of these two gravitational forces give rise to Spring and Neap tide variations. The rotation of the Earth and the associated centrifugal force also has a substantial effect on the Tidal rage of a body of water. The mechanisms of tidal phenomenon are covered extensively within Elements of Tidal-Electric Engineering (Robert H.Clark. (2007). Tidal Phenomenon. In: Mohammed E.El Hawary *Elements of Tidal-Electric Engineering*. USA: John Willey & Sons. P7-14.)

This tidal information is not solely of interest to engineers but also to all seafarers, the information is readily available in the form of tide timetables.

2.2 Tidal Range technologies

Tidal range technologies utilise the gravitational potential energy of water similarly to traditional Hydro-Electric Power schemes (HEP), however they operate on a Low Head (low range) large volume theory with a maximum head of less than 10 metres, traditional HEP schemes operate above 50 metres. The potential energy is created by the impoundment of a volume of water at high water and its release as low water approaches, this potential energy can be converted into electrical energy via a turbine coupled generator.

The impoundment of the water resource currently takes two forms; tidal barrage a dam is place across an estuary to create an area of impoundment within the upper estuary, the holding of the water at high tide and the sinusoidal action of the tide to low water creates the tidal range. Examples of tidal barrage exist globally the largest being La Rance in France which has a generating capacity of 240 MW. Downsides to tidal barrage are the effect on the environment impounded during construction and operation and the disruption to shipping and the construction of locks to maintain the required tidal range. The effect to the environment of the construction La Rance is summarised within Elements of Tidal-Electric Engineering (Robert H.Clark. (2007). Tidal Phenomenon. In: Mohammed E.El Hawary *Elements of Tidal-Electric Engineering*. USA: John Willey & Sons. Page 192.)
The second proposed form of impoundment is the construction of offshore enclosures, Tidal Lagoons created in shallow water by the dredging and dumping of material to create the enclosures a turbine house would then be constructed into the structure. Downsides to tidal lagoons are the proposed capital costs with impoundment construction and the lack of any examples of this form within the world. Proposed developments in Swansea Bay in Wales by Tidal –Electric are currently being undertaken.

2.3 Potential theory

The estimated potential energy available within the Tidal Basin(s) is directly related to the volume and the available range i.e. the difference between the high and low tide marks for the given tide. Calculations as given in Elements of Tidal-Electric Engineering (Robert H.Clark. (2007). Tidal Power Potential. In: Mohammed E.El Hawary *Elements of Tidal-Electric Engineering*. USA: John Willey & Sons. P18)

Using the formula to calculate potential energy for each part tide.

V= Volume of basin = Basin Area (A) x Range (R)

ρ = density of sea water (1025kg/ m^3)

R = Tidal range (metres)

g = acceleration due to gravity

Available potential energy (single effect) = $\frac{\rho VRg}{2}$ (2.1)

However for use in a combined ebb and flood system to be discussed later the energy would be extracted during the fill and flood sequence giving.

Available potential energy (Double effect) = ρVRg (2.2)

Substituting V=AR

Available potential energy (Double effect) = ρgAR^2 (2.3)

With area in metres squared and the range in metres.

Gross potential energy (GEP)

$$GEP = 1025 \times 9.81 \times A \times R^2 \text{ Watts} \cdot \text{second}$$
$$GEP = 1.005 \times 10^4 AR^2 \text{ W} \cdot \text{s}$$
$$= 2.793 \times 10^{-3} AR^2 \text{ kWh per tide} \quad (2.4)$$

For a given year of 705 tides per annum

$$GEP(annual) = 0.197 \times AR^2 \text{ kWh} \quad (2.5)$$

3. Site Overview and Potential

3.1 Site Overview

The pre-selection as Hayle harbour is derived as previously stated from childhood memories and the lessons learnt through study towards an Open University Technology degree. A period of working in the renewables industry reinforced my belief that an opportunity exists to explore the viability of a tidal electric scheme within the Hayle harbour area.

Hayle harbour contains two tidal lagoons (pools) within an estuary system; both lagoons were constructed during the boom time of Cornish mining in the early 19th century associated with the Industrial Revolution. The port of Hayle was constructed to serve the export of copper and tin and the import of coal from the South Wales coal fields. Copperhouse pool developed by the Copperhouse Copper Company (CCC) as a navigable area for shipping access to facilitate import/export.

Carnsew pool was created by the rival Harvey's Company to sluice the main channel to their operations for shipping access.

The Harvey's eventually took over the CCC and intern ceased to operate leaving the two pools as redundant infrastructure, usage of both pools to sluice the main channel continued into the 1970`s Copperhouse pool ceased to be navigable long before that date. The Harbour area is also the site of a former coal fired power station and still possess the electrical grid distribution system of 132 kVA, the cost reduction of this distribution infrastructure was attractive to RegenSW who commissioned the development of a Wave Hub, an offshore wave powered renewable energy technology

In summary the chosen site possess the following advantages.

- Existence of two tidal pools that significantly reduce the overall capital cost of the project, removing the requirement to build of impoundment barriers.
- The non-navigable nature of both pools removes the requirement for lock gates.
- A requirement exists within the Hayle area plan for the development of renewable energy technology.
- Existing grid connection infrastructure with ½ mile of both pools.

- Requirement from Hayle Harbour redevelopers ING Real estate to recommence sluicing to improve the navigable channel in the lower estuary.
- A location with a tidal range in excess of 6 meters, from equation (4.3) the energy potential ids related to the square of the range.
- Opportunity to dovetail with the “Wave Hub” project to produce water based renewable technology centre of excellence.

3.2 Site Potential

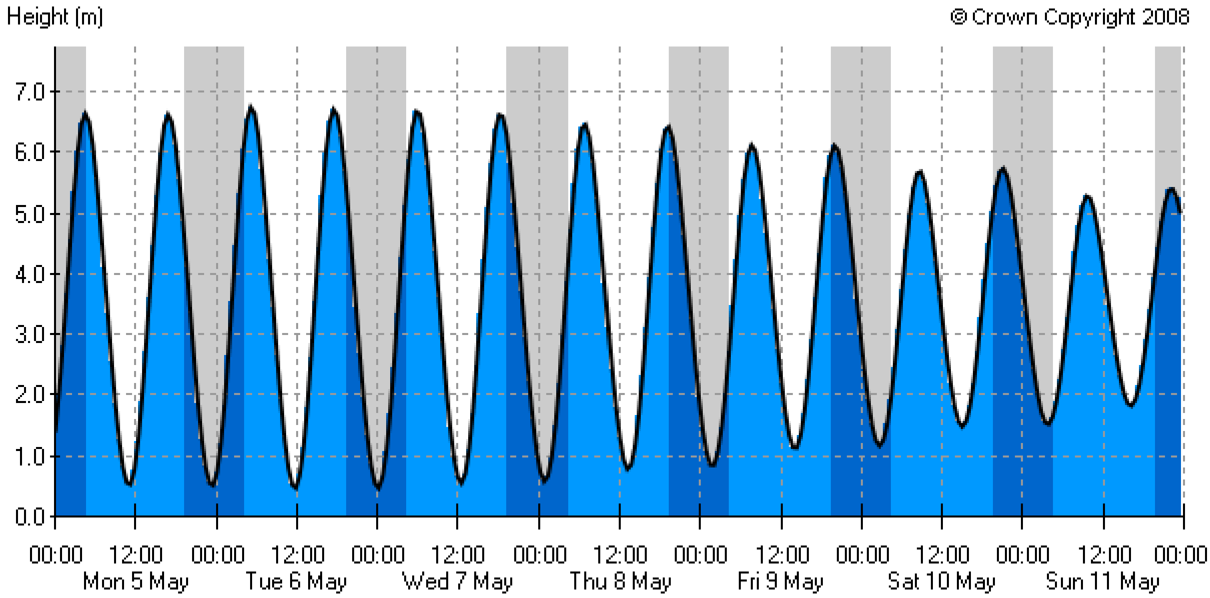
This phase of the project involved researching the different techniques available to quantify the water volumes of both Copperhouse and Carnsew pools and therefore the available stored energy at both spring and neap tides. Initial contact with the Environment agency that are responsible for the flood defence of the harbour site was initially encouraging but proved fruitless, a resistance to change culture is promoted from the local environment agency office and was noted as a possible obstacle as the project progresses.

Next a physical estimate was carried out by walking the perimeter of both pools using a map and a pedometer. This also enabled a very rough estimate of the topography of the pool bottom to be carried out as it is far from flat. This information in conjunction with a Tide time table would give a rough estimate of volumes. On the route of the Copperhouse pool is the local library that has access to the Ordnance Survey OS Mastermap which permitted the areas of the pools to be sectioned and summed to give an area.

Networking with a local councillor John Bennett, provided information into a study conducted by consultant engineers Buro Happold for Hayle Harbour owners ING Real Estate, the report contains information on the volume of the two pools at 0.25metre intervals as the pools fill. The data for the last technique is presented in Annex B.

A decision to utilise the data from the report by Buro Happold which is the most accurate was taken, because of the incremental study at 0.25m intervals rather than estimations of area and volumes. However its comparison with the available tidal data for the area (Figure 1) with a high tide of 7 metre and a tidal range of 6 metres shows that silting of the area harbour area has affected the volumes by as much as 4 metres. This can be seen as an obstacle but could also be viewed as an opportunity to increase the productivity by removal of silt particularly Copperhouse pool which has a greater area of 19,500 square metres compared to Carnsew pool 14,600 square metres but a volume at 3 metre range of 287,125 cubic metres compared 338,922 cubic metres.

Figure 1. Tidal range data for St Ives Cornwall (nearest (2 miles) available data)



The difference in available range from Figure 1 the Tidal range at St Ives and the data collected by consultants Buro Happold defines the degree of silting that has occurred in both pools (most markedly Copperhouse pool) since the suspension in the 1980`s of sluicing, amounts up to 4 metres. This can be addressed to 3 ways.

- Remove the silt by dredging or excavation, this will add greatly to the capital costs of the project. Specify the turbine power house for this new capacity.
- Accept the loss of capacity and design on today's values for pool volumes.
- Take into account the gains that will occur in volume on recommencement of sluicing during the power generation phase. Then design the turbine power

house to be sunk by excavation into the harbour floor to take advantage of the extra capacity. This will also require recalculation of potential energy storage and turbine house specification.

Re evaluation of the potential energy for each case is presented below, but the outcome decision will impact the sizing of the turbine and generating equipment.

The decision to model available energy utilising potential theory calculations in Chapter 2.3 has been taken, both at current volumes and estimated volumes to maximise the available tidal range of 6 metres, this would require the removal of silt in particularly at Copperhouse pool. Taking into consideration the Buro Happold data it is reasonable to estimate that both pool volumes could be at a depth of 6 metres 750,000 cubic metres. Whether this is achieved in total or to some degree it is worth for a business case to explore the theoretical maximum.

The decision to specify the same volumes for both pools is achievable and allows for commonality of turbine generator reducing costs and improving the supply chain support of service parts.

Figure 2 Simplified cross section of Copperhouse pool

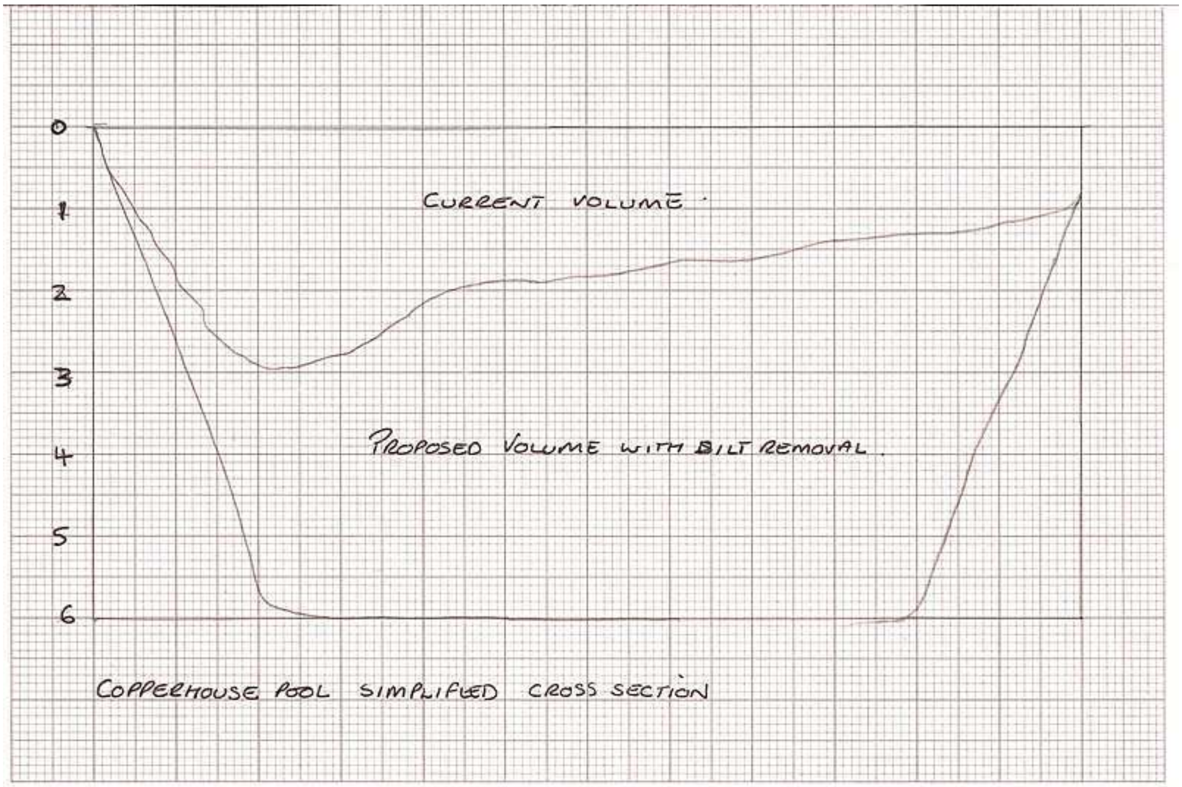


Figure 3 Site potential existing and maximised

Carnsew Pool (today prior to dredging)

Tidal	3m volume m^3	Complete cycle energy	Gross PE per tide	Gross Potential Energy annually
Mean Spring Tide	338923	10.2GJ	2.834 MWh	2 GWh
Mean Neap Tide	127883	1.9 GJ	536 kWh	378 MWh

Copperhouse Pool (today prior to dredging)

Tidal	3m volume m^3	Complete cycle energy	Gross PE per tide	Gross Potential Energy annually
Mean Spring Tide	287125	8.7 GJ	2.417 MWh	1.70 GWh
Mean Neap Tide	43146	0.65 GJ	183 kWh	130 MWh

Carnsew Pool (dredging to 6 metre)

Tidal	6m volume m^3	Complete cycle energy	Gross PE per tide	Gross Potential Energy annually
Mean Spring Tide	750000	45 GJ	12.56 MWh	8.855 GWh
Mean Neap Tide	495000	27 GJ	4.84 MWh	3.41 GWh

Copperhouse Pool (dredged to 6 metre)

Tidal	6m volume m^3	Complete cycle energy	Gross PE per tide	Gross Potential Energy annually
Mean Spring Tide	750000	45 GJ	12.56 MWh	8.855 GWh
Mean Neap Tide	495000	27 GJ	4.84 MWh	3.41 GWh

“Tidal engineering practice, based on the results of preliminary studies of tidal sites at various locations on the globe, usually allows an optimal annual energy production (AEP) for a single basin generating on the ebb flow of about one-third of the GEP.

Thus taking the dredged maximum GEP of 8.855 GWh
Optimal AEP = 8.885 GWh x 0.33 = 2.9 GWh
Optimal PE per tide = 12.56 MWh x 0.33 = 4.15 MWh.

The conclusion to the above calculations that a Mean spring tide the dredging of material to 6metre depth of both pools gives a five fold increase in gross energy potential. Even if the funding is not available at the start of construction to complete the dredging operation, the turbine houses should be sunk to make use of the theorised site potential.

4. Operating Regimes and Turbine Selection

4.1 Operating regimes

A number of different operating regimes could be utilised, these are detailed in Boyle, Godfrey (2004). *Renewable Energy, Power for sustainable future*. Oxford: Oxford University press.

Ebb Generation. The incoming tide is allowed to flow into the pool and is trapped behind sluice gates at high tide. The water is held normally for 3 hours and then released through the turbine on the out going ebb tide to power. 2 output phases per 24 hours 50 minutes

Flood Generation. The incoming tide is held back by sluice gates until sufficient water head is achieved then the water is allowed to pass from the turbine into the pool. 2 output phases per 24 hours 50 minutes.

Combined or two way operation. By using a variable pitch turbine power can be extracted in both the ebb and flood cycles however efficiency is affected as the full head of water can not be utilised.

The availability of two pools within the harbour system allows for a wider choice in operating regimes. A combined ebb/flood offers the following advantages

- Greater available production period. More useful as a base load generator.
- Opportunity to extract energy in the both directions while giving primacy to the most efficient or need for a secondary purpose
- Facility to increase the available head within the fill stage of the ebb selected pool by reverse running the turbine as a pump. This facility would be utilised when the energy release phase coincided with periods of high grid demand and an increased price for the energy exported to the grid beyond the commercial value of the energy to increase the available head.

Initial research indicated that a utilising each pool as an individual asset with Copperhouse operating as an ebb and Carnsew as a flood pool would simplify the system and offer a longer time period of operation more commensurate with a base load generator.

Discussions with Alan Travers of Buro Happold at an ING consultation day in Hayle, he expressed his concerns about the removal of energy from the tidal flow during the release of the Ebb generation Copperhouse pool. The reduction in energy would effect the sluicing capability required for the re development of the Harbour and the affect the proposed improvement to the navigation of the harbour channel.

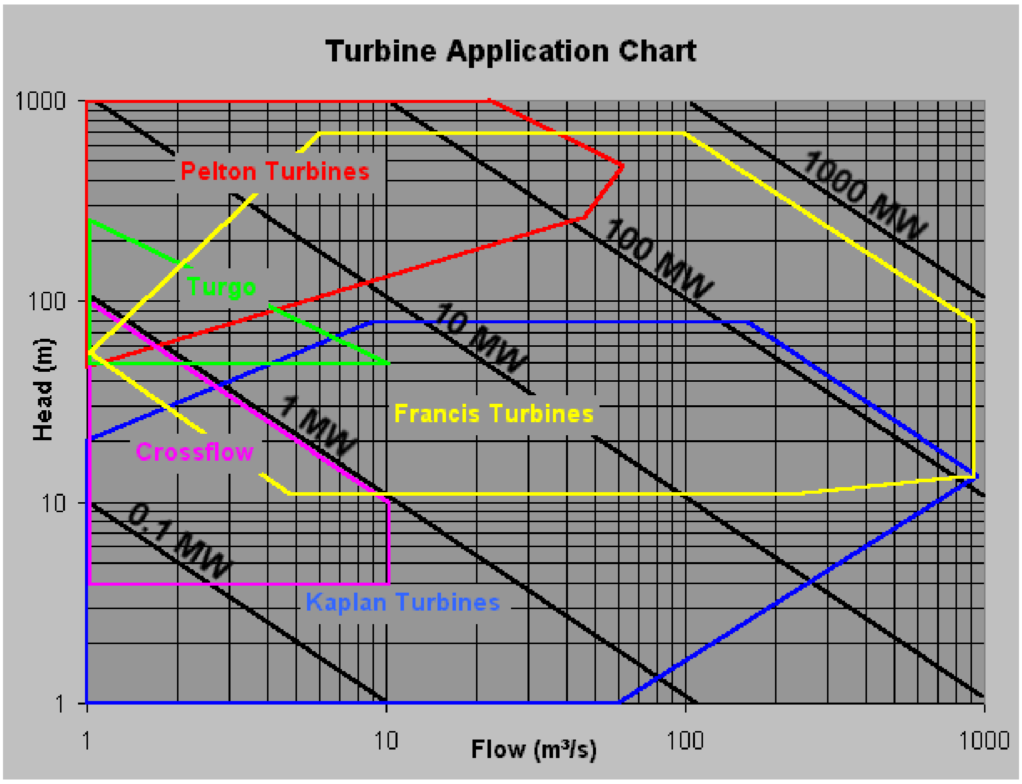
Reappraisal of the operating regime concluded that the operation of both pools in a dual mode ebb and flow generation would mitigate the loss of sluicing power. However additional systems work would be required to be undertaken covering the output, the souring effect of sluicing and it's re-timing to produce the energy when it most needed by the grid. Two examples of differing operating regimes are illustrated at Annex B. The average single tidal cycle high to low water last 6 hours the hold in both ebb and flow would last 3 hours leaving 3 hours for the release and power generation phase. Therefore taking the;

Optimal PE per tide = 12.56 MWh x 0.33 = 4.15 MWh acting over 3 hours requires a generating capacity of 1.38 MW, thus specifying a Turbine Generator of 1.5MW for each pool would be valid.

4.2 Turbine Selection

Low head tidal turbines differ greatly in design and function from the high head river system based Hydro Electric Power (HEP) systems.

Figure 4 Application of turbines for water head and flow



The suitable designs of a low head site <10 m are the Bulb, Straight flow and Tubular turbines (grouped under Kaplan in figure 4) they are available from different manufacturers and applicable of differing, locations, head, flow rate, output and capital investments.

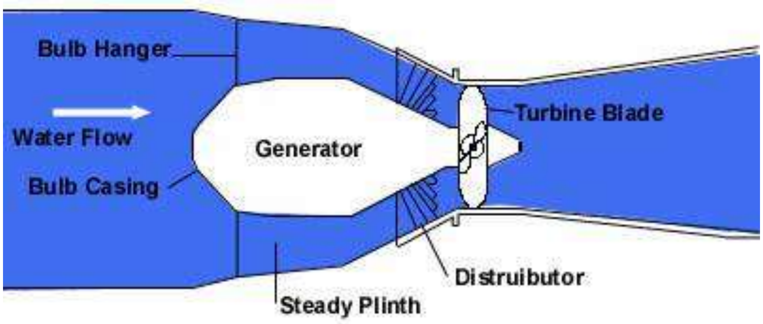


Figure 5: Bulb Turbine (Copyright Boyle, 1996)Sourced: (ACRE) Australian CRC

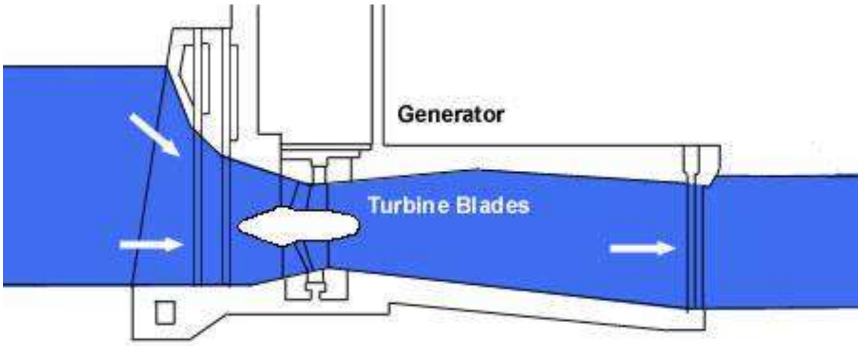


Figure 6: Straight flow Turbine (Copyright Boyle, 1996) Sourced: (ACRE) Australian CRC

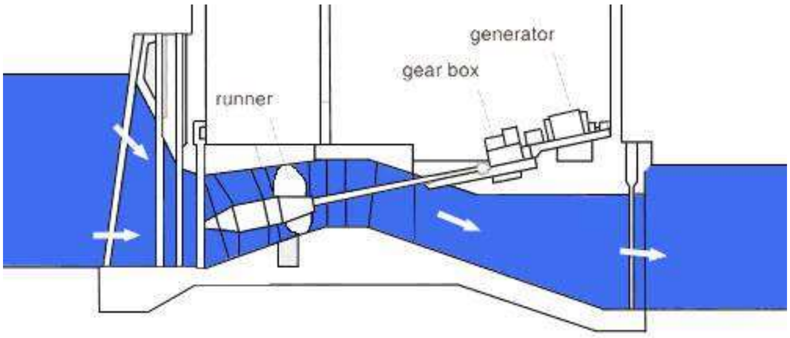


Figure 7: Tubular Turbine (Copyright Boyle, 1996) Sourced: (ACRE) Australian CRC

4.3. Electro mechanical system specification

As outlined in the background three differing types of turbines are suitable for a generic low head tidal site. The matching of the turbine design and output to the site is the most critical single process to ensure the viability of the project. As an exercise in cost saving and commonalty, reduction in supply chain holdings the decision has been made to utilise the same design system within both Copperhouse and Carnsew pools.

The bulb turbine operates as an axial flow turbine which encloses the generator within the bulb. The flow is regulated by guide vanes know as wicket gates which direct the water flow onto the turbine blades which are variable in pitch allowing the turbine to generate in both ebb and flow know as double regulation. Due to the placement of a larger bulb structure within the water flow tube, the diameter of the required tube is increased to permit the required flow rate.
This may preclude its use by the nature of the available sites, due to the increased size of the turbine house structure to derive the available power.

The straight flow (Straflo) incorporates the generator rotor into the periphery of the runner blades; it removes the bulb restriction from the axial water flow increasing the hydraulic efficiency. The removal of the generator from a bulb to outside the water passages increasing the accessibility for maintenance. The increase in efficiency allows for a corresponding reduction in size for a given power output over the bulb turbine.

The tubular turbine possess the size advantages of the Straflo turbine, its is more simplistic utilising a conventional gearbox and generator arrangement, the separation of components will reduce costs as an “off the peg” generator will be considerably less complex than a Straflo generator. Larger turbines of the tubular design, 20MW plus, experience vibration through the large inclined driveshaft.

Without associated costs available from Tidal turbine producers, we are unable to specify a Turbine generator beyond a 1.5 MW generator of tubular or Straflo design with the ability to flow 750,000 cubic metres in 3 hours.

5. Environmental Evaluation

5.1 Environmental Aspects

Man has influenced the shape and environmental make up of the Hayle Harbour area since the industrial revolution. Both Copperhouse and Carnsew pools are man made tidal pools that have fallen into disuse; the natural ecology has adapted to populate the environment of both pools. The larger area of Lelant Water has been deemed out of scope because of its designation as an RSPB reserve.
The reuse of the impoundment of structures to there original purpose would affect the current ecosystems that inhabit the area. The affects however may be also be positive locally by making available feeding areas within the pools to intertidal birds at times opposed to the natural sinusoidal tidal regime, it must be remember that actions of man are a part of the ecosystems within the Hayle Harbour area. Mitigation and enhancement of Lelant Water's capability to support a "denser" ecosystem during the construction and "re-establishment of ecosystem" phase of both Copperhouse and Carnsew pool systems. Extensive ecological surveys are detailed at wave hub.co.uk for the area but do not cover the exact areas of both pools however the data contained in these documents are a guide to the indigenous species of the greater Hayle Harbour area.
Concerns raised by Buro Happold for the extraction of energy from the water flow on the ebb tide would effect the silting of the navigable channel downstream. These concerns would be offset by the increase in potential energy caused by the hold phase and the establishment of a "tidal head". Detailed modelling of water flows under differing operating regimes within the harbour would be required to establish a desired sluicing effect.
Copperhouse pool currently possesses a tidal gate for the prevention of flooding during exceptionally high tides in conjunction with storm surges; the gate can either be in an open or closed position but cannot be moved during the flow of the tide. When closed to prevent flooding the affect on the pool ecosystem would be affected and any short notice requirement for closure cannot be met, the installation of a turbine house and associated sluices would only enhance the protection afforded to Hayle and the ecosystem of Copperhouse pool.

Construction methods built on site, wet; and pre-built caisson and floated in, dry are the two options. The dry method of floating in the turbine house would reduce the time that both tidal pools are not exposed to the natural tidal sinusoidal regime. Extensive surveys on the impacts to the Hayle harbour ecological system would be required on the selection of operating regimes; however the impacts should be assessed against whole system and the impacts locally, nationally and globally if the proposed development is or is not undertaken.

5.2 System Lifecycle Analysis

The expected production life of the proposed Severn barrage is 120 years, which compares well to a wind turbine which has an expected life of 25 years however from personal experience with the wind industry 20 years is a more conservative estimate. Thus the energy invested into the development in the form of embedded carbon i.e. the energy utilised to construct, transport and commission use and decommissioning the Tidal plant would if necessary, due to its longevity the through life “emissions factor” i.e. the amount of carbon produced per kWh throughout its lifecycle be far lower than most comparable energy generation schemes. The degree of carbon offset is a variable as it is uncertain to what form of energy generation a Tidal pool will displace. However the predictable and quantifiable nature of a Tidal Resource makes it more suitable a base load generator than Wind Turbines so is more likely to offset a fossil fuel generator. A DEFRA spread sheet sourced from the Carbon Trust will be utilised to assist with embedded and carbon saving Annex D.

Utilising the data contained within annex c of the DEFRA spreadsheet and using the Grid rolling average of 0.53702kg/kWh.

Optimal annual energy production (AEP)

Thus taking the dredged maximum GEP of 8.855 GWh

Optimal AEP = 8.885 GWh x 0.33 = 2.9 GWh

A saving in carbon terms

$$0.53702 \times 10^{-3} \times 2.9 \times 10^{9} = 1557.358 \text{ tonnes per annum}$$

For a proposed life of 120 years a saving of 186.9 Kilotonnes of carbon

This saving must be balance primarily taking into account the “invested” carbon required for construction, dredging, operation and decommissioning.

Table 1 Carbon emissions associated with primary construction, component and electrical materials (Appendix 2 of AEA/ED02701/Issue 1)

	min	max	
Concrete	0.2	0.374	$tonnes\ CO_2 * m^3$
Steel	1.63	1.75	$tonnes\ CO_2 * tonne$
Copper	1.652	1.652	$tonnes\ CO_2 * tonne$

This is yet to be performed but working back from the saving, will give a lifecycle carbon saving. The time to “achieve carbon payback” estimated by other large proposed schemes contained within *AEA ED02701 - Issue 1* are sub 12 months. However the invested energy in construction of this project will be far less than larger proposed projects.

6 Economic considerations.

6.1 Economic assessment

The primary driver for this project within sustainable design is to “reuse” redundant infrastructure to reduce costs in both terms of capital and carbon terms.
The availability of 2 tidal pools and a connection to the national grid available in the same location is an attractive proposition in both terms of cost reduction.
The funding of the project though not as large a scale as the proposed Severn Barrage would due to the timescale of operation and capital investment require a degree of public funding inline with the Wave hub scheme.
Total costings are unavailable at this time but variables include.

- Increasing costs of electricity (from higher oil gas prices)
- Construction costs.
- Costs associated with comparable generating capacity.
- Real interest rate (actual interest rate minus inflation).
- Public funding sources.

The bottom line is that unless a new disruptive technology alters the national generating capacity (stand fast tidal) that the unit price per kWh will increase year on year above the inflation rate. Thus any proposed business case today will strengthen with the passage of time.
Using the data from 1.5 as a construction cost of £6 million per installed MW for offshore wind gives us a working capital of £9 million for each pool assuming full dredging. The estimated operating life of a tidal plant is 120 years compared to 20 years for offshore wind, so for the installation of offshore wind for the same period would require 6 offshore Wind turbines equating to £ 54 million per pool installation. Even at a lower onshore wind price a £ 27 million would be available.

The investment into this project at an early stage, obviously in depth costings for turbine house construction and associated infrastructure works are required, however a working figure has been calculated in comparison the existing renewable resources.

7. Conclusions

7.1 Introduction

The UK government targets for renewable energy need to be met and surpassed for the sustainability of the UK electrical grid supply. The reliance on short term fossil fuel production in the terms of rising costs and environmental impacts are unsustainable. Tidal electric generation offers an opportunity to produce predictable renewable energy supply over a large period of time within a greater renewable energy generating portfolio.

Within the UK no existing tidal range developments have been operated to date, major existing worldwide developments are limited to less than ten in number.

The opportunity exists to produce a low cost operational tidal range project that can both be commercially successful; be utilised as an innovation and demonstration tool for the larger proposed schemes like the Severn barrage.

The Hayle Harbour Power Generation scheme fits within the Hayle Area Plan and fulfils an objective of Harbour owners ING Real Estate with the recommencement of sluicing to establish and maintain a navigable water way.

7.2 Conclusions

It is the UK government has signed up to an EU target to obtain 20% of all energy from renewable sources by 2012 and “close to” 60% by 2050.

Within the UK no existing tidal range developments have been operated to date, major existing worldwide developments are limited to less than ten in number.

The opportunity exists to produce a low cost operational tidal range project that can both be commercially successful; be utilised as an innovation and demonstration tool for the larger proposed schemes like the Severn barrage to align with the EU targets

The Hayle Harbour Power Generation scheme fits within the Hayle Area Plan and fulfils an objective of Harbour owners ING Real Estate with the recommencement of sluicing to establish and maintain a navigable water way.

Calculations for production and carbon savings have been produced for a dredged maximum pools potential. Cost for producing the potential of energy of the site has been quantified in terms of current renewable energy costs between 27 and 54 million.

The pools have been matched in their capacities to allow for duplicity of turbine generator components to further reduce costs.
The environmental context must be taken as a whole effect not just within Hayle but globally. Actions to reduce effects on the indigenous ecosystem have been taken by excluding Lelant water from the scope and suggesting the use of smart construction methods and artificially supporting the two pools until similar ecosystem is re established.

7.3 Recommendations

This Project Initiation Document is the initial concept and background into the first commercially productive Tidal range generation scheme in the UK. Obviously this project needs to be taken on by a major utilities company or/and RegenSW in conjunction with other local stakeholders such as Harbour owners ING Real Estate.

- Greater technical detail, involvement from Turbine manufactures is required.
- Construction of a business case and capital resources
- Detailed environmental studies and hydro dynamic modelling of the harbour.

7.4 The future of Tidal resource.

Because of it predictable nature, Tidal resource within the UK has a major part to play in the future of the countries electrical generating requirement. Due to the nature of design and the iterative nature it is unwise to put all the eggs in one Severn Barrage basket at first. The reuse element within the Hayle Harbour Power Generation Scheme should allow for a reduced cost commercially viable small scale project. Lessons learnt from the Hayle scheme enabling a “better designed” large scale Severn Barrage type project to address the 2050 target of 60%.

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Index of appendices

Annex A Copperhouse and Carnsew Pools

Copperhouse pool

Carnsew Pool

Annex B

Buro Happold data for Carnsew Pool.

```
Project:      Tidal Pools
User:         nauger
Organization: Buro Happold
Date:         Fri May 11 17:58:02 2007
Report File:  carnsew.rpt



 Storage calculations to tin "carnsew pool" - (with plan polygon
"Cont 3m->contour 3")

    cut volumes are negative
    fill volumes are positive


======================================================================
=================================
   Height                  Vol to Height                 Plan Area
Slope Area
             Delta Ht                    Delta Vol
Delta Area                 Delta Area

======================================================================
=================================

      3.000                 338922.847                    145742.109
146182.796
                 0.250                       36274.323
1300.034                   1355.262
      2.750                 302648.524                    144442.075
144827.534
                 0.250                       35941.513
1362.451                   1421.177
      2.500                 266707.011                    143079.624
143406.356
                 0.250                       35593.098
1424.868                   1487.093
      2.250                 231113.913                    141654.756
141919.263
                 0.250                       35229.079
1877.872                   1943.596
      2.000                 195884.834                    139776.884
139975.667
                 0.250                       34468.364
3789.925                   3830.226
      1.750                 161416.470                    135986.959
136145.441
                 0.250                       33533.579
3688.354                   3728.504
      1.500                 127882.891                    132298.605
132416.938
```

```
                 0.250                       32624.187
3586.783                 3626.781
      1.250                95258.703                   128711.822
128790.156
                 0.250                       31740.188
18878.513                18918.360
      1.000                63518.515                   109833.309
109871.796
                 0.250                       24400.090
24251.536                24259.079
      0.750                39118.425                    85581.773
85612.717
                 0.250                       18497.976
22965.378                22972.706
      0.500                20620.449                    62616.395
62640.011
                 0.250                       12917.401
21679.220                21686.333
      0.250                 7703.048                    40937.175
40953.678
                 0.250                        7658.366
40865.450                40872.348
      0.000                   44.682                       71.725
81.330
                 0.000                           0.000
0.000                    0.000
      0.000                   44.682                       71.725
81.330

======================================================================

 Polygon plan area = 146373.424


Project:      Carnsew pool
User:         nauger
Organization: Buro Happold
Date:         Mon May 14 10:27:59 2007
Report File:  carnsew.rpt



 Storage calculations to tin "Lid" - (with plan polygon "3m Contour-
>contour 3")

    cut volumes are negative
    fill volumes are positive



======================================================================
   Height                  Vol to Height               Plan Area
Slope Area
             Delta Ht                        Delta Vol
Delta Area               Delta Area

      3.000               346398.545                   145639.360
146468.840
```

```
                  0.250                       36347.874
739.384                    789.986
      2.750                 310050.672                     144899.976
145678.854
                  0.250                       36048.516
1458.339                   1546.070
      2.500                 274002.156                     143441.637
144132.784
                  0.250                       35640.378
1818.459                   1904.448
      2.250                 238361.778                     141623.179
142228.336
                  0.250                       35138.538
2187.318                   2265.135
      2.000                 203223.240                     139435.861
139963.201
                  0.250                       34552.596
2498.561                   2569.659
      1.750                 168670.643                     136937.300
137393.541
                  0.250                       33880.301
2967.925                   3032.776
      1.500                 134790.342                     133969.375
134360.766
                  0.250                       32948.218
4933.331                   4998.048
      1.250                 101842.124                     129036.044
129362.717
                  0.250                       31182.464
9204.320                   9267.397
      1.000                  70659.660                     119831.724
120095.320
                  0.250                       28831.224
10267.970                  10336.951
      0.750                  41828.437                     109563.753
109758.369
                  0.250                       26140.653
9664.146                   9731.627
      0.500                  15687.784                      99899.607
100026.742
                  0.250                       15611.749
98206.665                  98320.548
      0.250                     76.035                       1692.942
1706.194
                  0.250                          39.269
1624.998                   1630.484
      0.000                     36.766                         67.944
75.710
                  0.000                           0.000
0.000                      0.000
      0.000                     36.766                         67.944
75.710

======================================================================
==================================

 Polygon plan area = 146155.703
```

Buro Happold data for Copperhouse Pool.

```
Project:      Copper House Pool
User:         nauger
Organization: Buro Happold
Date:         Mon May 14 14:15:41 2007
Report File:  Copper_House_Pool.rpt
```

Storage calculations to tin "lid" - (with plan polygon "3m Cont->contour 3")

cut volumes are negative
fill volumes are positive

Height	Vol to Height	Plan Area	Slope Area
Delta Ht	Delta Vol	Delta Area	Delta Area
3.000	287125.119	194042.092	195481.725
0.250	48393.258	1318.395	1347.315
2.750	238731.861	192723.698	194134.411
0.250	47849.809	2816.378	2898.287
2.500	190882.052	189907.320	191236.124
0.250	46280.847	10563.045	10681.260
2.250	144601.205	179344.275	180554.864
0.250	42511.689	25346.064	25501.974
2.000	102089.516	153998.211	155052.890
0.250	33919.629	36135.047	36323.648
1.750	68169.888	117863.164	118729.242
0.250	25023.429	32876.635	33059.929
1.500	43146.459	84986.528	85669.312
0.250	17177.711	30863.231	31068.512

```
      1.250                 25968.748                  54123.297
54600.800
                 0.250                 10749.690
21785.202            21962.438
      1.000                 15219.059                  32338.095
32638.362
                 0.250                  6716.900
9817.764             9943.603
      0.750                  8502.158                  22520.331
22694.759
                 0.250                  4649.783
7568.614             7657.324
      0.500                  3852.375                  14951.717
15037.436
                 0.250                  2820.868
7896.335             7955.761
      0.250                  1031.507                   7055.382
7081.675
                 0.250                  1031.068
6998.161             7024.367
      0.000                     0.439                     57.221
57.308
                 0.000                     0.000
0.000                0.000
      0.000                     0.439                     57.221
57.308

======================================================================
=================================

 Polygon plan area = 194949.821
```


Annex C

Operating Regimes

Table of operating regime

Both pools double effect ebb flow function

Time	Tide	Copperhouse Pool		Carnsew Pool	
		Pool Function	Sluice Gate	Pool Function	Sluice Gate
00.00 to	Low	Hold Empty	Closed	Hold Empty	Closed
03.00 to	In	Flood Generation	Open	Flood Generation	Open
06.00 to	High	Hold Full	Closed	Hold Full	Closed
09.00 to	Out	Ebb Generation	Open	Ebb Generation	Open
12.00 to	Low	Hold Empty	Closed	Hold Empty	Closed
15.00 to	In	Flood Generation	Open	Flood Generation	Open
18.00 to	High	Hold Full	Closed	Hold Full	Closed
21.00 to	Out	Ebb Generation	Open	Ebb Generation	Open
00.00 to	Low	Hold Empty	Closed	Hold Empty	Closed

Table of operating regime

Dual pool opposed single effect operation (one ebb one flow)

Time	Tide	Copperhouse Pool Ebb		Carnsew Pool Flood	
		Pool Function	Sluice Gate	Pool Function	Sluice Gate
00.00 to	Low	Empty	Open	Empty	Closed
03.00 to	In	Fill	Open	Release	Open
06.00 to	High	Full Hold	Closed	Full	Open
09.00 to	Out	Release	Open	Drain	Open
12.00 to	Low	Empty	Open	Empty	Closed
15.00 to	In	Fill	Open	Release	Open
18.00 to	High	Full Hold	Closed	Full	Open
21.00 to	Out	Release	Open	Drain	Open
00.00 to	Low	Empty	Open	Empty	Closed

Green: Power production

Yellow: Passive Production

Red: Increased Pumped Storage

Annex D Carbon Trust Spreadsheet

Annex 3 - Electricity Conversion Factors from 1990 to 2006
Last updated: Apr-08
Table 2
2
UK Grid Electricity Year Amount used per
year, kWh
kg CO2 per kWh Total kg CO2
1990 0.77000
1991 0.75000
1992 0.70000
1993 0.62000
1994 0.61000
1995 0.58000
1996 0.56487
1997 0.52102
1998 0.52276
1999 0.49064
2000 0.51946
2001 0.53524
2002 0.51879
2003 0.53481
2004 0.53478
2005 0.53485
2006 0.56185
Type of electricity factor
Grid Rolling Average7 0.53702
Long-term marginal factor 8 0.43000
Electricity from CHP9 0.30400
Renewables10 0
Total 0
Sources
Notes
Electricity conversion factors from 1990 to 2006
per unit of electricity consumed from the DTI's Digest of UK Energy Statistics (DUKES) 2007
Table 5.6
Based on UK Greenhouse Gas Inventory for 2006 (AEA Energy & Environment) according
to the amount of CO2 emitted from major power stations
http://www.defra.gov.uk/environment/business/envrp/conversion-factors.htm
7-10, See accompanying notes at:
Page

Annex E Project Initiation Document Planner.

ID		Task Name	Duration	Start	Finish	Predecessors
1		Concept trigger generation	14 days	Thu 07/02/08	Tue 26/02/08	
2	✓	TMA 01	21 days	Fri 29/02/08	Fri 28/03/08	
3		Stored energy calculations	14 days	Mon 17/03/08	Thu 03/04/08	1
4		Operating Regimes	28 days	Fri 04/04/08	Tue 13/05/08	3
5		TMA 02	28 days	Wed 02/04/08	Fri 09/05/08	2
6		Technical specifications	25 days?	Wed 14/05/08	Tue 17/06/08	4
7		Lifecycle Analysis	21 days	Fri 20/06/08	Fri 18/07/08	6
8		TMA 03	41 days?	Mon 12/05/08	Mon 07/07/08	5
9		Project summary	26 days?	Fri 01/08/08	Fri 05/09/08	7
10		ECA	31 days?	Fri 01/08/08	Fri 12/09/08	8