PRELIMINARY WORKS ASSOCIATED WITH 1MW TIDAL TURBINE

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The work described in this report was carried out under contract as part of the DTI Technology Programme: New and Renewable Energy, which is managed by Future Energy Solutions. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the DTI or Future Energy Solutions.
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EXECUTIVE SUMMARY

The original complete DTI submission for funding for the Seagen project included all activities associated with the site selection, site consenting, design, manufacture, assembly, testing and decommissioning of the proposed tidal turbine device was submitted in June 2003. Through consultations with DTI and FES, it was decided to split the overall project into two phases;

- Phase I: Preliminary Works – associated with site selection, consenting and conceptual design and additional work associated with the Seaflow project.
- Phase II: Construction and Operation – associated with detail design, manufacture, testing, installation, testing, extended operation, environmental monitoring and de-commissioning.

The contract for Phase I was awarded to the project vehicle company Seageneration Limited (SGL) for work to commence in April 2004.

This report details the activities for the “Phase I: Preliminary Works” contract associated with the tidal turbine Seagen. However, as part of this contract some additional funding for research associated with the previous Seaflow project was included.

This additional research has been conducted on the Seaflow tidal turbine and has been reported in the previous Seaflow final report published under contract T/06/00210/00 and is available on the DTI website, so it is not included in this report.

The first objective for the initial concept design phase for the Seagen tidal turbine was to complete the conceptual studies of a machine capable of producing in excess of 1.0MW of electricity comprising twin two bladed rotor horizontal-axis turbines that resemble a 2-bladed wind turbine, but with the rotors underwater. The turbine powertrains are mounted either end of a cross beam which slides vertically up and down a pile for servicing. The pile is fixed into a drilled socket in the seabed. The powertrain comprises a rotor, gearbox and generator.

The second objective of the project was to identify a site for the turbine and obtain all the necessary permissions to install it, part of which involved conducting an Environmental Impact Assessment into the turbine’s effects on marine life and processes, the landscape, and other sea users.

In parallel to this activity as part of the overall design process Marine Current Turbines Ltd then evolved the design to pre-detailed design stage, refined concepts and established relationships with key suppliers.

The project was managed by the tidal device developer, Marine Current Turbines Ltd on behalf of the project vehicle company Seageneration Limited. All other parties involved with this phase of the project were employed as contractors to support the Seagen activity, the major contributors being: Seacore, a marine construction and geotech site investigation company; Titan Surveys Ltd, an oceanographic survey company; Royal Haskoning, an environmental consultant; and Corus, the steel manufacturer.

1 Development, installation and testing of a large-scale tidal current turbines: Partners IT Power, Marine Current Turbines Ltd, Seacore, Bendall's Engineering, Corus
The project was granted FEPA consents in December 2005 by the Environment and Heritage Service (EHS) of Northern Ireland and subsequently The Crown Estate prepared a seabed lease document in May 2006.

1. BACKGROUND

1.1 Previous Work

The origins of the *Seagen* project can be traced back a long way, starting with a river current turbine project that ran from 1976-84. One of the instigators was Peter Fraenkel, initially from within ITDG but then in the newly-formed IT Power. The turbine used a vertical-axis Darrieus-type rotor, and was moored off the bank of the river Nile in Juba, Sudan, where it was used for irrigation pumping. The turbine performed well, pumping 2000 litres/hour through a head of 5m from a current of 1m/s. The design was subsequently developed further, and has been marketed with a horizontal-axis rotor as both a water pump and an electric generator.

![River current turbine on the Nile, Sudan, 1982](image)

*Figure 1: River current turbine on the Nile, Sudan, 1982*

The river current turbine demonstrated the potential of kinetic-energy water turbines, or “zero-head hydro”. There was clearly a large amount of energy in flowing water, and it was realised that this could be used to generate electricity. It took a number of years before a follow-on project could be put together, but in the 1990’s IT Power began work on another turbine, this time designed specifically to
produce electricity from tidal currents\(^2\). The turbine, shown in Figure 2, was suspended beneath a floating raft moored in the Corran Narrows, at the entrance to Loch Linnhe in Scotland. The turbine had a 3.5m diameter rotor, and had a rated electrical power of 10kW. It was successfully tested in 1994, and produced a maximum of shaft power of 15kW. The project demonstrated that such a rotor could generate power with a reasonable efficiency, but also showed significant difficulties working with moorings.

\[\text{Figure 2: The Loch Linnhe turbine being deployed.}\]

In the following years, IT Power was involved with several feasibility studies for tidal turbines\(^3\). During this time the concept of a pile-mounted turbine was developed in conjunction with Seacore, a company which already used large-diameter monopiles for general marine construction work.

The Seaflow project started with a grant from the European Commission in 1998. The partners also approached the DTI for support, and this led to an independent study being commissioned on the feasibility of the concept\(^4\), which was generally supportive of the technology. The DTI awarded grant support to the Seaflow project in June 2001.

\(^2\) Tidal Stream Energy Demonstration Project; Partners: IT Power, Scottish Nuclear Ltd. & NEL; 1994

\(^3\) Feasibility Study of Tidal Current Power Generation for Coastal Waters: Orkney & Shetland; Project for Orkney Islands Council and Shetland Islands Council under EU Contract XVII/4 1040/92-41; Partners: International Centre for Island Technology, IT Power; 1995

The Seaflow system was installed in May 2003. The project has been very successful and is reported in detail in reference 1.

Figure 3: The Seaflow 300kW tidal turbine at Lynmouth

Peter Fraenkel, a director of ITP at the time of the grant award for Seaflow, decided to establish a limited company known as Marine Current Turbines Ltd to commercialise the technology. During the establishment of this business, Marine Current Turbines Ltd acquired all of the previous IPR vested in ITP.

1.2 Resource & Cost Estimates

In parallel with technology development, Marine Current Turbines Ltd was studying the potential tidal resource for future business planning. Several independent studies have been completed investigating the tidal resource and economics of this technology in the UK. This work has recently been complemented by the Carbon Trust Report. The conclusions were that there was a very significant potential for deployments of commercial tidal stream arrays, and that electricity can be generated at economic rates.

1.3 Partnership & Complementary Projects

The project relating to the preliminary works of Seagen has been a projected managed by MCT Ltd with no consortium partners.

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7 Atlas of UK Marine Renewable Energy Sources; DTI report 04/1532, UK; Partners: ABP Mer, The Met Office, Garrard Hassan, Proudman Oceanographic Laboratory
8 OptCurrent, Optimising the Performance (Electrical and Economic) of Tidal Current Turbines, EC Contract No. JOR3CT980205; Partners: Robert Gordon University, IT Power, University College Cork, Thetis; 1998-2001.
9 Future Marine Energy, Results of the Marine Energy Challenge, Cost Competitiveness and Growth of Wave and Tidal Stream Energy; The Carbon Trust, UK.
MCT Ltd has retained the relationships with some of the partners of the previous Seaflow project, but using these relationships on consultancy rather than consortium basis (i.e. Seacore, Bendalls and ISET). During the project MCT Ltd has established strong consultancy based relationships for ongoing work relating to the environmental monitoring requirements.

Under the agreed FEPA license, an agreed Environmental Monitoring Programme (EMP) has been implemented. The EMP has been designed to include large elements of generic research that will benefit the wider turbine community. These generic research areas have attracted direct funding to the consultants conducting the scientific research (The Sea Mammal Research Unit – SMRU) from sources such as the DTI’s Renewable Action Group (RAG) and Npower/Greenpeace Juice fund.

Marine Current Turbines Ltd. will be the ultimate owners of the Intellectual Property Rights arising from the project, as it would be developing the subsequent commercial tidal turbine arrays.

2. COMPETITIVE TIDAL STREAM TECHNOLOGIES

2.1 Designs

As in the early stages of other technologies, such as wind and wave, many different tidal stream concepts have been, and continue to be, proposed. Most are based on rotating rotors, either horizontal or vertical-axis. Some horizontal-axis machines have flow enhancers, in the form or diffusers or concentrators, that take the flow from a larger area and funnel it into a smaller rotor. The main types are summarised below:

- Horizontal axis turbines: e.g. Seaflow, Hammerfest Strøm, TidEl, THGL.
- Horizontal-axis turbines with concentrators or diffusers: e.g. Lunar Energy, Teamwork Technology, UEK.
- Vertical axis turbines: e.g. Davis, Kobold, Gorlov, Edinburgh University, Waverotor.

There are a few turbines that work on fundamentally different principles, notably the Stingray turbine which has a single “wing” that flaps up and down in the current, and the Rochester Venturi which runs a conventional turbine on the pressure drop generated by a constriction in the flow.

2.2 Competitors

A brief description of various competitive turbines is given below. It is not appropriate here to enter into a discussion of the merits of the various concepts, particularly since a number of the projects have also received grant funding from the DTI.

This list shows the major projects. In addition to these there are numerous academic groups, individuals and small companies that have proposed different forms of tidal turbines. Many of these are simply ideas, but some have been tested at a small scale.
2.3 **Commercial Status**

As yet, no tidal turbines are commercially available. A number of devices have been, or are being, tested on a small scale, and a handful of machines have been tried as full-scale prototypes. Having had a large-scale prototype installed for over three years, the *Seaflow* concept is one of the forerunners in the race to a commercial machine, and the MCT *Seagen* product is effectively a pre-commercial prototype, after satisfactory development during the ensuing phase of this project, it is proposed that Seagen systems will be deployed as a small array under the Marine Development Fund (MDF).
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<th>Company/Organisation and device name(s)</th>
<th>Description</th>
<th>Website</th>
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<tr>
<td>Seaflow/Seagen</td>
<td>Marine Current Turbines Ltd</td>
<td>Axial flow rotors with full-span pitch control mounted on monopile support structure – Seaflow 300kW single rotor experimental test system installed May 2003 and Seagen is 1MW twin rotor commercial prototype under development for installation in 2006.</td>
<td><a href="http://www.marineturbines.com">www.marineturbines.com</a></td>
</tr>
<tr>
<td>Blue Concept</td>
<td>Hammerfest Strøm</td>
<td>Horizontal-axis turbine, 3-blade rotor, rated at 300kW. Fully submerged on gravity foundation. Installed in Norwegian fjord in December 2002. Has support from Statoil and formerly from ABB (Norway) and Rolls Royce. No new information released from web site since 2002.</td>
<td><a href="http://www.e-tidevannsenergi.com">www.e-tidevannsenergi.com</a></td>
</tr>
<tr>
<td>Rotech Tidal Turbine</td>
<td>Rotech/Lunar Energy</td>
<td>Horizontal-axis turbine in a double ended duct-diffuser. Model tests completed at Glasgow University. Technology developed by Rotech of Aberdeen which produces suction dredging pumps. A 1MW system to be tested in 2005(?), with larger turbines to follow. The project has been part-funded by a DTI New and Renewable Energy R&amp;D grant.</td>
<td><a href="http://www.lunarenergy.co.uk">www.lunarenergy.co.uk</a></td>
</tr>
<tr>
<td>Stingray</td>
<td>The Engineering Business</td>
<td>Full-scale prototype tested for two short periods in Shetland. Rated at 150kW. The project has been part-funded by a DTI New and Renewable Energy R&amp;D grant. Future development “on hold”.</td>
<td><a href="http://www.engb.com">www.engb.com</a></td>
</tr>
<tr>
<td>TidEl</td>
<td>SMD Hydrovision</td>
<td>Twin-rotor horizontal axis machine on a mooring system attached to the twin anchorages on the seabed by chains or cables so that the turbines can be flipped over in a vertical plain when the current changes direction. Tested at NaRec on a small scale in a tank. The project has been part-funded by a DTI New and Renewable Energy R&amp;D grant. DTI funding also announce for a 1MW turbine to be installed in Orkney in 2006.</td>
<td><a href="http://www.smdhydrovision.com">www.smdhydrovision.com</a></td>
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<tr>
<td>Kobold Turbine</td>
<td>Enermar &amp; Ponte di Archimede nello Stretto di Messina S.p.A.</td>
<td>A small 20kW vertical-axis (Darrieus) turbine which has been tested under a floating moored buoy in the Straits of Messina in 2002. Developed by technical staff from Naples University. Not clear if future development is planned.</td>
<td><a href="http://www.dpa.unina.it/english/edag/eng/renewable-energy.htm">www.dpa.unina.it/english/edag/eng/renewable-energy.htm</a></td>
</tr>
<tr>
<td>HXE</td>
<td>Hydrohelix Energies, France</td>
<td>A row of short-ducted axial-flow turbines set in a row across the seabed.</td>
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<tr>
<td>Gorlov Turbine</td>
<td>GCK Technology</td>
<td>Vertical axis, helical Darrieus turbine. Believed only tested in model form. Understood to be involved with project in South Korea and in cooperation with Verdant Power (qv)</td>
<td><a href="http://www.gcktechnology.com">www.gcktechnology.com</a></td>
</tr>
<tr>
<td>Underwater Electric Kite</td>
<td>UEK Systems</td>
<td>Twin, ducted axial flow rotors, attached to a moored raft and intended for uni-directional currents as in rivers (i.e. not suitable for reversing tidal flows).</td>
<td>uekus.com</td>
</tr>
<tr>
<td>Stream Turbine</td>
<td>Seapower</td>
<td>Seapower is proposing a small Savonius rotor for getting energy from currents.</td>
<td><a href="http://www.seapower.se">www.seapower.se</a></td>
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<tr>
<td>Rochester Venturi</td>
<td>RVCo Ltd, Gentec</td>
<td>This consists of an array of venturis on the seabed aligned with the tidal flow producing a reduced pressure at their throats. The pressure difference then being used by interconnecting the venturi throats with manifolde pipes to drive a conventional turbine by sucking air or water through it.</td>
<td><a href="http://www.hydroventuri.com">www.hydroventuri.com</a></td>
</tr>
<tr>
<td>THG</td>
<td>Tidal Hydraulic Generators Ltd</td>
<td>An array of small horizontal-axis rotors mounted on a frame/platform resting on the seabed. A simple single-rotor prototype of about 2kW has been briefly tested on a floating platform.</td>
<td>No web site</td>
</tr>
<tr>
<td>Open Center Turbine</td>
<td>Florida Hydro Power and Light Company</td>
<td>Axial flow fixed pitch high-solidity contra-rotating rotors on same axis, with rim drive, tethered for uni-directional use in the Gulf Stream. Small prototype has been built and tested (circa 10 or 20kW). Believed to be receiving technical co-operation from the US Navy research centre.</td>
<td><a href="http://www.floridahydro.com">http://www.floridahydro.com</a></td>
</tr>
<tr>
<td>Open Centre Turbine</td>
<td>Open Hydro Ltd</td>
<td>Dublin based company established to design develop and the ultimate commercial exploitation of the Florida Hydro Power and Light Concept. The will be deploying a system at EMEC in August 2006.</td>
<td><a href="http://www.openhydro.com/company.html">http://www.openhydro.com/company.html</a></td>
</tr>
<tr>
<td><strong>Seasnail</strong></td>
<td>Robert Gordon University &amp; AREG</td>
<td>Primarily a tidal turbine fixing system, to use hydrodynamic downforce to hold the system to the seabed, tested with a very simple powertrain.</td>
<td><a href="http://www.rgu.ac.uk/cree">www.rgu.ac.uk/cree</a></td>
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<tr>
<td><strong>Tocardo Tidal Current Turbine</strong></td>
<td>Teamwork Technology, Netherlands</td>
<td>Proposed an array of small, shrouded horizontal-axis rotors with rim drive</td>
<td><a href="http://www.waveswing.com">www.waveswing.com</a></td>
</tr>
<tr>
<td><strong>Tidal Stream Turbine</strong></td>
<td>J.A. Consult, UK</td>
<td>A horizontal-axis turbine on a rigid mooring that allows the powertrain to be floated to the surface for maintenance. Tested as a small model in the Thames. The project has been part-funded by a DTI New and Renewable Energy R&amp;D grant.</td>
<td><a href="http://www.tidalstream.co.uk">www.tidalstream.co.uk</a></td>
</tr>
<tr>
<td><strong>Davis Turbine, Tidal Fence</strong></td>
<td>Blue Energy Canada Inc</td>
<td>A vertical-axis Darrieus turbine derived from Canadian government supported projects in the 1980s. Turbines are mounted in rectangular ducts through a so-called “tidal-fence” across the flow.</td>
<td><a href="http://www.bluenergy.com">www.bluenergy.com</a></td>
</tr>
<tr>
<td><strong>Various</strong></td>
<td>Verdant Power, USA</td>
<td>Have tested 16kW 10ft diameter axial flow turbine under a raft moored in the East River in NY. Now developing a site with the Gorlov Turbine. Have announced a development of numerous 50kW axial flow turbines off New York.</td>
<td><a href="http://www.verdantpower.com">www.verdantpower.com</a></td>
</tr>
<tr>
<td><strong>Waverotor</strong></td>
<td>Ecofys</td>
<td>A slanting-blade, Darrieus-type rotor that works on both wave and tidal currents. Tested on a small scale in Denmark.</td>
<td><a href="http://www.ecofys.com">www.ecofys.com</a></td>
</tr>
<tr>
<td>Tidal Stream Generator</td>
<td>Edinburgh University</td>
<td>Large vertical axis turbine with self adjusting vertical blades, suggested by Stephen Salter. Scale prototype proposed.</td>
<td><a href="http://www.mech.ed.ac.uk/research">www.mech.ed.ac.uk/research</a></td>
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<tr>
<td>Statkraft, Norway</td>
<td>Promoting a floating tidal turbine concept with two pairs of contra-rotating axial flow rotors cantilevered out below a raft</td>
<td><a href="http://www.statkraft.com">www.statkraft.com</a></td>
<td></td>
</tr>
<tr>
<td>Clean Current, Canada</td>
<td>Believed to be promoting a kind of axial flow Wells Turbine for use in bidirectional flows. Website closed to the public.</td>
<td><a href="http://www.cleancurrent.com">www.cleancurrent.com</a></td>
<td></td>
</tr>
<tr>
<td>University of Strathclyde, Prof. Joe Clark</td>
<td>Contra-Rotating Tidal Current Turbine for Power: the aim of this project is to demonstrate the successful operation of a 1/3-scale model through a combination of computational modelling and laboratory/field testing.</td>
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<tr>
<td>Tidal Generation Ltd</td>
<td>Established in 2005. Developing a device with an axial flow turbine targeted at water depths of greater than 30m with a novel seabed attachment system – believe to be targeted for installation at EMEC in 2008</td>
<td><a href="http://www.tidalgeneration.co.uk/">www.tidalgeneration.co.uk/</a></td>
<td></td>
</tr>
<tr>
<td>Swanturbines</td>
<td>Established in 2001 as a technology offshoot from Swansea University. Believed to be developing a single rotor axial flow fully submerged device in association with a nine member consortium, with the objective of installing a 350kW scaled demonstrator in 2008 followed by a 1MW device in 2010.</td>
<td><a href="http://www.swanturbines.co.uk/">www.swanturbines.co.uk/</a></td>
<td></td>
</tr>
<tr>
<td>Pulse Stream 100</td>
<td>Consortium of BMT Renewable, IT Power, CIC Omec, Econnect, Pulse Generation and University of Hull</td>
<td>Pulse Generation own the IPR of the technology which is targeted at shallow water exploitation of oscillating tidal stream energy, First device expected to be tested in 2007 in the Humber generating 100kW, funded by the DTI (£0.9M).</td>
<td><a href="http://www.pulsegeneration.co.uk">www.pulsegeneration.co.uk</a></td>
</tr>
</tbody>
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3. **PROJECT OBJECTIVES**

The objectives for the *Seagen* Project – Phase 1: Preliminary Works were:

1. To undertake a site selection process and justify the selection of the proposed installation location.

2. To complete the required site assessments for the detailed design phase to be conducted under a separate Phase II contract, this work included:
   - Oceanographic surveys at the proposed test location.
   - Bottom mount ADCP current profiling surveys
   - Desk top metocean studies
   - Cable route assessments
   - Geotech site evaluation – desk top study
   - Geotech site investigation – core sampling

3. To undertake the necessary environmental due diligence process resulting in consents for the installation, this work included:
   - Environmental Scoping
   - Environmental Impact Assessment
   - Issue of appropriate licenses

4. Conceptual design activities including reviewing:
   - Pile design concepts
   - Installation methodologies
   - Producing initial specifications for major outsourced components (gearboxes, generators, control systems, blades etc)
   - Product structure documentation etc

5. The project also included additional support for extended testing on *Seaflow* in the following areas:
   
   (i) To gain an increased understanding of the complex tidal flows and the interaction of the rotor with the varying velocity profile of the water column, with the aim of improving the control system and minimising dynamic components of thrust, torque and power areas.

   (ii) To obtain a more complete measurement of the load pattern applied to the blades; to better understand the structural response to turbulence; and also to potentially assist in the investigation of blockage effects on rotor performance.

   (iii) To measure and analyse the sea borne acoustic noise generated by a tidal turbine, to be reviewed by marine biologists as input to future
environmental impact assessments and assess the impact on maritime navigation equipment.

4. SITE SELECTION

4.1 Geographic Site Selection Process

A detailed site selection report was included as Annex 1 of the Environmental Statements (ES) completed by Royal Haskoning (RH) in June 2005.

In summary the site selection report considered two alternative locations, Lynmouth and Strangford Lough.

Whilst it is often questioned why MCT did not consider EMEC, it should be noted that when MCT Ltd initiated the Seagen project process, the EMEC tidal test site was only a concept that had then to secure funding. If the Seagen project had gone to plan, it would have been installed in 2005, at the time of writing EMEC are stating that the tidal technology test site in Orkney will be operational in late 2006. The inherent risk of running two development processes in parallel only added to the risk of the overall programme, and the potential for EMEC being ready in time to test the Seagen device was considered a significant commercial risk.

MCT Ltd therefore considered the sites in Strangford Lough and the Lynmouth location.

The site selection process concluded that Strangford was the preferred location as:

- The site is sheltered, and based on MCT Ltd’s experience in Lynmouth, exposed sites hamper access, cause delays in technology development and incur additional cost during the development phase.

- The potential energy at Strangford Lough is representative of early commercial locations with high energy yields and would enable MCT Ltd to achieve the agreed DTI development objectives.

- It was established through stakeholder consultation that the area occupied by a single, temporary installation was not perceived to have a significant environmental impact.

- The site has an interesting and diverse ecology, and provided an excellent opportunity to monitor the impacts with species found throughout the UK. The Queen’s University Belfast marine research laboratory in Portaferry, less than 1 km from the proposed installation, offered an ideal capability to monitor any potential impacts.

- Access to the location was within a reasonable travel time from MCT Ltd’s offices in Belfast, the travel time being similar to that to Lynmouth.

- The marine support infrastructure exists in the proposed location, divers, workboats, RIB’s etc, plus the location is close to several significant ports which have no tidal access constraints.

- The requirement for a 11kV, 1MW grid connection exists within 500m of the proposed installation site, the Lynmouth grid connection was circa 3 km by sea then several miles by road.
- The south west facing lough provides an ideal sheltered installation which allows year round opportunities for installation. Exposed locations such as Lynmouth tend to prohibit installation between October and April over the autumn/winter periods.

4.2 **Site Selection Process Within Strangford Lough Narrows**

4.2.1 **Physical Site Selection Criteria**

The key physical criteria for selecting a site within the Strangford Narrows were:

- 2-3m/s maximum spring peak current (4-6 knots), in order to achieve an economic size of rotor;
- Uniform flow with strong currents for long periods to maximise power available;
- Minimum depth 24m to chart datum or lowest astronomical tide (LAT), to provide adequate space for a rotor;
- Maximum depth 28m, to remain within capability of Seacore’s largest available jack-up barge at the time;
- Close (less than 1km) to an 11kV, 1MW established grid connection.
- Not too exposed to open sea waves and wind, to reduce the risk of weather-induced delays and to maximise time available for installation and servicing;
- No major conflicts with other sea users
- Position 75m from main navigation line

4.2.2 **General Site Selection Principles**

Once the Strangford Lough Narrows location had been identified and agreed, finalising the location of the device within the Narrows was undertaken based on the following information:-

- All options for grid connection within the Narrows were assessed. A existing grid connection of 11kV, 1MW capacity was identified with the Narrows within 25m of the shore at the Strangford sewerage pumping station.
- Cable installation methods were assessed and reviewed with stakeholders. It was obvious that any form of cable burial or surface laying were not appropriate within the lough, so Horizontal Directional Drilling (HDD) was confirmed as being the preferred option by EHS.
- MCT liaised with several HDD subcontractors, based on the known geology in the area (via the desk top geotechnical studies) it was concluded that the safe range to consider for HDD was 500m.
- Through consultation with the MCA, it was suggested that the pile be positioned a minimum of 75m away from the navigation line shown on the relevant UKHO Admiralty charts.
- The depth constraint for the device had been established based on the rotor size of 16m diameter.
- The tidal velocity constraint was defined.
- The direction of flow of the current on ebb and flood would ideally be 180° apart.
- The preferred location on the seabed for the pile installation would have minimal overburden.
- The preferred location would be as far away from known common seal haul out locations as possible.

Taking all of these factors into consideration, the position selected is 54°22.119N, 5°32.749W (WGS84).

Figure 4: Agreed Location of Seagen in Strangford Lough Narrows
4.3 Site Permissions

The regulatory framework governing construction at sea off the coast of Northern Ireland is complex. There are several relevant pieces of legislation and EC Directives that cover coastal waters, and these are administered by different government departments depending on the output of the machine.

The consents to be obtained for the Seagen marine current turbine in Strangford fell into four broad categories:

- Environment & Heritage Service FEPA license for temporary deposit in the sea
- The Crown Estate Lease arrangements for the seabed subject to FEPA license
- Commissioner of Irish Lights - Navigation and shipping interests;
- Cable and electrical connections on land.

Lease arrangements for the seabed are relatively straightforward, and are handled by The Crown Estate, which owns nearly all the seabed around the UK within the 12 nautical mile limit.

In Northern Ireland the Coastal Protection Act (CPA) legislation does not exist and was therefore not applicable to this process.

The legislation covering the marine environment and usage in Northern Ireland is the responsibility of the Environment and Heritage Service, EHS. Permission needs to be obtained under the Food and Environmental Protection Act, 1985 (FEPA). EC Directives on Environmental Impact Assessments (Directives 85/337/EEC and 97/11/EC) are also implemented through FEPA. The FEPA process involves widespread consultation with environmental groups, fishermen and other sea-users, so the process can be lengthy and involved if objections are raised.

Usually the land-based consents for bringing a cable ashore and erecting switchgear are the responsibility of the local planning authority and the landowners, however in Northern Ireland Northern Ireland Electricity, NIE, have statutory “permitted development” rights to build substations and lay cables. A lease was agreed for the substation site within a field adjacent to the shore of the lough. The Planning Service Northern Ireland, a division of the Department of the Environment Northern Ireland (DoENI) has been kept full informed of the proposal. The land based construction impacts have been included in the overall ES.

Consultation was carried out with all the official bodies that have a statutory input to the consents process, in advance of submitting formal applications. Discussions were also held with many other local government representatives, local non government organisations and wider stakeholders who would have strategic interest when the technology comes to commercial fruition. There was general enthusiasm for the tidal turbine concept, and the responses were nearly all positive or neutral.

Official applications for permission to install were made in November 2003. A FEPA licence was granted by DEFRA on 16 December 2005. A rental agreement was made with The Crown Estate dated May 2005, after the other permissions were received, as this was conditional upon the granting of all other licences.
A stringent requirement for the FEPA license was that an Environmental Monitoring Programme should be implemented and that there should be an agreed environmental baseline prior to operation of the turbine. This monitoring activity has been ongoing since April 2005.

4.4 Environmental Impact

One of the pre-requisites for the FEPA licence was that the project produce an Environmental Statement, ES. In December 2003 the EHS provided a letter outlining the scoping requirements for the Strangford location.

In April 2004, once the DTI had agreed to fund the project, an independent environmental consultant was appointed to undertake the ES. The initial phase of this work was to produce a formal Environmental Scoping Study document, that included the recommendations from EHS as the basis. This document was provided to EHS who distributed it to their statutory consultees, MCT Ltd also distributed the document to a wider list of non government organisations (NGO's), quasi autonomous government organisations (QUANGO's), local and national government representatives and other interested individuals.

The EIA and licence applications for Seagen were groundbreaking in both Northern Ireland and European contexts, requiring the various authorities to think through the implications of granting consents for the deployment of the Seagen system in a protected European habitat.

Figure 3: Artist impression of the turbine prepared for the Environmental Statement.
### 4.4.1 Possible Impacts

The EIA scoping document required that the following impacts be evaluated:

- The impact on benthos;
- The impacts on cetaceans (harbour porpoises etc), pinnipeds (common seals, grey seals) and elasmobranches (basking sharks, thresher sharks etc);
- The physical/chemical characteristics of material arising from the installation of the turbine and the effects of their deposition;
- Effects on water flows;
- Effects on sediment transfer;
- Impacts of construction on fish resources and invertebrates;
- Impacts on marine flora and fauna in terms of scouring of the sea bed;
- Potential for physical contact with fish, sea birds and mammals;
- The visual impact of the turbine structure above the water;
- The noise disturbance implications of the development;
- Possible effects on tourism;
- Highway access implications.

### 4.4.2 Objections & Concerns Raised

Concerns raised during the consultations were relatively few, and all were addressed within the Environmental Statement with suggested mitigation and reactive measures to be detailed in a required Environmental Action and Safety Management Plan.

There were no concerns with the local shell fish potters, as the turbine location was in a deeper water area and central in the Narrows in a more energetic area than they usually deploy their pots. In addition currently all commercial fishing with mobile gear has been banned within Strangford Lough.

A number of ecological concerns were raised by the Environment and Heritage Service Natural Heritage (EHS-NH) section and the Ulster Wildlife Trust (UWT), World Wildlife Fund (WWF) and Joint Marine Partnership.

These concerns were focused in several areas:

1) All parties were concerned about the potential for the presence of the system to cause dislocation of the current common seal population. Within Strangford Lough the common seal colony is one of the protected features under the European Habitats designations for the site.

2) All parties expressed concerns about the potential for impact of common seals, harbour porpoises and basking sharks with the turbine whilst operational.
3) EHS-NH were concerned about certain rare corals and sponges which were included in the European Habitats designated reef sites within the proximity of the turbine. There were several concerns in this area relating to:-
   a. Disturbance by the jack up during installation and decommissioning, would the benthic ecology recover or would the damage be permanent.
   b. Smothering during the pile socket drilling operations
   c. Quasi-permanent reduction in area due to pile and cable installation
   d. Effects of scour

4) Strangford Lough has a very active Sailing community, with the leisure boat fraternity dominating the use of the Lough. During the summer several large sailing regattas are held that cover several days. Whilst the clearance above the turbine is adequate to offer safe passage to all sailing vessels whilst the turbine is operational, as mitigation on safety grounds MCT has offered to switch the turbine off when sail boat racing occurs close to the pile.

5) There are only two significant size boats that enter the Lough each year, the Commissioner of Irish Lights Inspection vessel Granuaile and the SS Waverley. The MCA has some concerns about the manoeuvrability of these vessels and have requested that the turbine be shut down when these vessels are in close proximity, the turbine has also been located 75m to the west of the main navigation line on the UKHO chart.

6) Notably there has been no significant issue of concern expressed about the visual impact of the system within this declared Area of Outstanding Natural Beauty, and this maybe due to the fact that the residents have accepted this as a temporary installation.

4.4.3 EIA Survey Results

The Environmental Scoping Study was circulated in June 2004, and as a result of the feedback from this study, either in written form or through verbal consultation, the final definitive issue of the Environmental Statement was issued in June 2006.

In general the conclusion of the ES was that the environmental impacts of the scheme were “minor” or “insignificant”.

However, the proposed location in Strangford Lough has the following designations:-
   - RAMSAR
   - Special Area of Conservation (SAC under the European Habitats Directive)
   - Special Area of Preservation (SPA under the European Habitats Directive)
   - Marine Nature Reserve (MNR)
   - Area of Outstanding Natural Beauty (landscape only, does not include seascape)
During the consenting process a European Court ruling had been made on mechanical cockle farming activity in Wadensee in the Netherlands, the ruling provided an interpretation of the “precautionary principle” which effectively prohibited any developments in areas designated European Habitats Directive. The ruling of the case C127-02 was published on 7th September 2004 and ruling 4 states:

“Under Article 6(3) of Directive 92/43, an appropriate assessment of the implications for the site concerned of the plan or project implies that, prior to its approval, all the aspects of the plan or project which can, by themselves or in combination with other plans or projects, affect the site’s conservation objectives must be identified in the light of the best scientific knowledge in the field. The competent national authorities, taking account of the appropriate assessment of the implications of mechanical cockle fishing for the site concerned in the light of the site’s conservation objectives, are to authorise such an activity only if they have made certain that it will not adversely affect the integrity of that site. That is the case where no reasonable scientific doubt remains as to the absence of such effects”

Royal Haskoning thus proposed an adaptive management approach for the system operation association with the EMP. All EC Habitat Directive designated features within the vicinity of the turbine would be monitored before installation and the pre-installation baseline agreed with EHS. Any adverse or significant deviations from the baseline after installation would then be detected through the EMP, and pre-agreed reactive measures would be implemented as necessary. The ultimate caveat being that if a significant environmental change did occur, then the turbine would be decommissioned.

Royal Haskoning prepared a draft appropriate assessment for EHS. It is the regulator’s responsibility to conduct an Article 6 appropriate assessment. The results of the Royal Haskoning draft appropriate assessment are included in Appendix III.

The non technical summary of the ES is included as Appendix IV.

4.4.4 Opportunities For Generic EIA Research

The EIA process for Seagen has highlighted that there are some ideal opportunities for generic research with the Seagen installation. The outcomes of this work will then benefit the wider tidal stream energy community.

Examples of these studies include:-

- Impacts of operational noise on cetaceans, pinnipeds, elasmobranches and fish
- Monitoring interactions of cetaceans, pinnipeds, elasmobranches through visual and potentially active sonar techniques
- Long term impacts in benthic communities
- Establishment of tidal energy extraction impacts

The generic benefit of this work has been recognised by DTI Rag, the work being undertaken for SEA 6 and Npower Juice.
5. **DESCRIPTION OF THE TURBINE**

Seagen resembles a wind turbine, but with the rotor totally submerged in seawater when working. It has two 2-bladed, horizontal-axis rotors, 16m in diameter mounted on the end of a cross beam. The rotors are directly mounted onto shafts of speed-increasing gearboxes, which in turn drive the generators. The rotors are turned by the flow of water, and the generators produce electric power. The orientations of the rotors are fixed, but the blades can be pitched through 180° so that it can be used for currents in both directions, either on the ebb or the flood tide. In the proposed installation the turbines will be facing down the lough facing directly into the flood tide.

The cross arm is mounted on a steel tube or “monopile” which is fixed into the seabed. The powertrains (rotors, gearboxes and generators) are mounted on the cross beam, which is equipped with a collar which can slide up and down the pile. With the cross beam out of the water, there is easy access to the working components for inspection and maintenance. Apart from the powertrains, all the other systems are housed in a ‘pod’ on the top of the pile. This means they can be kept in a controlled, dry environment, which is especially important for the electrical and control components.

5.1 **Concept Design**

The basic principles of the Seagen concept were:

- It would be mounted on a monopile, giving a stable platform both to operate the machine and to access it.

- No divers or underwater operations should be required at any point in the life of the machine for servicing and maintenance. Servicing would be by sliding the collar holding the powertrain up the pile and out of the water using a hydraulic lifting mechanism integral to the turbine.

- Access should be by small boat or RIB (Rigid Inflatable Boat).

- Only the powertrain would be submerged. All the control and power electronics to be housed in a control pod on the top of the pile, in the dry.
5.2 Rotor

Rotor performance is the key to the successful exploitation of the technology, and the loads on the rotor are the starting point for the design of the turbine. It was therefore important to develop a means of modelling the rotor performance, and this was done by MCT Ltd. MCT have refined the model used for the Seaflow project using the data acquired from testing.

The rotor diameter was set at 16m based on the measured tidal flow data at Strangford to produce 1MW of electricity at 2.8m/s, during the optimisation process the water depth constraints were also considered in association with the required nominal 3m clearance above the rotor required for safe yacht passage. In 24m depth of water at LAT this leaves 5m below the blade tips to the seabed. This depth was considered acceptable by Seacore for the safe operation of their jack up Excalibur.

Wind turbines need to be yawed in order to face into the wind, the direction of which varies. A tidal turbine has the advantage that the direction of the flow is predictable, and the ebb and flow are very often along roughly the same line. The Seaflow turbine can be changed from operating on a flood tide to an ebb tide simply by reversing the blades, pitching them through 180°. The ability to pitch also meant that the blade angle could be optimised in any given current, the blades could be feathered to brake the rotor gently, and the maximum power generated could be limited by angling the blades away from the optimum position. It was therefore decided to implement full-length blade pitch control.

Figure 4: The Seagen concept.
The choice of two blades was made after considering both 2 and 3-blade options. Rotors with three blades have the advantage of being slightly more efficient, and they are also more balanced, inducing less fatigue load on the gearbox and the structure. However, 2-blade rotors are much more easy to handle, as they can be laid flat on the deck of a ship, and do not need to be raised so far to clear the water. This is likely to be an important consideration for commercial turbines, where easy removal and replacement of the powertrain will increase the availability of the machines. 2-blade rotors are more simple mechanically (with only two blades, two pitch drive mechanisms etc), and are therefore cheaper. For Seaflow it was also found that the dynamic interaction between the rotor and the structure was less for a 2-blade rotor. The blades are made of composite.

5.3 Powertrain & Electrical System

The rotor is mounted on the front flange of a gearbox, which steps up the speed to drive a generator. During the course of the powertrain design six alternative gearbox suppliers were considered.

The final gearbox selected has an input drive from the turbine to two primary step up planetary epicyclic gears followed by a parallel shaft speed increasing gear which then drives the main generator shaft. This allows for a compact, light weight gearbox with low cross sectional area.

The generator is asynchronous, and bolts directly onto a flange on the rear of the gearbox. Unlike in wind turbines, the gearbox and generator are not enclosed in a nacelle, but are out “in the open”, submerged in seawater.

The electrical power from the generator is fed by cables up to the pod, where it is conditioned by a frequency converter. This turns the alternating current from the generator to direct current and back again, and allows the speed of the generator to be controlled.

The power will be exported to an existing 11kV connection on shore within 500m of the proposed turbine location. The grid connection will have an adequate export capacity for initial commissioning which will be increased to 1MW by the grid operator. The cable will be routed from the pod via a J-tube to the sea bed, and then through a 160mm Poly-Ethylene (PE) duct to the shore where it will be connected to the substation. The PE duct will be installed through a 300mm diameter hole created by a HDD operation.

5.4 Control System, Instrumentation & Communications

The turbine control software will be developed on an industrial PC. This software will then be compiled for use in an embedded controller identical to that used in the wind turbine industry.

The machine will be capable of being started automatically by the control system, or manually by adjusting the parameters on a control screen.

The turbine rotating speed will be a function of the tidal velocity. Between startup and reaching rated power, the speed will be varied in order to maximise the power output. This is done with a maximum power point tracking algorithm, which
effectively runs the rotor at its design tip speed ratio whatever the current speed. At maximum rated power the blades will start to pitch and the speed and power will be regulated.

In practice both speed and pitch will be varied to influence power quality and the fatigue loads on the structure. As waves or turbulence pass the rotor, energy can be stored in or given up from the rotor by allowing its speed to change, and rotor torque can be shed or increased by varying the pitch. Various inputs can be used to determine what response to make (generator power, current, pile acceleration, bending moments…). It has been the experience on Seaflow that the interactions between the variations and the responses are complex. Setting the correct gains for the various sub-systems is critical, and will require extensive optimisation during commissioning.

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**Table 1: Main instrumentation**

The Seagen turbine is a pre-commercial demonstrator machine intended to advance the understanding of power extraction from tidal flows, and is therefore comprehensively instrumented; a list of the main instrumentation is given in Table 1. All data will be passed to a data logger and available remotely for interrogation.

Communications to the machine will be via a fibre optic cable embedded in the power cable, which will in turn be connected to ISDN/Broadband communications link, which allows the turbine to be accessed remotely over the internet. It will therefore be possible to control and monitor the turbine from the shore, or from a PC on a broadband connected network located anywhere else.
5.5 **Structure & Foundation**

The main structural element of *Seagen* is the tubular steel pile. This carries the weight of all the other components, the operating forces on the rotor, and the environmental loads. A maximum diameter and weight were imposed on the pile design by the capabilities of the jackup barge used to install it. Working within these limits, the pile was designed to carry all the loads with an acceptable life. The pile is a steel tube 3.5m in diameter below the mudline and 3.0m diameter above, circa 55m long, and weighs circa 270 tonnes.

Geotechnic information from the site acquired in April 2005 was acquired by taking two Geobore S samples using Seacore’s *Excalibur* vessel. The results of these findings have been made available to the British Geological Survey and the cores have been donated to the Geological Service in Northern Ireland and reside in their repository.

Analysis of the geotechnical site investigation survey indicated that there was sufficient strength in the seabed to drill a self-supporting hole, or “socket”, into which the pile could be grouted.

![Figure 7: Proposed Seagen foundation.](image)

The cross beam that supports the powertrains is made of steel fabrications. It slides up and down the pile. The cross beam “collar” is attached to two vertical steel “lifting tubes” which pass up through the pod. A lifting mechanism consisting of...
two hydraulic rams and an arrangement of pins and holes is used to jack the cross beam up incrementally. One significant proposed enhancement on the Seagen system over the Seaflow system is that this process will be totally automatic. The lifting tubes also carry all the cables and services from the pod down to the cross beam and drive trains; these services have to be disconnected from the top of the tube before the cross beam is lifted.

One lesson learnt from the Seaflow project was that symmetrical access ladders up and downstream would be of great benefit for man transfer on ebb and flood tides. Seagen is thus equipped with two ladders which are attached direct to the main pile. These are positioned off the centreline of the turbine so that a rigid inflatable boat (RIB) can be brought up alongside them in a current, and the most appropriate ladder used for the state of the tide, and staff can transfer safely from the boat to the ladder.

The final structural element is the pod. Significant consideration was made to the visual impact of the system due to the proposed proximity to the towns of Strangford and Portaferry, and based on the feedback from comments about visual impact made on the Seaflow system in Lynmouth. The pod is thus aesthetically designed, and the structure will be a simple composite fabrication. The pod houses the lift mechanism, the main electrical and control components, and all the ancillary systems. A foldable hydraulic crane is fitted to a gantry that surrounds the pod for maintenance of the turbine.

Within the pile below the pod level are three machinery levels of equipment, housing the main export transformer on one level and frequency convertors associated with each drivetrain generator on the other two levels.
5.6 Access

The turbine is planned to be position circa 1km from the nearest quayside facilities. These will be at either Portaferry or Strangford, both are small, but quayside access is available at all states of the tide. Both quaysides are suitable for supporting work boats or RIBs.

It is only planned to use a jack-up barge for installation and decommissioning, the jack-up would have to operate from a nearby major port such as Belfast, Barrow-in-Furness or Birkenhead.

These considerations mean that it is planned to access the turbine using a RIB as has been successfully demonstrated during the Seaflow project. Due to the sheltered location of the proposed installation site it will be possible to get onto the turbine in strong currents and moderate waves, there are infrequently weather situations where the access will be limited for more than 24 hours due to wave height.
An access system has therefore been devised which uses two alternative ladders depending on the state of the tide, one positioned for access during ebb tides and another positioned for access during floods. These ladders go through the collar, and additional ladder access is provided on the cross beam to provide an alternative route when gaining access to the system with the cross beam lifted. The ladders come through the mezzanine deck surrounding the pile providing easy access.

For access from the sea, it is proposed that a RIB is brought alongside the pile on the appropriate ladder, motoring against the current to hold it still. Personnel then step from the RIB onto the ladder and climb up into the pod.

A further enhancement over the Seaflow system to be adopted by the Seagen design is the incorporation of a fall arrest system required for the ascent and descent of the ladder.

5.7 Servicing

The turbine will be designed so that as many operations as possible are conducted from on the pile, and that any exchange of parts can be done using a workboat. A jack-up would only be required in an emergency if there was a failure of one of the main structural components: the collar, pod or pile.

The crane mounted on the walkway around the pod will have sufficient capacity to lift off each of the blades and other significant components mounted inside the pod, but not the whole powertrain as a single unit - which would require a very much larger crane. The crane can also be used to manoeuvre a man basket to give access to the front of the rotor and hub when the collar is raised. A cover plate on the hub can be removed from the man basket to get access to the pitch control mechanism.

Concepts for removing the drive train as a complete assembly will be developed during Phase II of the project.

The cross beam will be lifted using a mechanism similar to that employed for jack-up barge legs. This uses a pair of hydraulic rams to pull up two long tubes attached to the cross beam collar. The proposed system will be fully automatic which is an enhancement over the Seaflow system. The lifting system works in automated steps, using two removable pins which engage with holes in a metal strip welded to the side of the tube. The power comes from a hydraulic pump driven by mains electricity provided by the shore connection.

Once the cross beam is up, dry access to it is via the main access ladders fixed to the pile that provide access to the pod. The top of the cross beam is nominally flat and will be equipped with a fall arrest system so that personnel walking to the drive trains are secure.

5.8 Intellectual Property Rights (IPR), Patents

MCT Ltd has a policy of seeking to gain patent protection for key ideas stemming from its research programme. To this end it has secured eight UK patents so far (with several more applications in process) and several of the UK patents have been internationalised with versions granted in a number of foreign countries. The main topics covered by our patents are as follows:-
• A floating near neutral buoyancy device mounted under a moored floating raft with a mechanism for raising the turbine to the surface for maintenance (based on work carried out originally by IT Power in partnership with Scottish Nuclear and NEL on Loch Linnhe in 1994-5).

• A series of arrangements in which a turbine (or several turbines arranged side by side), generally with axial flow rotors, can be mounted on a monopile such that it/they can be raised above the surface for maintenance or repairs

• The use of full span active pitch control to permit a fixed axial flow rotor to operate efficiently in a bi-directional flow (using the flow from either direction) plus other methods of addressing bidirectional flow such as pitching the rotors either around a vertical axis or around a horizontal axis

6. MANUFACTURE & PRE-INSTALLATION TESTING

The manufacturing of the Seagen tidal turbine is covered by Phase II of the project in will be detailed in the final report associated with that contract.

7. INSTALLATION

The installation of the Seagen tidal turbine is covered by Phase II of the project in will be detailed in the final report associated with that contract.

8. ADDITIONAL SEAFLOW TEST RESULTS

Under this contract the following additional areas of the Seaflow tidal turbine performance and impacts were assessed.

(i) To gain an increased understanding of the complex tidal flows and the interaction of the rotor with the varying velocity profile of the water column, with the aim of improving the control system and minimising dynamic components of thrust, torque and power areas (see the Seaflow Preliminary Test Report, R005, Issue 01 / October 2003).

This work has been previously reported in confidential annex to the Seaflow final project report, MCT report reference SF-RE-000-00316-RevA. No further detail is thus included in this report.

(ii) To obtain a more complete measurement of the load pattern applied to the blades; to better understand the structural response to turbulence; and also to potentially assist in the investigation of blockage effects on rotor performance.

This work has been previously reported in confidential annex to the Seaflow report, MCT report reference SF-RE-000-00316-RevA. No further detail is thus included in this report.

(iii) To measure and analyse the sea borne acoustic noise generated by a tidal turbine, to be reviewed by marine biologists as input to future environmental impact assessments and assess the impact on maritime navigation equipment.
This work has been previously reported in confidential annex to the *Seaflow* report, MCT report reference SF-RE-000-00316-RevA and was included as Annex 20 of the ES. No further detail is thus included in this report.

9. **PHASE I: SEAGEN PRELIMINARY WORKS PROJECT COSTS**

The *Seagen* project will provide a reference point for the economics of tidal turbines. On completion of this phase of the *Seagen* project insufficient design detail had been completed to refine the previous cost predictions. The detail design work to be undertaken in Phase II of the project will provide a basis for accessing the future economic viability of the technology.

The cost of electricity from tidal turbines has several major elements:
- Site surveys and permissions (EIA, oceanographic surveys, baseline environmental monitoring, geotechnical surveys etc)
- Site engineering (foundation design, design certification etc)
- Turbine quayside cost (including procurement, assembly and test)
- Grid connection cost
- Turbine installation cost (including cable installation and commissioning)
- Energy produced and negotiated value of Power Purchase Agreement including ROC’s etc
- Operation and maintenance costs;

For the Seagen project the following are the budgeted costs for the major elements of work associated with site surveys and permissions not including MCT labour costs:

<table>
<thead>
<tr>
<th>Task</th>
<th>External Spend Budget</th>
<th>Actual Expense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current and Bathymetry Surveys</td>
<td>£40,000</td>
<td>£40,250</td>
</tr>
<tr>
<td>Bottom mount ADCP surveys</td>
<td>£6,000</td>
<td>£23,829</td>
</tr>
<tr>
<td>Metocean (Desktop Study)</td>
<td>£6,000</td>
<td>£8,000</td>
</tr>
<tr>
<td>Geotech Site Evaluation (walkover and literature survey)</td>
<td>£15,000</td>
<td>£15,714</td>
</tr>
<tr>
<td>Geotechnical Site Investigation</td>
<td>£200,000</td>
<td>£238,276</td>
</tr>
<tr>
<td>Environmental Scoping Report</td>
<td>£15,000</td>
<td>£9,984</td>
</tr>
<tr>
<td>Environmental Statements (including all ancillary and supporting studies) – not including surveys etc</td>
<td>£98,100</td>
<td>£211,145</td>
</tr>
</tbody>
</table>
There were significant variations from the original budget in three major areas:

i) Bottom Mount ADCP Work
Due to iterating towards an ideal location for the turbine based on navigation constraints etc, several more ADCP deployments had to be conducted that originally planned.

ii) Geotechnical Site Investigation
The original budget was based on the SI being conducted when the jack-up vessel was operating in the Irish Sea, as it transpired additional mobilisation costs were incurred as the jack-up vessel was moved from the North Sea to conduct the work. In addition the estimated costs did not include for the provision of the client representative present during the SI works.

iii) Environmental Statements
As explained earlier, part of the way through the EIA process it became apparent that there was significant issues with the FEPA licensing process due to the September 2004 Waddensee ruling. This required a significant increase in effort to fulfil the EHS requirements for additional information for them to complete the Article 6 appropriate assessment, and protracted the whole consenting process from 10 to 20 months effectively doubling the efforts and thus costs.

10. FUTURE WORK
The subsequent contract for Seagen Phase II: Construction and Operation was awarded in March 2005.

This phase of the project allows for the following activities:-

- **Detail Design**
  Completion of the design of the system sufficient for the system to be manufactured

- **Procurement Support**
  All activities, tooling costs etc associated with the production of the Seagen turbine.

- **Quayside Costs**
  All costs associated with the supply of the tidal turbine components to the mobilisation quayside.

- **Quayside Test Facility**
  All activities associated with the provision of spares and equipment necessary to development safe marine maintenance regimes and ensure ongoing operation of the Seagen turbine.

- **Assembly & Test**
  All activities associated with the sub-system assembly and test, primarily related to the electrical subsystems, drivetrains, pile/collar
support structure and overall systems integration.

**Installation**
All activities from quayside mobilisation to pile installation, top side assembly, HDD, cable installation, grid connection and initial commissioning.

**Testing**
All activities associated with performance testing, characterisation, environmental monitoring and ongoing maintenance activity.

**De-Commissioning**
All activities associated with decommissioning the tidal turbine on completion of testing.

**Certification**
All activities associated with working with certifying authorities for approval of the design and performance of the system in accordance with agreed design codes.

**Maintenance Demonstration**
All activities associated with the physical demonstration of a change of drive train in the marine environment.

**Project Management**
All activities associated with the management process of the project including the CDM process.

All of these areas will be reported on in the final project report for Phase II of the *Seagen* project.

**11. CONCLUSIONS**

The *Seagen* project has been subjected to one of the most comprehensive EIA processes for any offshore renewable technology. The process has successfully resulted in the relevant licenses being granted for the installation of the *Seagen* project.

The *Seagen* concept design process has resulted in a design that meets the technical requirements for the location, and meets the functional requirements for the technology. This concept has been progressed to the detail design stage under Phase II of the project, and at the time of writing the installation is scheduled for late 2006.

The proposed extension investigation activities for the *Seaflow* tidal turbine have been completed and reported in a separate confidential report.
Figure 9: Artists impression of a future farm of twin-rotor marine current turbines.