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Final Report

for

Severn Embryonic Technology Scheme (SETS)

3	Re-Issued to SETS Board				
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ANNEXES

VerdErg planned its work as a series of Work Packages, with the resulting work product of each summarised in a Deliverable Report specific to that Work Package. The ANNEXES to this document are those Deliverable Reports, segregated into three categories A, B and C, below.

A) Scheme Description

Document Number	Deliverable Report Title
0974-100-DBD-001	**Design Basis**
0974-101-TRP-001	**Intertidal Flood Variations and Final Route Selection Confirmation**
0974-102-EIR-001	**Preliminary Environmental Impact Statement**
0974-201-TRP-001	**BHR Group Experimental Report and Results**
0974-203-TRP-001	**Annualised Electricity Generation Report**
0974-300-DF-001	**Design File**
0974-300-TN-001	**Technical Evaluation of Materials**
0974-301-DF-001	**Structural and Foundations Design File**
0974-302-TRP-001	**Power Generation and Offtake Report**
0974-303-PR-001	**Fabrication and Installation Procedure**
0974-304-TN-001	**Operation, Maintenance and Repair**
0974-401-TN-001	**Economic Parameters**

B) Development Route Map

Document Number	Deliverable Report Title
0974-400-PRG-001	**SETS Development Road Map**

C) Risk Register

Document Number	Deliverable Report Title
0974-402-RSK-001	**Risk Review Report**

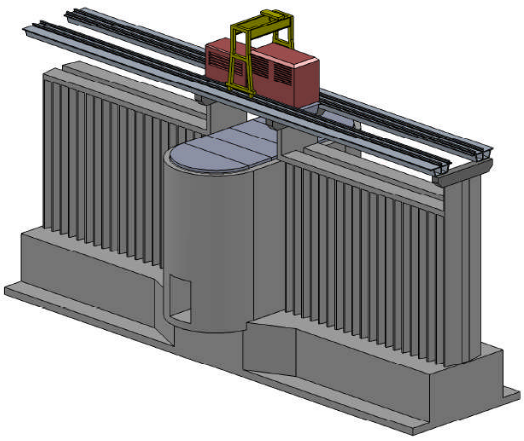
PREAMBLE

For readers unfamiliar with SMEC and/or SETS.

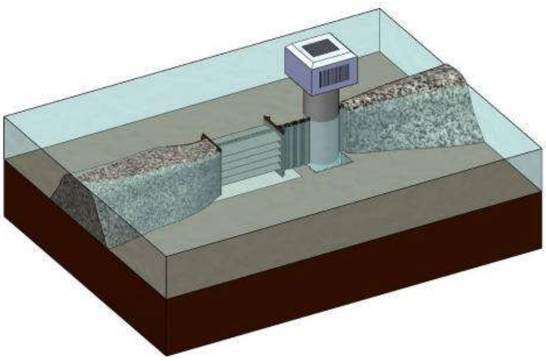
Other readers should turn to Section 1, Executive Summary.

Background:

VerdErg Renewable Energy Ltd. (hereinafter "VerdErg") is developing a tidal current technology called SMEC, short for Spectral Marine Energy Converter. SMEC is a technology rather than a "device" and it can be built for any size body of moving water. A SMEC intended to cross an Estuary looks like a fence of bridge piers placed quite close together; a small one for a stream or tidal lagoon more like a large venetian blind:



Severn Estuary module

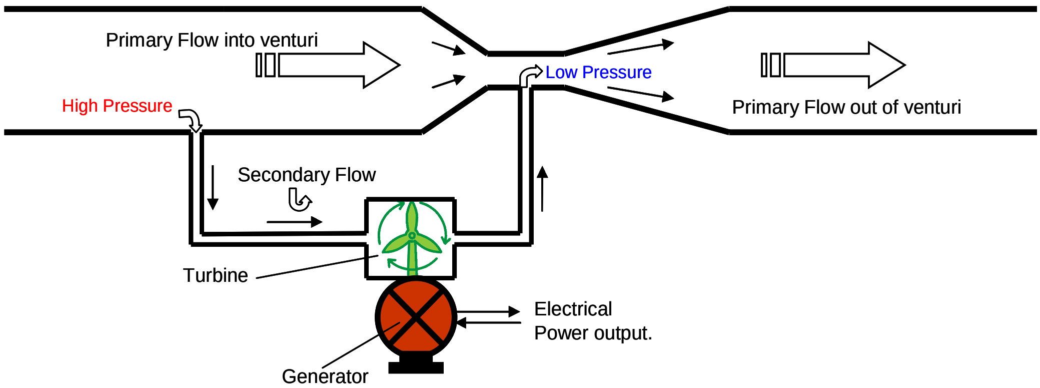


Small 300Kw SMEC

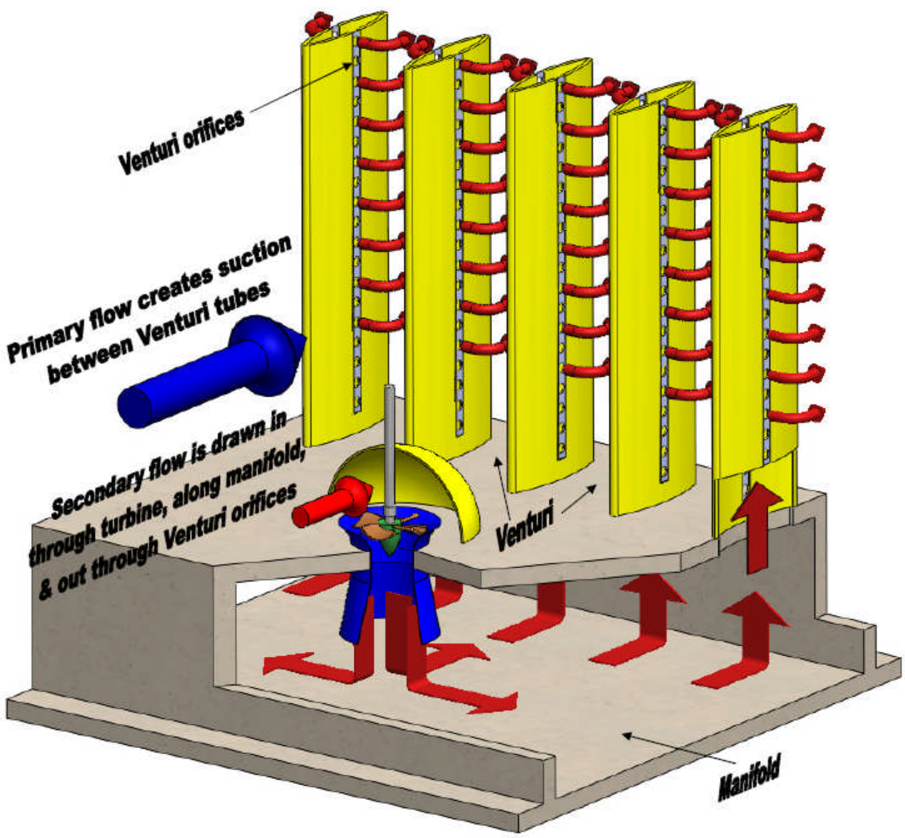
Artist's Impression of the Severn Estuary Crossing

The technology is the same in all cases: the piers or vanes are actually hollow streamlined tubes, perforated down the centre line so that as the water flows between the tubes, it sucks water out from inside them. All the tubes are joined together by a large manifold on the sea bed and a substantial secondary flow of around 20% of the free stream flows through turbines into this manifold and back out through the thousands of small holes in the tubes. The turbines drive generators above the water surface. SMEC is a no-moving-parts venturi pump used to drive conventional turbine-alternator sets, which are highly efficient at the head drops available from SMEC. Unlike a full barrage, moreover, the SMEC is porous and causes much less environmental damage.

SMEC creates its own continuously replenished, modest head drop between its upstream and downstream sides that in turn produces a much higher head drop across the turbines. It is also bi-directional; it works on the ebb and flow. A simplified "circuit diagram" of SMEC looks as follows:



The disposition of the Primary and Secondary flows in a real SMEC is in essence exactly as shown in the above circuit diagram but can usefully be shown in the following sketch:



So SMEC is actually a "Zero-Head Hydro" technology that concentrates the useless energy from a large flow of water into a high-head secondary flow from which the energy can be extracted efficiently. In this respect it works like the fluid equivalent of an electrical transformer.

SMEC has been identified by the UK Government as one of the Embryonic Technologies potentially suitable for the Severn Estuary when fully developed. VerdErg's preferred development path is to design and build increasingly large SMECs over a period of years.

At the launch of the first Severn Tidal Power Consultation in January 2009, Ministers announced the creation of a Cross-Government fund for developing schemes incorporating embryonic technologies, which may offer the potential for less impact than conventional technologies on the natural environment of the Severn Estuary. This initiative is called the Severn Embryonic Technologies Scheme or "SETS" for short.

SETS is supported by the Department of Energy & Climate Change (DECC), Department for Environment, Food and Rural Affairs (DEFRA), Welsh Assembly Government (WAG) and South West Regional Development Agency (SWRDA).

The Objectives of the SETS are:

- To develop to outline design stage embryonic design and technology proposals with the potential to contribute to the Government's plan for tidal power generation in the Severn Estuary (i.e. to deliver a strategically significant amount of electricity at acceptable cost and with acceptable impact, including on the natural environment and on navigation).

- To increase the level of confidence in the technical feasibility of proposals (construction and operation), construction costs, energy yields and profiles, and cost of energy.
- To increase confidence levels in timescales for development and deliver a broadly costed technology development route map which sets out the path(s) to commercial deployment.

The programme is developed with the expectation that the technologies presented could be deployed commercially at scheme scale within 10-15 years.

On 19 August 2009, VerdErg Renewable Energy Limited was awarded a grant by The Secretary of State for Energy and Climate Change to assist it to carry out an initial work programme designed to raise the development status of its Spectral Marine Energy Converter (SMEC) technology towards compliance with these Objectives by the end of January 2010.

This report gives an overview of the SETS work undertaken by VerdErg between August 2009 and January 2010, which is presented in the Annexes in more detail. The report starts with an Executive Summary.

1.0 EXECUTIVE SUMMARY

Aims:

VerdErg's initial work programme was intended to:

- Provide auditable documentary back-up to the economic and environmental performance claims made for SMEC.
- Perform a Conceptual Design of a SMEC installation across the Severn Estuary to establish a credible cost basis.
- Demonstrate that the development status of SMEC can be raised to a level compatible with a Severn Estuary installation in a reasonable time frame.

Key Study Areas and Methodology:

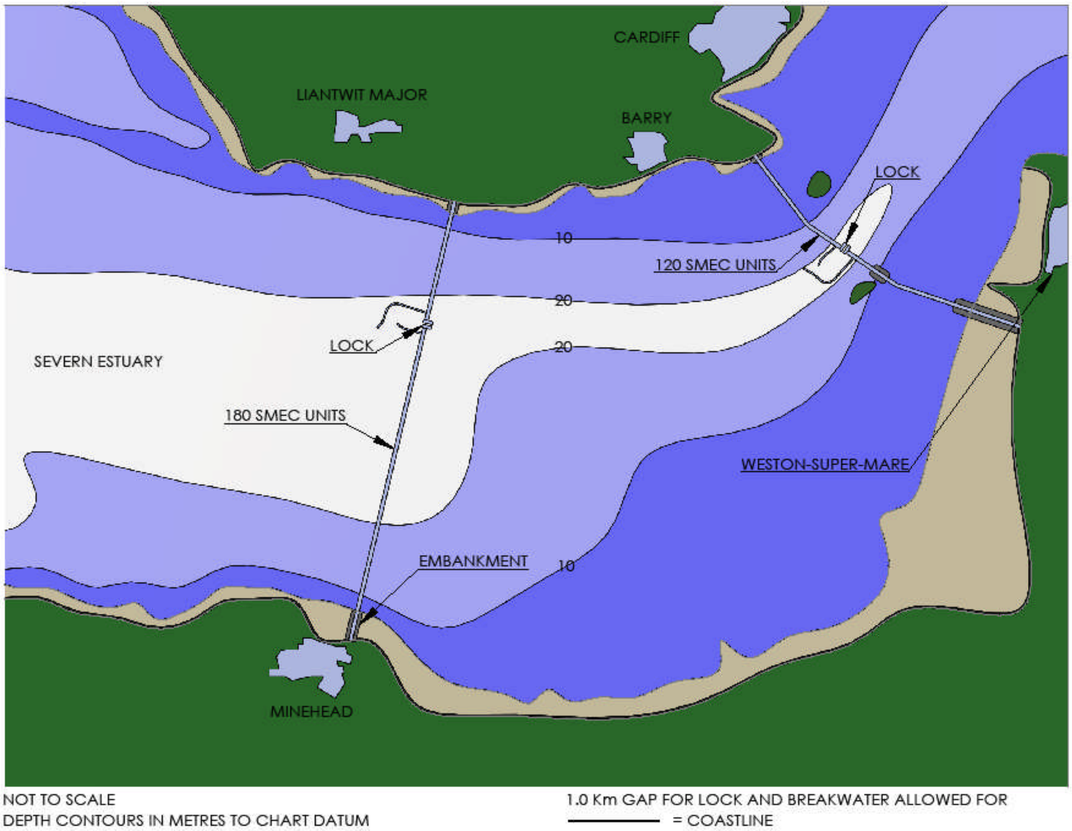
- Full-scale tests were needed on a section of SMEC's Venturi Pump "engine", which is susceptible to scale effects and exhibits flow patterns beyond current computer simulation capabilities. This permitted dependable power output and inter-tidal inundation estimates to be made.

The traditional framework for a Conceptual Design was adopted:

- Collation of all necessary design data including Design Life and possible Global Warming design challenges.
- Conceptual design of Foundations, Structure, and Power Generation facilities.
- Construction, Installation, Operations and Maintenance studies.
- Capital and through-life Operational cost estimates could then be made and the overall economics presented.
- Development of a quantified Risk Register detailing the risk reduction achieved during the work and establishing that sufficient design maturity

for the Severn application will be achieved by 2020 if the proposed steps along the Development Road Map are followed.

- Both the Aberthaw-Minehead and Cardiff-Weston alignments were studied throughout the SETS work undertaken.



Main Findings:

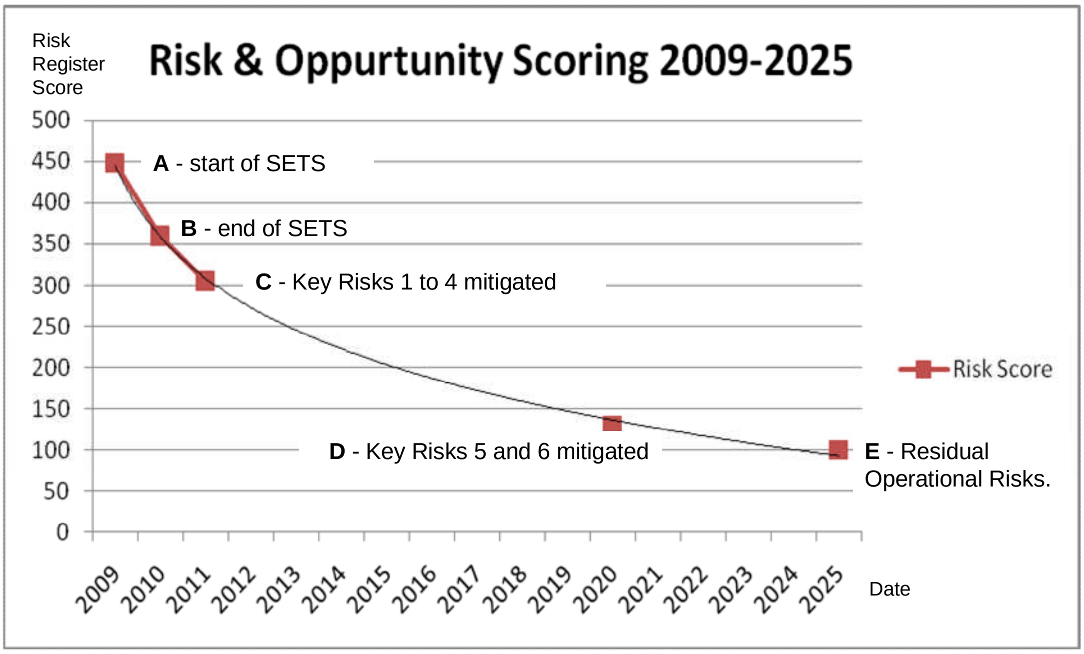
Name of scheme(s) and alignment(s)	**Power Output** (MW)	**Annual Output** (TWh)	**Construction Cost** (Inc comp habitat@ 2:1 and contingency @15% but exc optimism bias)	**Energy Cost** (£/MWh)	**Annual Carbon Saving** (CO_2 pa) (t)	**Estimated year of 1st generation in Severn** (*Year Project complete*)	**Environmental Impacts** (Impacts on Receptors)
Cardiff-Weston	**1,340 (7,500)***	**11.74**	**£9.85 bn**	**68**	**5,050,000**	**2025 (2026)**	**1,775 ha of bird habitat loss**
Aberthaw-Minehead	**1,580 (11,250)***	**13.84**	**£14.41 bn**	**84**	**6,000,000**	**2026 (2027)**	**1,715 ha of bird habitat loss**

* Actual Installed Rated Power Capacity

The Cardiff-Weston alignment presents an attractive cost of energy with minimal known environmental impact and is carried forwards for further consideration. The Aberthaw-Weston alignment is currently less economic but has potential that warrants its further evaluation under the Development Road Map (see document 0974-400-PRG-001).

Have the SETS Objectives been met?

Yes, they have. The 20% Risk Reduction achieved during SETS shown on the graph below leads confidently to the risk levels needed prior to selection of SMEC for the Severn Estuary around 2020:



This statement is conditional on adequate Government Funding being available to support the Mitigation of Key Risks 2, 3 and 4 during 2010 and 2011. The work needed to mitigate these risks is further testing and analysis leading up to getting the first SMEC into the water. The cost of this work cannot be estimated accurately without further Stakeholder discussion but can be characterised in the order of £1 million.

<table>
<tr><th>TIME
Years from 1 Jan 2010</th><th>Key Risk
Desired Outcome to be addressed</th><th>Work Package
Summary of steps required to address Key Risk.</th><th>Auditable Success Factors
Evidence Base to support mitigation of Key Risk</th></tr>
<tr><td>0 - 1</td><td>1) Find a client and supporting Grant Funding for the first small Commercial Demonstration SMEC installations.</td><td>1) Key Risk 1 is addressed by soliciting proposals from various successful investment–raising specialists and awarding an incentive contract to the winning Bidder. VerdErg has completed this process and has Franklin Associates under contract, seeking a suitable client. A major Strategic Investment Partner will also be identified in response to Key Risk 6.</td><td>Key Risk 1 has clearly been met when a client for the first Commercial Demonstrator has been found and supportive Grant Funding put in place.</td></tr>
<tr><td>0 - 1</td><td>2) Complete optimisation of the venturi diffuser detailed design through continued test programme.</td><td>2) Key Risk 2 is addressed by finding a University host facility into which the test rig can be re-located together with sufficient Grant Funding support, or sufficient Grant funding support to continue testing at the present commercial test house.</td><td>Key Risk 2 will be judged to have been met when the “water to wire” efficiency has been raised to a predetermined percentage of the theoretically available power.</td></tr>
<tr><td>0 - 1</td><td>3) Develop practical by-pass design to facilitate safe free passage of fish at acceptable risk level.</td><td rowspan="2">3) Key Risks 3 and 4 are addressed by building a CFD (Computational Fluid Dynamics) model under Work Package 3 of a SMEC containing an open gap suited to fish passage together with various mitigating configurations to minimise the head loss across the SMEC by encouraging helpful flow patterns to be created.</td><td rowspan="2">Key Risks 3 and 4 will each be judged to have been substantially mitigated when a free passage can be opened up to the transit through the SMEC of either fish or shipping without loss of more than a predetermined percentage of power, provisionally set at 10%.</td></tr>
<tr><td>0 - 1</td><td>4) Develop practical by-pass design to facilitate safe and convenient free passage of shipping.</td></tr>
<tr><td rowspan="3">2 - 10</td><td rowspan="3">5) Secure a sequence of increasingly large SMEC commissions between 2011 and 2020 for commercial operation of installations as needed to validate Severn Estuary design. There are three steps:
SMEC installations into rivers.
Tidal Current SMECs installed into increasingly large sites.
The final award in 2020 of the contract for the Severn Estuary SMEC.</td><td>4) The earlier elements of Key Risk/Opportunity 5 is mitigated/promoted in this Work Package 4. The additional enabling work is to define the market for small SMECs in Inland Rivers which is thought to be potentially huge.</td><td rowspan="3">Key Risk 5 (or opportunity) has clearly been met when the nominated commissions for SMEC installations are awarded, culminating in the award of the Severn Estuary contract.</td></tr>
<tr><td>5) Key Risk/Opportunity 5 is subsequently further promoted in this Work Package 5. The work is the marketing activity of securing a sequence of increasingly large tidal SMECs.</td></tr>
<tr><td>6) Key Risk/Opportunity 5 is mitigated/promoted in this Work Package 6. This is the preparation of a major EIA specifically to enable the Severn Estuary SMEC to proceed.</td></tr>
<tr><td>0 - 2</td><td>6) Secure a major Strategic Investment Partner able to finance the rapid development of increasingly large SMEC installations.</td><td>Key Risk /Opportunity 6 is met by the ongoing commercial activity of Work Package 1.</td><td>Key Risk 6 has clearly been met when a major Strategic Investment Partner is in place.</td></tr>
</table>

Development Road Map Summary Matrix

2.0 AIMS AND OBJECTIVES

The Objectives of the Severn Embryonic Technology Scheme are:

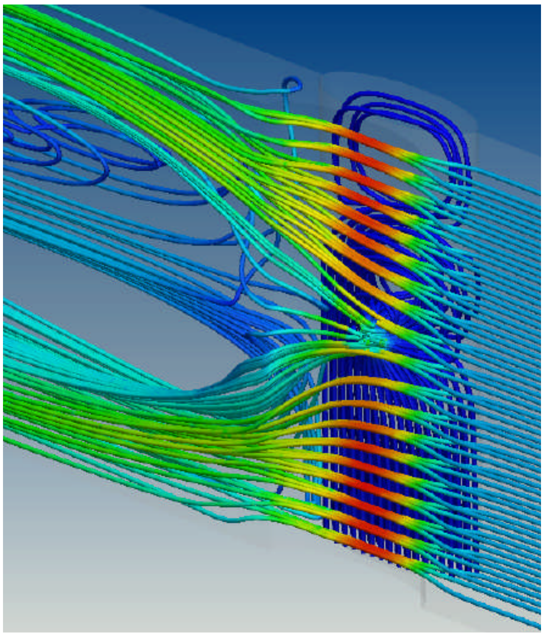
- **To develop to outline design stage** embryonic design and technology proposals with the potential to contribute to the Government's plan for tidal power generation in the Severn Estuary (i.e. to deliver a strategically significant amount of electricity at acceptable cost and with acceptable impact, including on the natural environment and on navigation).
- **To increase the level of confidence in the technical feasibility** of proposals (construction and operation), construction costs, energy yields and profiles, and cost of energy.
- **To increase confidence levels in timescales** for development and deliver a broadly costed technology development route map which sets out the path(s) to commercial deployment.

VerdErg chose to meet these Objectives through development of an appropriate schedule of activity organised into Work Packages. The Aims of VerdErg's initial work programme were to:

- **Provide auditable documentary back-up** to the economic and environmental performance claims made for SMEC. SMEC had been under development since 2006 and the performance claims made for it prior to the SETS award were based on a computer model, containing numerous coefficients, of the flow through a SMEC. These coefficients were informed but not fully calibrated by early test tank experiments at one sixth scale.

During 2007-9, a better understanding of SMEC's fairly complex hydrodynamics had been developed that enabled the computer model to be improved. An Audit Report prepared by W S Atkins under Carbon Trust funding was one significant input to this evolving understanding.

Calibration by full-scale model tests was then the immediate priority to improve the estimates that could be made of power output and habitat loss through intertidal wetlands inundation. The need for full-scale model tests was apparent from earlier attempts to build a computer model of the water flow through the Venturi Tube Orifices using Computational Fluid Dynamics (CFD). Despite the power of modern computers, the complexity of turbulent flow puts confident quantitative modelling beyond reach. An indication is shown in this computer output of one "frozen" flow simulation that was achieved with some difficulty in 2007.



The problem is that the random flow pattern shown changes rapidly and radically in a real life example and the resulting averaged performance can only reliably be modelled physically. Furthermore, the performance of SMEC is known to vary with factors controlled by the water surface elevation, (technically, the "Froude Number") and by the skin friction and viscosity of the water (technically, the "Reynolds Number"). These two parameters change differently at different scales and hence large-scale tests are essential.

One feature of SMEC is that the area of intertidal wetlands permanently inundated is also an indirect function of its power output as it controls the elevation difference on the water on either side of the SMEC. Improving the quality of the power output projections also therefore directly improves the confidence with which a Habitat Loss projection can be made.

- **Perform a Conceptual Design** of a SMEC installation across the Severn Estuary to establish a credible cost basis. Prior to SETS, VerdErg focused its development effort on the power output rather than the cost. A comprehensive conceptual design and full capital cost estimate of a SMEC designed to meet the environmental loadings of the Severn Estuary was therefore needed to improve confidence levels in the claimed cost per KWh. Also needed was a full investigation into how to install and maintain this SMEC design, together with an estimate of associated installation and operational costs.

- **Demonstrate that the development status** of SMEC can be raised in a reasonable timescale to a level compatible with a Severn Estuary installation. The SETS Programme was scheduled to run for around 6 months. This is insufficient time to significantly raise the Development Status of a major infrastructure technology from pre-TRL 6 to TRL 8. "TRL" is short for Technology Readiness Level and is a scale developed by NASA and adopted by DECC to calibrate Development Status on a common metric.

VerdErg's aim was to develop a Quantified Risk Register and document the score achieved at the start and finish of the SETS work. This was intended to then provide a quantified indication of the Development Gap that would have to be closed between SETS concluding in early 2010 and being considered for selection as the technology preferred in the Severn Estuary a decade or so later. From that, a direction indication is available of the ongoing work program needed, referred to here as the "Development Road Map".

3.0 METHODOLOGY

VerdErg planned its SETS work as 15 Work Packages or Tasks, each defined on a Cost-Time-Resource ("CTR") sheet. These Task sheets presented for each Task:

- the Scope of Work to be covered,
- the required inputs (establishing an execution sequence),
- the deliverable work product to be produced,
- the Task duration,
- the manhours and other consumables needed,
- the resulting estimated cost for that Task.

An overall SETS Programme schedule was drawn up showing the sequence and duration of each Task. The schedule and task sheets follow. Notes are attached to each Task sheet including issues arising during the work such as trade-offs and over-runs.

Two external organisations participated with VerdErg in the SETS work:

1. VerdErg did not consider its in-house Heavy Electrical Engineering knowledge to be sufficient to undertake the appropriate design work on High-Voltage DC cabling, Power Management and Grid Interfacing. This was sub-contracted by negotiation to the relevant specialist office of Parsons Brinkerhoff, in Glasgow. Pre-existing job knowledge of similar design work was one of the attractions of this arrangement and a very satisfactory work product was delivered.

2. The full-scale model testing was put out to Tender, against a VerdErg specification, to a short-list of Bidders drawn up methodically from an initial long-list of commercial and University facilities. In the event, the only one compliant bid was received from BHR Group Cranfield, a well-respected Commercial Test House, which originated as the British Hydraulics Research trade association. BHR Group Ltd was awarded the contract. Photographs of the substantial test apparatus constructed by BHR Group are enclosed below.

Excellent collaboration was given by BHR Group and where possible, its existing equipment was employed to save cost. This is particularly relevant to the 600l/sec pumping capacity BHR Group was able to mobilise from its own inventory.

Upstream Feeder Tank to right, Modular Receiving Tank to left

Test Section in foreground feeding into the Modular Receiving Tank

The catalogue of 15 Tasks drawn up by VerdErg and agreed with DECC before the start of the SETS work is as follows:

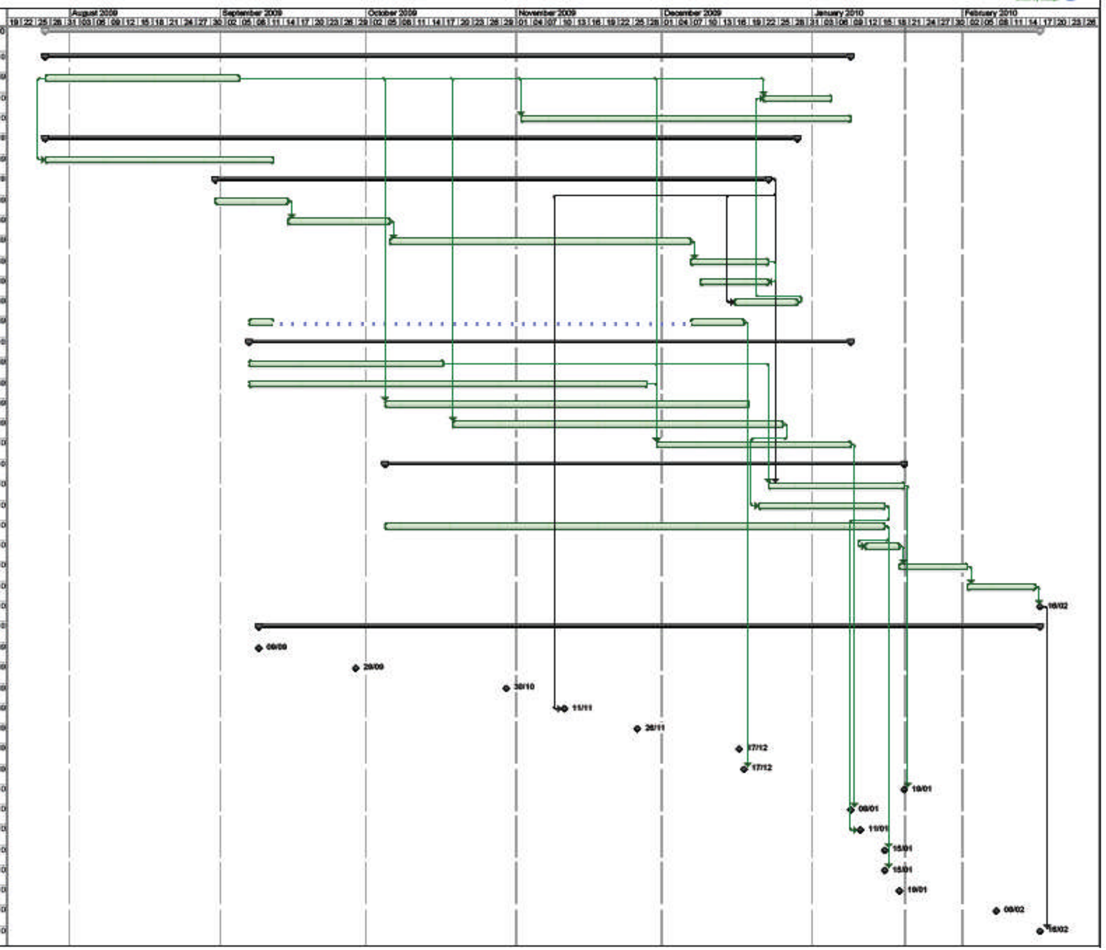
SETS PROGRAMME – WORK BREAKDOWN STRUCTURE

Task No.	Task Heading
100	Site Location Study
101	Inter-Tidal Flood Variations and Final Route Selection Confirmation
102	Preliminary Environmental Impact Statement
200	SIMULINK Model Pre-Test Update
201	Hydrodynamic Performance Evaluation
202	SIMULINK Model Post-Test Update
203	Annualised Electricity Generation Estimate
300	System Preliminary Design
301	Structural & Foundations Design
302	Power Generation & Offtake Facilities Design
303	Fabrication & Installation Procedure
304	Operation, Maintenance & Repair
400	System Development Road Map
401	SMEC Economic Parameters
402	Project Risk Evaluation

A summary of each Task is presented in Appendix 1.The execution schedule of these activities follows. Weekly progress meetings were held in-house, plus six Gateway Reviews which were held with DECC.

SETS Programme - Spectral Marine Energy Converter (SMEC)

ID	Task Name	Duration	Start	Finish
0	SETS Work Programme (18-Jun-08)	147 days	Mon 27/07/09	Tue 16/02/10
1	Site Study Activities	120 days	Mon 27/07/09	Fri 08/01/10
2	100 Design Basis	6 wks	Mon 27/07/09	Fri 04/09/09
3	101 Intertidal Flood Variations and Final Route Selection Confirmation	2 wks	Tue 22/12/09	Mon 04/01/10
4	102 Preliminary EIS	10 wks	Mon 02/11/09	Fri 08/01/10
5	Power Generation Capacity	111 days	Mon 27/07/09	Mon 28/12/09
6	200 SIMULINK Pre-Test Update	35 days	Mon 27/07/09	Fri 11/09/09
7	201 Hydrodynamic Performance Evaluation	82 days	Mon 31/08/09	Tue 22/12/09
8	201a SOW for Test	11 days	Mon 31/08/09	Mon 14/09/09
9	201b Solid Model & Test Lab Bids	15 days	Tue 15/09/09	Mon 05/10/09
10	201c Test Preparation	44 days	Tue 06/10/09	Sun 06/12/09
11	201d Test Execution	12 days	Mon 07/12/09	Tue 22/12/09
12	201e Test Reporting	10 days	Wed 09/12/09	Tue 22/12/09
13	202 SIMULINK Model Post Test Update	9 days	Wed 16/12/09	Mon 28/12/09
14	203 Annualised Electricity Generation	2.8 wks	Mon 07/09/09	Thu 17/12/09
15	Facilities Design Activities	90 days	Mon 07/09/09	Fri 08/01/10
16	300 System Preliminary Design	6 wks	Mon 07/09/09	Fri 16/10/09
17	301 Structural & Foundations	12 wks	Mon 07/09/09	Fri 27/11/09
18	302 Power Generation & Offsite	11 wks	Mon 05/10/09	Fri 18/12/09
19	303 Fabrication & Installation Procedure	10 wks	Mon 19/10/09	Fri 25/12/09
20	304 Operation, Maintenance & Repair	6 wks	Mon 30/11/09	Fri 08/01/10
21	Project Development to Implementation	77 days	Mon 05/10/09	Tue 19/01/10
22	400 System Development Road Map	4 wks	Wed 23/12/09	Tue 19/01/10
23	401 SMEC Economic Parameters	4 wks	Mon 21/12/09	Fri 15/01/10
24	402 Project Risk Evaluation	15 wks	Mon 05/10/09	Fri 15/01/10
25	Draft Report	5 days	Tue 12/01/10	Mon 18/01/10
26	Review & Comment	2 wks	Tue 19/01/10	Mon 01/02/10
27	Update Report with Comments	2 wks	Tue 02/02/10	Mon 15/02/10
28	Final Report	1 day	Tue 16/02/10	Tue 16/02/10
29	Key Milestones	115 days	Wed 09/09/09	Tue 16/02/10
30	Prelim Power Gen Performance Estimate	0 days	Wed 09/09/09	Wed 09/09/09
31	6-week Progress Meeting	0 days	Tue 29/09/09	Tue 29/09/09
32	Workshop 1/Individual Progress Review	0 days	Fri 30/10/09	Fri 30/10/09
33	Intermediate Test Progress Report	0 days	Wed 11/11/09	Wed 11/11/09
34	Regular Review Meeting	0 days	Thu 26/11/09	Thu 26/11/09
35	Workshop 2 - Individual Workshop	0 days	Thu 17/12/09	Thu 17/12/09
36	Final Power Gen Performance Estimate	0 days	Thu 17/12/09	Thu 17/12/09
37	Road Map Complete	0 days	Tue 19/01/10	Tue 19/01/10
38	Preliminary Design Study Complete	0 days	Fri 08/01/10	Fri 08/01/10
39	Cost Data Complete	0 days	Mon 11/01/10	Mon 11/01/10
40	Draft Study Complete	0 days	Fri 15/01/10	Fri 15/01/10
41	Study Presentation to DECC	0 days	Fri 15/01/10	Fri 15/01/10
42	Preliminary Review date	0 days	Tue 19/01/10	Tue 19/01/10
43	Presentation to Programme Board	0 days	Mon 08/02/10	Mon 08/02/10
44	Final Report Complete	0 days	Tue 16/02/10	Tue 16/02/10

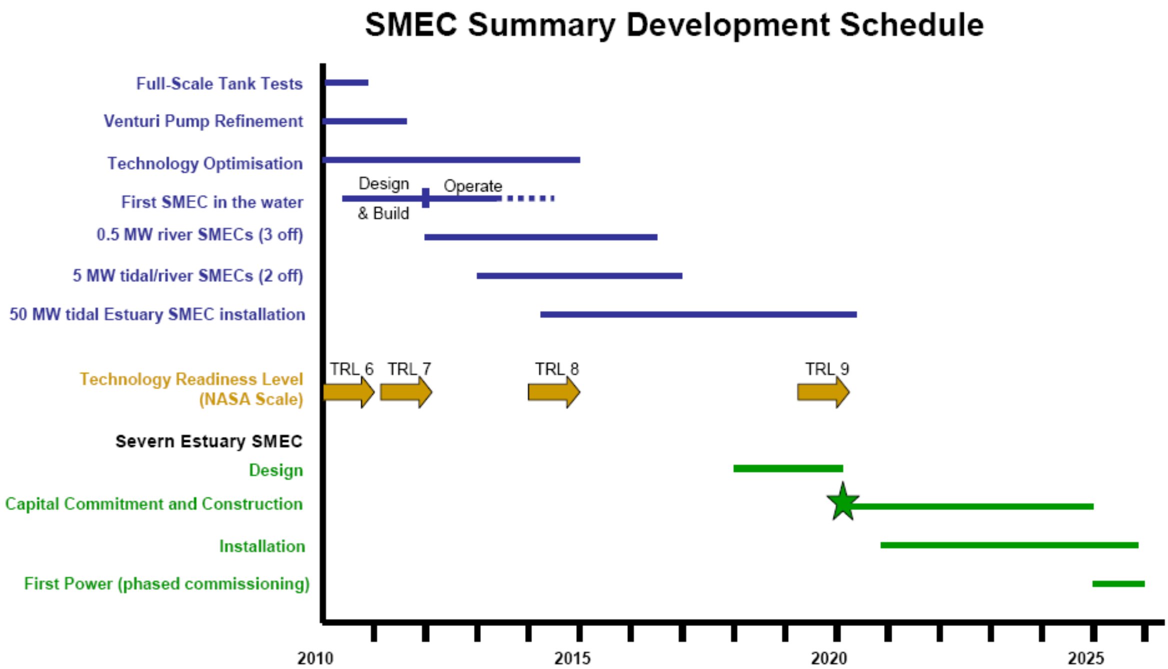


4.0 RESULTS

Technical Risk

The Risk Register and associated report is attached under Annex C. During the course of the SETS work, three important positive conclusions were reached:

- The risk profile score for SMEC was reduced by approximately 20%.
- Quantified insight into risk importance was gained, permitting 6 Key Risks to be selected for priority mitigation in the next stages of SMEC development. This is more fully discussed in the SETS Development Road Map attached in Annex B. However, a Summary schedule for this work, leading up to Capital Commitment for the Severn Estuary installation in 2020, is copied here:

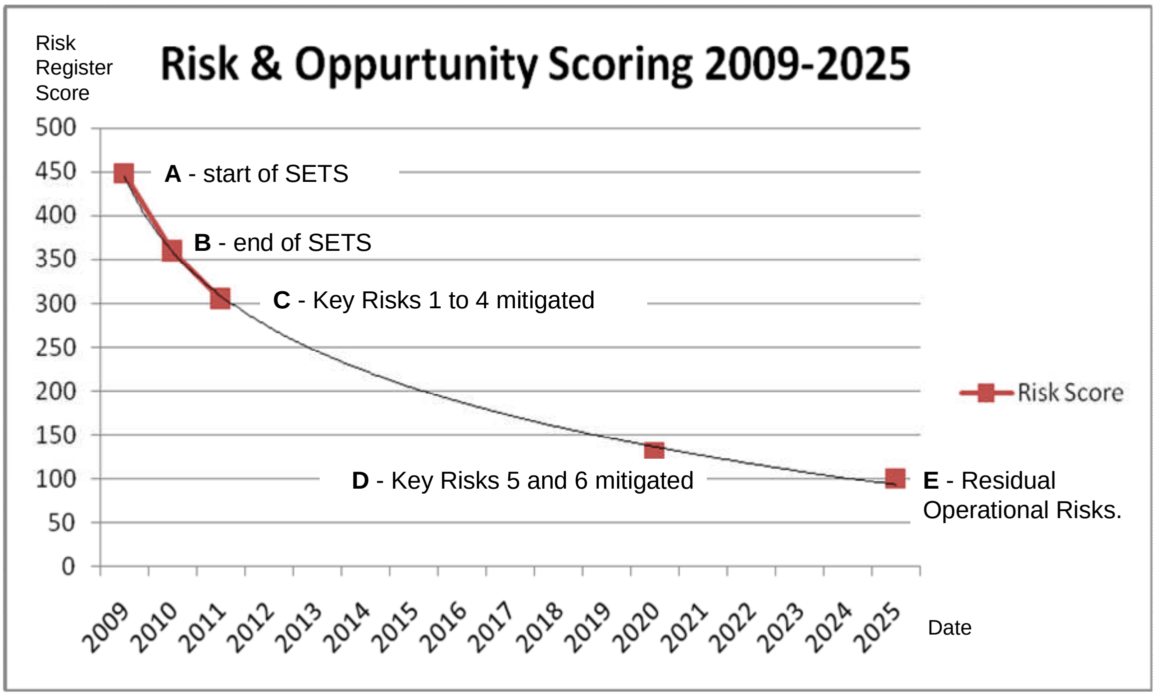


- The Risk Register scoring methodology adopted permitted projections to be made of the key further mitigations planned for 2010/11 as Key Risks 1 to 4 are addressed. It also allows for the reduction in Risk Score as mitigation of Key Risks 5 and 6 are addressed through accumulating operational experience and further data gathering during the period 2012 to 2020. This is the point at which the Severn Estuary Capital Commitment is expected, after sufficient design has been undertaken to facilitate this decision.

  Inspection of the Risk Register then permits identification of the risk score associating with those risks that will still apply even when the Severn Estuary SMEC is operational. This irreducible minimum score includes such risks as sabotage and impact from shipping.

  Plotting all these scores against a time scale provides convincing evidence that the total SMEC risk score by 2020 will have been reduced by the planned mitigation measures to a point close to this irreducible minimum risk level. This is exactly where it needs to be to ensure that the detailed design of the Severn Estuary SMEC has little or no further risk to mitigate, beyond those small confidence improvements that occur during project execution undertaken in any familiar, mature technology.

This graph of falling risk level (which is the same as rising confidence) against time follows:



Cost and Amount of Energy

Document 0974-401-TN-001 was prepared as the work product output of Task 401. This is called "Economic Parameters for Severn Embryonic Technology Scheme" and draws on the performance and cost estimates prepared in the 300 series Tasks, together with the SETS Programme Financial Norms.

The results are summarised in the following table:

Name of scheme(s) and alignment(s)	Power Output (MW)	Annual Output (TWh)	Construction Cost (Inc comp habitat@ 2:1 and contingency @15% but exc optimism bias)	Energy Cost (£/MWh)	Annual Carbon Saving (CO_2 pa) (t)	Estimated year of 1st generation in Severn (*Year Project complete*)	Environmental Impacts (Impacts on Receptors)
Cardiff-Weston	1,340 (7,500)*	11.74	£9.85 bn	68	5,050,000	2025 (2026)	1,775 ha of bird habitat loss
Aberthaw-Minehead	1,580 (11,250)*	13.84	£14.41 bn	84	6,000,000	2026 (2027)	1,715 ha of bird habitat loss

* Actual Installed Rated Power Capacity

Sensitivity of Overall Costs to Turbine Costs

In the cost estimation given above, turbine-alternator costs suggested by a manufacturer of the same type of traditional, simple axial flow turbines adopted for SMEC were applied. As might be expected, the cost per unit of installed capacity of these simple, traditional turbines is less than the estimating metric used by Parsons Brinkerhoff in its Interim Option Analysis Report (IOAR). In the IOAR, a conventional barrage is being costed, which uses sophisticated, horizontal bulb turbine units. These require complex dry maintenance access arrangements to the generating equipment, housed below the water-line in a sealed nacelle behind the turbine. In SMEC, all this equipment is up above the water in the dry because the turbines are vertical specifically to obtain this benefit by simplifying maintenance access. Adopting the bulb turbine figure on the Cardiff-Weston alignment would increase the CAPEX cost by 18 % to £11.64 and the Energy Cost by nearly 20% to £81/MWh. These figures still compare very favourably with a barrage. It is believed that the Parson's Brinkerhoff bulb turbine metric can be taken as an absolute upper bound figure for the SMEC turbines if the price point obtained by VerdErg from the manufacturer of the simpler turbines adopted were to be called into question for any reason.

Impact on Energy Market and Security of Supply

No explicit quantified modelling has been made of the interaction of the renewable energy from the Severn Estuary with the wider Energy Market. That falls outside of the scope-of-work commissioned from VerdErg by DECC. However, it can be noted as a generality that the power generated by the Severn estuary SMEC is similar to that from a full-sized Fossil Fuel plant and that, moreover, it is generated in the South-West of England/South Wales which is thought currently to be a net importer of power from the North of England. The local sourcing of this power, therefore, removes the need to pay the transmission premium, and provides a better strategic balance to the UK power distribution system.

The proposed SMEC configuration lends itself to roughly equal division of the power delivered with one part going North into South Wales and the other part going South into North Somerset. One reason for this is that no cabling would then have to cross the lock or passage provided for shipping. This division of power distribution is again believed to be desirable. It is also worth noting that the maximum power sent in either direction will be less than 1GW, which is considered to be the point at which provision of facilities that permit isolation of the supply from the grid becomes increasingly complex and expensive.

Regarding Security of Supply, the power output is predictable into the indefinite future (a 120 year design Life has been adopted) since the energy source is the fully-defined future tidal cycle. No significant threat to power output projections from Global Warming has been discovered other than the almost trivial precaution of allowing for some water level rise by making the Venturi Tubes a little taller at a marginal capital cost increase.

The design of the Severn Estuary SMEC is modular; the conceptual design prepared during this SETS Programme study features 80m or 100m long modules each one of which contains 5 turbines. The Power Management philosophy developed under sub-contract for VerdErg by Parsons Brinkerhoff, Glasgow, permits individual elements to function independently. It is, for example, possible and is indeed recommended, that incremental power generation commence a year before construction completes, as the modules are installed one by one. By the same token, SMEC will continue to generate power whilst individual modules are under maintenance, being back-flushed one by one to clear internal sediment, for example, or being cleaned of marine growth. Likewise, even massive damage from ship impact can be accommodated.

In conclusion, therefore, it is thought that the Supply Security of power from the Severn estuary SMEC will be high.

Affordability and Value for Money

Two parameters are relevant: Initial Capital cost and Cost per Kilowatt-hour. Regarding Value for Money, the Cost per Kilowatt-hour reported above, particularly for the Cardiff-Weston alignment, appears attractive by comparison with energy cost data available in the literature for other renewable energy sources.

Regarding Affordability, very large infrastructure projects are believed to be exposed to commercial and financial feasibility issues that do not engage with the more commonly executed projects. In practice, the absolute CAPEX of a very large project is a relevant factor in its own right. Instances are known to have occurred, for example, when a large capital project was split into multiple, smaller, separate projects which together were less economic in terms of unit costs than the single large project, simply because the single project exceeded the Global Re-Insurance Market capacity for Builders' All-Risk insurance on a single project. Again, methodical investigation of these seldom-met issues was outside of the scope of the work undertaken but comfort is taken from the observation that both the Cardiff-Weston and Minehead-Aberthaw SMEC installations have an estimated Capital Cost that is less than that quoted in the literature for a conventional Cardiff-Weston barrage.

Environmental Impact

Regarding damage to the habitat of migrating birds, the maximum loss of intertidal wetlands caused by SMEC is calculated in report "Intertidal Flood Variations and Final Route Selection Confirmation" number 0974-101-TRP-001 which is included in Annex A.

The existing intertidal wetlands permanently flooded behind a SMEC under Spring tides on the Cardiff-Weston alignment is calculated as 1,775 ha, which is just 9% of the 18,898 ha of existing wetlands reportedly used by migrating birds.

For a SMEC on the Minehead-Aberthaw alignment, the calculated area of flooded wetlands is even less at 1,715 ha. This is despite the fact that around 40% more inundation would be expected than for a Cardiff-Weston SMEC simply because the Minehead-Aberthaw alignment is further West down the estuary. This counter-intuitive result is because of the lower flow velocities on the Aberthaw-Minehead alignment, despite there being twice the volumetric flow rate of that across the Cardiff-Weston alignment.

The Preliminary Environmental Impact Statement in Annex A however, document 0974-102-EIR-001, shows that the majority of the wetlands actually used by migrating birds lies to the East of the Cardiff-Weston alignment. It therefore follows that the effective habitat impact of a SMEC on the Aberthaw-Minehead alignment, already less than for a SMEC from Cardiff to Weston, could be even less as some of the inundated wetlands behind it that lie to the West of Cardiff-Weston are wetlands but not habitats.

The Aberthaw-Minehead SMEC produces more power annually than is available from a similar SMEC placed from Cardiff to Weston-super-Mare. However, the water volume flow rate past Aberthaw-Minehead is twice the volumetric flow rate across the Cardiff-Weston alignment which might have been expected to yield twice the power, although only 18% more power output has now been calculated.

In reality, however, SMEC technology permits increased blockage to be built into the configuration of an Aberthaw-Minehead SMEC, either as extended embankments or as a feature of every section, or as more shipping locks. Partially blocking off some of the flow area will increase the flow velocities and raise the power output back up towards the initial expectations, but to an unknown extent. Increasing the flow velocities in this way will, however, inevitably add more resistance to the flow, reducing the volume passing over the alignment into the upper estuary in any given time with unknown environmental consequences.

It can be observed therefore that if, after further study, an Aberthaw-Minehead SMEC were favoured, it would probably be to a modified design giving increased power output. Increasing the power offtake will increase the area of tidal wetlands permanently inundated to an unknown extent. For this reason, the Cardiff-Weston alignment is carried forwards within SETS and the

Aberthaw-Minehead alignment proposed for further investigation in the Development Road Map.

Regarding Severn Estuary fish, the SMEC has some inherent advantages over other technologies in that there are gaps between the Venturi Tubes through which fish may be able to swim and only around 20% or so of the main flow goes through the turbines, reducing the statistical risks of impact with fish. These risk factors may be proved beneficial over time but have not been taken into account as the main mitigations, at this stage. For one thing, the sudden pressure reduction as a fish passes through the narrow point of the venturi potentially may damage fish swim bladders in Severn Estuary species that have them.

The proposed primary method of protecting fish, therefore, is to locate gaps in the SMEC at points where fish transit up and downstream at present, and to deter them from getting into other parts of the SMEC using commercially available equipment such as bubble screens, strobe lights or high-frequency sound. The detailed configuration of these techniques and evaluation of their effectiveness is scheduled for completion on the Development Road Map.

It is thought that there is a significant lack of detailed knowledge regarding the behavioural patterns of fish in the Severn Estuary. This shortcoming has to be addressed before a confident prediction can be made of the impact any particular SMEC design will have on estuary fish, when the various protection strategies mentioned here are deployed. A major EIA is proposed in Work Package 6, one early activity of which will be re-assessment of the Body of Knowledge then available regarding fish patterns of behaviour in the Severn Estuary and definition of any specific data collection campaigns necessary to fill gaps in the Data Base.

One further mitigating strategy to be investigated in the Development Road Map is the selective management of power output levels to achieve specific environmental objectives. The head difference across a SMEC is a measure of the power being extracted, as is the attenuation of the upstream tidal cycle. It may prove to be a useful technique under future investigation to draw power from elsewhere in the Grid on occasions to lower the head difference across the SMEC and simulate, for example, an un-attenuated tidal cycle to expose more wetlands at particular times, or to deliberately "refresh" coastal marshlands with an un-attenuated high tide.

A SMEC could be designed to additionally act as a flood defence barrier but this has not been studied.

Regional Level Economic and Social Impacts

Regarding the broader social impact, a major EIA has been scheduled as a key precursor to selection of SMEC for deployment starting 2020. Investigation of the Regional Level Economic and Social Impacts is part of that EIA.

Under the SETS Programme work, only limited investigation has been undertaken but discussion was held with the Bristol Port Authority. All its Risk Factors have been included in the Risk Register discussed earlier. In that respect, all comments made here regarding Risk and Risk mitigation include this aspect of Regional Level Economic and Social Impact. The Development Road Map addresses those shipping-based issues that are appropriate to ensure compliance with Severn Estuary requirements by 2020.

The Bristol Port Authorities expressed a view that SMEC had some significant advantages from their viewpoint including:

- A marked preference for the Minehead-Aberthaw alignment which was identified by VerdErg as a SMEC option under consideration. This was because the more Westerly alignment leaves much more room upstream for ship manoeuvring.
- A conventional Barrage on the Cardiff-Weston alignment is configured with its sluice gates in the deepest channel, just where a shipping lock would be best located. Any lock gates required in the SMEC, by complete contrast, can be located where most convenient to shipping patterns. Again, the Minehead-Aberthaw alignment offers most flexibility as much of that alignment is in relatively deep water.
- The lock required in a conventional Barrage retains a head of water several times higher than that experienced across a SMEC. This means that the transit time for a ship through a Barrage lock will be far longer than the time taken to transit a SMEC lock.
- VerdErg's specialist sub-contractor is already working on the conceptual design of an open gap in a SMEC, in which the loss of power output through by-pass flow is reduced by strategic location of the Secondary Circuit intakes. Such a device is likely to permit fish to pass unhindered, but if a large enough gap could be engineered, it could allow unhindered through access to shipping. This work is an early activity along the Development Road Map.

It is therefore apparent that the Minehead-Aberthaw alignment has some Regional Level Economic and Social Impact advantages over Cardiff-Weston, to be balanced against the higher unit cost of energy it produces. The final choice of alignment has been scheduled as the starting point in proposed Work Package 6.

As a final comment, although outside of the scope-of-work of SETS, it can be seen by inspection of the Severn Estuary SMEC design sketch at the beginning of this document that it would be very straightforward to add a roadway across the top, adding utility to the local community. Such a four lane road on top of a SMEC linking Cardiff and Weston-super-Mare, for example, would cost an additional CAPEX of around £400 million.

It has also been noted during the preparation of this study that there is a body of opinion that the presence of a SMEC across the upstream estuary would promote the emergence of Port Talbot as a deepwater port. This opinion has not been researched in this study as such activity falls outside of the specified scope of work.

5.0 CONCLUSIONS

1) A SMEC on the Cardiff-Minehead alignment can produce an annualised 1.34GW of electrical power from the Severn Estuary at an attractive cost of 6.8p/KWh at 8% discount rate, including 2:1 habitat compensation costs.

2) Subject to the proposed Development road Map being followed, SMEC can be brought to a sufficiently developed status by 2020 to support its adoption at that time as a mature technology for the Severn Estuary. First power delivery would be at the end of 2025.

3) Government funding support is essential to timely prosecution of this Development Road Map, particularly over the period early 2010 to end 2011.

4) A SMEC on the Cardiff-Weston alignment is currently carried forwards in preference to the Aberthaw-Minehead alignment because it offers a superior cost of energy. Aberthaw-Minehead offers some Environmental/Stakeholder benefits including for migrating bird habitat, shipping movements and dredging activity, however. This provisional conclusion in favour of Cardiff-Weston, therefore, should be re-evaluated in good time prior to final alignment selection, because improving knowledge of detailed SMEC performance over coming years may permit additional flow velocities to be induced through the device on the Minehead-Aberthaw alignment, improving the power output to a point where an attractive design compromise can be struck giving equal or superior economics to the Cardiff-Weston alignment as well as some measure of the Environmental/Stakeholder benefits mentioned above.

6.0 RECOMMENDATION

It is recommended that SMEC be adopted for further Grant Funding during 2010 and 2011 to permit Key Development Risks 2 to 4 to be addressed.

Appendices

APPENDIX 1

1. Work Breakdown Structure and SETS Scope-of-Work

<table>
<tr><td align="right">Task 100</td><td>Site Location Study</td></tr>
<tr><td align="right">Methodology</td><td>Existing design data regarding the various route alignments already studied will be reviewed and information extracted as required to create a Design Basis for a SMEC tidal fence installed across the Severn estuary.

A Document Register of deliverable reports will be prepared.

This activity is proposed to be initiated by holding a Round Table “seminar” lasting one to two days between the VerdErg team and the SETS/Parsons Brinkerhoff/Black & Veatch team to overview the existing data library and identify possible useful sources of relevant existing Design Basis information.

This work will also identify a Target Design Life for the SMEC facility.

A route selection exercise will then be performed in three stages:

▪ First, an evaluation matrix will be drawn up for a SMEC sited on each alignment in turn. Using the approximate data already to hand at the start of the study, the approximate power output, approximate CAPEX and Environmental impact on sedimentation, mud flat inundation, birds and fish will be listed to enable two front-running alignment options to be identified.

▪ Secondly, the two best alignments will be compared in more detail by reference to the same parameters plus cost per Kilowatt hour of electricity produced, using the performance data available to VerdErg from previous work.</td></tr>
<tr><td align="right">Required Inputs</td><td>Available design basis for other barrage options, which may include the following data:

• Metocean conditions – including wind, wave, current, and tidal histograms (hindcast analysis)

• Environmental conditions in the estuary – including flora, fauna, and water conditions

• Geophysical survey and bathymetric maps of the Severn crossing

• Geotechnical survey & soils characterisation of the Severn Crossing

• Sediment Transport Studies

• Infrastructure in the crossing area – including desired tie-in point to electrical grid

• Previous local construction and maintenance studies for the barrage alternative</td></tr>
</table>

Task 101	Inter-Tidal Flood Variations and Final Route Selection Confirmation
Methodology	Using results of the optimised hydrodynamic design for SMEC, the change in water level within the tidal estuary will be determined. The implications of this data will be discussed as part of the Gateway Review. Finally, a preferred route alignment will be recommended on the basis of the following selection criteria, in order of priority: • optimal environmental footprint, • acceptable cost per kWh of the power produced, • total CAPEX comparing favourably with a Cardiff-Weston conventional barrage.
Required Inputs	CTR 100 – Estuary Water Levels, Bathymetry and Flood Maps CTR 201 – Analysis Results
Outputs	Report on Inter-Tidal Flood Area Comparative Map of the Severn Estuary with SMEC & without SMEC

Task 102	Preliminary Environmental Impact Statement
Methodology	The objective of this CTR is to review existing Environmental Impact Studies of the various existing designs, and provide a commentary to account for the differences that a SMEC design will exhibit, to facilitate assembly of a preliminary Environmental Impact Statement. This preliminary Environmental Impact Statement will be structured in accordance with UK & EU requirements. As a result of potential hazards identified, the SMEC preliminary design will include an options evaluation to identify those design modifications that provide the most appropriate balance between minimising impacts and an economically viable solution.
Required Inputs	Local Environmental Requirements CTR 100 – Environmental Condition in the Estuary CTR 101 – Inter-Tidal Variations CTR 300 – Preliminary Design of SMEC CTR 303 – Fabrication & Installation Procedure CTR 304 – Operation, Maintenance & Repair Plan
Outputs	Preliminary Environmental Impact Statement Input to the Risk Register (CTR 402)

Task Heading 200	SIMULINK Model Pre-Test Update
Methodology	In the material previously supplied to the SETS Group, full details were given of the work undertaken to date to establish the power generation capacity of SMEC: ▪ A mathematical model of SMEC was initially developed in early 2006. This was built in the SIMULINK software, and power output predictions for a full sized SMEC module 150m long to be placed into a tidal flow just under 20m deep were documented. This is the basis of all power claims made for SMEC to date. A number of assumptions were made regarding parametric flow coefficients. See Appendix 2. ▪ Model test were made at the IFREMER flume tank in Boulogne in April and September 2007 under METRI II funding at around one sixth scale of a Severn Estuary SMEC. This was to validate the assumptions made in the ORECon report. Validation of the SIMULINK mathematical model was achieved. Relevant model test results and interpretation reports were prepared by IFREMER and BMT Ltd. and are in Appendix 2. ▪ It was recognised after these tests that despite validation of the power prediction model, there were a number of design areas requiring further investigation. The venturi is the “engine” of SMEC and optimisation of its detailed design (including the diffuser) was identified as most important. A small-scale test rig to test various venturi tube cross-sections was built in late 2007 and encouraging qualitative results obtained, but funding for a larger-scale quantitative test programme was not found at that time. In November 2008, Strand “A” funding was provided by the Carbon Trust for an audit by W S Atkins of the work described above with particular reference to the SMEC mathematically modelled by ORECon, placed into a tidal flow peaking at 2.5m/s and having approximately 10MW calculated generating capacity. This report accepts the power output as predicted by the SIMULINK model but contributes an elegant mathematical definition of the limiting performance envelope achievable for turbine power offtake from a venturi-induced secondary flow. Although still under discussion, this insight should add further integrity and refinement to the SIMULINK model and any such “Lessons Learnt” will also be incorporated under this CTR into the upgraded power offtake prediction metric.
Required Inputs	CTR 200 – Test Results SIMULINK software Original SIMULINK Model
Outputs	Updated SIMULINK Model

Task 201	Hydrodynamic Performance Evaluation
Methodology	A laboratory-based study of the secondary circuit pumping will provide further insight into the optimal profile of the venturi tubes in cross-section at large scale, and to refine the optimal shape and size of the venturi slots, in order to clarify the efficiency of the secondary circuit pumping in a SMEC. The work in question is summarised as follows: • Design of Experiment. • Model Construction. • Instrumentation. • Tank Hire • Conduct of the tests. • Installation, Setup, Removal, Transport and Storage • Data Analysis, Report This work reflects the need to clarify the real-World effects of fluid viscosity on SMEC performance such as skin friction, boundary layer breakaway and turbulence, by testing at a scale appropriate to the Froude and Reynolds numbers of both the test and full-sized SMEC. An Audit by WS Atkins of the performance claims made for SMEC has been undertaken for the Carbon Trust under Strand “A” funding. This report is still in draft at the time of writing but it supports the electrical power generation claims made for SMEC. However, the report also includes an elegant mathematical prediction of the theoretical upper limit of the performance of the Venturi Pump function of a SMEC which is under discussion at the time of writing. Once modified and approved by the Carbon Trust, this metric may beneficially be used to assist in the design of the experiments to be undertaken under this task. The test results may then be used to validate and calibrate the W S Atkins metric and help form an input to the SIMULINK model of SMEC, CTR 201, As a further task, an evaluation will be made of the comparative performance expectations of the various forms of industrial turbine compared to that of a ship’s Controllable Pitch propeller working in reverse. This work is closely linked to the configuration design of the preferred power offtake system in CTR 302 and is reported there for convenience.
Required Inputs	Carbon Trust Audit Report on SMEC performance (appended with comments) BMT Technical Note 09-004 (date March 2009) describing the scope of the laboratory testing recommended (see Appendix 2)
Outputs	Test Results Report Test Interpretation and Updated Design Metric Report Recommendations for Venturi Tube Design Configuration – Input to CTR 300

Task 202	SIMULINK Model Post-Test Update
Methodology	In the material previously supplied to the SETS Group, full details were given of the work undertaken to date to establish the power generation capacity of SMEC: ▪ A mathematical model of SMEC was initially developed in early 2006. This was built in the SIMULINK software, and power output predictions for a full sized SMEC module 150m long to be placed into a tidal flow just under 20m deep were documented. This is the basis of all power claims made for SMEC to date. A number of assumptions were made regarding parametric flow coefficients. See Appendix 2. ▪ Model test were made at the IFREMER flume tank in Boulogne in April and September 2007 under METRI II funding at around one sixth scale of a Severn Estuary SMEC. This was to validate the assumptions made in the ORECon report. Validation of the SIMULINK mathematical model was achieved. Relevant model test results and interpretation reports were prepared by IFREMER and BMT Ltd. and are in Appendix 2. ▪ It was recognised after these tests that despite validation of the power prediction model, there were a number of design areas requiring further investigation. The venturi is the "engine" of SMEC and optimisation of its detailed design (including the diffuser) was identified as most important. A small-scale test rig to test various venturi tube cross-sections was built in late 2007 and encouraging qualitative results obtained, but funding for a larger-scale quantitative test programme was not found at that time. ▪ CTR 200 addresses the methodical undertaking of these tests in a structured, monitored, quantified programme. This CTR incorporates the test results into an improved SIMULINK model. In November 2008, Strand "A" funding was provided by the Carbon Trust for an audit by W S Atkins of the work described above with particular reference to the SMEC mathematically modelled by ORECon, placed into a tidal flow peaking at 2.5m/s and having approximately 10MW calculated generating capacity. This report accepts the power output as predicted by the SIMULINK model but contributes an elegant mathematical definition of the limiting performance envelope achievable for turbine power offtake from a venturi-induced secondary flow. Although still under discussion, this insight should add further integrity and refinement to the SIMULINK model and any such "Lessons Learnt" will also be incorporated under this CTR into the upgraded power offtake prediction metric.
Required Inputs	CTR 200 – Updated Model CTR 201 – Test Results SIMULINK software Original SIMULINK Model
Outputs	Updated SIMULINK Model

Task 203	Annualised Electricity Generation Estimate
Methodology	Analysis with the SIMULINK model will be made to calculate the annualised electricity generation capacity from the Severn Estuary. Calculations will consider tidal input data and availability of the SMEC system. An estimate will be made of the enhancement of the tidal flow velocity regime caused by the blockage of the SMEC structure, past which the flow must accelerate. A preliminary estimate will be prepared based on the pre-test model developed in CTR 200. This will allow preliminary verification of performance claims. Provided acceptable, the estimate will be revised again after hydrodynamic testing to further refine the confidence interval in the estimate. A further output from this CTR will be the loading criteria used as input to the structural design calculation in CTR 301.
Required Inputs	CTR 100 – Tidal Characteristics CTR 200 & 202 – Updated SIMULINK Model
Outputs	Annualised Energy & Availability Estimates Structural design loadings.

Task 300	System Preliminary Design
Methodology	The work to be undertaken under this CTR is: Evaluate the technical requirements of the Severn Estuary SMEC and determine the tidal fence configuration most effective to meet the location requirements. Configuration options will include steel or concrete construction, and hybrid variations using post-tensioned concrete and steel, glass fibre reinforced polymer, syntactic foam and composite structures. Based on the results of the evaluation, the preliminary design will be developed based on the following activities: • Structural and hydrodynamic design to give selection of scantlings and materials grades • Review of tidal range and its accommodation by the design • Foundations design from published information on the site • Fabrication and installation study • Operation, Repair and Maintenance Study • Capital & Operating Cost Estimates It is probable that facilities must be provided to facilitate the passage of shipping. A conventional lock suited to a conventional barrage is one obvious candidate solution but it is believed that cost and configuration details of such a lock will be available from other work undertaken previously for SETS, so no resource consumption has been associated with development of this data. SMEC, however, may lend itself to use of a simple “gate” device, with only one portal to be opened rather than the two necessary in a lock. An outline concept for such a gate has been developed by VerdErg, (possibly requiring a further patent application to be first filed), which if appropriate will be included in the configuration options listed above.
Required Inputs	CTR 100: Design Data CTR 203: Results of hydrodynamic loadings imposed on the SMEC. Details of shipping locks previously studied by the SETS Group.
Outputs	Technical Note on the evaluation of alternative designs. Preliminary Design Dossier (Compiling all 300 Series Activities)

Task 301	Structural & Foundations Design
Methodology	A more detailed design will be made under this CTR for the SMEC configuration selected in CTR 300. General force and soil bearing analysis will be undertaken as well as structural analysis to determine the size, weight and foundation design of the SMEC structure. The outline configuration of the generator platforms will be determined and an outline design prepared. The local structural effects of the low-pressure regime inside the throat of the venturi will be investigated and appropriate strengthening provided. Material-Take-Off estimates will be generated for tubular materials (steel or concrete), plated steel sub-assemblies, manifolding system, foundation type, scour protection, and structural reinforcement. This will form the basis of the capital cost estimate.
Required Inputs	CTR 100 Design Data CTR 203 Results of hydrodynamic loadings imposed on the SMEC. CTR 300 Selected design configuration and its preliminary design
Outputs	Material Take-Off Summary Functional Specification of Key Structural Components, including: • Venturi Tubes • Manifolding structure • Duct entry/Impeller Shrouding • Generation support platforms • Gravity Base or Piled Foundation • Excavation & Backfill Volumes • Rip-Rap Quantities for Soil Protection and stabilisation. • Lock or gate for passage of shipping

Task 302	Power Generation & Offtake Facilities Design
Methodology	General definition will be made by a Parsons and Brinkerhoff team in Manchester and Newcastle of the generator and electricity transmission system required to supply electricity to the nominated grid tie-in location for the single recommended SMEC scheme. Weight, sizing, maintenance frequency and spares philosophy for the power generation and electrical system will provide input to the system capital and operating cost estimate. General definition will also be incorporated into this CTR of the ducted impellers from CTR 200, generator and electricity transmission system required to supply electricity to the nominated grid tie-in location.

	A desk study will be made of the comparative cost-effectiveness of ship's propeller-shaped impellers against conventional turbine configurations to permit recommendation of a preferred power offtake mechanism. The intent is to ensure that the entire impeller-generation assembly can be readily removed as a unit for maintenance and repair. Weight, sizing, and spares philosophy for the power generation system will provide input to the system capital and operating cost estimate. This impeller definition work will be conducted in conjunction with the structural design in CTR 301, and will be funded within the costs quoted in CTR 301, but reported here together with the electrical work. Particular attention in this context will be given in both CTRs to achieving rational flow rates within the secondary circuit such that an economically reasonable number of realistically sized generators can be recommended. (If the generators are large and far apart, the flow rate in the lower manifold may become excessive.)
Required Inputs	CTR 100 Design Data CTR 200 & 202 Results It is expected that these will identify one SMEC and one power offtake option to be considered.
Outputs	Functional specification of the generation and offtake system, including: • Number and size of generators • Electrical Transmission system including cabling, switchgear, transformers and grid connection arrangements • Space requirements and weights of offshore electrical equipment • Offshore electrical arrangements given civil and structural constraints Functional specification of the generation and offtake system, including: • Ducted impeller size and type • Number of impellers per unit length • Number of primary and back-up generators • Transmission cable • Metering and Power Control design • Emergency Shut-down & Safety systems Assessment of outline capital and operating costs (to a pre-feasibility study level) for electrical systems

Task 303	Fabrication & Installation Procedure
Methodology	A fabrication and installation procedure will be outlined. Key construction equipment, site requirements and post-construction rectification will be generally defined for the fabrication and installation of the SMEC and supporting infrastructure for input to the Capital Cost Estimate.
Required Inputs	CTR 100 Design Data CTRs 300, 301, 302. CTR 202 Results
Outputs	Fabrication and Installation Sequence Identification of Capacity and Quantity of Key Construction Equipment Estimate of Time for Fabrication and Installation Activities as Input to the Capital Cost Estimate Identification of Regional Suppliers to the SMEC fabrication, construction and installation activities to maximise local involvement

Task 304	Operation, Maintenance & Repair
Methodology	Regular operating, maintenance and repair activities for the SMEC will be identified. Performance degradation will be evaluated versus frequency of inspection and repair activities. Regular activities and frequencies will be bench-marked from similar types of structures to form a basis for estimating the Operating Expenditure, during the design life.
Required Inputs	CTR 100 Design Data CTR 202 Results CTRs 300, 301 and 302 CTR 303 – Preliminary Results
Outputs	Operation, Maintenance and Repair Philosophy Operational Cost Estimate

Task 400	System Development Road Map
Methodology	This activity firstly exercises oversight and coordination of all other elements of the Work Programme enabling an understanding of the schedule and cost characteristics of a commercial SMEC installation to be formed in the context of the Severn Estuary. Based on this understanding of the SMEC Value Drivers, as documented in the deliverable reports, a 10-year sequence of events will be proposed with the objective of assuring that by 2020, the development status of SMEC is compatible with its confident selection as the preferred option for large scale generation of power from the Severn Estuary in an environmentally acceptable manner. There are International Codes of Practice regarding technology development programmes, including codes by Det Norske Veritas and the American Bureau of Shipping. A suitable code will be selected and its process recommendations adopted for the System Development Road Map. The starting point for this Road Map may be summarised as the following proposed sequence of events. This high-level activity schedule will firstly be challenged, then validated, then expanded into a more detailed schedule. The first suggested sequence of events is as follows, following VerdErg's existing Business Model for SMEC commercialisation which will have already secured, prior to this activity starting, the incorporation of VerdErg Renewable Energy Ltd. as the SMEC development vehicle and Centre of Excellence. It is hoped that appropriate Equity Partners to capitalise this company will also have been identified by that time: ▪ Solicitation of joint financial participation by local industry and Government Agencies in the installation of a Commercial Demonstrator SMEC into a local river. This might cost up to £1 million in total and generate around a Megawatt of electrical power. SMEC appears to be well suited to river sites; WS Atkins agrees that SMEC has unique capability as a low-head hydro energy conversion device, and its design is simplified where the flow is uni-directional. Multiple SMEC installations in series down the gradient of a medium-sized river could be a very cost-effective application. ▪ Parallel to this activity, further support from the appropriate Agencies of the UK Government will be solicited for remaining technology development resolution as identified during Activity 402 "Assembly of the Risk Register". It is hoped that the Carbon Trust can broker and possibly participate in this activity. ▪ Design and installation of a Commercial Demonstration model into a more exposed estuary location, but smaller than the Severn Estuary. Government support, possibly on a reduced percentage, may still be found appropriate. Initial approaches have been made, as one example, to Peel

	Energy Ltd. in the context of a Mersey Estuary installation and contact has been maintained over several years with the North West Regional Development Agency (VerdErg has test and assembly facilities on Merseyside). ▪ Fully commercial SMEC "Design and Build" contracting activity Worldwide will subsequently continue to contribute to the advancing maturity of SMEC technology, possibly from around 2015 onwards. The aim is therefore to have at least 5 years of documented operating experience and "Lessons Learned" supporting the technical and commercial pedigree of the SMEC proposed for the Severn Estuary, prior to 2020. The underlying schedule for the System Development Road Map will be assembled under this CTR with reference to as wide a group of Stakeholder as possible: ▪ Key system suppliers will be contacted to validate lead times for delivery and unit costs. ▪ VerdErg will target Equity Investors in its development company that offer relevant industrial experience as well as finance. ▪ Parsons Brinkerhoff, Black & Veatch and the SETS Programme Management Board will be requested to make all possible input from the background of their advanced understanding of the Severn Estuary requirements. ▪ Contact with major industrial parties established in the SETS area and beyond are already underway with a view to soliciting industrial support for the fabrication of increasingly large SMEC installations, as mentioned above. ▪ Full cooperation will be maintained with Government Agencies, initially the Carbon Trust and SETS Programme Board with which contact is already established, plus other bodies as may be recommended by them such as the Technology Strategy Board and the Environmental Transformation Fund.
Required Inputs	Status & Completion Monitoring of Existing Activities. International Code requirements for new technology validation. Fabrication & Installation Plan Lead Times for Key Suppliers Outline agreement with industrial partners on technology input and/or funding support. Outline agreement with Carbon Trust, SETS Programme Board and/or other Government Agencies on funding support.
Outputs	Phased System Development Road Map report.

Task 401	SMEC Economic Parameters
Methodology	The objective of this CTR is to provide calculated quantities of power generated together with corresponding cash flows, capital expenditure estimates and operating expenditure estimates through the full design life of the SMEC. These inputs will be used by SETS as input to their economic model to assess the commercial viability of the SMEC on the Severn Estuary.
Required Inputs	CTR 300 Series Capital Cost Estimates Operational Cost Estimates Risk Mitigation Costs SETS Financial Model Norms
Outputs	Cost of Energy and Revenue Report

Task 402	Project Risk Evaluation
Methodology	A Risk Register and Risk Matrix will be set up and preliminary HAZID and FMEA exercises undertaken to identify and then propose, and to subsequently cost out, appropriate mitigation measures. The wide range of disciplines and risks involved suggests the joint participation of the Parsons Brinkerhoff, Black & Veatch, SETS and VerdErg Team in an initial open-forum HAZID "seminar". Note that the manpower cost to organize, moderate, analyse and report on this activity with costed mitigation proposals is carried in this CTR but that much of the manpower cost of team members attending and offering technical contributions to the Seminar is booked under the task-specific CTR work which these team members will represent. It may be considered appropriate to invite the Carbon Trust to be represented in this Risk Management Seminar. This is appropriate firstly because of their detailed insight into the Audit undertaken by W S Atkins, and secondly because of the intent expressed under CTR 400 to interface with all Stakeholders including the Carbon Trust, and other agencies and potential funding sources as may be recommended by them such as the Technology Strategy Board and the Environmental Transformation Fund. Risks expected to populate the Risk Register will include but will not be limited to the following. This list will evolve as the work progresses, with some topics added and possibly some removed if closure is achieved on one or more risk issues identified below: ▪ **Residual cost and schedule impact of introducing an emerging technology into large scale use.** This is a risk with

any technology programme and is best illuminated and calibrated by adoption of a System Development Road Map that complies with the most appropriate International Code of Practice, as is proposed.

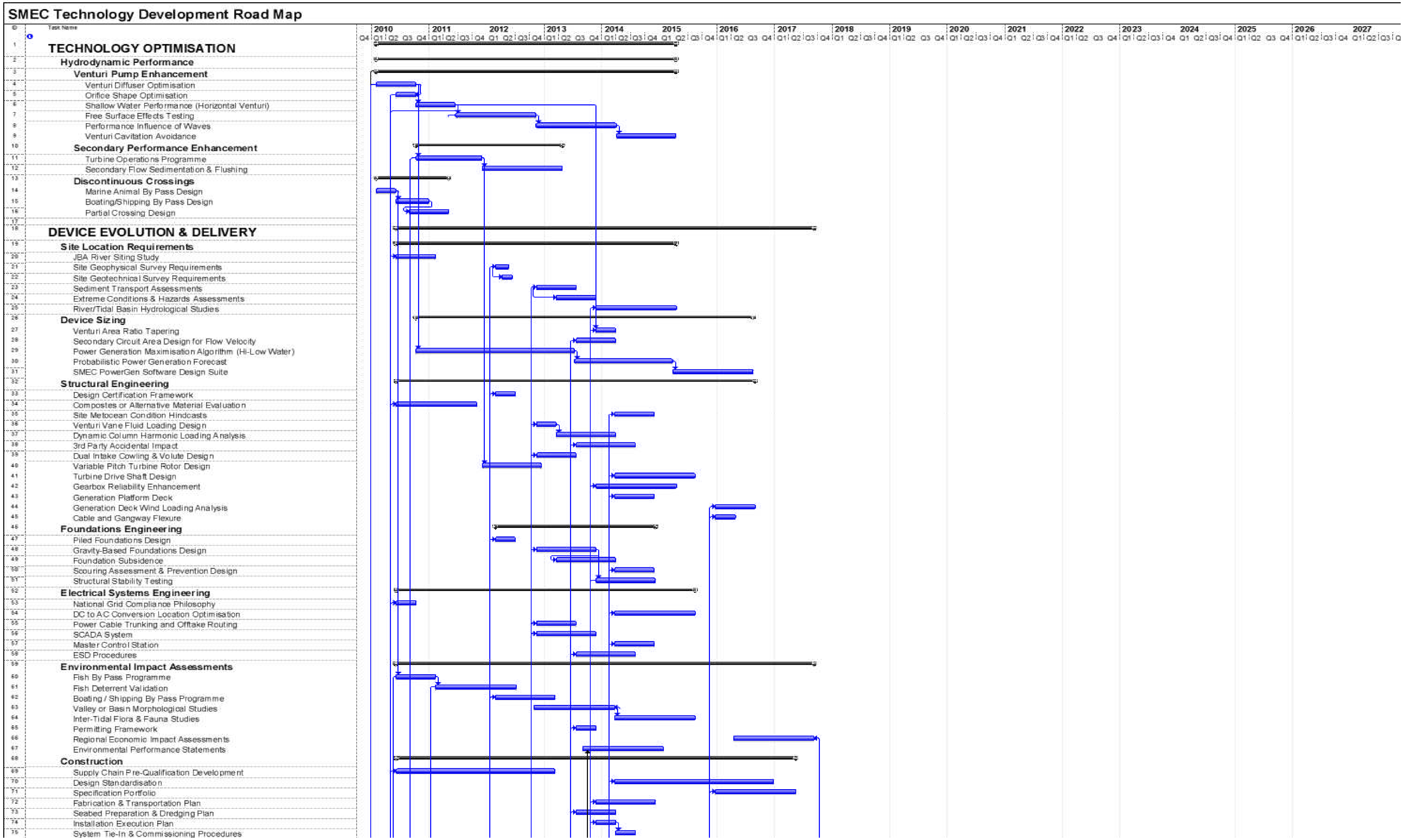
- **Scaling risks from Model to Full Size.** The work performed under this programme will greatly improve the credibility of power offtake calculations, but the most recent tank tests of a full SMEC module will still be those undertaken in 2007 at around one sixth scale, relative to a Severn Estuary installation.
  It may be thought prudent to undertake a further series of tank tests at full scale. SMEC performance is a function of both Froude and Reynolds Number and their simultaneous identity can only be preserved at full scale. This will involve building a model of a section of the SMEC recommended for the Severn Estuary, limited to several meters height (as dictated by the test facility) and with only a few venturi tubes (as dictated by the test facility width).
  SMEC lends itself to confident testing of a small modular section of the device at full scale, so long as by-pass flow around the free edges of the model section is prevented, to permit the test section to remain representative of prototype performance.
  Amongst the important parameters whose definition would be further improved by this testing is expected to be:
  - The global drag force on the SMEC which defines the overall horizontal structural loading to be resisted.
  - The localised loading within the venturi caused by significant pressure drops, which defines the exposure of the venturi tube cross-section to structural distortion or failure.
  - The consequences if any, of venturi slots becoming exposed as the tides falls. Also, the consequences, if any, of the tops of the venturi tubes remaining open to the atmosphere.
  - Further study of the behaviour of the water free surface to establish that the transition from the upstream to the downstream elevations, which is a function of the power offtake, is made in a benign fashion. Various flow management strategies for this phenomenon have been conceptually developed by VerdErg should they be found experimentally to be beneficial.
  - In a general way, any early stage Commercial Investor without relevant technical knowledge will probably want to see a full-sized SMEC generating useful power. Although possibly not strictly necessary technically, having such a model powering some dynamometer device or equivalent at the side of the test tank may become necessary to permit uninterrupted funding to be found. This would be the first available opportunity to satisfy any such commercial requirement.
- **Further technical evaluation of the optimal power offtake configuration** (e.g. turbine vs ships's propeller). A desk study on

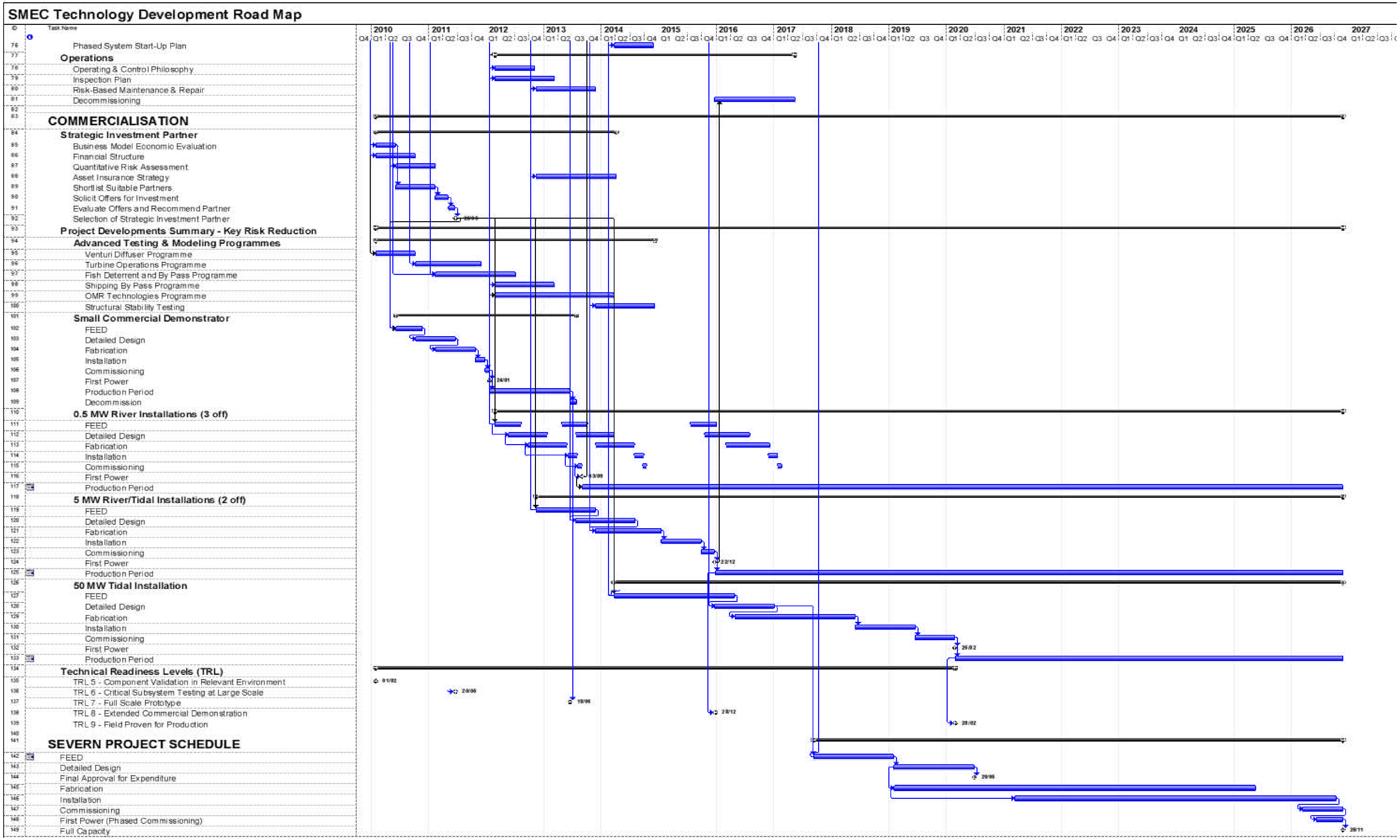
	this topic is included in CTR 302. This study may reveal that further design work, or even a test programme, is needed to refine the most cost-effective through-life power offtake technology for the Severn Estuary SMEC. ▪ **Flow patterns associated with the secondary flow.** Characteristically, 10% to 15% of the free stream flow will pass into the inlet duct on each SMEC modular section, through the power offtake impeller, and down along the lower manifold to feed the venturi outlets up each tube, before diffusing back into the residual through-flow that passes between the bars at low pressure, immediately downstream of the SMEC. The inlets to the secondary flow paths that power SMEC may be sited, as an example, every 15m to 20m along the SMEC fence, each one servicing, perhaps, a 1MW to 1.5MW capacity generator. This secondary flow into discrete intake locations will modify the free-stream flow patterns locally and any performance degradation resulting from this disturbance should be considered a risk. The mitigation measures are to be determined but will presumably include development of a CFD model of the expected real flow patterns, as a first step. This work might usefully complete before undertaking further full-scale model tests as mentioned above to permit the performance impact of the incident free stream not being quite normal to the SMEC fence to be determined by angling the model in the tank. A similar phenomenon may be found where the lower manifold (and/or the generator support towers) of the SMEC are of such a size that significant blockage is presented to the flow, particularly in shallow sections, causing turbulence or deleterious re-alignment of the flow. Once again, investigation by building a CFD model is possibly the first mitigation measure. Note that such blockage by the SMEC structure has the beneficial first order effect of increasing the local flow velocity; this effect will have been considered under CTR 202. ▪ **Combined Wave & Tidal effects.** SMEC will generate power and experience hydrodynamic loading from any incident waves as well as from currents. Only tidal effects are modelled in the work programme and the consensus of opinion remains that any wave effects will be small. Until better defined, however, waves in the estuary may be considered to pose a residual risk both to structural integrity and possibly to the power generation train. ▪ **Seabed & Sediment Transport risks**. These will have been studied during the work programme but residual concerns may remain. Regarding sedimentation of the SMEC itself, an electrical cross-connection may be available to permit high-velocity back-flushing to remove any sediment. One possible source of concern regarding the estuary is that the blockage of the SMEC structure mentioned above will cause an unacceptable level of estuary sedimentation. This issue will be investigated to the point where an initial understanding can be documented during the work programme, however. Further definition thereafter will probably require access to or development of a CFD model of the estuary with and without a

	SMEC in place. SETS may be able to undertake this work using existing models before or after Spring 2010. ▪ **Marine Fouling potential impact.** It is probable that marine fouling will occur around the SMEC and possibly degrade the performance. This is a common problem with many marine structures however, and numerous conventional mitigation strategies are available. Their costs should be allowed for under CTR 401. ▪ **Residual environmental impact** on birds and fish after the design work undertaken under the 300 Series activities is complete. The risk factor of this type thought to be least resolved at the time of writing is the danger to fish swim bladders as they pass through the low-pressure zone of the venturis. This may require ongoing study after the Work Programme to further define the risk severity. ▪ **Shipping interference.** Any continuous structure across an estuary interferes with shipping to some extent. SMEC does not generate electricity at high tide, so that a simple gateway rather than a two-gate lock may suffice. ▪ **Longer-term modifications to the wider marine environment** on the seawards side of the SMEC installation. It may be found that the SMEC has some residual impact on the coastal areas around the wider environment. The Work Programme should identify if this impact is, as may be supposed, much less marked than with a conventional barrage. ▪ **Sabotage potential.** This may well be comparable to other conventional barrage solutions for which SETS may hold existing projections. A comparison of mitigation and repair logistics may be worthwhile, to determine the extent of any device-specific discriminants. ▪ **Compatibility** issues of such a large power source with the National Grid. ▪ There are also a number of **potential commercial risks.** These include further changes in relevant commodity prices and ambient electricity wholesale prices. Also possible is a relaxation of Government Green Energy targets and incentives in the teeth of the current recession. Other commercial risks are Patent infringement problems of various types and the complexity of the regulatory regime that applies to grid connection of marine renewable energy.
Required Inputs	CTR 102 CTRs 300 - 304 CTRs 400 – 401
Outputs	Risk Evaluation Matrix Costed Risk Mitigation Report

APPENDIX 2

2. SETS Development Road Map Schedule


SMEC Technology Development Road Map
ID
Task Name
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
1 TECHNOLOGY OPTIMISATION
2 Hydrodynamic Performance
3 Venturi Pump Enhancement
4 Venturi Diffuser Optimisation
5 Orifice Shape Optimisation
6 Shallow Water Performance (Horizontal Venturi)
7 Free Surface Effects Testing
8 Performance Influence of Waves
9 Venturi Cavitation Avoidance
10 Secondary Performance Enhancement
11 Turbine Operations Programme
12 Secondary Flow Sedimentation & Flushing
13 Discontinuous Crossings
14 Marine Animal By Pass Design
15 Boating/Shipping By Pass Design
16 Partial Crossing Design
17
18 DEVICE EVOLUTION & DELIVERY
19 Site Location Requirements
20 JBA River Siting Study
21 Site Geophysical Survey Requirements
22 Site Geotechnical Survey Requirements
23 Sediment Transport Assessments
24 Extreme Conditions & Hazards Assessments
25 River/Tidal Basin Hydrological Studies
26 Device Sizing
27 Venturi Area Ratio Tapering
28 Secondary Circuit Area Design for Flow Velocity
29 Power Generation Maximisation Algorithm (Hi-Low Water)
30 Probabilistic Power Generation Forecast
31 SMEC PowerGen Software Design Suite
32 Structural Engineering
33 Design Certification Framework
34 Compostes or Alternative Material Evaluation
35 Site Metocean Condition Hindcasts
36 Venturi Vane Fluid Loading Design
37 Dynamic Column Harmonic Loading Analysis
38 3rd Party Accidental Impact
39 Dual Intake Cowling & Volute Design
40 Variable Pitch Turbine Rotor Design
41 Turbine Drive Shaft Design
42 Gearbox Reliability Enhancement
43 Generation Platform Deck
44 Generation Deck Wind Loading Analysis
45 Cable and Gangway Flexure
46 Foundations Engineering
47 Piled Foundations Design
48 Gravity-Based Foundations Design
49 Foundation Subsidence
50 Scouring Assessment & Prevention Design
51 Structural Stability Testing
52 Electrical Systems Engineering
53 National Grid Compliance Philosophy
54 DC to AC Conversion Location Optimisation
55 Power Cable Trunking and Offtake Routing
56 SCADA System
57 Master Control Station
58 ESD Procedures
59 Environmental Impact Assessments
60 Fish By Pass Programme
61 Fish Deterrent Validation
62 Boating / Shipping By Pass Programme
63 Valley or Basin Morphological Studies
64 Inter-Tidal Flora & Fauna Studies
65 Permitting Framework
66 Regional Economic Impact Assessments
67 Environmental Performance Statements
68 Construction
69 Supply Chain Pre-Qualification Development
70 Design Standardisation
71 Specification Portfolio
72 Fabrication & Transportation Plan
73 Seabed Preparation & Dredging Plan
74 Installation Execution Plan
75 System Tie-In & Commissioning Procedures


SMEC Technology Development Road Map
Task Name
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
Phased System Start-Up Plan
Operations
Operating & Control Philosophy
Inspection Plan
Risk-Based Maintenance & Repair
Decommissioning
COMMERCIALISATION
Strategic Investment Partner
Business Model Economic Evaluation
Financial Structure
Quantitative Risk Assessment
Asset Insurance Strategy
Shortlist Suitable Partners
Solicit Offers for Investment
Evaluate Offers and Recommend Partner
Selection of Strategic Investment Partner
Project Developments Summary - Key Risk Reduction
Advanced Testing & Modeling Programmes
Venturi Diffuser Programme
Turbine Operations Programme
Fish Deterrent and By Pass Programme
Shipping By Pass Programme
OMR Technologies Programme
Structural Stability Testing
Small Commercial Demonstrator
FEED
Detailed Design
Fabrication
Installation
Commissioning
First Power
Production Period
Decommission
0.5 MW River Installations (3 off)
FEED
Detailed Design
Fabrication
Installation
Commissioning
First Power
Production Period
5 MW River/Tidal Installations (2 off)
FEED
Detailed Design
Fabrication
Installation
Commissioning
First Power
Production Period
50 MW Tidal Installation
FEED
Detailed Design
Fabrication
Installation
Commissioning
First Power
Production Period
Technical Readiness Levels (TRL)
TRL 5 - Component Validation in Relevant Environment
TRL 6 - Critical Subsystem Testing at Large Scale
TRL 7 - Full Scale Prototype
TRL 8 - Extended Commercial Demonstration
TRL 9 - Field Proven for Production
SEVERN PROJECT SCHEDULE
FEED
Detailed Design
Final Approval for Expenditure
Fabrication
Installation
Commissioning
First Power (Phased Commissioning)
Full Capacity

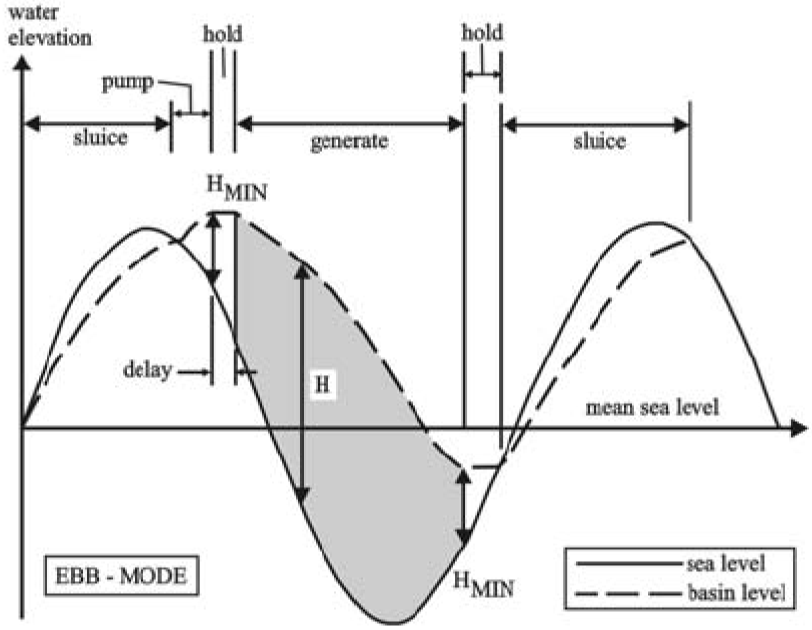
APPENDIX 3

3. How does SMEC compare to a Barrage?

How does SMEC compare to a Barrage?

Barrage Performance

The literature describes three main ways of operating a conventional Barrage, namely on the Ebb, on the Flow, or in Dual Mode. It is also apparent from the literature that the total power generated under each mode is similar. It is believed that the proposed Barrage across the Severn Estuary is recommended to work in Ebb Flow mode. Characteristically, the operating cycle is as shown below.



A simplified description of this operating mode is as follows:

During the first quarter-cycle of the tide, starting with mean sea level on both sides of the barrage, a volume of water V flows through open sluices in the barrage from the estuary into the basin on the landward side of the barrage until high tide is reached, after which no more water flows naturally into the basin and the sluices are closed, trapping the volume V in the basin. There is then a pause for **part of the second quarter-cycle** until the water level in the estuary falls to give a head drop sufficient to power turbines.

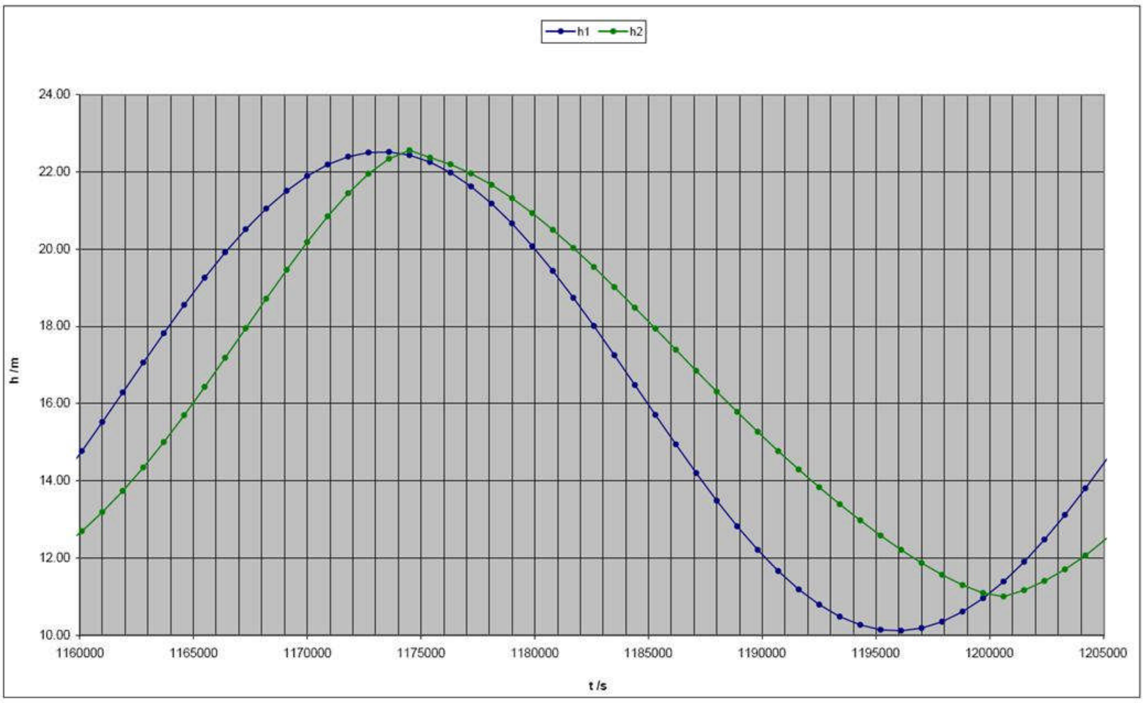
During the rest of the second, all of the third and part of the last quarter-cycles of the tide, this volume V of water flows back out again through turbines, generating electricity. Power generation stops when the height of the incoming tide in the estuary approaches the height of the falling water level in the basin and the turbines stop working. There is then a pause for **the rest of the last quarter-cycle** until the rising water level in the estuary and the falling water level in the basin both reach mean sea level and the sluices can be opened again.

Ignoring the efficiency of the turbine generators for the moment, the energy produced per square metre over that complete tidal cycle will therefore be a multiple of $\mathbf{V*H_b}$ where $\mathbf{H_b}$ is the average head difference across the Barrage. The average head difference $\mathbf{H_b}$ at Spring tide on the Severn Estuary is around 6m so it can be said that:

Energy during one tidal cycle from a Barrage is a multiple of 6V

SMEC Performance

A very simplistic first estimate of the maximum possible power from a SMEC can be gained in the same way from looking at a complete Springs tidal cycle:



A simplified description of this operating mode is as follows:

During the first quarter-cycle of the tide a volume of water V flows through the SMEC from the estuary into the basin on the landward side of the SMEC until high tide is reached. The average head difference is H_S.

During the second quarter-cycle of the tide the volume of water V flows back through the SMEC from the basin into the estuary again with an average head difference a little less than H_S, until mean sea level is reached.

During the third quarter-cycle of the tide a further volume of water V flows back through the SMEC from the basin into the estuary (assuming the estuary has a rectangular cross-section) with an average head difference a little more than H_s, until low water is reached.

During the fourth quarter-cycle of the tide a volume of water V flows through the SMEC from the estuary into the basin as the water level rises back up to mean sea level. The average head difference is $\mathbf{H_s}$.

Ignoring the efficiency of the turbine generators and of the SMEC venturi pump for the moment, the energy produced per square metre over that complete tidal cycle will therefore be a multiple of $\mathbf{4V*H_s}$ where $\mathbf{H_s}$ is the average head difference across the SMEC. The average head difference $\mathbf{H_s}$ at Spring tide on the Severn Estuary is around 2.5m as can be seen so it can be said that the first-cut estimate of energy during one tidal cycle from a SMEC is 10V

So at first sight, SMEC has the potential to output 66% more power than a Barrage. This ignores the energy losses inherent in the Venturi Pump, however which is significant. This "first cut" estimate, although non-conservative, does make the point that a SMEC creates power from the water moving up and down the estuary on all four quadrants of the tidal cycle rather than simply from the water moving up the estuary during the first quadrant.

To account for the inefficiencies ignored in this initial comparison, it is necessary to look at the effect of the Venturi Pump whereby the primary flow between the bars of the SMEC sucks a secondary flow through the turbines at an amplified head drop.

A very simplified characterisation of the massively complicated simulation of this process presented in the relevant detailed VerdErg documentation is that only 15% to 20% of the flow goes through the turbines but that at Springs, the average head drop of that secondary flow across the turbines is around 5-8 metres, an head amplification of 2-3 times. This head drop is similar to that found in the Barrage and so a fair comparison can be made without factoring the turbine efficiencies.

So the first cut estimate of the SMEC energy output during one tidal cycle can be refined by applying these two range factors of 2-3 and 0.15-0.2 to the first-cut estimate which now becomes an estimate range of 10V*0.15*2 = 3V to 10V*0.2*3 = 6V, which averages 4.5V. It can now therefore be said that as an improved estimate:

Energy during one tidal cycle from a SMEC is around 4.5V

The conclusion therefore is that at the current early state of venturi pump design refinement, a **SMEC will produce around 75%** of the power from an equivalent Barrage. For a Barrage averaging 1.8 GW output, an equivalent SMEC would therefore be expected to produce around 1.35GW,

The cost of a Barrage compared to the cost of a SMEC

There are numerous physical differences between a Barrage and a SMEC. The main difference is that the maximum overturning force that a SMEC has to withstand is a head of around 2.5m whereas a Barrage will be designed to hold back the full tidal range of around 10m. The resulting CAPEX reduction will be very substantial and should exceed 40%.

It is also believed that by designing SMEC to use simple traditional axial flow turbines rather than more complex bulb turbines, a substantial saving in unit costs will be made.

The net result is that in general terms, the comparison between a SMEC and a barrage should be **"two thirds of the power for half of the cost"**.

Further substantial cost benefits are seen where differential environmental impact is monetised. A SMEC permanently inundates a calculated 9% of the upstream basin wetlands, whereas the literature suggests that a Barrage inundates 75%. The preservation of the basin tidal cycle behind a SMEC also suggests that the impact on sedimentation patterns will be minor. It may also be noted that the concentrated turbine outflow from a Barrage has an environmental damage potential completely absent with a SMEC where the outflow is distributed uniformly back over the full estuary flow.

APPENDIX 4

4. Table of Comparative Construction Costs

GENERATING PLANT

Turbine and generators costs	5.5	£m/12.5 MW turbines (installed)

CAISSON/SMEC UNIT COSTS

Reinforced Concrete construction costs	600	£/m3 concrete
Ballast Concrete	110	£/m3 concrete
Steel Orifice and sealing Plates	3000	£/m3 steel

HABITAT COMPENSATION

Rate per hectare of inter-tidal loss	65000	£/ha

TABLE OF CONSTRUCTION COSTS

Option Name	Cardiff-Weston Barrage	Cardiff-Weston SMEC	Aberthaw-Minehead SMEC
Number of 12.5MW turbines	-	600	900
Reinforced Concrete Volume of Caisson/SMEC units (m3)	3,196,730	1,871,181	2,888,712
Ballast concrete (m3)		468,000	632,000
Steel sealing plates		824	1,235
Steel plate for orifices (m3)		12,748	20,684
PRE-CONSTRUCTION	209,225,373	108,703,922	159,552,080
CONSTRUCTION			
Preliminaries & site overheads	1,035,722,544	412,688,909	646,813,323
GENERAL CIVILS			
Embankments	505,365,908	505,365,908	288,780,519
Other civils			
Navigation Locks	1,001,840,886	1,001,840,886	1,001,840,886
Surface Buildings	83,100,000	83,100,000	83,100,000
TOTAL GENERAL CIVILS	1,590,306,794	1,590,306,794	1,373,721,405
CAISSONS/SMEC UNITS			
Casting Yards	96,000,000	96,000,000	148,203,916
Dredging costs	562,000,000	132,386,160	126,360,000
Installation	475,510,167	475,510,167	734,088,218

Ballast Concrete	included	51,480,000	69,520,000
Steel sealing plates	0	2,472,000	3,705,000
Fit Out Works	313,000,000	313,000,000	483,206,518
Construction of Caissons/SMEC Units	3,868,000,000	1,160,952,600	2,938,367,418
TOTAL	5,314,510,167	2,231,800,927	4,503,451,070
M & E			
Generating Plant	5,841,000,000	3,300,000,000	4,950,000,000
Grid Connection	500,000,000	605,000,000	635,000,000
Gates	1,160,000,000	0	0
TOTAL M&E	7,501,000,000	3,905,000,000	5,585,000,000
ADDITIONAL ITEMS			
Design and supervision	271,489,685	89,137,752	115,632,015
Site Investigation	3,975,767	3,975,767	3,434,304
Ancillaries	300,000,000	300,000,000	300,000,000
Contingencies	1,209,722,544	573,316,158	881,575,871
Contractors Oncosts and Profit	745,995,569	353,544,964	543,638,454
TOTAL ADDITIONAL ITEMS	2,531,183,565	1,319,974,641	1,844,280,644
TOTAL CONSTRUCTION COSTS	17,972,723,070	9,459,771,271	13,953,266,442
COMPENSATORY HABITATS			
Loss of intertidal areas (ha)	20,000	1,775	1,715
Cost of compensatory habitats @2:1	2,600,000,000	230,750,000	222,950,000
PROMOTIONAL COSTS			
Client Project Management Costs	89,863,615	47,298,856	69,766,332
TOTAL PROJECT COST	**18,271,812,059**	**9,846,524,050**	**14,405,534,854**

Record of Amendment

COMMENT FROM	DATE	REFERENCE	NOTES
P Downey	25 Feb 2010	Rev 2	Appendix 2,3,4 added
P. Roberts	01 Mar 2010	Rev 3	Appendix 2 updated.

2	Re-Issued to SETS Board				
	P.M. Roberts	P. Downey		R. Martins	26 Feb 10
	Issued to SETS Board				
1	P.M. Roberts	P. Downey	-	-	29 Jan 10
REV	PREPARED BY	CHECKED BY	QA REVIEW	APPROVED BY	DATE