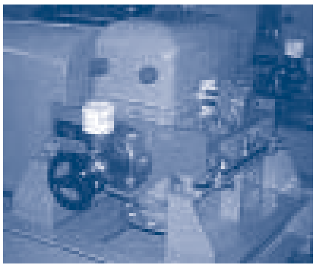
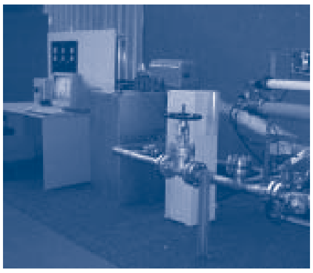
RENEWABLE ENERGY HOLDINGS PLC

TECHNICAL APPRAISAL OF THE "CETO" WAVE POWER GENERATION DEVICES





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PB 100 YEARS ®

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CONTENTS

EXECUTIVE SUMMARY

PB Power (PBP) was commissioned by Renewable Energy Holdings PLC (REH) to provide a “competent person’s report” on the present CETO I wave power device prototype tests and future design of a further step in the development of a commercial system, CETO II. The CETO devices have been developed by Seapower Pacific PTY Ltd (SPPL), with recent involvement of REH in Western Australia. This report presents the findings from the review of the project, and forms a preliminary view on the robustness of the concept.

The information for this review has been provided by SPPL based upon initial questioning aimed at understanding both the performance of CETO I and the nature of CETO II. PBP carried out a visit to the CETO testing site near Fremantle in order to meet the SPPL team and review the on-shore facilities and equipment. After further review, a meeting in Newcastle, UK with the device’s inventor Alan Burns and Mike Proffitt of REH was held to clarify the operating principles. This was followed up by a telephone conference between PBP staff in the UK and SPPL staff in Australia.

PBP understand that lessons learned in the development and testing of CETO I have been used to inform the design of CETO II, which is a smaller scale version of the commercially envisaged CETO III. It is intended as a next step to deploy CETO II at the same test site in Fremantle where CETO I was deployed.

This report is an abridged version of the full report that was issued in December 2006. Commercially sensitive information, and some design detail, has been removed to produce this report.

PRINCIPLE OF OPERATION

It is understood that the original idea behind CETO was to harvest a proportion of the high density of energy from waves with a low cost mass produced device, while also simplifying the associated infrastructure by pumping pressurised sea water ashore, rather than electricity. This has the additional benefit of allowing onshore based desalination depending on the deployment area. It is therefore apparent that, considering differing geographic availability of wave energy resource and demands for electrical energy or potable water, the system may be tailored for best use of the resource considering local needs.

It is understood that CETO III will be the commercial sized device (approximately 6 times the size of CETO II devices). The intention of SPPL/REH to fabricate the commercial sized units in commercially competitive regions such as China is a logical step to minimise the capital costs of projects.

CETO OBJECTIVES AND TARGETS

SPPL’s stated objective for CETO I was to achieve sustained high pressure and flow of sea water ashore. Although PBP is not aware of specific targets relative to the energy recovery devices included in the test rig (reverse osmosis plant and Pelton water turbine) it is apparent that the tests were successful in proving this objective and therefore the operation of the desalination. The principle of a commercial CETO device would require a number of pump units (CETO I only comprised 2 pump units operated by a single actuation mechanism) to derive electrical power and/or water. Therefore this test proved that the CETO system can derive energy from the waves using pumped high pressure sea water.

CETO device deployment is suitable for those regions where a high energy wave environment coincides with a need for electricity and / or potable water. Such areas where there is a scarcity of water and a promising wave energy resource include the West coast of the Americas, Southern Africa and Western Australia. Other countries with high wave energy potential and reasonable water supplies would lend themselves simply to generation of electricity eg Northern Europe.

In terms of testing a full scale CETO II there are established marine energy test centres such as WaveHub, Emec etc which should be included in the future review of possible sites pending a successful outcome from CETO II tests. SPPL consider that a good commercial project test site may be in Northern Ireland, where there is economic support available for renewable energy projects in terms of the NIROC, combined with a good wave energy resource.

FINANCIAL MODELLING

A cash flow operational model has been prepared to enable the analysis of the CETO wave energy plant and is based on discounted cash flow techniques that are widely used and accepted within the investment community for the assessment of power generation and desalination projects globally.

The assumptions used in this assessment are based on those provided by SPPL for the scaled up CETO III commercial design. The basis of these assumptions is that the targeted manufacturing cost reductions and scalability is achievable and that the overall nature of the device operation, efficiency and reliability is proven over an extended period by the CETO II pre-production device.

Sensitivities were calculated to understand the range of likely outcomes from the project assuming a +/-30 % tolerance on the capital and operation and maintenance cost estimates provided by SPPL. These are summarised below.

RANGE OF REQUIRED ELECTRICITY PRICES (PRE-TAX VIABILITY)

Pre tax	Base	O&M +30%	O&M -30%
Base	£53/MWh	£63/MWh	£44/MWh
Capital +30%	£57/MWh	£67/MWh	£48/MWh
Capital -30%	£50/MWh	£60/MWh	£41/MWh

RANGE OF REQUIRED ELECTRICITY PRICES (POST-TAX VIABILITY)

Pre tax	Base	O&M +30%	O&M -30%
Base	£60/MWh	£70/MWh	£51/MWh
Capital +30%	£64/MWh	£74/MWh	£63/MWh
Capital -30%	£57/MWh	£67/MWh	£48/MWh

The highlighted cells represent PBP's best estimate of the likely outcome of price for the CETO III project at this stage in the development process. The CETO II unit is yet to start its trial and, until this is complete, PBP would expect the maintenance costs to bias towards the upper bound with the capital costs remaining around the base case.

OBSERVATIONS ON FINANCIAL MODEL OUTPUTS

Recent studies into the evolution of the wave power generation sector indicated that the lower expectation for wave energy capture devices at present is 12 p/kWh. The main drivers for the differential between the CETO III expectations of 7 p/kWh and this range is the marginally lower discount factor used in the assessment and the lower specific capital cost of the CETO device (£1500/kW versus £4000 kW). Even with this price advantage, the CETO device will require financial support either through capital grants at the front end or through ongoing support as is available through the Renewable Obligation arrangements in the UK.

There are still uncertainties relating to the plant capital costs and the ongoing costs associated with maintenance and operation of the plant. These should be better understood following the completion of the CETO II development.

The CETO device has an implicit capacity factor of around 43 % on the basis of the data provided by SPPL. This is within the expectations for wave energy capture devices, albeit towards the upper end of expectation (45 %). This will vary from site to site with the wave conditions; however, one of the most significant factors in this will be the unit's reliability. This will be clearer once the CETO II project has completed.

CONCLUSIONS AND RECOMMENDATIONS

Generally it appears that the development of the CETO devices is following a logical progression and that experienced, competent and qualified staff are working on the project. Whilst no guarantee can be provided at this stage in the technology's development cycle, on the basis of the information made available to date, PBP believes there to be a reasonable chance of commercial success.

Clearly, the best way of managing the project and its risks is to test the project in a series of discrete steps to help ensure success at the next stage. SPPL has been following this principle with CETO I, design and testing of CETO II, CETO II prototype tests and subsequent plans for CETO III.

PBP's primary recommendations are made below. PBP considers that the management of risks is possible by management, through the project lifecycle, of these key items and any other issues that may arise. The presence of a particular recommendation is not to say that SPPL is not already aware of and/or actively managing many of the issues, rather to provide an aide memoir.

It is recommended that:

1. When CETO II is tested it is fully instrumented (eg with upstream and down stream Waverider buoys, stroke detection, pressure sensors etc) to allow a detailed comparison with the predicted results from CFD modelling. Observations on the equipment must also focus on reliability, to understand any potential failure mechanisms (eg fatigue) to inform the design of the commercial CETO III device. Comprehensive environmental surveys and monitoring should also be undertaken.

2. A short period at the end of design stage is included in the project timeline to allow for checking quality issues (eg cross referencing of part drawings, tolerances, materials etc).

3. Variables such as coastline profile, water depth at device, bathymetry, incident wave spectra and directional spreading are considered by SPPL in order that subsequent design of CETO III commercial devices may be successfully deployed in a range of global sites.

4. Consideration is given to the safety of divers and how the need for diver intervention may be minimised through design.

5. A detailed document defining the objectives, success factors and the measurement methodology for the CETO II testing is produced by SPPL in advance of its manufacture and deployment. This will help ensure the maximum benefit is achieved from the tests and help provide confidence in the evolution of the design. The key outputs must focus on reliability, energy conversion and installation and maintenance processes as well as review of costs.

6. In advance of the design for CETO II SPPL incorporates implicit reliability into the design. There are a number of options available to achieve this: redundancy, streamlined design (by reducing connection points and areas that are known to have frequent maintenance requirements), design for robustness, low utilization of mechanical strength (a higher resulting reserve or safety factor), environmental simulation testing of components subject to various environmental loads, use of well-proven components, Failure Mode and Effects Analysis study, control of manufacturing, fabrication and commissioning in such a way to reduce the incidence of failures induced by poor workmanship or human induced problems, etc.

7. For the CETO device consideration should be made of fatigue of components and piston rod; buckling of the piston rod; wear properties of the seals, pins and bearing surfaces involved; accumulation of debris, bacterial growth, and resulting increase in viscosity of the fluid; filter arrangements and filter quality mesh size and cleaning arrangements; heat generation and dissipation,

8. Fatigue life of the hydraulic piping will need to be considered. BS EN 13480 is a comprehensive standard for the design of industrial piping. Alternatively, ASME codes are also used in the hydraulic industry.

9. Avoidance of piston type accumulators with air as the compressible medium, as the increase in oxygen partial pressure with compression combined with potential catalytic action from debris accumulating over time can lead to auto-ignition and explosion of the accumulator.

10. The design of any handling equipment and vessels for deployment should be considered to ensure safety and economy.

11. Due consideration must be made of the effects of seawater on the water turbine unit.

12. The control and monitoring requirements for the device should be summarized describing the objectives and attributes of the control system

13. Special attention be given to effects on monitoring and control systems from the following - vibration (wave slamming, sloshing of tank contents, local structural vibration, impact, excitation from hydraulic, pneumatic and mechanical systems etc); temperature, humidity, salinity, electromagnetic interference, atmospheric pressure (may fluctuate in sealed compartments), and assumptions on quality and variability of, hydraulic, pneumatic, fibre optic devices and power supplies.

14. An additional Waverider buoy is installed during CETO II, ensuring that there are buoys located both in front of, and behind, the array.

15. SPPL, as an organisation, should consider the operational management requirements for a commercialisation.

16. Further consideration should be given to production engineering of CETO III when appropriate.

17. A systematic approach to documentation throughout the operation of the device's life be ensured as the level of documentation is an important step in order to obtain the recognition from financiers and underwriters that the risks (including those affecting performance and production) have been identified and were controlled to the defined risk levels and have been appropriately mitigated through design or operational constraints.

18. Procedures for maintenance, inspection and repair should be developed at an early design stage. Consideration should be given to access to areas to be inspected and the extent, frequency and choice of inspection methods.

19. In developing future project costs a detailed maintenance strategy is developed. This should incorporate planned and unplanned maintenance, spares to be stocked, and maintenance staff and equipment requirements. SPPL suggest that, for larger array installations a trained dive team and workboat would form the core maintenance team. Although the majority of subsea components are bespoke, consideration could be given to undertaking a reliability assessment to estimate the failure rate of specific components when developing the maintenance strategy.

20. A spare parts philosophy be defined taking into account the time from ordering to the availability of replacement parts, criticality of part (regarding survivability and functional requirements), maintenance requirements and costs of stock, preservation and storage of spare parts. A list of spare parts should be produced and included in the maintenance plan.

1. INTRODUCTION

1.1 Background and Objectives

PB Power (PBP) was commissioned by Renewable Energy Holdings PLC (REH) to provide a "competent person's report" on the present CETO I wave power device prototype tests and future design of a further step in the development of a commercial system, CETO II. The CETO devices have been developed by Seapower Pacific PTY Ltd (SPPL), with recent involvement of REH in Western Australia. This report presents the findings from the review of the project, and forms a preliminary view on the robustness of the concept.

The information for this review has been gathered by first collecting written information from SPPL from an initial list of questions aimed at understanding both the performance of CETO I and the nature of CETO II. There was a visit to the CETO testing site near Fremantle by PBP staff based in Australia to meet staff involved and clarify some information. After further review there were follow up questions, a meeting in Newcastle (UK) with the device's inventor Alan Burns and Mike Proffitt of REH to better understand the operating principles, followed up with a telephone conference between PBP staff in the UK and SPPL staff in Australia.

Information provided by SPPL has generally been presented to a high standard and has been used in part within this report.

Lessons learned in the development and testing of CETO I have been used to inform the design of CETO II, which is a smaller scale version of the commercially envisaged CETO III. It is intended as a next step to deploy CETO II at the same test site where CETO I was deployed.

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1.2 The Authors

As useful background for the reader short biographies of the key team members for the production of this report are presented below:

Mark Denny MEng, MBA, CEng, FIMechE

Mark is the project manager for this assignment and as well as managing PBP's wind power and renewable group in Newcastle has relevant previous hydropower experience. Mark brings his qualifications as a mechanical engineer and business administrator to add technical input, business knowledge and direction to the work of the team.

Chris Lomax BSc, MSc CGeol FGS

Chris is a marine renewables specialist and brings extensive experience to this assignment from his previous involvement as the project manager of the 'Stingray' tidal stream project at the Engineering Business based in Northumberland. Prior to this he was a Director of a marine geotechnical consultancy specialising in marine foundations and the routeing, installation and protection of subsea pipelines and cables.

This experience allows him an excellent insight into bringing a marine energy device from inventor's concept through the process of development to deployment for a full scale test. This includes the technical and environmental aspects as well as commercial issues related to funding and grants.

Dominic Cook, BEng, MSc, BTec, CEng, MIET, ACMI

Dominic is a specialist on the costs of generation. Dominic brings an overview of the commercial situation for renewables within the context of different markets. Dominic is presently a Principal Consultant within the Energy and Utilities Consulting Division of PBP with 14 years energy industry experience and 5 years involvement in international energy consulting. He has had direct involvement in business and consulting activities in the UK, European, CIS, African and Middle Eastern energy markets encompassing power generation development, energy supply contracts, distribution and transmission and regulatory matters.

With a solid understanding of both bilateral and pool based electricity market structures having been involved in the development of power projects, electricity trading systems and business processes within both environments, he has provided professional advice to major lending institutions on the structure and risk associated with long-term electricity sales and gas off-take agreements and third party trading arrangements and routes to market for electricity supply.

Thomas McKay, BEng (Hons), MIET, AMIMechE

Tom is an Energy Economist who is predominantly responsible for technical, economic and financial appraisals of low and zero carbon energy developments. His engineering experience extends to the design, review and analysis of various renewable power projects. Tom has a broad knowledge and understanding of differing types of generation technology, project and client. Tom has worked as an Energy Planner on numerous sustainable energy developments both in the UK and overseas and has participated and led on a wide range of power projects, including: feasibility studies, due diligence, market studies, technical advisory services and economic and financial appraisals.

Other staff within PBP have contributed to specific issues, such as environmental issues, computational fluid dynamics etc.

1.3 The Project Team

It is important to consider the competence of the REH/SPPL team in considering the possibilities for success of the CETO project. Short biographies of key team members are presented below:

Alan Burns – Chairman SPPL, Director REH

Alan is Chairman of SPPL and Technical Director of REH (since 11 February 2005). Alan is the inventor of the CETO Device, which SPPL operates and is owned by UK AIM listed company REH. This was initially developed by Alan privately before ASX listed Carnegie Corporation and Pacific

Hydro joined as co-developers/investors during the Research and Development phase of CETO. Alan has won a number of international awards for commercial engineering inventions and has successfully commercialised a number of inventions including the Pursuit Marine Drive (now owned by Pursuit Dynamics Plc) and Crocodile Tyres.

In addition to his technology activities, Alan has been actively involved in the natural resources industry in Australia and worldwide for over thirty years. In this period he has participated in the exploration and development of oil and gas fields, both onshore and offshore, and gold and diamond mines in Australia. Alan is a Board member and Chairman of Carnegie Corporation Ltd since 28 April 1993 and a Director of Westralian Gas and Power Ltd (since 18 September 2004). He has recently retired as Chairman of Hardman Resources Limited and was formerly a Director of Global Petroleum Ltd (from 14 October 2001 to 2 July 2003).

Dr Michael Ottaviano BEng, MSc, DBA

Dr Ottaviano is the Managing Director of SPPL. He is primarily responsible for commercialisation of the CETO technology and oversees all commercial and technical aspects including operations, engineering and design, intellectual property and finance administration.

Prior to joining SPPL, he was a Senior Manager specialising in Technology and Innovation consulting at a global accounting and advisory firm. He has advised companies on new product development, intellectual property, innovation portfolio management and technology commercialisation across various industries and ranging from start-ups to ASX-listed companies with market capitalisations in excess of $1billion. He previously worked in research and development and was a divisional manager for a private Australian engineering company.

He completed his Master's of Science in Germany and his Doctorate in Business Administration in Melbourne in the field of Corporate Entrepreneurship and Innovation. Dr Ottaviano is also CEO of ASX-listed Carnegie Corporation Ltd where he oversees the commercialisation of clean energy technologies.

Patrick Gillen - Operations Manager

Patrick joined SPPL in August 2006 in the role of Operations Manager, assuming responsibility for SPPL project activities including project management, contract management, project procurement, operations and maintenance. Current activities include decommissioning and removal of the CETO I unit, the procurement, fabrication, deployment , and O&M of the CETO II project, and front end planning for the CETO III activities.

Patrick has more than 20 years experience in the industrial and municipal water treatment and desalination industry and brings to SPPL a valuable mix of 'hands - on' project related experience in general management, commercial, technical, project management and project execution roles.

Industrial project experience includes supply, installation and commissioning, and O&M of water treatment equipment projects for power generation, mining, offshore oil and gas facilities, with many of these projects in remote or demanding locations. Municipal projects have included potable water and wastewater reuse applying membrane technologies including MF, UF and SWRO.

Over this period Patrick was employed by Permutit Company, Memtec Limited, Memcor, US Filter, Vivendi, Veolia Environment, Ionics Incorporated and GE Infrastructure Water and Process Technologies.

Matt Keys, BEng (Civil), Computational Fluid Dynamics/Structural Analyst

Matt has a total of eight years engineering experience of which the majority has been spent in the Offshore Industry, the remainder working in the commercial and mining areas.

Matt's expertise in the Offshore Industry is primarily in the use of advanced analysis techniques applied to the solution of fluid and structural problems. The majority of analysis work has used Computational Fluid Dynamics (CFD) software, primarily FLUENT®, to optimise the performance of offshore process equipment, blast, heat transfer, VIV and dispersion analysis. Experience has also been gained in conceptual and detailed structural analysis of topside modules and decks in addition to steel jackets. Matt's experience in the commercial and mining sectors included both civil and structural projects. These projects included analysis of fluid flows for waste water and groundwater treatment plants, design of steel, timber and concrete structures, bridge design and inspections, major storm water design for road networks and rural areas.

At SPPL Matt is the Lead CFD Engineer using the FLUENT® suite of CFD software to simulate and optimise the CETO technology. The CFD analysis involves setting up a virtual 3D ocean in which it is possible to place multiple prototypes. Then through the dynamic mesh capabilities and numerous User Defined Functions that have been added into FLUENT® it is possible to simulate the movement of the CETO II device as well as calculate any forces and pumping actions that are generated as a result. Current developments include incorporating Fluid-Structure Interaction (FSI) through self developed UDFs to get a full picture of CETO II movement and forces.

Laurence D Mann PhD

Laurie has a wealth of experience in Australia and Silicon Valley, USA, as a manager of, and active participant in, basic research, high technology product development, technical marketing, intellectual property development, and R&D. He has worked in academia (Stanford University), industry (NASA and US Government sponsored projects), research and consulting environments in Australia and the USA and has a well-developed instinct for research and development coupled with a high level of strategic thinking and problem solving ability. His core competencies are in the areas of intellectual property development and the application of physics-based problem solving to a wide range of practical technology developments in mechanical, thermal, electrical and electronic engineering.

Laurie was previously head of Electronic Engineering at AIM-listed firm CustomVis plc whose R&D base is in Perth, WA. CustomVis is a TGA and CE mark company that develops and manufactures custom laser eye surgery equipment for the world market. Prior to that Laurie was Senior Research Scientist at SPPL where he worked on the creation of the patent applications necessary to protect the intellectual property developed by Alan Burns. It is in this role that Laurie returned to SPPL in August 2006.

Laurie is involved in the translation and refinement of the ideas, as well as researching the entire prior art, and in creating draft specifications for SPPL's patent attorneys. He is also responsible for maintaining the patent portfolio and dealing with the necessary progression of patent applications to world wide and national phase applications and for the creation of due diligence documentation based around the intellectual property.

Mr Petru (Peter) Tinc, B Mech E, GradTIEAust

Peter is the Chief Design Engineer for SPPL. He is responsible for taking ideas from concept sketch to proof of concept and prototype commissioning. Peter has over twenty years' experience as a design engineer in a wide variety of environments including R&D for automotive, aircraft, marine, electronics and heavy engineering/manufacturing, from which over ten years' experience in computer aided design and drafting, (CADD), CNC programming and specialist design techniques within the automotive and aviation industries.

Peter also has particular experience in the offshore oil industry fabrication and design sector being a senior designer at Coflexip Stena Offshore Perth involved in the production of flexible oil lines for subsea oil completions worldwide.

Mike Parfitt PNIA, Dip CM

Mike has over 37 years experience in Engineering and Finance sectors of industry. He commenced his career with HM Dockyard - Chatham, Kent, UK working on a number of naval projects and has spent a combined service period of 11 years working for British Gas and the Water Authority in the UK, primarily in the Distribution and Technical Services departments. Mike also spent some time working for a privately owned company that specialised in the development and manufacture of Gas Turbine Engines. Since emigrating to Australia in 1987, Mike has worked in the following industry sectors: Mining, shipping, research and development, rubber manufacture and, more recently, renewable energy.

Mike is responsible for the financial and accounting functions of the company, including development of policy and plans. Mike also oversees the company secretarial and administration functions to ensure the company conforms to statutory and legal regulations concerning corporate activities.

1.4 The CETO Principle

It is understood that the original idea behind CETO was to harvest a proportion of the high density of energy from waves with a low cost mass produced device, while also simplifying the associated infrastructure by pumping pressurised sea water ashore, rather than electricity. This has the additional benefit of allowing onshore based desalination depending on the deployment area. It is therefore apparent that considering differing geographic availability of wave energy resource and demands for electrical energy or potable water, the system may be tailored for best use of the resource considering local needs.

1.4.1 CETO I

CETO I is a seabed mounted device. It was designed to utilise water pressure from waves travelling overhead to move a large diaphragm in an immersed chamber. The diaphragm in turn drives a lever pivoted between 2 pumps, giving a pressure stroke in one of the pumps with the diaphragm either rising or falling. The pumps take sea water from outside the submersed chamber and feed it ashore via a pipe work system.

PBP understands that, in advance of deployment offshore, the principles of CETO I (diaphragm operation and pump design) were verified by SPPL in a laboratory. From a mechanical engineering point of view the CETO I pump design was very simple. It comprised a rubber sheathed piston (including high pressure seawater lubrication systems) moving in a chamber to draw sea water in through a non-return valve on the suction stroke and expel water through another non-return valve to the pressurise pipe work leading ashore on the pressure stroke.

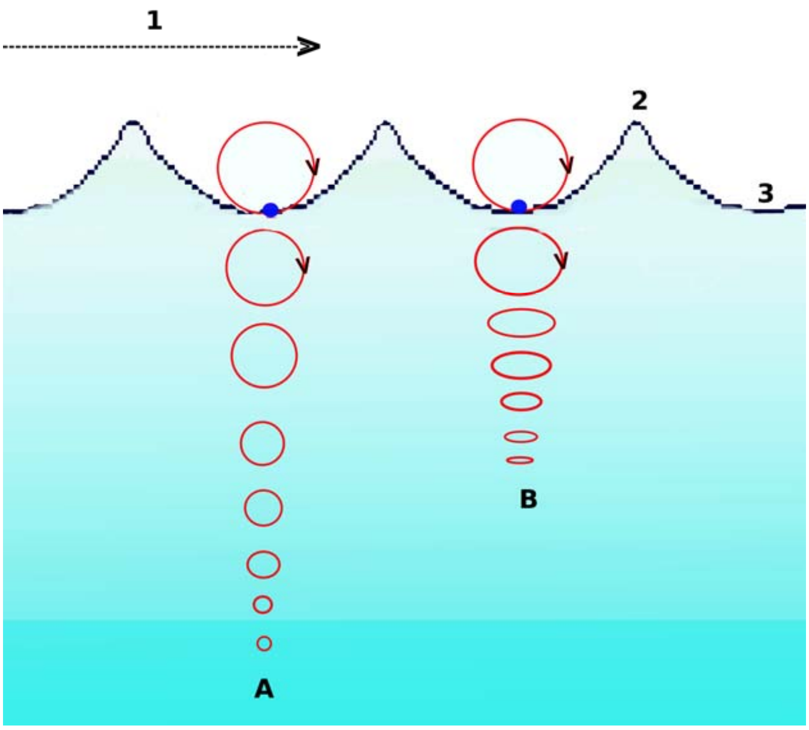
The testing of CETO I on the sea bed included connecting the pipework onshore to ‘off the shelf’ reverse osmosis type desalination and Pelton type water turbine generator units. The pump unit was instrumented, and measurements were taken of pressure, desalinated water and Pelton turbine rotational speed (never loaded). There was no measurement of instantaneous available energy at the device (eg by wave-rider buoy), rather the available energy was assessed from a nearby meteorological recording buoy.

It is believed that there was some storage of pressurised sea water upstream of the equipment to be driven. This storage may be an important consideration in a commercial system, considering not only the requirement to smooth the flow of water to a desalination unit(s), but also to allow for an optimum storage of ‘energy’ if, as seems likely, the off take plant is sized below the maximum delivery capacity of the pumping system as a whole. This is also linked to the ‘tunability’ of the pumps to achieve at, or near, maximum output in varying wave conditions. Assuming this storage is on the sea water side there is then in a system including desalination and power generation, a choice of which commodity to produce after a period of high energy inputs (electricity or water). This may also be planned with any potable water storage downstream if available on a system including desalination (ie to minimise seawater storage in advance to maximise capture of available energy).

The CETO I test verified that the original pumps and system were able to sustain a pressure such as to provide sufficient volume at that pressure to produce quantities of desalinated water over sustained periods. In any future commercial application it is reasonable to expect there would be an array of many devices.

1.4.2 CETO II

As with CETO I, CETO II is a seabed mounted device. However, it is fundamentally different in that it has a much reduced overall size and mass, reducing manufacturing costs. Rather than using the water column pressure CETO II uses a submerged buoyant spherical ‘actuator’ moving with the sub-surface water in a cyclical and elliptical manner, as shown in Figure 1.1 below.



A particle motion in an ocean wave.

A = At deep water.
B = At shallow water. The circular movement of a surface particle becomes elliptical with increasing depth

1 = Progression of wave
2 = Crest
3 =Trough

Figure 1.1 Circulation of water particles in a wave

This motion is used to pull the pump in one direction on the pressure stroke and allows the suction stroke to occur under gravity. Each 'actuator' operates a single pump. The pumps take sea water from a seabed mounted filter unit. Similar to CETO I high pressure water is collected from an array of pumps and fed ashore via a pipe work system for extraction of energy and/or potable water.

The pump design uses rubber as a sealing medium for the moving piston in CETO II, which was demonstrated to be a robust solution by the CETO I tests and subsequent bench testing of a CETO II type prototype pump.

This design also leads to a system of multiple anchor points (one for each device) in an array, with a flexibly piped collection system. It should also be noted that multiple devices mean that there must be check valves at various locations in the pipe systems to avoid large energy loss from a single failure. This appears to have been taken into account within the conceptual design.

Another implication, to be expected, of this multiple device approach confirmed by SPPL's modelling is that a maximum of 3 'rows' of devices should be placed in the wave direction as subsequent devices will see reduced energy reducing their efficiency to a significant degree. This has led to the adoption of a logical 3 x 3 cluster size, with multiple clusters then arranged to optimise harvesting the resource in any given site. The option also exists, if proven beneficial, to consider further rows for energy recovery in above average (storm type) conditions. Careful consideration need to be given to the economics in this respect.

1.4.3 CETO III

It is understood that CETO III will be the commercial sized device (approximately 6 times the size of CETO II devices). The intention of SPPL/REH to fabricate the commercial sized units in commercially competitive regions such as China is a logical step to minimise the capital costs of projects.

1.5 CETO Objectives and Targets

SPPL's stated objective for CETO I was to achieve sustained high pressure and flow of sea water ashore. Although PBP is not aware of specific targets relative to the energy recovery devices included in the test rig (reverse osmosis plant and Pelton water turbine), it is apparent that the tests were successful in proving the operation of the desalination. The principle of a commercial CETO device would require a number of pump units (CETO I only comprised 2 pump units operated by a single actuation mechanism) to derive electrical power and/or water. Therefore this test proved an amount of energy can be derived from the waves using pumped high pressure sea water. Even though the tests were not used to validate specific predictions, the results can be fed forward into future design work.

It is also clear that SPPL understand that the CETO I device was not likely to be a commercial device considering its relatively high cost due to the large structure, and that a low cost device is the longer term objective. Considering this, a CETO II device is proposed by SPPL as a scale test of the presently envisaged CETO III full size commercial device. This smaller scale test allows for a lower cost test in waters shallower than proposed for the commercial device.

It is recommended, as proposed by SPPL, that CETO II when tested is fully instrumented (eg with upstream and down stream wave rider buoys, stroke detection, pressure sensors etc) to allow a detailed comparison with the predicted results from CFD modelling. Observations on the equipment must also focus on reliability, to understand any potential failure mechanisms (eg fatigue) to inform the design of the commercial CETO III device.

A detailed document defining objectives and how they will be measured with success criteria for CETO II testing should be produced by SPPL in advance of manufacturing and deployment. This will help ensure the maximum benefit is achieved from the tests and help provide confidence in the evolution of the design. The key outputs must focus on reliability, energy conversion and installation and maintenance processes as well as review of costs. It is also important to keep other future CETO III sites in mind to try and assess solutions for different seabed conditions, wave regimes and environmental issues etc other than at the Fremantle site proposed for the CETO II tests.

1.6 Project Timeline

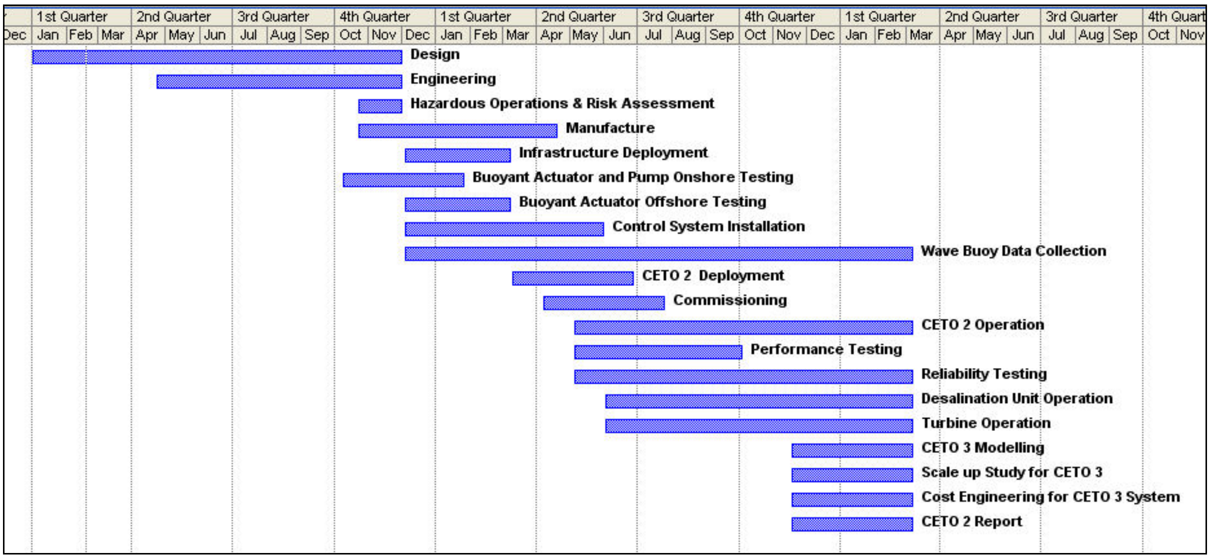


Figure 1.2 Project Schedule

The periods in the programme produced by SPPL seem generally feasible. As mentioned above care needs to be taken in planning appropriately prior to manufacture. As well as planning the tests this includes finalising the CETO II design, which seems to be undergoing final adjustments considering the phased delivery of drawings to PBP for information. It is recommended that a short period is included at the end of design to check quality issues (eg cross referencing of part drawings, tolerances, materials etc).

2. REVIEW OF CETO I

2.1 Overview

This Section reviews the design, performance and development of the CETO I device and is based upon communication with SPPL and the associated documentation provided, in addition to on-site surveys carried out in partnership with PBP engineers based in Western Australia.

SPPL has stated that the original objectives of the CETO I prototype design, deployment and testing were to:

1. demonstrate that seawater could be pressurised by their pumping mechanism and sent to shore above the threshold of 800 PSI required to allow seawater reverse osmosis (SWRO);

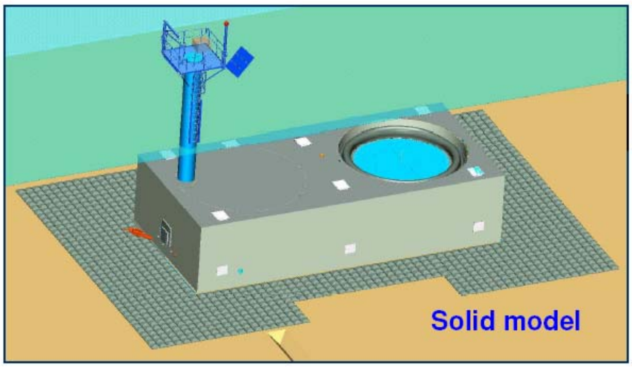
2. demonstrate that SWRO could be powered directly from the pressurised water stream to produce potable water from seawater using entirely renewable energy;

3. demonstrate that off-the-shelf energy recovery turbines could be used to generate electricity from the pressurised seawater stream; and

4. demonstrate within the limits of the technology available, that the mathematical modelling of the system behaviour was able to predict the energy output, by comparing input sea state with output energy.

Therefore, the test environment in which SPPL conceived CETO I to perform was one that solely provided a platform upon which SPPL could evaluate the operation and performance of its high-pressure pump. The primary design and evaluation criterion for CETO I, as stated by SPPL, is delivery of seawater at pressure onshore. In seeking to achieve this, SPPL enabled the subsequent evolution towards CETO II design objectives to proceed with an increased level of confidence in the core operational concept.

It is upon this basis that the CETO I prototype design incorporated a single flat-plate collector with a large collection area moving in one degree of freedom, suitably over-engineered, to ensure that available energy capture was accessible for suitable pump operation during the test period, shown in Figure 2.3 and Figure 2.4 below.



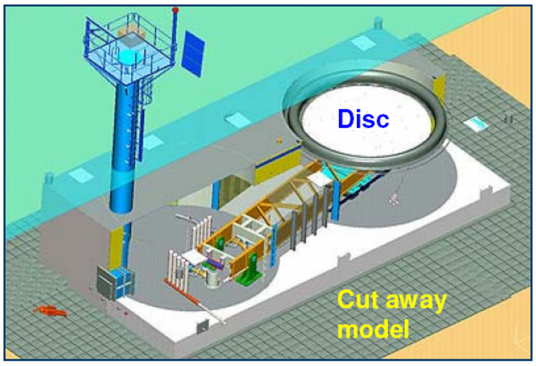


Figure 2.3 CETO I – solid model

Figure 2.4 CETO I – cut away model

The pump pressure is generated by the hydraulic action of the mass of moving water generated by the wave which converts the relatively low dynamic pressure captured over a large area to deliver a high pressure acting over the smaller area of the pump piston. The ratio of disc to piston area is greater than 1,000 and this, coupled with the leverage ratio in the arm, produces pressures of several MPa in the pumped fluid if the system performs as designed.

The rigid disc is attached to a long lever arm that amplifies the forces applied to the disc by wave motion and transfers these forces to custom-made pumps at the opposite end of the lever. The stroke lengths of these pumps are reduced to account for the lever action but the pressures that can be generated are similarly enhanced. Seawater filtered through sand filters is drawn into the pumps on the stroke as the arm moves in one direction and then this water is pressurised as the arm reverses direction. One way valves ensure that water does not pass back between high and low pressure regions and also that it enters the high pressure manifold at a predetermined pressure. The flow of high pressure seawater is returned to the onshore facility via a small diameter pipe where it is available for use in either the turbine or the RO desalination unit after suitable preparation, or simply as a stream of water whose energy content can be recorded by measuring flow rate and pressure.

Figure 2.5 Pelton turbine

Figure 2.6 Desalination equipment

It is critical, therefore, that investigation of the central tenets held by SPPL that determine the operation and performance relating to the high-pressure pump be made. Sections 2.2 – 2.5 discuss these further but may be summarised here as:

- reviewing the mathematical model employed by SPPL in order to determine forces acting on the piston and resultant outputs;
- examining the actual achieved outputs of the CETO I device during the testing period;
- comparing the results and assumptions against that which have been predicted;
- discussing the device performance and lessons learnt following operation in situ;
- reviewing the design, operation and performance of the pump mechanism and its evolution.

2.2 Model

Following deployment of the CETO I in the waters off Rous Head, two domains were constructed for representation of the Fremantle site using the latest in Computational Fluid Dynamics (CFD) techniques via the Finite Volume Method (FVM). These included variation of a number of parameters to enable design optimisation to be undertaken.

The wave environment at the site of any near shore wave energy converter is very much site specific, dependent upon the following variables:

- Coastline profile,
- Water depth at device,
- Bathymetry,

- Incident wave spectra and
- Directional spreading.

It is recommended that these variables be considered by SPPL in order that subsequent design of CETO III commercial devices may be successfully deployed in a range of global sites. In light of this, risk against failure of successful deployment may be mitigated by taking due consideration of the factors above.

Best practice in the assessment of the locally available resource ensures that the annual wave climate at the site of the device be derived from actual measurements. SPPL has utilised data collected from a nearby meteorological wave buoy a few kilometres out to sea. PBP understands that SPPL has transformed the data to site using a derived transfer function.

2.3 Results

During the period of operation the performance of CETO I was monitored via an array of sensors located upon the device. Figure 2.7 depicts the control panel of SPPL's monitoring software and indicates the location of the sensors used for data collection:

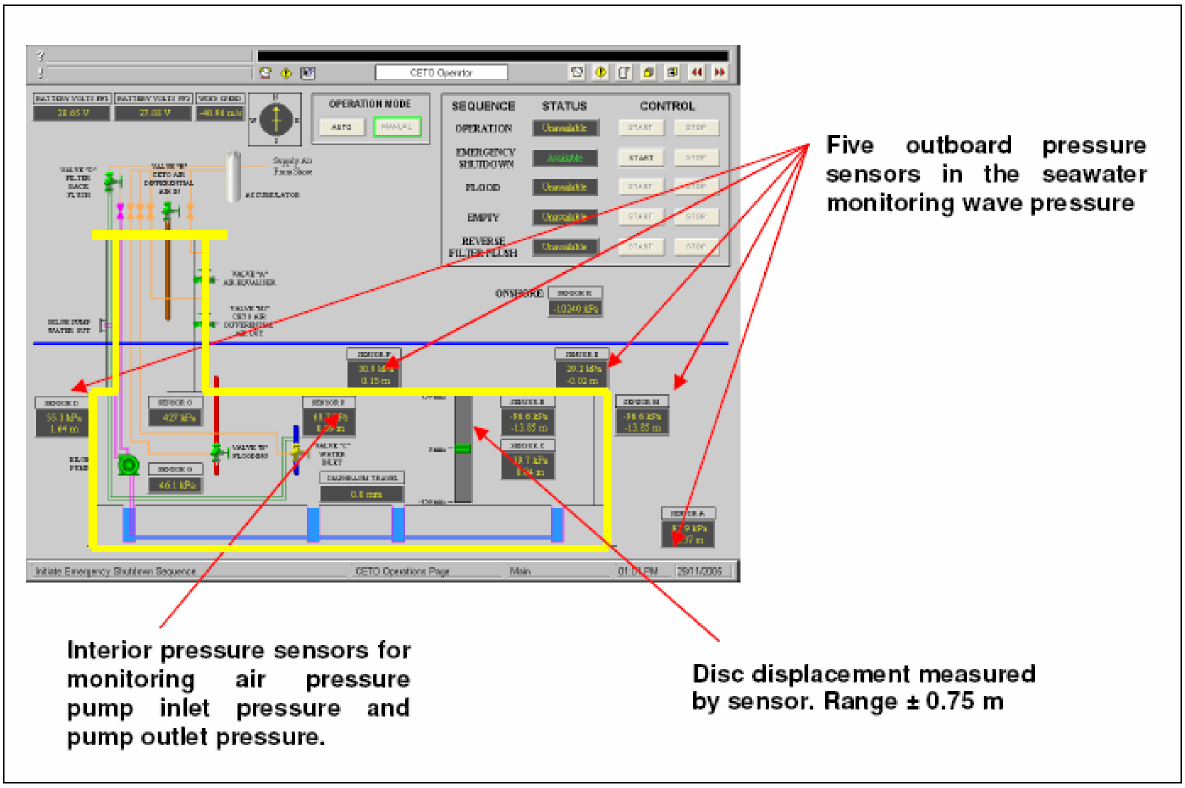


Figure 2.7 Control software

Available wave energy incident upon the diaphragm of CETO I was determined indirectly via monitoring of the wave pressure upon pressure sensors located at five points on the device.

SPPL has indicated that the data captured from the wave pressure data has been analysed and, at the time of writing this report, is being correlated with other system data. Analysis undertaken to date has focused on peak output pressure verification, desalinated water analysis and Pelton turbine performance. Nevertheless, SPPL has stated that key performance data has been verified in order to finalise impending CETO II design requirements.

Data capture of the performance of the device was made at the onshore facility at Rous Head during CETO I operation. The SPPL onshore facility is equipped with sufficient control and instrumentation equipment for the CETO I project.

The pipe outlet, located at the landing point close to the SPPL facility, could be fed into an accumulator for storage and monitoring. SPPL has indicated that pressures of around 6.4 MPa (64 bar/921 psi) could be obtained and sustained in the pressurised fluid flow onshore.

A typical data capture of a pressure run is shown below:

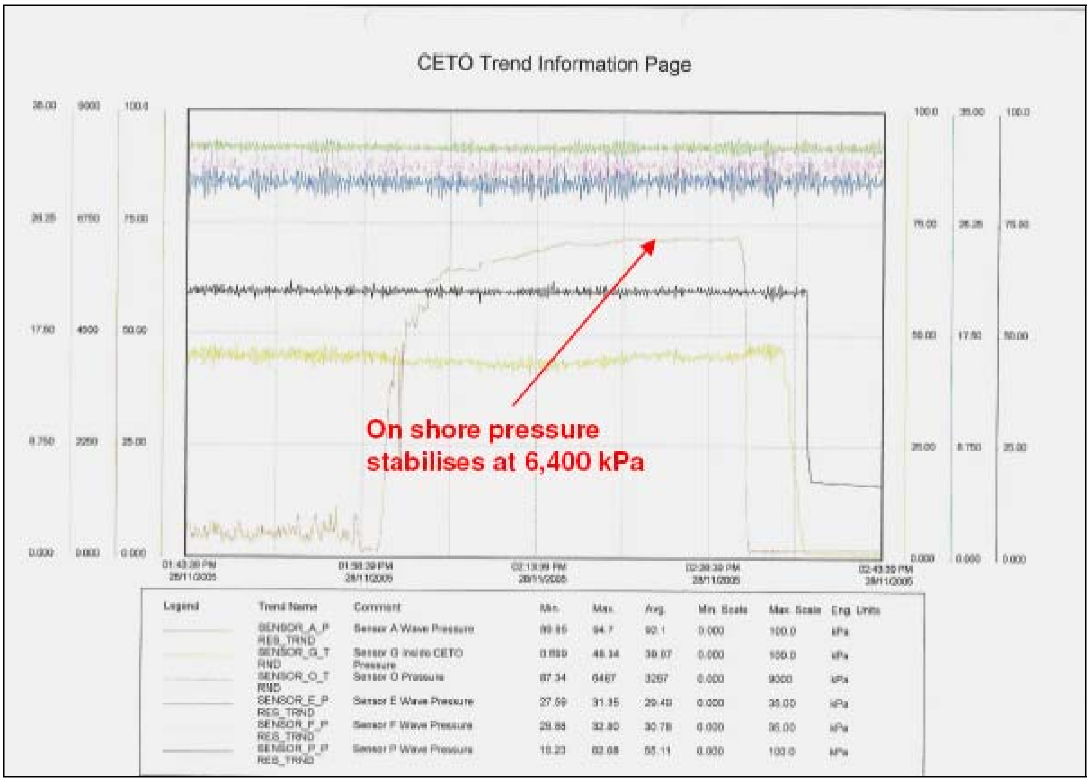


Figure 2.8 Data capture during throttling event

It is of note that SPPL has not indicated for what duration such performance was achieved. Nevertheless, this result is pivotal in that it demonstrated that CETO I could pressurise and send seawater to shore at pressures above the threshold of 800 psi required for seawater reverse osmosis with sufficient flow from multiple devices and underpins the feasibility of the whole CETO approach.

Figure 2.9 Delivery of pressurised seawater ashore

As a result of exceeding the required seawater pressure threshold, SPPL was then able to demonstrate that reverse osmosis desalination to produce potable water could be powered by the pressure generated by CETO I, and thus renewable energy, alone.

Figure 2.10 Desalination equipment

SPPL demonstrated that in addition to producing potable water, the pressurised stream of seawater could be passed through proprietary power generation equipment.

Figure 2.11 Pelton turbine

2.4 Areas of Necessary Improvement

The CETO II pump is a reciprocating positive displacement piston pump.

Mutual to the designs of CETO I through II and III is the central premise that the device can achieve an improved performance attainable from the effective operation of the high-pressure pumping mechanism. By replacing the conventional pump mechanism with one that is novel and has neither undergone a period of testing nor operation in situ, SPPL has increased the risk in the likelihood of success in subsequent stages of deployment.

Furthermore, it must be noted here that the evolution to the CETO II design (discussed further in Section 3) has departed from the original principle by which it converts the incident wave energy upon the actuator to provide the required force upon the piston shaft.

Development of a point buoyant actuator has replaced the single-flat plate collector design and associated infrastructure as shown in **Error! Reference source not found.** below.

SPPL has stated that the CETO II design concept entails stripping away the original housing of CETO I and allows the pump to stand at the seabed surrounded by seawater. The previous application of the large rigid plate of CETO I that captured the moving water mass is now replaced by a buoyant actuator.

The intended CETO II phase of project operations will include deployment and testing of an array of up to 9 of the CETO II units at the existing Rous Head location. Despite the major changes in design from CETO I to II the purpose of this secondary stage of testing will be to verify and debug a scale model of the proposed CETO III device in situ, and to further develop know-how for multiple unit arrays. The testing will also be used to calibrate and validate the CFD modelling, and confirm the scale up requirements for the CETO III unit and system design.

Therefore it can be determined that resolution of the above areas of necessary improvement has not compromised the design and development ideology. Identification of the areas of necessary improvement and subsequent modification and evolution develop upon the original objectives of CETO I design and operation – to demonstrate that seawater can be pressurised and sent to shore above the threshold of 800 PSI required to allow SWRO, powered directly from the pressurised water stream to produce potable water from seawater using entirely renewable energy using off-the-shelf energy recovery turbines economically and reliably.

3. REVIEW OF CETO II

3.1 Overview

SPPL in meeting the objectives outlined in Section 2.1 subsequently sought to focus on a commercial design evolution - CETO II - where costs are reduced, energy capture is increased and acceptable in-sea reliability standards are met. CETO II is a revised concept retaining some elements of the CETO I design. Therefore the review of CETO II is primarily design based, utilising operational data from CETO I where available.

SPPL has defined CETO II as an R&D activity centred on the provision, deployment and testing of the next phase of the design that will validate key elements of the commercial design. Additionally, the CETO II operations phase intends to validate CETO II unit performance and reliability by analysis of operating performance data within the marine environment at the Fremantle site. Such components are to include:

- anchors and moorings
- attachment device
- filtration equipment
- pumping equipment
- flexible connections
- pipework
- flotation devices
- instrumentation

Managing the design aspects and quality during the manufacturing stage has a considerable impact on controlling the early failures. It is recommended that SPPL incorporate implicit reliability into the design. There are a number of options available to achieve this: redundancy, streamlined design (by reducing connection points and areas that are known of frequent maintenance requirements), design for robustness, low utilisation of mechanical strength (a higher resulting reserve or safety factor), environmental simulation testing of components subject to various environmental loads, use of well-proven components, FMEA study tightening up of manufacturing, fabrication and commissioning procedures in such a way to reduce the incidence of failures induced by poor workmanship or human induced problems, etc. It is therefore suggested that SPPL consider the above items.

The outcome of the component reliability testing will enable specification of components for the future CETO III phase of commercial unit testing.

Additionally, the costs of producing, operating and maintaining the basic scalable device unit will be quantified subsequent to this stage and will thus establish a sound foundation in order to determine the cost-basis for the full-scale commercial CETO II unit and ensuing CETO III device. It is noted that the original intention was that many of the components and equipment deployed as part of CETO II operations were a combination of proprietary and commercially available components. It appears that there are now increasingly more 'new' or bespoke components. Robust analysis and testing of novel components is required to help ensure reliability and minimise maintenance.

CETO II is intended as a test bed for evaluating and proving the technology that will be employed commercially. It is not at full commercial scale. The CETO II equipment design draws on the operational performance and reliability of the CETO I design and material selection, in that all materials are seawater compatible and will not contain any lubricants, nor require lubrication other than from the seawater. This avoids complexity in retaining lubricants and avoids the risk of environmental contamination of the surroundings.

The major components of the CETO II system are show below.

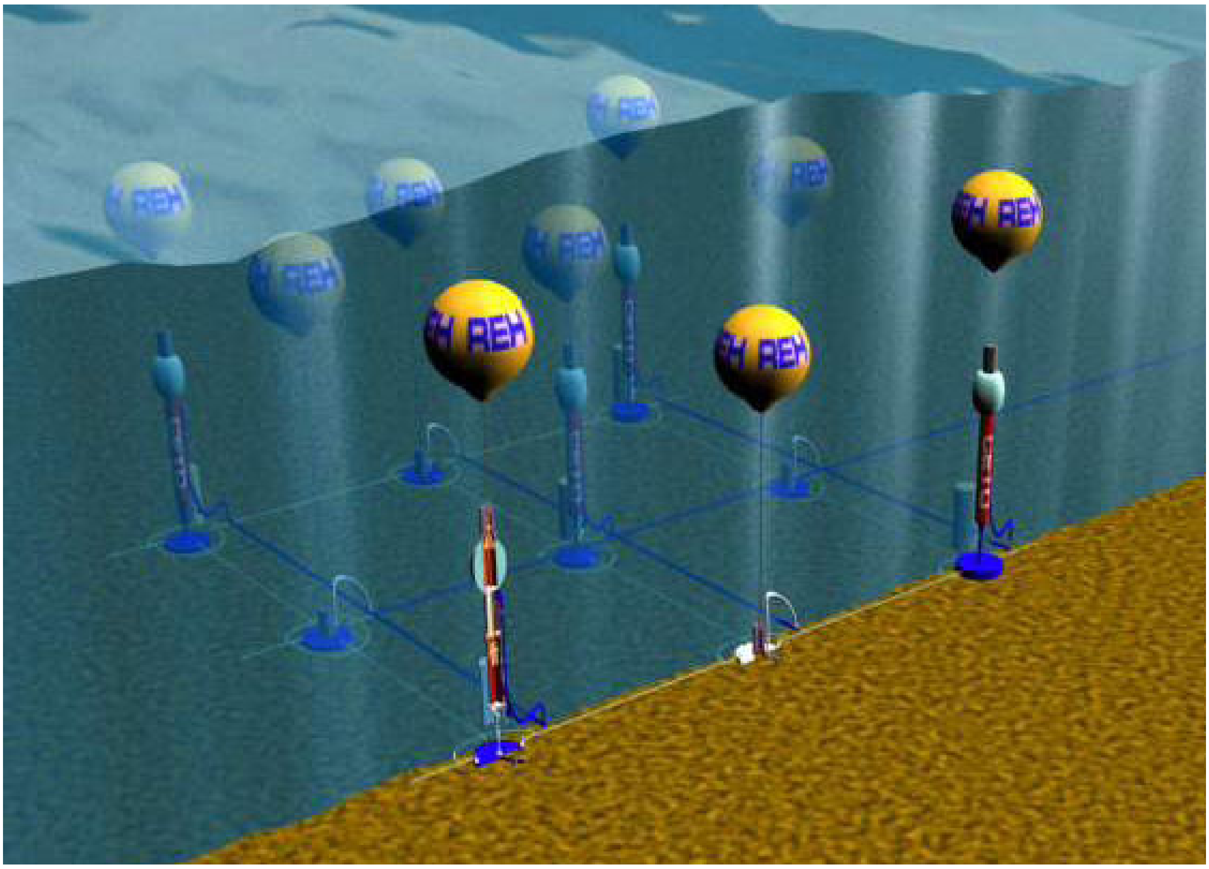


Figure 3.12 General arrangement of CETO II

The major components comprising the CETO II device may be summarised as being the pump, the buoyant actuator, the line joining the buoyant actuator to the pump, the inlet filter, the high pressure line and the anchoring means. Note that, in this illustration, some of the pumps are shown embedded into the seabed. It is understood that this related to an early concept. However, this report only considers the arrangement with the pump above seabed level and moored by a clump weight.

CETO II is to be deployed on exactly the same site area that CETO I occupied and will utilise the same pipeline to shore and control lines. Likewise the onshore facilities, the piping, pressure handling, measurement, control, desalination and Pelton turbine will all be reused under CETO II.

During the passage of an overhead wave the buoyant actuator raises and tension is transferred to the pump. This produces lift in the piston and expulsion of pressurised seawater from the pump into the high pressure manifold via a one-way valve. After the passage of a wave peak the weight of the pump piston and attached assemblies causes it to fall and the pumping chamber receives a fresh charge of filtered seawater from the inlet filter via another one-way valve.

3.2 Seabed Pump and Housing

SPPL has stated that the pump and housing will be lowered separately and connected to auxiliary equipment by divers. In addition, when the device is to be raised, during times of planned maintenance and decommissioning, the divers again must descend in order to break the connection between related equipment. It is recommended that the design minimises the requirement for diver operations, to avoid them working in the likely high energy environment.

The pump unit is a reciprocating positive displacement piston pump.

The CETO II pump unit is designed in accordance with Standards Australia AS1200 Pressure Equipment and AS1210 Pressure Vessels and associated codes. These standards have ISO and ASME equivalents.

Additional consideration should be given to the hydraulic cylinder. The primary consideration for the hydraulic cylinder is pressure containment. For the CETO device consideration should be made of:

- Fatigue of pressure containment and piston rod;
- Buckling of the piston rod;
- Wear properties of the seals, pins and bearing surfaces involved;
- Degradation rate of hydraulic fluids through oxidation, accumulation of debris, bacterial growth, and resulting increase in viscosity of the fluid;
- Filter arrangements and filter quality mesh size and cleaning arrangements;
- Heat dissipation,

As the hydraulic cylinder will be subjected to heavy cyclic loading, the fatigue aspect of the cylinder is very important. In addition, the sealing system for the piston will need to be of a suitable type to withstand the same level of cyclic loading.

Buckling strength is also an important factor within cylinder design. Obviously the more slender the cylinder, the lower the limiting axial load before buckling starts. In general, this axial load is inversely proportional to the square of the slenderness of the rod.

Finally, in addition to the normal pressure and temperature loading, the hydraulic piping system will also undergo many cycles of pressurisation. Therefore the fatigue life of the hydraulic piping will need to be considered. BS EN 13480 is a comprehensive standard for the design of industrial piping. Alternatively, ASME codes are also used in the hydraulic industry.

3.3 Mooring Anchor / Foundation

The CETO II and III systems have been designed such that, in many locations, a very simple, low cost, easy to deploy mooring system can be used, based around a clump weight design. At the CETO II site, the reduced water depth and wavelength (7 m as opposed to about 25-50 m water depth and 80 m wave length anticipated for CETO III sites) results in the use of a buoyant actuator smaller than the one anticipated for CETO III.

Whilst the CETO II clump weight foundation design, with its associated scour protection mats, is suitable for the sandy seabed conditions of the CETO II test site, anchor foundations for CETO III onwards will require specifying on a site-by-site basis depending on the geotechnical properties of the seabed and forces acting on the anchor.

The extent of site investigation and the choice of investigation methods should take into account the intended size of the wave energy device, the uniformity of soil and seabed conditions. For anchor / foundation design the soil stratigraphy and range of soil strength properties need be assessed. Site investigations in later commercial applications should provide information about the soil to the depth required to check the effect of possible weak formations.

SPPL has identified the potential use of clump weights, suction anchors, suction piles, driven and screw piles. In reality, the foundation will have to remain as simple, cost- effective and easy to install as possible. In many locations in the northern hemisphere the high energy wave environment, coupled with the regional geology, will have resulted in a 'hard' seabed comprising firm to stiff glacial tills, dense sands and gravels, or bedrock (either scoured or with a thin veneer of sediments above it). In these circumstances, depending on specific geotechnical conditions, it is likely that the most cost-effective solutions will include gravity weights (possibly incorporating skirts to increase lateral resistance where appropriate) and small suction anchors. If geotechnical conditions dictate that more complex systems, such as piles, are required, their use should only be considered after the full impact of design, manufacture, installation and decommissioning has been considered with regard to the project cost model.

SPPL has identified that anchor moorings will be designed to offshore mooring codes API RP 2SK and DNV-OS-E301. It is recommended that, in addition, and where appropriate, consideration is given to use of appropriate foundation design codes including DNV Classification Note No. 30.4 Foundations, DNV Recommended Practice DNV-RP-E303 Geotechnical Design and Installation of Suction Anchors in Clay, and API RP 2A-Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms.

Where required by permit/consent conditions, decommissioning of the mooring system may also be undertaken. In the past, in some UK waters, this has included requirements such as cutting off piles approximately 1 m below seabed level. This is, therefore, another strong justification for keeping the mooring type simple and avoiding systems such as piles where possible.

3.4 Subsea Pipelines and Cables

Instrumentation on CETO II will be controlled by the existing CETO I umbilical. SPPL proposes that there is no instrumentation on CETO III and therefore there is no requirement for control umbilicals. Therefore the only connection to the shore will be via the water pipeline. CETO II will use the existing CETO I pipeline.

The overall system will need to be protected from the possibility of overpressure. Suitably sized relief valves should be installed to protect the system from overpressure.

Non-return valves should be placed in the correct places in order to avoid undesired back flow, and loss of system pressure in event of a failure.

Filters should be installed at suitable points to protect the device from unwanted blockage or wear and to limit any damage occurring. Consideration needs to be given to how to clean and maintain filters. Pressure setting of any pressure regulating valves should be established and documented. Any changes in the system control/modelling/demands may require the setting to be altered. If relief valves are to be used as a means of regulating, the long term reliability of the valves needs to be assessed.

The short lengths of flexible hoses adjoining the device and the pipework will need to be robust.

Whilst it is recognised that the surface-laid pipeline has proven acceptable for CETO I and will remain acceptable for CETO II, pipeline protection requirements will have to be considered for CETO III and later projects. The protection of pipelines (and cables) is a mature technology developed from the offshore oil and gas and subsea telecoms industries. The most significant threats to pipelines and cables (generically termed product) arise from the interaction of the product with fishing equipment and ships anchors. Less frequently damage can arise through mechanisms such as chafing, strumming, suspension, etc, resulting from natural seabed processes, including sediment bedforms, rock outcrops, landslides, etc.

It is likely that the protection methodology (and associated decommissioning requirements) will be incorporated in the various permit/consent conditions applied to future development stages of development. In UK waters it is likely that this will require burial to a specified depth (3 m has been the common requirement for cables to offshore wind farms in UK waters to date) or protection by means such as mattresses or rock dump. These would be in addition to system specific requirements such as armouring or protection (eg uraduct-type sleeves).

3.5 Anticipated Performance

An array of devices, up to nine in total, on a three by three grid will be installed at the CETO II site.

The 3×3 array at Fremantle was selected as the minimum number of units that would be required to enable assessment of expected life cycles and calibration of CFD models. PBP would recommend 2 wave buoys be employed so that energy levels behind the array can be directly compared with those in front. These two sets of information will then enable modelling of any size of the array using the

CFD models. PBP would therefore recommend that an alternative methodology, using two wave buoys located simultaneously ahead of and behind the CETO II array, is adopted.

The number of units that will be activated (and hence the efficiency) will vary if the waves are larger or smaller than the design wave. Studying both the design wave, as well as larger and smaller waves will enhance understanding of array effects and enable further validations of the CFD models.

The CETO units can be adjusted to operate in any wave environment and combination of wave environments. The standard design is intended to operate at 50 % capacity in a combined 2 m swell. With the standard setup the system will not be able to operate in swells less than 1 m.

The CETO units will be optimised for the specific site conditions. However, they will continue to operate outside the designed-for wave and tidal conditions albeit with some loss in efficiency.

The system is unaffected by small changes in tidal current due to the source of power being the vertical movement of the actuator. If the change in current (including change of direction) is greater than 3 m/s under normal conditions then the system would start to be affected. In this situation, SPPL has stated that the minimum wave required for operation would be higher than normal for the same system.

Due to the modular setup and symmetry of the system, CETO units are omni-directional ie they operate equally effectively regardless of the direction of the waves. With a multiple array system the direction of the wave will effect how much residual energy the wave has as it reaches each unit.

Under the standard design wave, SPPL has calculated that a single CETO unit will convert 20 % of the wave's total energy into pumped high-pressure water. Depending on distance from shore, up to 5 % capacity may be lost transferring the high-pressure water to shore. The Calder energy recovery turbines have a 90 % recovery rate through the turbine. A basic table for energy conversion would be as follows:

TABLE 3.4
WAVE ENERGY

Wave Size (m)	*Wave Energy (kJ/wave)	High-Pressure Water Energy (kJ/wave)	Calder Recovery (kJ/wave)
1	691	138	118
2	2765	553	472
3	6220	900	769
4	11060	1106	945
5	17280	1106	945

*Assuming a wave period of 6 seconds

Water pressure and flow rate losses are very particular to each site location and number of units installed. It is expected that losses of less than 5 % will be encountered.

Based on the figures from the tables above, and utilising the maximum anticipated losses given above, the power generation for each wave height and period would be as follows:

TABLE 3.5
POWER GENERATION

Power Generation (kW) per wave height and period for each unit						
	Wave Period (sec)					
Wave Height	5	6	7	8	9	10
1	23.6	19.7	16.9	14.8	13.1	11.8
2	94.6	78.8	67.5	59.1	52.5	47.3
3	153.9	128.3	109.9	96.2	85.5	77.0
4	189.1	157.6	135.1	118.2	105.1	94.6
5	189.1	157.6	135.1	118.2	105.1	94.6

Based on a 45 % conversion of high-pressure seawater to fresh water, the following amount of desalinated water can be created for each unit:

TABLE 3.6
WATER PRODUCTION

Fresh water in liters/sec						
	Wave Period (sec)					
Wave Height	5	6	7	8	9	10
1	1.71	1.43	1.22	1.07	0.95	0.86
2	6.84	5.70	4.89	4.28	3.80	3.42
3	11.13	9.28	7.95	6.96	6.18	5.57
4	13.68	11.40	9.77	8.55	7.60	6.84
5	13.68	11.40	9.77	8.55	7.60	6.84

The by product of the production of water by desalination from the above table is power generation through energy recovery, this would amount to 45 % of the values in Table 3.5 above. As a comparison with a standard energy cost for water desalination of 2 kWh/m^3, the following total water quantities could be derived if the power was transferred to a desalination plant:

TABLE 3.7
FRESH WATER PRODUCTION

Fresh water liter/sec						
	Wave Period (sec)					
Wave Height	5	6	7	8	9	10
1	3.28	2.74	2.35	2.05	1.82	3.28
2	13.13	10.95	9.38	8.21	7.30	13.13
3	21.38	17.81	15.27	13.36	11.88	21.38
4	26.27	21.89	18.76	16.42	14.59	26.27
5	26.27	21.89	18.76	16.42	14.59	26.27

4. ONSHORE FACILITY

4.1 Site

The plant and equipment for the CETO II will utilise the same power generation and desalination equipment as used for the CETO I operations phase and will be housed in the same building. In addition to the turbine, generator and reverse osmosis desalination system, the plant includes associated instrumentation, electrical equipment and PC based monitoring equipment that is to be located in the existing onshore facility.

The onshore facility comprises a 250 m^2 steel framed building and a substantial sealed hardstand car park/unloading area. The building provides adequate space for plant and equipment, tool and parts store, secure lay down area and site office.

Future site requirements will require that, for CETO III, connection to the mains water supply grid is made. CETO I and II operations are outwith this requirement and as such the lack of connection capacity at the Fremantle site is irrelevant.

Finally, the CETO III units are designed to be transported in standard ISO dimension containers. Therefore, future onshore facilities will need the capacity to accommodate normal road transport vehicles. This is present at the current site.

4.2 Pelton Turbine

The CETO I power generation system will be re-used for the CETO II Project. CETO I utilised a Pelton wheel hydro turbine which converted the energy of the pressurised seawater into electricity. These generators are manufactured from stainless steel and have been in commercial use for over 20 years as energy recovery units for large scale desalination projects. Again, the power generation system will be commissioned when all CETO II units are operational.

As seawater passes through the turbine, issues related to corrosion and marine growth are now inside the turbine and are more difficult to inspect and maintain.

4.3 Reverse Osmosis Plant

SPPL has declared that the CETO I desalination system will be modified and re-used for the CETO II project. CETO I utilises standard reverse osmosis technology which has been used in multiple applications for the purification of seawater since the 1970s. Freshwater is extracted from seawater under pressure by the use of a semi-permeable membrane using conventional technology. The desalination system will be commissioned when all CETO II units are operational. PBP does not anticipate any risk over and above that which would otherwise be expected through the employment of such technology in this environment.

Figure 4.13 Seawater Reverse Osmosis desalination arrangement

4.4 Control and Instrumentation

The CETO II control and instrumentation system will be based around the existing CETO I hardware and systems infrastructure.

The principal difference between CETO I and CETO II control requirements is that CETO II requires very little, if any, offshore feedback whereas CETO I required the air pressure and water level inside the large structure to be controlled regularly.

Data logging equipment will be used to capture operational performance trends.

The SPPL onshore facility at Rous Head is equipped with sufficient control and instrumentation equipment for the CETO II project. The equipment was installed for the CETO I phase, and is operational, however equipment reconfiguration and software is planned for the CETO II phase.

It is recommended that the control and monitoring requirements for the device should be summarised describing the objectives and attributes of the control system

Special attention should be given to effects on monitoring and control systems from the following:

- vibration (wave slamming, sloshing of tank contents, local structural vibration, impact, excitation from hydraulic, pneumatic and mechanical systems etc);
- temperature,
- humidity,

- salinity,
- electromagnetic interference,
- atmospheric pressure (may fluctuate in sealed compartments), and
- assumptions on quality and variability of, hydraulic, pneumatic, fibre optic devices and power supplies.

PBP would recommend an additional Waverider buoy as mentioned above.

4.5 Grid Connection

There is no grid connection planned for CETO II, hence no provision has been made for one at the site. However, grid connection issues facing a future commercial CETO system will be similar to those already addressed by onshore wind power operators. SPPL has stated that it will utilise the experience and expertise of its parent REH PLC and others, who are heavily engaged in wind farm development given that CETO III is a distributed energy device generating its power onshore similar to wind power generation. All CETO devices will utilise the same technology as wind power generation grid interconnections.

5. CETO II INSTALLATION, OPERATION, MAINTENANCE AND DECOMMISSIONING

5.1 Installation

CETO I was installed in approximately 7 m water depth, 300 m from the shore. The design has since evolved from a single, large, unit breaking the water surface to smaller, discrete submerged units.

As described previously, the CETO II design is to be installed at the same location as CETO I. Each device is moored to the seabed by an embedded clump weight. Up to 9 devices will be installed on a 3 × 3 grid. CETO II will use the same seabed pipeline infrastructure as CETO I.

Commercial devices (CETO III and beyond) are anticipated to be installed in 25-100 m water depth, with 80 m wave length. They will have a larger diameter actuator buoy, compared to the CETO II buoy. These devices will require in-field and export flow lines to be installed for the pumped water.

SPPL has proposed that the CETO II installation will be undertaken utilising similar resources to those required for CETO I – namely workboats and commercial divers. SPPL has identified that the CETO III installation sequence is as follows:

1. Undertake site surveys and pegging
2. Deploy and position CETO III anchor unit (anchor type depends on site conditions)
3. Manifold installation
4. Deployment of CETO III pumping unit, and connection to the anchor
5. Installation and connection of low pressure inlet and high pressure outlet flexible pipework from the CETO III units to the array header.
6. Deployment of the CETO III buoyant actuator and connection to the CETO III pumping unit.

It is assumed that the (smaller) CETO II deployment is anticipated to follow the same sequence.

Whilst the first CETO II unit reuses the existing CETO I export pipeline, additional units in CETO II, CETO III and later developments will require new in-field and (CETO III onwards) export pipelines to be laid. As discussed previously, the burial requirements (armouring, covering and/or burial) will depend on the pipeline specification, the seabed conditions, the local threat level, and any requirements imposed by the applicable local permits and constraints.

For CETO III and future sites, it must be borne in mind that, as indicated previously, seabed conditions may be ‘harder’ than those encountered at the CETO I/CETO II site. If pipeline burial is required, this will be undertaken by subsea plough, jet-tool or trencher (either disc or chain cutter), depending on factors such as required burial depth, required backfill, bend radius of pipeline, seabed conditions, cost and availability of equipment. If protection through the use of rock dump or mattressing is preferred, approval for this must be obtained from the relevant stakeholders (note that rock dump is becoming increasingly environmentally unacceptable in certain locations). In addition, although beach fabrication and launching has been identified as the preferred option, many locations exist where the nearest suitable beach is a significant distance away. In this case, installation from a vessel must be considered. This will have implications on schedule, available installation window, weather risk and cost of the works.

5.2 General

Whilst recognising that the installation system used to date has proved safe and appropriate for the CETO I/CETO II site, it is recommended that consideration is given to reducing the involvement of divers for deeper water, higher energy sites where practicable. There are a number of reasons for this:

- Health and safety – diving is a hazardous operation and any reduction in the time required for diving is beneficial. In UK waters many regulations apply to operations such as this, including the CDM regulations which require, where possible, hazardous installation, operation, maintenance and decommissioning operations to be minimised through careful design.
- Although much of the wave energy will have been dissipated below about 10 m from the surface, any operations relating to the buoyant actuator are likely to be taking place in this higher energy zone.
- The allowable air dive time (from leaving the surface to leaving the bottom) decreases from approximately 20 minutes at 25 m depth to just 10minutes at 50 m depth, significantly reducing the useful time available for undertaking any work
- As the water depths increase, the availability (both in terms of geographically and of utilisation) of suitably experienced and equipped dive teams reduces – this applies particularly in water depths exceeding 50 m, the cut-off point for air diving and the point below which saturation diving techniques must be used.

Options to consider that will reduce the required number of dive operations may include:

- Selection of foundation types that require no, or minimal, remote intervention
- Use of Remotely Operated Vehicles (where sea conditions permit) instead of divers
- Use of flexible pipework and connection of pipework and manifolds at the surface (additional lengths of pipework can be anchored down adjacent to the CETO array)
- Use of acoustic releases, pennant wires, etc for recovery of units, clump weights and hoses.

Furthermore, temporary phases like transportation to site, installation or removal may require a marine operations type of assessment and Warranty Survey for insurance purposes. The design of any handling equipment and vessels for deployment should be considered to ensure safety and economy.

The management of Health, Safety and Environment issues are pivotal to the success of installation, maintenance, operation and decommissioning operations such as these. SPPL identifies that safety planning, logistics, equipment required and procedures required are typical of commercial diving and salvage activities. However, it is recommended that the local requirements for different countries are investigated and their implications considered in the appropriate cost model.

These comments apply equally to installation, operation, maintenance and decommissioning.

5.3 Operation

In terms of a commercial onshore set up for this technology, the operation of desalination plant and small hydro plant is well understood and should not present any significant problems. In advance of a particular project it would be necessary to determine the best use of the energy (for water, power or a combination of both) and implement an appropriate operating procedure. Economically the optimum “installed capacity” will need to be decided (eg for a percentage of maximum output, with a defined level of storage to optimise “spillage” of generated energy from high energy periods). It should be noted that some amount (perhaps only small) of “storage” is inherent in smoothing the pressure for feed into a desalination unit.

Operation of the offshore equipment is theoretically limited by the fact that the devices operating will provide varying amounts of pressurised sea water ashore. This water will then be utilised (or “spilled” if too great for the installed capacity/storage ashore) by the onshore operation. Whilst there is a desire to minimise or even eliminate instrumentation on the commercial CETO III unit, it is accepted by SPPL that some instrumentation is necessary to allow for determining maintenance requirements, etc.

In addition to this, for any development, SPPL will have to bear in mind the lifecycle risk of the development. A typical risk assessment would include the follow category of events (consideration should be given to all phases during the device’s life: fabrication, installation, in-service and decommissioning):

- Anchor/foundation failure
- Mooring failure
- Breach of water integrity of compartments or equipment
- Stability failure
- Collision risks
- Interference with commercial and recreational marine activities

- Structural failure
- Fishing gear impact
- Personnel risks to operators and to the general public
- Pressure containment failure from hydraulic or pneumatic systems
- Electrical failures and shore connector failures
- Seismic events
- Fires
- Interference floating debris with device.

SPPL as an organisation should clearly reflect operational responsibilities. An Operations Manager would normally be the focal point responsible to the Board for the daily running of the operation. The Board should ideally include a director responsible for health, safety and environmental issues and a director with a technical background (the nature of this should reflect the company's philosophy for deploying or manufacturing its devices). SPPL has stated that manufacture of the commercial CETO III devices will take place in China, therefore appropriate quality assurance and inspection is essential. Value may be derived from the inclusion of production engineering expertise in the refinement of the final CETO III design to ensure production costs are minimised. As SPPL intends to operate a number of devices, a maintenance management function would be required, depending on the scale of operations this may be combined with other responsibilities.

Furthermore, a systematic approach to documentation throughout the operation of the device's life should be ensured. The level of documentation will vary with the complexity of the design and stage of development of the project. However, all final documentation should:

- provide a basis to verify that safety and operation of critical parts of the device comply with requirements of the standards or with the objectives set out in the qualification basis;
- allow traceability of conclusions and results to be obtained;
- confirm and document all assumptions and conditions used during design process;
- demonstrate how changes and deviations were monitored and satisfactorily dealt with;
- demonstrate and document the control of all interfaces during design, fabrication and installation;
- demonstrate control of documents issued (numbering, revisions, approval and review process, etc);

- provide information on the operation of the device, including maintenance.

The level of documentation is an important step in order to obtain the recognition from financiers and underwriters that the risks (including those affecting performance and production) were identified and were controlled and mitigated appropriately.

Finally, it is recommended that independent third party witnessing and certification is obtained for any electricity and desalinated water generation during CETO II operations.

5.4 Maintenance

SPPL identifies that the CETO III unit has low maintenance requirements which may include, but are not limited to:

- Regular removal of excess marine growth
- Replacement of worn rigging shackles etc.
- Replacement of power transmission
- Replacement of pump seal
- Repair or replacement of buoyant actuator
- Repair or replacement of interconnecting pipework
- Replacement of inlet filter media

For major maintenance, the CETO III unit to be serviced would be swapped with a ‘spare’ CETO III, thereby enabling continuity of generation. However, minor maintenance activities may be undertaken subsea by divers.

Procedures for maintenance, inspection and repair should be developed at an early design stage. Consideration should be given to access to areas to be inspected and the extent, frequency and choice of inspection methods.

For the CETO device, maintenance will strongly depend on access to the device and it is likely that weather window for access to the devices will not be easily available (and difficult to forecast) during certain seasons of the year. Thus, the maintenance strategy needs to consider this important issue.

Considering the novel aspects of the wave device, it will be necessary to apply experience from the earlier prototypes in addition to experience transferred from other industries such as offshore oil and gas, which is evident within the SPPL organisation.

A spare parts philosophy should be defined taking into account the time from ordering from supplier to the availability of replacement part, criticality of the part (regarding survivability and functional requirements), maintenance requirements and costs of stock, preservation and storage of spare parts. A list of spare parts should be produced and included in the maintenance plan.

It is recommended that, in developing future project costings, a detailed maintenance strategy is developed. This should incorporate planned and unplanned maintenance, spares to be stocked (emergency and lifed items), and maintenance staff and equipment requirements. SPPL suggest that, for larger array installations a trained dive team and workboat would form the core maintenance team. Although the majority of subsea components are bespoke, consideration could be given to undertaking a reliability assessment to estimate the failure rate of specific components when developing the maintenance strategy. Where possible it is recommended that widely available off the shelf components are used, to reduce requirements for holding of spares and to benefit from competitive costs. Consideration could be given to the use of in situ performance monitoring, particularly of subsea items, to strengthen the maintenance strategy.

5.5 Decommissioning

Although not addressed in detail in the information supplied by SPPL, consideration must be given to the decommissioning and disposal requirements of the system, since these are increasingly being required as part of the consents process and form an important part of the projects whole life costing. This applies to the foundations and pipelines as well as the actual CETO structure.

The device should be designed to allow for a safe and economic decommissioning. Recycling of materials and possible re-use of equipment should be considered at the design stage.

United Nations Convention on the Law of the Seas (UNCLOS) refers to removal of any installation or structures that are abandoned or disused shall be removed to ensure safety of navigation.

The IMO Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matters (London Convention) addresses the disposal of waste and material at sea and it also addresses the removal of offshore platforms while the IMO Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone states: “Abandoned or disused offshore installations or structures on any continental shelf or in any exclusive economic zone are required to be removed, except where non-removal or partial removal is consistent with the following guidelines and standards”. This allows the decision to be made by coastal state with jurisdiction over the installation on a case-by-case basis.

Further development, for European waters, on the extent and the reasons for removal is the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR) that requires the complete removal of any decommissioned installation at the sea. It is expected that, in Europe this will be extended to wave devices. In other parts of the world, the legislation may differ allowing, in some case, that clean structures and equipment may be sunk to form artificial reefs.

6. PERFORMANCE

6.1 Site Description

The CETO I/CETO II test site lies in approximately 7, water depth, 300 m off the coast. This reduced water depth (compared to the anticipated 25 m to 100 m for commercial systems) has resulted in a number of design and environment compromises in comparison with the anticipated commercial design. These are highlighted below:

- Shallower Water depth (7 m compared to 25-100 m)
- Reduced wavelength (20 m compared to 80 m)
- Smaller buoyant actuator diameter
- Reduced piston size
- Shorter power transmission connection

6.1.1 Site Selection Criteria

Key items to be considered in selecting future development sites include:

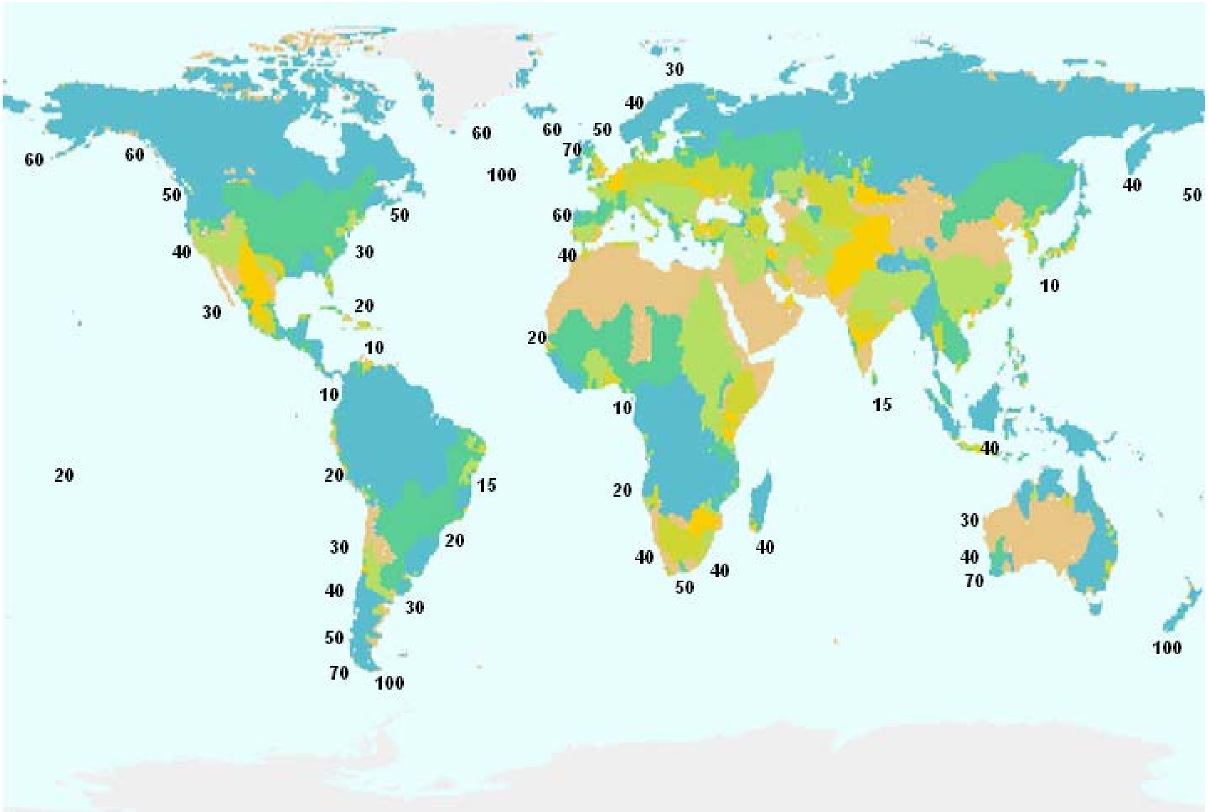
Parameter	
Water depth	The CETO III unit can operate in any depth from 15 m to over 100 m. The preferred depth is 25 m as this is the shallowest depth before waves start losing energy to seabed drag losses Affects: Sizing of CETO system; marine operations
Wave regime (wavelength, height, direction, spectra)	The CETO III units can be adjusted to operate in any wave environment and combination of wave environments. The standard design is based to operate at 50 % capacity in a combined 2 m swell. With the standard setup the system will not be able to operate in swells less than 1 m. However if a site has regular swells less than 1 m the system can be altered easily to allow production in swells as low as 0.5m, albeit with a reduction in efficiency. Due to the modular setup and symmetry of the system CETO units are omni-directional ie they operate equally effectively regardless of the direction of the waves. With a multiple array system the direction of the wave will effect how much residual energy the wave has as it reaches each unit Affects: Available resource; marine operations, efficiency.

Parameter	
Distance from shore and onshore facilities	The distance from shore is mainly based on the depth of water available close to shore. Due to cost of pipe laying and head losses associated with long lengths of pipe it is preferred to be as close to shore as possible however it is estimated that units can be located up to 10 km from shore and still be economical. Site locations that are of a distance from shore that makes pressure drop losses significant, can utilise a variation of design that incorporates an offshore platform in where desalination and generation equipment are located, although this would have an impact on the project costs. Affects: Pipe laying, head losses, operation and maintenance
Seabed conditions	CETO III can be deployed in most seabed conditions. Clump weights, suction anchors, suction piles, driven and screw piles are all capable of providing the required foundation capacity. It would depend on the geomechanics of the seabed as to which anchor system would be used in each location. Any seabed material is adequate to rest the pipeline on, depending on the surface. Different protection methods would be used similar to the Offshore Oil and Gas industry. Affects: Foundations, pipe laying
Grid Connection Requirements	CETO III is a distributed energy device generating its power onshore similar to wind power generation. All CETO devices will utilise the same technology as wind power generation grid interconnection. Affects: Unit energy cost; connection to electricity network; project costs
Requirements for Desalinated Water	Due to the power and pumped high pressure water being provided by the CETO III units there is no other site specific requirements to generate desalinated water. As with any desalination plant it would require connection to the main water supply grid. Affects: Connection to water infrastructure; project costs
Distance from Harbour	Installation of the CETO III units will require a 60-80T vessel. The closeness of the site to a harbour would assist with this requirement but is not essential. Maintenance would also require a launching point for a small maintenance dive vessel. Local port facilities suitable for the establishment and maintenance of a Maintenance and Operations base would also be beneficial. Affects: Installation, operation and maintenance.
Road Access	The CETO III units are designed to be transported in standard ISO dimension containers. The location or the nearby harbour/launching point will need the capacity to accommodate normal road transport vehicles.

Parameter	
Effects of Tidal Range	The system is designed to sit below but close to the water surface. If the normal tidal range in any location was greater than 1.5 m the efficiency of the system would start to decrease slightly. There would be an approximate 5 % reduction in efficiency for each additional meter (over 1.5 m) of tidal change. Affects: Efficiency, unit energy cost, buoyancy.
Effects of Tidal Current	The system is unaffected by small changes in tidal current due to the source of power being the vertical movement of the actuator. Waves higher than the design normal operating wave would also become more efficient under tidal currents by 7 % for every additional 1m/s of current. Affects: Efficiency, unit energy cost, marine operations
Array geometry	With the spacing between CETO III units it is expected that each unit will extract approximately 15-20 % of the wave's incident energy. Affects: Efficiency, unit energy cost, marine operations
Environmental constraints	Designated sensitive areas, other users (fishing, aquaculture, military, recreation, etc) Affects: Operations, project costs, project schedule
Stakeholder interest	Official bodies and other stakeholders. Applicable consents and leases. Affects: Project schedule and success.

6.1.2 Possible Sites

It can be observed from the figure below which specific countries are in most need of water and therefore where the value of potable water is the greatest. Superimposed on this figure are available predicted energy levels in the waves in kW/m^2. It is clear that there are areas where there is a scarcity of water and a promising wave energy resource. Such areas include the West coast of the Americas, Southern Africa and Western Australia close to Fremantle. The political arena in Western Australia is currently debating future water solutions for the state, recent press articles can be found relating to this in Appendix E. Islands may also be favourable, with a lower wave energy availability (eg Caribbean). Other countries with high wave energy potential and reasonable water supplies would lend themselves to only electricity generation eg Northern Europe.



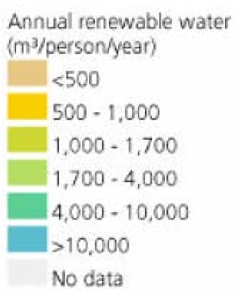


Figure 6.14 Wave energy atlas of the world (kW/m) and water scarcity map[1]

In terms of testing a full scale CETO II there are established marine energy test centres such as WaveHub, Emec etc which should be included in the future review of possible sites pending a successful outcome from CETO II tests. SPPL consider that a good commercial project test site may be in Northern Ireland, where there is economic support available for renewable energy projects in terms of the NIROC, combined with a good wave energy resource.

[1] **EarthTrends 2001 World Resources Institute.**

SPPL indicates that one of the key strengths of the CETO system is its inherent flexibility to adapt to any environmental/geographical location. This has led to SPPL being able to identify the following sites as potentially viable:

Australia	A large proportion of the Australian coastline provides suitable conditions for wave power generation. Western Australia is an ideal location for the CETO III unit due to the high and constant wave energy (waves over 2 m occur 90 % of the time) that occurs along the south west coast. The majority of towns in Australia are located on the coast with the required infrastructure to tie the power or water generation into.
Ireland	The northern coast of Northern Ireland has an average wave height of over 2 m and also has water depths of over 20 m within short distances of the shoreline. Appendix C contains a description of the wave resource.
UK - WaveHub	As CETO III is designed to make maintenance easy and less expensive due to the majority of power generation equipment located onshore rather than inside the units, the location of WaveHub being 10 miles offshore, whilst feasible, may not entirely be suitable to CETO III due to the cost of piping the pressurised water to shore. Alternatively, an offshore platform incorporating the desalination and generation equipment could be utilised. Appendix C contains a description of the wave resource.
UK - Emec	The Emec site located off the Orkney mainland in the Northern Atlantic is in 50 m of water and only 2 km from shore. This is within the range of CETO III preferred location areas and, if an export pipeline was present, would have been a perfect testing range for the CETO III system. However, REH believes CETO is beyond the EMEC stage now. Appendix C contains a description of the wave resource.
Western Europe	Investigations of opportunities on the western European cost revealed wave conditions highly suited to CETO III. Prospective areas include the coast of Portugal and the north west of Spain.

7. STAKEHOLDERS AND THE ENVIRONMENT

7.1 Environmental

It is essential, for a project of this type, that a responsible attitude to site selection and stakeholder consultation is taken. Whether a formal Environmental Impact Assessment is required or not, undertaking the required processes would be beneficial to the successful delivery of a CETO III development.

Environmental Impact Assessment (EIA) is the process by which information about the environmental effects of a project is collected, evaluated and presented in a form that provides a basis for consultation and enables decision-makers to take account of these effects when determining whether or not the a project should proceed. The process also includes environmental monitoring and other work that is carried out following any decision to allow the development to proceed (eg monitoring carried out during the installation phase or after decommissioning).

The existing environment, and its interaction with the project, should be considered in terms of:

- Planning context
- Flora and fauna (terrestrial and marine)
- Noise and vibration
- Hydrography, sediments and coastal changes
- Fisheries and aquaculture
- Navigation, Radar and other uses of the sea
- Archaeology

In terms of navigation and radar requirements devices will normally be required to be provided with navigation lights having a secure power supply in line with normal coastal regulations for moored devices. Approval by the relevant authority is likely to be required. Marking of the outer perimeters of a field of devices may be required by authorities.

Adequate radar reflection should be provided, addition of special radar reflecting device should be considered for ease of detection by ships and pleasure craft in line with General Lighthouse Authority (GLA) requirements. Clarification may be required by the Ministry of Defence for radar interference and military strategic consequences.

SPPL undertook environmental surveying before the installation of CETO I. The summary report concluded that “it is considered that the benthic communities of the site of the generator and the associated cabling have no significant environmental value. The vegetation found is common and there are no seagrass beds within the site. No limestone reef communities were found. We recommend that damage to the limited seagrass found be avoided where this is possible. It is recommended that six monthly or annual monitoring be performed to confirm that these seagrasses are not being degraded during the life of the project."

Ledge Diving carried out an examination of the CETO seabed site, referred to as 'Area 7' to gather bathymetric data and to conduct a grid survey of the proposed CETO footprint area within that site. They also inspected the area between Area 7 and the shore where the pipeline would be deployed. They found the seabed site to be a desolate sandy plateau with small amounts of rock rubble. In respect of the footprint area, they found that "over the 40 x 20 m area that was surveyed in detail, there is virtually no seagrass. During the 6 hours of survey work, there was no other visible marine life observed by the divers".

SPPL conducted regular dive surveys of the site post-installation. It became apparent that the presence of CETO I was attracting marine life to the region. However, it should be noted that any change to the marine environment, including attraction of increased levels of marine flora and fauna, should be considered to be an environmental impact. The significance of such an impact, whether major or minor and beneficial or detrimental should be determined by an experienced environmental specialist.

Specific issues relevant to CETO I, II and III are considered below:

- Equipment will be periodically cleaned to remove marine growth during routine maintenance. The CETO II/III has been designed to minimise the fouling effects of marine growth through environmentally friendly means. However, if in future there is a requirement for anti-fouling paint to be specified, this needs to satisfy environmental requirements and restrictions. A guide for this may be the requirements for shipping as established under the International Maritime Organisation (IMO) conventions and codes, usually implemented in statutory regulations by maritime member states (International Convention on the Control of Harmful Anti-Fouling Systems on Ships (IAFS Convention). Eg lead based or tin (TBT) based compounds are not permitted. Any antifouling agents need to be considered. Countries such as the UK, Ireland, the Netherlands, USA and Australia have a very restrictive legislation regarding sale and use of any TBT based paint.

- Paint – the mild steel components of CETO II/III will be coated to a standard marine paint specification.

- Generated noise - the noise levels generated by the pump in normal operation are estimated to be generally of a low level and at low frequencies, corresponding to the wave frequencies, as the noise would be comprised of piston motion noise.

- The issue of hypersaline water return into protected waters is well understood from desalination projects, for example in the Middle East. Environmental effects are avoided either by using return pipes exiting into the waters outside of harbours and protected areas, or via locating desalination and generation equipment on an offshore platform an appropriate distance from shore to safely disperse the hypersaline waters. This needs to be considered in the economics of potential commercial applications.

In summary, it appears that CETO I and II have been designed to have negligible environmental impact. The CETO I unit has a proven low environmental impact, with increased local marine populations since installation. However, whilst this level of survey and reporting has proved adequate for the CETO I/ II prototype operations, its value for operations beyond the CETO I test location is reduced because of the limitation in the aspects that it covers (marine flora and fauna observed at the test site). A fuller, wider-ranging, Environmental Statement would be required for commercial applications in UK waters, and those of many other countries.

In addition, wider environmental monitoring should be undertaken. This should include marine and terrestrial (shoreline) flora and fauna, bird activity, noise and vibration (subsea and terrestrial, operational and background) and sediment movement. As well as pre-installation and operation phase monitoring, full post-decommissioning surveys should be undertaken. It is recommended that, for the CETO II project, consideration is given to further subsea flora/fauna surveys supplemented by:

- Shoreline, bird and marine mammal surveys
- Subsea and terrestrial acoustic surveys with 3rd party analysis of recordings
- Wave monitoring simultaneously ahead of and behind the CETO units

7.2 Consultation

For the CETO I project, SPPL successfully consulted with local communities, authorities and regulatory bodies.

In addition, investment support was received from both Federal and State governments in Australia; federally through the Department of industry and Resources, through their AusIndustry program, and at a state level through the Sustainable Development Office (SEDO). AusIndustry provided seed funds through a one-to-one matching R&D Start Grant while SEDO provided funds to allow SPPL to fund the mapping of offshore wave energy resources along the south-west of Western Australia.

Media coverage of the launch in April 2005 and at the one-year anniversary of deployment in May 2006 was extensive. The Profile of the CETO project continues to grow internationally off the success of CETO I, with CETO now being cited in the trade and professional press that service the renewables industries.

Feedback has been positive on all fronts. There have been no adverse incidents or bad publicity arising from the deployment or operation of the unit, nor were any expected. On the government and the political front, SPPL is building relationships with local members of parliament and key players in the water and energy generation industries in Western Australia.

Specific consent discussions were held with:

Fremantle Port Authority (FPA) - as the body with prime jurisdiction over the proposed onshore and offshore facilities for CETO I. Moreover the FPA was prepared to act as the single point of contact for SPPL in this matter, representing a considerable convenience and cost-saving to the project. As part of this role the FPA liaised with other stakeholders, including the Western Australian Government through its various agencies, and the City of Fremantle through its elected Council officials.

Department of Land Administration - SPPL also initiated direct dialogue with the Department of Land Administration (DOLA), which is the state agency responsible for land title administration in Western Australia.

Aboriginal Native Title - whilst an extremely important consideration in Australia, this is currently extinguished by legal agreement between the FPA and the traditional aboriginal owners for those areas under the jurisdiction of the FPA. Consequently SPPL was not required to undertake Native Title negotiations as the CETO I facility lay entirely within the FPA jurisdiction zone. This is also the case for CET0 II.

Required IALA navigation Aids/beacons - hazard marking requirements and chart notification to local Marine and Harbours approval.

The location of SPPL seabed lease and onshore facility has been governed by the limited availability of commercial/industrial zoned land adjoining the coast in Fremantle. In this instance the onshore facility at Rous Head is adjacent to a breakwater and is sited on reclaimed land constructed to create a commercial harbour. The location is several kilometres from urban development and within the operational boundaries of the Fremantle port. The seabed lease lies within the boundaries of the 'outer harbour'.

The seabed lease is with the Fremantle Port Authority ('FPA') and the onshore facility is a sub-lease from FPA via Lobster Australia.

The deployment and operation of the CETO I unit has had minimal impact upon the general public in this location due to its isolation from urban development.

The organisations that were approached to obtain approval for deployment included:

- State Government of Western Australia : Minister for State Development
- Department of Land Administration (DOLA)
- Sustainable Energy Development Office (SEDO)
- Fremantle Port Authority
- Yachting Association of Western Australia

Approval for deployment was obtained without significant objection. An environmental bond and appropriate insurances were required. The FPA remains the key stakeholder, and as such issued a lease to SPPL which comprised:

- A Lease over the site known as Area 7
- A lease of pipeline area
- Sub-lease of premises at 21 North Mole Drive, for the purpose of securing the onshore facility

This lease agreement was subject to the following conditions which were met by SPPL:

- Obtaining an independent environmental impact report
- Providing a Bank Guarantee
- Securing commercial insurance to cover public liability.

All of the above provisions remain in force for CETO II.

It is recommended that, for CETO III, wider non-statutory consultation is carried out for marine and terrestrial stakeholders. This should include:

- Environmental special interest groups (eg cetacean societies)
- Military use
- Fishing and aquaculture
- Recreation and tourism users
- Mineral extraction
- Oil and Gas
- Other renewable projects
- Transport
- Local community councils

Where possible and appropriate, local stakeholders should be used for environmental monitoring and marine and terrestrial supply and operations.

8. FINANCIAL MODELLING

A cash flow operational model has been prepared to enable the analysis of the CETO wave energy plant. This model is based on discounted cash flow techniques that are widely used and accepted within the investment community for the assessment of power generation and desalination projects globally.

Provision is made to allow the specific attributes of the CETO device location to be captured as inputs to the model and also to allow the analysis of the CETO plant in either power only, water only or as a hybrid output plant (some water and some electricity).

The assumptions used in this assessment of the technology are based on those provided by SPPL for the scaled up CETO III commercial design. The basis of these assumptions is that the targeted manufacturing cost reductions and scalability is achievable and that the overall nature of the device operation, efficiency and reliability is proven over an extended period by the CETO II pre-production device.

8.1 Model Structure

- **Summary** sheet shows the key inputs and variables used in the model. The project returns and present value for the project are also shown.

- **Capital costs** sheet allows the various elements on the project capital cost to be allocated to one of four categories: Marine Facilities; Sea-Land Interconnection; Land Facilities or Grid Connection. This also converts the capital costs into the local currency unit.

- **Construction** sheet allows the user to allocate the capital costs across a period up to 24 months in duration on a monthly basis to prepare a realistic construction cost profile. This sheet also accounts for any capital grant money that may be received to support the project.

- **Operation** sheet calculates the electricity generation and water production for an array of the CETO units on a six monthly period basis. This uses a straight multiplication of the single unit output and the number of units in the array. This calculation process is likely to require amendment once the energy capture decay effect of multiple arrays has been proven and the final CETO III layout decided. It is possible to include the impact of various marine conditions should these be pertinent at any location. The number of ROCs allocated to the project is also calculated in this sheet.

- **Cash flow** calculates the income and costs associated with the operation of the units. The cost and repayment of any debt is also included. Simple tax costs are accounted for. The project returns are calculated for a 20-year, 25-year and 30-year economic life.

- **Debt** calculates the interest during construction, debt and equity drawdown profiles based on the construction schedule. The operational project loan is also calculated on a mortgage or straight-line repayment basis.
- **Tax** calculates the tax due making allowance for depreciation, interest paid and any carried forward tax losses.
- **Pricing** calculates the inflators and cost and price tracks for those variables and inputs that have indexation applied to them. Indexation is set to zero in the base case.
- **Energy capture** calculates the per-unit electricity production in MWh per year.
- **Water production** calculates the per-unit water production in litres per year.
- **kW performance** holds the input data for the unit power generation capacity on the basis of specified wave periods and wave heights
- **H_2O performance** holds the input data for the unit water production capacity on the basis of specified wave periods and wave heights.
- **Wave resource** holds the data relating to the measured wave height and wave period for the proposed project location.

8.2 Model Convergence

The model converges with the values reported by SPPL in their responses to PBP's additional questions. SPPL indicated a price of 9.3 cents/kWh for a 12 % real pre tax return. This compares with a value of 9.4 cents/ kWh calculated using the same assumptions in the PBP model.

8.3 Sensitivities

The base assumptions used by SPPL were amended slightly to reflect the costs associated with installation in a UK electricity environment and also to provide some conservatism in respect of the ongoing operation of the project ahead of comfort being provided by a successful CETO II outcome. The amendments were:

- Business Rates: increased to £100k per year to approximate the charges likely to be levied on the project by the Crown Estates for it occupying the seabed.
- Insurance: increased to £100k per year as an indicative amount for operational and business insurances.
- Connection Fees: This is included to reflect the potential cost of connecting to the electricity transmission system in the UK.
- Plant Reliability: to introduce an element of conservatism prior to a successful CETO II outcome.

This results in an increase in the electricity price required to make the project viable from £38/MWh (9.4 cents/kWh) to ~£53/MWh on a pre-tax basis.

Further sensitivities were calculated to understand the range of likely outcomes from the project given the +/-30 % tolerance on the capital and operation and maintenance cost estimates provided by SPPL. These are summarised in Table 8.8 and Table 8.9.

TABLE 8.8
RANGE OF REQUIRED ELECTRICITY PRICES (PRE-TAX VIABILITY)

Pre tax	Base	O&M +30%	O&M -30%
Base	£53/MWh	£63/MWh	£44/MWh
Capital +30%	£57/MWh	£67/MWh	£48/MWh
Capital -30%	£50/MWh	£60/MWh	£41/MWh

TABLE 8.9
RANGE OF REQUIRED ELECTRICITY PRICES (POST-TAX VIABILITY)

Pre tax	Base	O&M +30%	O&M -30%
Base	£60/MWh	£70/MWh	£51/MWh
Capital +30%	£64/MWh	£74/MWh	£63/MWh
Capital -30%	£57/MWh	£67/MWh	£48/MWh

The highlighted cells represents PBP's best estimate of the likely outcome of price for the CETO III project at this stage in the development process. The CETO II unit is yet to start its trial phase and, until this is complete, PBP would expect the maintenance costs to bias towards the upper bound with the capital costs remaining around the base case.

8.4 Observations

Recent studies into the evolution of the wave power generation sector indicated that the lower expectation for wave energy capture devices at present is 12 p/kWh. The main drivers for the differential between the CETO III expectations of 7 p/kWh and this range are the marginally lower discount factor used in the assessment and the lower specific capital cost of the CETO device (£1500/kW versus £4000 kW). Even with this price advantage the CETO device will require financial support either through capital grants at the front end or through ongoing support as is available through the Renewable Obligation arrangements in the UK.

There are still uncertainties relating to the plant capital costs and the ongoing costs associated with maintenance and operation of the plant. These should be better understood following the completion of the CETO II development.

The CETO device has an implicit capacity factor of around 43 % on the basis of the data provided by SPPL. This is within the expectations for wave energy capture devices, albeit towards the upper end of expectation (45 %). This will vary from site to site with the wave conditions; however, one of the most significant factors in this will be the unit's reliability. This will be clearer once the CETO II project has completed.

Future installations may benefit from the inclusion of some storage element in the design. The positioning of the storage element within the energy flow of the CETO installation would probably be best to be on the high pressure water side of the process since this would give the greatest flexibility to the scheme.

A storage element in the design may provide benefits in a number of ways:

- the storage element will allow the capital plant (electricity generation or desalination or both) to be optimised to suit the particular wave energy environment and local market requirements. This could present benefits in capital costs.

- the storage element could be sized to hold 'off-peak' energy captured for conversion to 'peak' power at times when electricity demand or prices are highest.

- for electricity and water arrangements the storage element will provide some 'optionality' to the plant allowing the owner/operator to choose between water or electricity output depending on the relative demands and values;

9. CONCLUSIONS AND RECOMMENDATIONS

Generally it appears that the development of the CETO devices is following a logical progression and that experienced, competent and qualified staff are working on the project. Whilst no guarantee can be provided at this stage in the technology's development cycle, on the basis of the information made available to date, PBP believes there to be a reasonable chance of commercial success.

Clearly, the best way of managing the project and its risks is to test the project in a series of discrete steps to help ensure success at the next stage. SPPL has been following this principle with CETO I, design and testing of CETO II, CETO II prototype tests and subsequent plans for CETO III.

PBP's key recommendations are made below. PBP considers that the management of risks is possible by management, through the project lifecycle, of these key items and any other issues that may arise. The presence of a particular recommendation is not to say that SPPL is not already aware of and/or actively managing many of the issues, rather to provide an aide memoir.

It is recommended that:

1. When CETO II is tested it is fully instrumented (eg with upstream and down stream Waverider buoys, stroke detection, pressure sensors etc) to allow a detailed comparison with the predicted results from CFD modelling. Observations on the equipment must also focus on reliability, to understand any potential failure mechanisms (eg fatigue) to inform the design of the commercial CETO III device. Comprehensive environmental surveys and monitoring should also be undertaken.

2. A short period at the end of design stage is included in the project timeline to allow for checking quality issues (eg cross referencing of part drawings, tolerances, materials etc).

3. Variables such as coastline profile, water depth at device, bathymetry, incident wave spectra and directional spreading are considered by SPPL in order that subsequent design of CETO III commercial devices may be successfully deployed in a range of global sites.

4. Consideration is given to the safety of divers and how the need for diver intervention may be minimised through design.

5. A detailed document defining the objectives, success factors and the measurement methodology for the CETO II testing is produced by SPPL in advance of its manufacture and deployment. This will help ensure the maximum benefit is achieved from the tests and help provide confidence in the evolution of the design. The key outputs must focus on reliability, energy conversion and installation and maintenance processes as well as review of costs.

6. In advance of the design for CETO II SPPL incorporates implicit reliability into the design. There are a number of options available to achieve this: redundancy, streamlined design (by reducing connection points and areas that are known to have frequent maintenance requirements), design for robustness, low utilization of mechanical strength (a higher resulting reserve or safety factor), environmental simulation testing of components subject to various environmental loads, use of well-

proven components, Failure Mode and Effects Analysis study, control of manufacturing, fabrication and commissioning in such a way to reduce the incidence of failures induced by poor workmanship or human induced problems, etc.

7. For the CETO device consideration should be made of fatigue of components and piston rod; buckling of the piston rod; wear properties of the seals, pins and bearing surfaces involved; accumulation of debris, bacterial growth, and resulting increase in viscosity of the fluid; filter arrangements and filter quality mesh size and cleaning arrangements; heat generation and dissipation,

8. Fatigue life of the hydraulic piping will need to be considered. BS EN 13480 is a comprehensive standard for the design of industrial piping. Alternatively, ASME codes are also used in the hydraulic industry.

9. Avoidance of piston type accumulators with air as the compressible medium, as the increase in oxygen partial pressure with compression combined with potential catalytic action from debris accumulating over time can lead to auto-ignition and explosion of the accumulator.

10. The design of any handling equipment and vessels for deployment should be considered to ensure safety and economy.

11. Due consideration must be made of the effects of seawater on the water turbine unit.

12. The control and monitoring requirements for the device should be summarized describing the objectives and attributes of the control system

13. Special attention be given to effects on monitoring and control systems from the following - vibration (wave slamming, sloshing of tank contents, local structural vibration, impact, excitation from hydraulic, pneumatic and mechanical systems etc); temperature, humidity, salinity, electromagnetic interference, atmospheric pressure (may fluctuate in sealed compartments), and assumptions on quality and variability of, hydraulic, pneumatic, fibre optic devices and power supplies.

14. An additional Waverider buoy is installed during CETO II, ensuring that there are buoys located both in front of, and behind, the array.

15. SPPL, as an organisation, should consider the operational management requirements for a commercialisation.

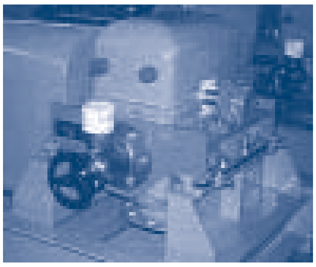
16. Further consideration should be given to production engineering of CETO III when appropriate.

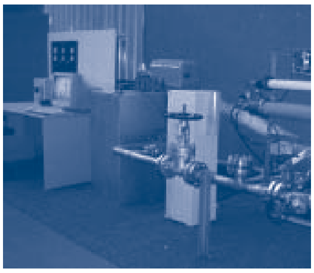
17. A systematic approach to documentation throughout the operation of the device’s life be ensured as the level of documentation is an important step in order to obtain the recognition from financiers and underwriters that the risks (including those affecting performance and production) have been identified and were controlled to the defined risk levels and have been appropriately mitigated through design or operational constraints.

18. Procedures for maintenance, inspection and repair should be developed at an early design stage. Consideration should be given to access to areas to be inspected and the extent, frequency and choice of inspection methods.

19. In developing future project costs a detailed maintenance strategy is developed. This should incorporate planned and unplanned maintenance, spares to be stocked, and maintenance staff and equipment requirements. SPPL suggest that, for larger array installations a trained dive team and workboat would form the core maintenance team. Although the majority of subsea components are bespoke, consideration could be given to undertaking a reliability assessment to estimate the failure rate of specific components when developing the maintenance strategy.

20. A spare parts philosophy be defined taking into account the time from ordering to the availability of replacement parts, criticality of part (regarding survivability and functional requirements), maintenance requirements and costs of stock, preservation and storage of spare parts. A list of spare parts should be produced and included in the maintenance plan.





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