Sustainable
Development Commission

Tidal Power in the UK

Research Report 2 - Tidal technologies overview

An evidence-based report by Entec for the
Sustainable Development Commission

October 2007

Sustainable Development Commission

Tidal Technologies Overview

Contract 2

Final Report

May 2007

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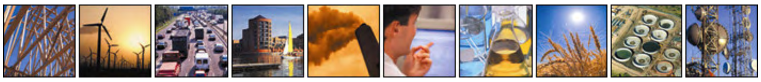

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Executive Summary

Purpose of this Report

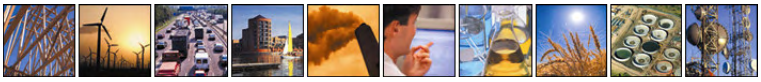
Entec UK Ltd. were commissioned as independent consultants by the Sustainable Development Commission (SDC) to produce this report, which explores the varied issues surrounding the generation of tidal power in the UK from the perspective of sustainable development. This report has been produced for the purpose of providing the SDC with a high-level overview of the main technological, environmental, economic and social issues relating to the UK's tidal energy potential. The SDC will use the information in this report (and reports from other consultants working on their tidal power project) as an evidence base for the preparation of a report (provisionally entitled 'Tidal Power in the UK') which will provide the basis for the SDC position on tidal power, and will inform its advocacy and advice to the UK Government, the Devolved Administrations and the South West Regional Development Agency (SWRDA) on this issue. The report is an overview of tidal energy in the UK, introducing key concepts and issues to the reader, and referring them to referenced information sources for more detailed analysis.

The technological, environmental, economic and social issues surrounding the generation of tidal power are multiple and interlinked. An attempt has been made in this report to unravel the complexities of the subject by presenting information in four clear sections which set out the key points and ideas in a coherent fashion. Following a general introduction to the concept of tidal power, which explores the different technologies available and their methods of action, wider issues surrounding the technologies, the environmental effects and the social and economic issues are set out in separate sections. The key points from each of these sections are summarised below. Sections use available information to differentiate between different tidal energy technologies, and to present the benefits and disbenefits of each technology type. The issues raised in each section are intended to relate to a generic technology type rather than to a specific device or proposed scheme. However, in some cases it has not been possible to avoid reliance on information from certain technologies or specific schemes as a result of a lack of general information.

Tidal technologies

The waters of the ocean rise and fall twice every 24 hours as a result of gravitational interactions between the sun, moon and earth. The rise and fall of tides can be used to generate electricity, and is a highly predictable source of renewable energy. There are two ways in which electricity can be generated from the tides:

- When tides rise and fall, water moves in and out of shallow basins and estuaries, and this causes a change in the height of the water. The **tidal range** is the difference in height between high and low tides. This difference in height can be used to generate electricity. The tidal range resource is greatest in shallow waters.



- As tides rise and fall, differences in pressure between areas of sea cause water to move from areas of high pressure to areas of low pressure. As the water moves, it can be accelerated around headlands and through channels. This is the **tidal stream**, and the movement of water can be used to generate electricity. The tidal stream resource is found in both shallow and deep water.

Tidal range technologies exploit the difference in height between high and low tides by holding back water at high tide and releasing it through turbines at low tide. Tidal barrages and tidal lagoons are tidal range schemes; barrages span an estuary or embayment, whereas tidal lagoons enclose a discrete area of water in shallow coastal locations.

Tidal stream technologies generate electricity using the flow of water created by the tides and accelerated by coastal topography. There are many different types of tidal stream devices, although they all work on the principle of the tidal stream causing a part of the device to move, and this movement being used to generate electricity. The moving part may be a hydrofoil, or a horizontal or vertical rotor. Some devices have a duct around the rotor to increase the flow of water. Some tidal stream devices are fixed to the seabed on monopiles or concrete bases, while others float and are moored to the seabed using chains and anchors. Some devices are completely submerged, while others may have parts above the water. In the majority of cases, the moving part of the tidal stream devices is directly moved by the tidal stream flowing past it; however, in venturi systems the movement of water is used to cause flow through a turbine in a secondary circuit.

Currently in the UK there are no functioning commercial tidal energy schemes, although there is a significant tidal range and tidal stream resource in UK waters, and therefore a strong potential for the generation of tidal electricity.

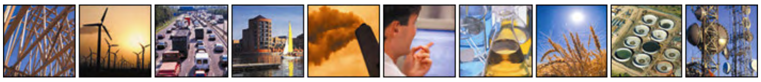
There are a number of functioning tidal barrages in the world, but no tidal lagoons. There are a wide range of tidal stream devices currently in development in the UK and elsewhere in the world. Several of these are at the stage of prototype or part-scale model deployment, and are receiving funding from various sources including the Department of Trade and Industry (DTI) and the Scottish Executive.

Technological differentiators

Tidal energy, in common with other renewable sources of energy, would have the advantage of reducing the UK's overall carbon emissions from electricity production. By replacing electricity production by fossil fuels, tidal energy schemes such as the Cardiff-Weston barrage could reduce carbon emissions by over 7 million tonnes per year; the Swansea Bay tidal lagoon scheme could reduce emissions by over 53,000 tonnes per year, and a tidal stream farm by up to 1 million tonnes per year (depending on the quality of the tidal stream resource exploited). Such emissions reductions are a significant environmental and political driver for the development of the UK's various renewable energy industries.

There are many different factors which affect the economic and commercial viability of tidal power generation in the UK, and many of these factors differ between different types of tidal energy schemes. The key issues are:

- The size and accessibility of the tidal range and tidal stream resource;



- The amount of electricity which can be generated by a scheme;
- The ability to transmit this electricity to consumers;
- The cost of constructing, maintaining and decommissioning the tidal energy scheme; and
- The cost (actual and competitive) of the electricity produced.

Resource size and accessibility

The tidal range resource of the UK is difficult to accurately assess, but has been estimated to be in the region of 19 TWh/y. This has the potential to supply almost 5% of the UK's electricity demand. Some sources estimate the tidal range resource in the UK to be as high as 50 TWh/y. The majority of the tidal range resource is located along the west coast of England and Wales, with the Severn Estuary alone accounting for 17 TWh/y. Smaller and shallower inlets around the coast have the potential for tidal range schemes, but there are engineering difficulties with exploiting the resource here, and barrage schemes in these areas may not be commercially viable.

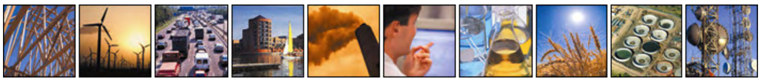
The UK has a comparatively high tidal range resource, with approximately 18 TWh/y of the estimated 150 TWh/y global extractable tidal stream resource being in UK waters. The majority of this resource is located in the Pentland Firth in northern Scotland, with Alderney being another significant site. More than half of this resource is in deep water, which is harder to exploit than shallow water as a result of engineering challenges.

Amount of electricity generated

The amount of electricity which can potentially be produced by a tidal power scheme is not the same as the amount of electricity which is actually produced by the scheme. The 'installed capacity' of a scheme is a measure of the maximum amount of electricity generated when operating at full production. However, tidal energy schemes would not be operating at full capacity all the time. This is particularly an issue for tidal range schemes, which are likely to generate electricity only on the ebb tide (although some schemes are designed to generate electricity on both the ebb and flow tides). Tidal stream devices would generate electricity more consistently, but would still not generate at full capacity all the time.

There is a large difference in the scale of electricity generation by different types of technology. The installed capacity of tidal range schemes (barrages and lagoons) is much higher than that of tidal stream devices. The installed capacity of the Cardiff-Weston barrage suggested for the Severn Estuary would be more than 8000 MW, and the installed capacity of the tidal lagoon scheme suggested for Swansea Bay would be approximately 60 MW. Individual tidal stream devices will have installed capacities in the region of 1 MW, but are designed to be modular (that is, they will eventually be deployed in 'farms' of 30 or more).

The actual electricity production by these schemes likewise has a large difference in scale. The Cardiff-Weston barrage could produce up to 17 TWh/y, the Swansea Bay lagoon up to 124 GWh/y and a farm of tidal stream



devices between 52 – 118 GWh/y (depending on the strength of the tidal stream in the area in which they are deployed).

Transporting electricity to consumers

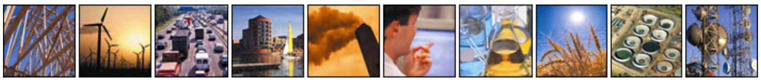
It is likely that the development of tidal energy schemes in the UK will require modifications to the existing UK electricity grid. Smaller schemes (for example, single tidal stream devices) may be accommodated by the existing grid, but larger schemes may require significant network upgrades. The location of the tidal resource is pertinent here; the centres of electricity demand are concentrated in the south of England, while some of the main areas of tidal stream resource are in the north of Scotland. This may pose a constraint to the development of some tidal energy sites in the UK.

Construction, maintenance and decommissioning costs

The scale of a tidal energy scheme, the method of construction and the current state of technological development all have implications for the overall cost of tidal energy schemes in the UK. The perceived investment risk of a scheme, and the consequent effect on returns required by investors will also have implications for the commercial viability of tidal energy schemes. As technologies are tested and proven, the investment risk decreases and the cost of financing decreases.

The capital cost of a tidal energy scheme probably represents the greatest expenditure on the project, because once the scheme is running the ‘fuel’ is free and the operation and maintenance costs are only a small proportion of the initial investment. Tidal barrages are likely to be large constructions which require significant amounts of raw materials (largely concrete and steel). This means that the up-front construction costs are high, and the long period of construction prior to the generation of electricity may affect the financing of such schemes. The same issues are likely to apply to tidal lagoon schemes, although these are likely to be smaller constructions requiring less raw material and shorter construction periods. Tidal stream devices are faster to build than tidal range schemes, require fewer raw materials, and have a shorter period of time before commencement of electricity generation. This means that the capital costs are likely to be much lower. Construction costs for tidal stream devices are currently disproportionately high, because they are all at design or prototype stage. However, as designs mature and devices are produced in larger numbers, the consequent reduction in financial risk and development of economies of scale will result in significant cost reductions.

Operation and maintenance costs are likely to be small compared to the capital cost of a tidal energy scheme. These are the costs of maintenance, overhauls, licensing, insurance, and on-going monitoring of the scheme’s performance. The absolute costs of operation and maintenance are likely to be higher for tidal range schemes than tidal stream schemes, as the constructions are much larger. However, when expressed as a proportion of capital cost, tidal range schemes have smaller operation and maintenance costs than tidal stream devices, because the capital costs of tidal range schemes are so high.



The developer of a tidal energy scheme must plan for the decommissioning of the scheme once it reaches the end of its useful life. This decommissioning may take several forms, but there are likely to be legal requirements to be fulfilled.

Revenue produced by selling the electricity generated by a tidal energy scheme needs to be high enough to make the scheme commercially viable. For this reason, some smaller tidal energy schemes (or schemes in areas of poorer-quality resource) may not be feasible.

Cost of electricity

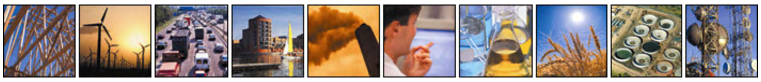
The cost of electricity produced by tidal energy schemes is crucial to the competitiveness of the industry and the opportunities for industry development. The cost of tidal electricity in the UK is likely to be governed by a number of factors including:

- The cost of the tidal energy scheme (including financing costs);
- The amount of electricity produced by the scheme (this is linked to the technology used and the quality of the resource exploited); and
- The state of the electricity market, including the value of additional market supports such as the UK Government's Renewable Obligation Certificates (ROCs).

There are large variations in the estimates of electricity costs from tidal energy schemes. Initial indications are that the costs will be higher than those of 'brown' electricity sources (that is, non-renewable sources). Initial costs of electricity from tidal stream devices are likely to be very high, but as the industry develops and begins to benefit from technological advances and economies of scale, the cost of electricity is likely to fall to more competitive levels. There is less scope for the cost of electricity from tidal range schemes to decrease over time.

Environmental differentiators

Although the generation of electricity from tidal energy has an obvious environmental advantage by reducing carbon emissions, the placement of artificial structures in the ocean and the removal of energy from the environment will have environmental effects. In addition to the amenity and commercial value of coastal areas in the UK, many sections of coastline are designated under national and international law as a result of the habitats and species which they support, and a number of marine species are legally protected or UK Biodiversity Action Plan (BAP) priority species. It is therefore important to consider the environmental implications of tidal energy schemes. The construction of such schemes is likely to require environmental baseline assessment and monitoring in the form of an Environmental Impact Assessment (EIA) which will also indicate mitigation measures to reduce environmental effects. The requirement for EIA, statutory consultation and granting of licences/permissions is likely to add a significant amount of time and cost to the implementation of tidal energy schemes in the UK.



Given that there are no functioning commercial tidal energy schemes in the UK, and that only a limited amount of information is available from schemes elsewhere in the world or from deployment of tidal stream device prototypes, it is difficult to predict the full range of environmental effects which may result from tidal energy schemes. The prediction is further complicated by the fact that the tidal resource is found in such a wide variety of areas, which have very different environmental characteristics.

The key environmental issues which should be considered as part of the EIA process are effects on:

- seabed, sediments and currents;
- airborne and underwater noise;
- visual environment (landscape and seascape);
- other users of the sea;
- water quality;
- air quality;
- archaeology and cultural heritage; and
- ecology (habitats and species).

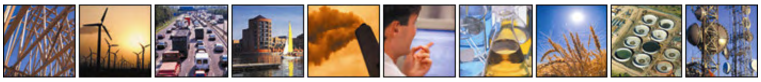
Different tidal energy technologies and different stages of individual projects (construction, operation, maintenance, decommissioning) may have very different effects on the environment. Not all these effects can be adequately mitigated.

Seabed, sediments and currents

The placement of tidal energy structures and their associated cables on the seabed will inevitably result in a change to the physical characteristics of the area, and the loss of habitat; however, the effects on the area are not likely to be limited to the ‘footprint’ of the tidal-energy scheme. Changes in water flow around the structure, and consequent changes in the patterns of erosion and deposition of sediments may result in effects on a much wider area. These changes in sediment and hydrodynamics have implications for water quality, habitat structure, coastal areas and flood risk.

Noise

The level of noise generated above the surface of the sea may increase as a result of activities associated with the construction, maintenance and decommissioning of a tidal energy scheme. Depending on the distance from shore, climatic conditions and wind direction, this noise may have impacts on local communities. Underwater noise may



also be generated by activities such as piling, drilling and cable-laying. This may have serious effects on marine mammals and fish, depending on the level, frequency and duration of noise.

Landscape and seascape

Many coastal areas have an important amenity value for recreational users and the tourist industry. The placement of a tidal energy scheme in waters close to shore may have an impact on the landscape/seascape of the area if there are surface-piercing structures. The level of impact is likely to depend on the landscape character of the coastal area and the type of tidal energy scheme.

Commercial and recreational use of the sea

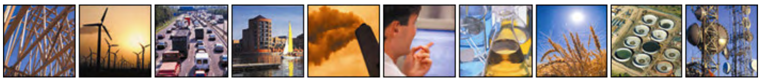
Coastal waters are used by a variety of vessels, including commercial shipping, fishing and recreational craft. Safety zones around tidal energy schemes, or the restriction of passage through locks in tidal barrages, may have effects on these users. There may be a requirement for new shipping lanes to be constructed around tidal energy schemes, and there may be effects on navigational safety as a result of increases in vessel traffic and the displacement of recreational craft into commercial shipping areas. Large diversions of commercial shipping, or delays in passing through locks, could have implications for the level of vessel emissions, and wider implications for the cost of transporting goods by sea. The presence of safety zones around tidal energy schemes may also have effects on the activities of local fishing vessels.

Water quality

Water quality in the vicinity of tidal energy schemes may be affected by large scale resuspension of sediments, and corresponding increased in turbidity. Leaching of substances from concrete or leakage of lubricants and hydraulic fluids from tidal stream devices may also affect water quality. There is also the chance that increased volume of vessel traffic associated with the scheme may result in increased levels of fuel and oil leakage into the water. The impoundment of water behind a tidal barrage may have additional effects on water quality, including a reduction in the dilution of riverine effluents, changes to the salinity structure of the estuary, and the possibility of algal bloom formation.

Air quality

Operational emissions to air from tidal energy schemes are negligible. However, construction processes and on-going maintenance operations are likely to involve dust and increased emissions from vessel traffic. The incorporation of transport links into barrage structures may also result in local increases in vehicle emissions and consequent decreases in air quality.



Archaeology and cultural heritage

There are many features of archaeological and cultural importance in UK coastal waters and coastlines, and many of them are legally protected. These features will vary from site to site, but may include wrecks, peat deposits and pre-historic artefacts as well as historic monuments and buildings onshore. They may be affected by construction methods (including cable laying), covered by tidal energy schemes, or affected by changes in sedimentation patterns. Onshore features may be affected by landward transport of electricity generated by tidal energy schemes.

Ecology

A number of species and habitats in UK coastal waters have the potential to be affected by tidal energy schemes. These include birds, fish, marine mammals, plankton, communities on the seabed and intertidal habitats such as mudflats, sand dunes, saltmarshes and rocky shores. Terrestrial habitats may also be affected by changes to infrastructure for landward transmission of electricity.

The main issues affecting habitats arise from changes to the physical environment (that is, changes in water flow and tidal mixing, wave action, tidal inundation, patterns of sedimentation and erosion, and disturbance of the seabed by construction and cabling). Changes to the physical environment can result in changes in the character of marine communities, or the displacement of organisms from feeding or breeding areas. Fish and marine mammals may be particularly affected by the generation of underwater noise, the potential for collision with underwater structures, and the electromagnetic fields generated by subsea transmission cables.

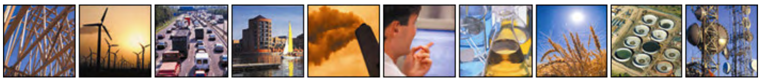
Social and economic differentiators

The social, economic and environmental effects of tidal energy schemes are closely related. In addition to the large-scale economic implications of tidal energy scheme construction, financing and electricity costs, local and economies may be affected by the tidal energy scheme in terms of factors such as job creation and regeneration, and this has knock-on social effects. An analysis of the local social and economic effects of a particular tidal energy scheme would be included in the EIA for that scheme.

Employment

The most significant economic effect of tidal energy schemes is likely to be job creation. This may be direct creation of jobs (that is, jobs which are directly connected with the tidal energy scheme) or indirect jobs (jobs which are created as a result of the increased income and demand in the economy as a result of the tidal energy scheme). This job creation will benefit the economy, but the extent to which it benefits local economies in the area of a tidal power scheme may be limited, depending on the maturity of the supply chain and the status of the local labour market.

The greatest direct employment opportunities are likely to arise during construction of a scheme, with fewer jobs supported during operation and maintenance stages. Tidal energy schemes such as barrages and lagoons, which



involve long periods of construction and significant amounts of maintenance, are likely to support the most jobs. It is difficult to estimate the indirect employment opportunities arising as a result of a tidal energy scheme.

A simple analysis of the local labour market in areas of high tidal resource shows that there are potential strengths in terms of construction and service industries. This may indicate that local economies could benefit from the development of tidal energy schemes.

Wider economic effects

Local industries may also be affected by the development of tidal energy schemes. These could include ports, commercial and recreational shipping, aggregates, commercial fishing and tourism. The development of new transport links in coastal regions as a result of tidal energy schemes may also benefit local economies and reduce the transportation costs for goods. Opportunities for wider regeneration may also arise, particularly if the tidal resource exploited is in a rural or deprived area.

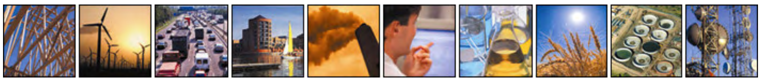
Social effects

Social effects of tidal energy schemes are likely to be highly location-specific, and it is difficult to make generalisations. The potential effects on local communities are likely to include effects on recreation and leisure activities, effects on landscape/seascape, effects on historical or cultural heritage, educational opportunities and changes in transport infrastructure. Positive public attitudes to renewable energy schemes are strongly linked to the level of understanding, but opinions of marine renewable energy schemes are higher than expected, given the level of public knowledge. Tidal energy schemes may suffer from a level of ‘nimbyism’ in a similar way to the wind industry.

Supply chain and barriers to growth

The UK Government has made a commitment to increase the contribution of renewable energy to the UK energy mix. This is likely to involve investment in a number of different renewable technologies, including tidal energy. The UK is a world-leader in tidal technology, and has a significant proportion of the world’s tidal stream resource, but the UK supply chain is not fully developed, and may be threatened by cheaper labour and development costs abroad.

A number of reports have identified barriers to the growth of the tidal energy industry in the UK. These include availability of finance, grid access, planning and permitting, variability of power generation and technological risks. It has been suggested that the industry could be assisted by significant investment inputs to support on-going research and development and to accelerate learning effects. Although a number of specialist skills are required for the industry, developers have not identified this as a critical constraint.



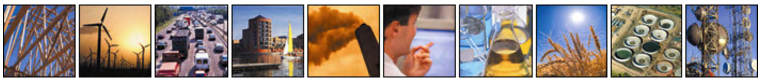
Conclusions

The potential for generating electricity from tidal energy in the UK is large. Exploitation of all the available UK tidal resource (tidal range and tidal stream) could generate in the region of 10% of the UK's electricity demand. However, in terms of the commercial viability of exploiting the UK tidal resource, there are a number of issues to be addressed with respect to the cost and financing of schemes, the amount of electricity produced and the cost of this electricity. Exploitation of the tidal resource is also likely to result in a number of effects on the environment and on local economies and communities.

There is a fundamental difference between tidal range and tidal stream schemes, both in terms of technology and commercial viability. Tidal range technologies use conventional methods of electricity generation which are more 'proven' than tidal stream technologies, and may therefore be more attractive to investors. However, the high up-front costs of barrage and lagoon construction, the large requirement for raw materials and the long period of time before electricity production commences may present some problems for investors. In contrast, tidal stream technologies are all under development, and the technology is in the process of being 'proven'. As such, research and development costs are still high, and it is likely to be some time before the technology is mature enough for commercial development. This presents a significant risk for investors. These issues have significant implications for the cost of electricity produced by tidal energy schemes. It is likely that in addition to continued funding of research and development, the UK Government will need to provide on-going support to the incipient tidal energy industry through schemes such as the Renewables Obligation.

There are a number of environmental, economic and social issues surrounding tidal energy in the UK which have been identified in this report. In some cases there are clear distinctions between the effects of tidal range and tidal stream technologies, and in other cases the distinctions are blurred. It is likely that the issues identified in this report will vary greatly in importance between different locations in the UK. An assessment of individual sites and schemes will need to be made on a case-by-case basis, and as part of this process additional issues may be identified. Larger-scale SEAs, such as the Renewable Energy SEA recently published for consultation by the Scottish Executive, will be instrumental in identifying the most suitable locations for development, and then detailed assessments of individual schemes would be carried out as part of the EIA process. The requirement to comply with UK and European legislation with respect to designated sites, protected species and licensing may impede the speed at which tidal energy schemes can be developed. The requirement for assessment, mitigation and on-going monitoring may also add significantly to the cost of tidal energy schemes.

An overriding conclusion of this report is that there are significant gaps in our understanding of the issues surrounding tidal energy in the UK. These gaps largely exist as a result of the fact that there are no commercial tidal energy schemes in UK waters. As the tidal stream industry develops it will become increasingly important closely to monitor the deployments of prototype tidal stream devices in order to increase understanding of the specific effects of tidal stream technologies. It is also important to understand baseline environmental, social and economic conditions in areas which are likely to support tidal energy schemes. This information will be vital in the assessment of the potential effects of specific schemes.



In order fully to realise the potential for tidal energy in the UK, a significant amount of further research and development is required. This should be on both strategic and specific levels. The industry will need to be closely supported and monitored in order to achieve its full potential.

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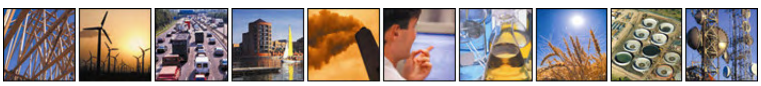

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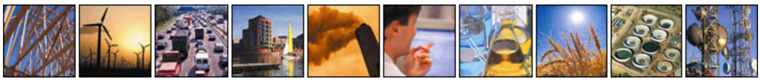

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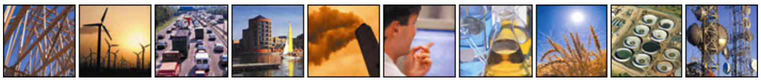

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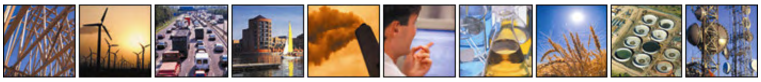

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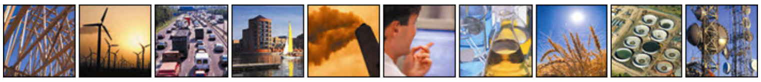
Appendix A References



1. Introduction

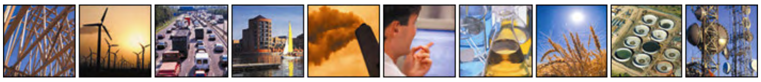
This report has been prepared by Entec UK Ltd. as part of a wider project managed by the Sustainable Development Commission (SDC) to produce evidence-based reports to support and inform SDC's tidal power in the UK project.

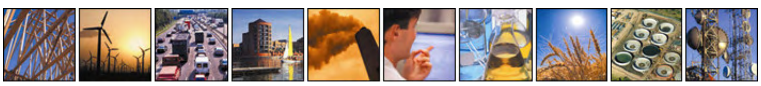
The primary aim of this report is to present an overview of tidal power in the UK, incorporating aspects of technology, environmental effects and socioeconomic implications. The aim is to give a grounding in the nature of the industry, the current state of the industry and the key factors which will potentially shape and limit the growth of the industry.

This is achieved by evaluating tidal power from technological, environmental and socioeconomic viewpoints, as outlined in the table below.

Table 1.1 Structure of tidal technologies overview

Chapter	Contents
Chapter 2: Introduction to tidal energy technology	Explanation of tidal energy technologies and their mode of action; a description of the main technologies available and their stage of development; an assessment of R&D priorities for tidal technologies.
Chapter 3: Technological differentiators	A comparison of tidal technologies based on resource location, power production, capital cost, energy cost, material volume and lifecycle carbon emissions.
Chapter 4: Environmental differentiators	A comparison of tidal technologies based on environmental effects, including sediment dynamics, hydrodynamics, coastal effects, noise, visual effects, effects on other users of the sea, air quality, water quality, archaeology and ecology.
Chapter 5: Economic and social differentiators	A comparison of tidal technologies based on socioeconomic factors such as employment, income, social and community effects, and an evaluation of the macro-scale economics of tidal power.
Chapter 6: Summary and conclusions	A summary which draws together the key points from the preceding chapters and assesses the growth potential of tidal power in the UK.





2. Introduction to tidal energy technology

2.1 Marine energy extraction

There are many ways of extracting energy from the marine environment. Some of the main methods are shown in Figure 2.1. The terms used in this diagram are used throughout the document to compare the different technology options.

Energy can be extracted from waves. The waves on the surface of the sea are caused by winds blowing across the oceans. These concentrate energy in the water at the surface. The stronger the wind and the longer the distance over which it blows, the larger the waves and the more energy they carry.

Different parts of the sea have different properties, such as differences in salinity (salt content) and temperature. Energy can theoretically be extracted from places where these differences occur over small distances. These are called ‘gradient’ technologies. It is possible to use these gradients to generate electricity.

Energy can also be extracted from the movement of the tides; from the differences in tidal height and from the fast-moving tidal streams and currents (hereafter called tidal streams).

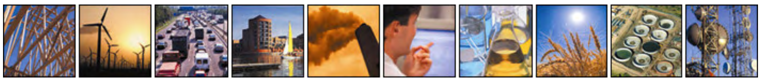
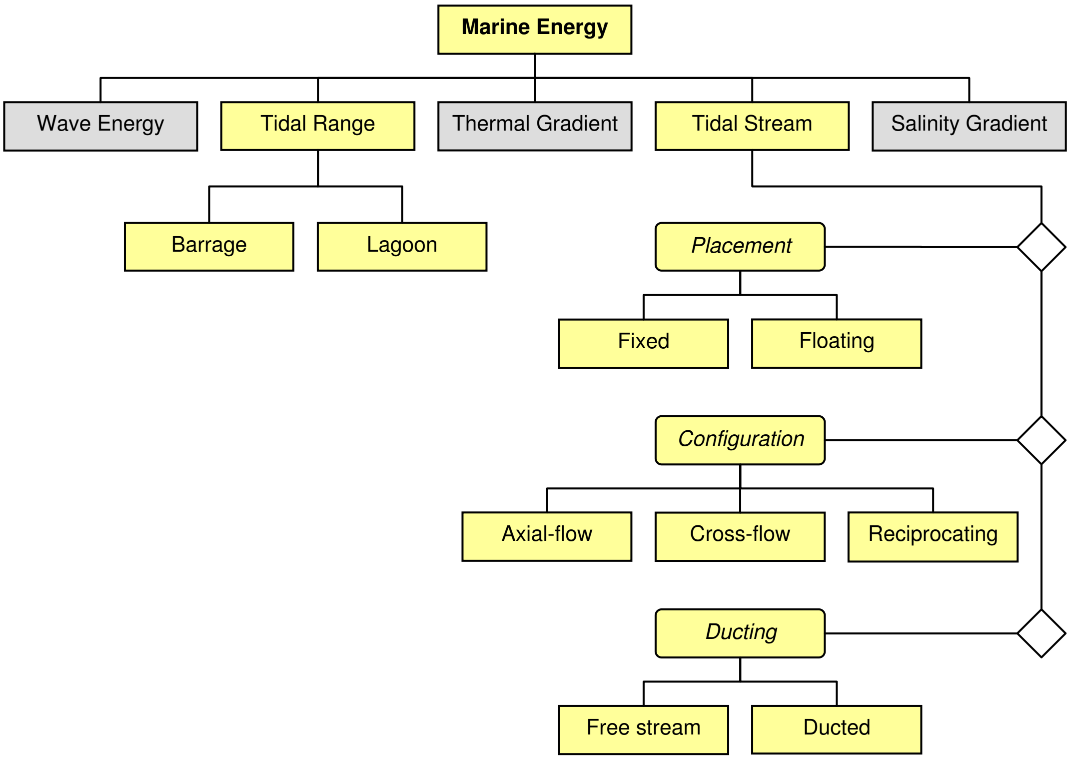


Figure 2.1 Methods of extracting marine energy



The terms shown this diagram are used throughout the document to compare the different technology options.

Tidal energy is derived from the movement of waters in the oceans. These movements are caused by the interacting gravitational fields of the sun, moon, earth and the bodies of water in the oceans. The gravitational fields create a twice-daily rise and fall in sea height ('ebb tide' when water level is falling and 'flood tide' when water level is rising). The lunar cycle also causes a variation in the height of high and low tides; the maximum difference between the heights of high and low tides (maximum tidal range) is called 'spring tide'. Minimum tidal range is called 'neap tide'. Although the amount of tidal power available varies from hour to hour, it is a completely predictable resource. The amount of power that can be extracted at any given time can be forecasted accurately.

Water movements that flow through channels and around landmasses can be accelerated. This can result in faster flows or the raising or lowering of the water level or 'tidal range'. Tidal streams[a] usually occur in channels and around headlands. Large tidal ranges occur in basins and estuaries.

---

[a] Some sources refer to tidal streams as tidal currents. This report uses tidal stream, as defined by the Marine Energy Glossary produced by the Carbon Trust, http://www.carbontrust.co.uk/technology/technologyaccelerator/glossary.htm.

- **Tidal range** technologies exploit the difference in water level between high and low tides.
- **Tidal stream** technologies exploit the fast-moving water found in channels and around some parts of coastlines.

Figure 2.2 Tidal barrage

Figure 2.3 Tidal lagoon

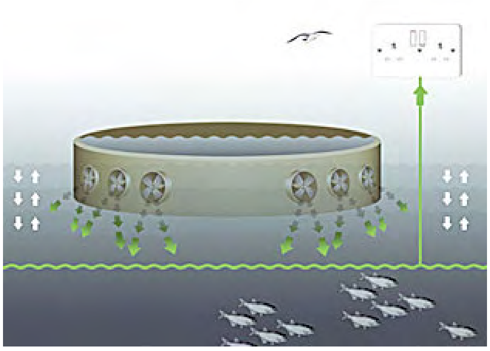
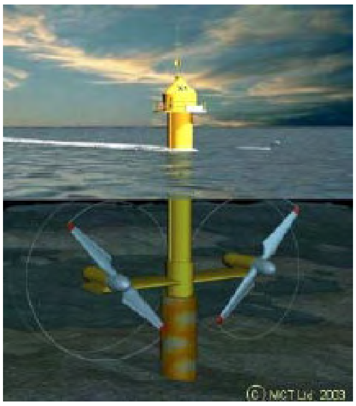


Figure 2.4 Tidal stream



In tidal range locations, there is water movement in and out of the basin or estuary, but this is not necessarily as fast as the water movements in a tidal stream location. Tidal streams can occur even in places where the water level does not change. Thus, these two types of technology are fundamentally different.

2.2 Tidal range

Tidal range technologies rely on a solid structure to impound water when it is at a high level, and release it back to the main body of water at the lower level. This can be accomplished whenever there is a change in water level, and so energy can be extracted on both the ebb and flood tides.

The energy potential of any tidal range scheme depends on the tidal range (the difference between high and low tide), and the amount of water that flows past the impounding structure. This is also partly related to the area of the impoundment.

The highest tidal ranges occur where several factors combine to enhance the natural tidal range. Two examples include the coriolis[b] forces that occur on spinning objects, and the shape of channels that cause resonance[c]. In the UK the Severn Estuary is unusual in that it is oriented such that it benefits from strong coriolis forces and its size and shape gives it a natural frequency[d] very close to that of the tides. As a result, the Severn Estuary has one of the highest tidal ranges in the world.

There are two slightly different approaches to providing this impoundment structure, which are described below.

2.2.1 Tidal barrage

One option is the tidal barrage. This works by building a wall across an estuary or basin, see Figure 2.5. As the tide comes in, the water is allowed through sluices in the barrage. The water level in the estuary then rises. The sluices are closed and the tide begins to ebb. When the water level outside the barrage is low enough the sluices are opened, and the water in the estuary is released back to the sea. The energy is extracted by fairly conventional hydroelectric turbines placed in the water flow through the barrage. These turbines generate electricity as water flows past them.

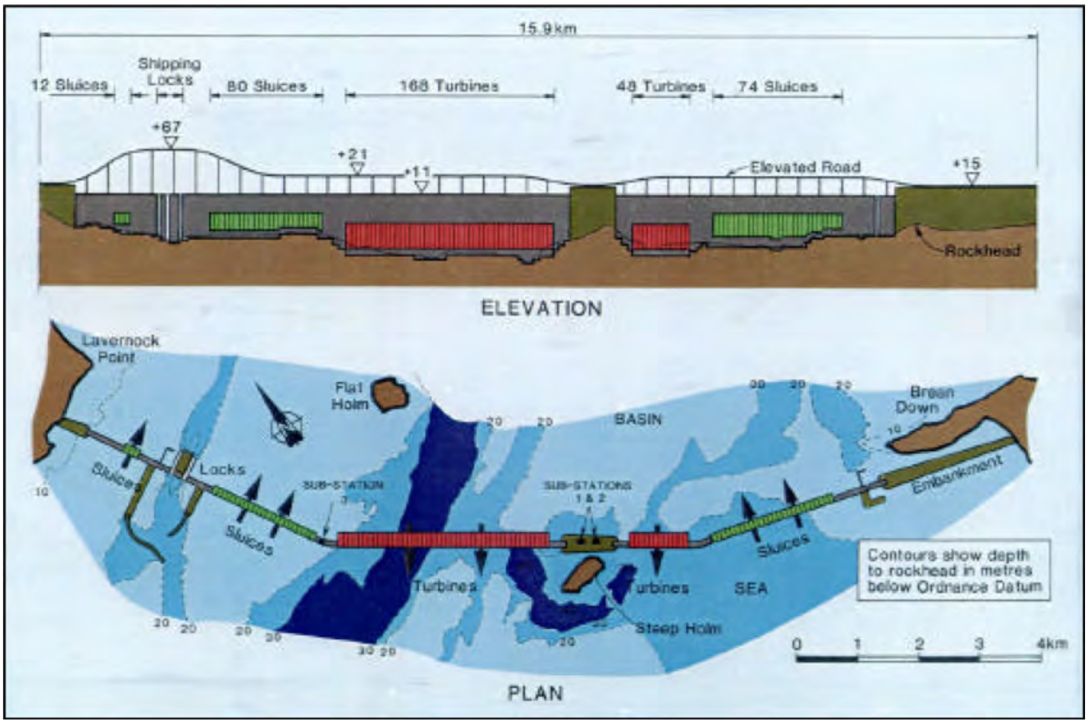
---

[b] An effect whereby a mass moving in a rotating system experiences a force perpendicular to the direction of motion and to the axis of rotation. In the sea the coriolis force comes from the flow of water due to the gravitational attraction of the moon and the spin of the earth. In tidal energy the coriolis force is important as it enhances tidal ranges and flows at certain locations.

[c] An increase in the oscillatory energy absorbed by a system when the frequency of the oscillations matches the system's natural frequency of vibration.

[d] The frequency of vibration of an oscillating system when vibrating freely.

Figure 2.5 **Tidal barrage (the Cardiff-Weston barrage, suggested for the Severn Estuary)[1]**



There is only one large-scale tidal barrage operating in the world at La Rance, near Mont Saint-Michel in Brittany, northern France. The 240MW facility has operated since 1967 and generates 600 GWh annually. Smaller barrages have been constructed in the Bay of Fundy, Canada; China and Russia[2].

2.2.2 Tidal lagoon

Tidal lagoons are similar to tidal barrages in that they comprise a solid structure that is used to impound water. The difference is that they do not span the entire width of a channel, but rather impound just part of it. A lagoon scheme has been suggested for Swansea Bay; this would be placed in shallow subtidal waters, and be constructed of rock and sand, and covered with rock armour. Another suggestion for the Severn Estuary is to construct a set of three lagoons which would be attached to the shoreline. Tidal lagoons are illustrated in Figure 2.6, Figure 2.8 and Figure 2.8 below. As with barrages, tidal lagoons work by holding back water behind the structure, and then allowing it to flow to the lower levels later. Tidal lagoons also use conventional hydroelectric turbines to extract the energy from the water. There have been no tidal lagoons constructed to date.

Figure 2.6 Artist's impression of a subtidal tidal lagoon[3]

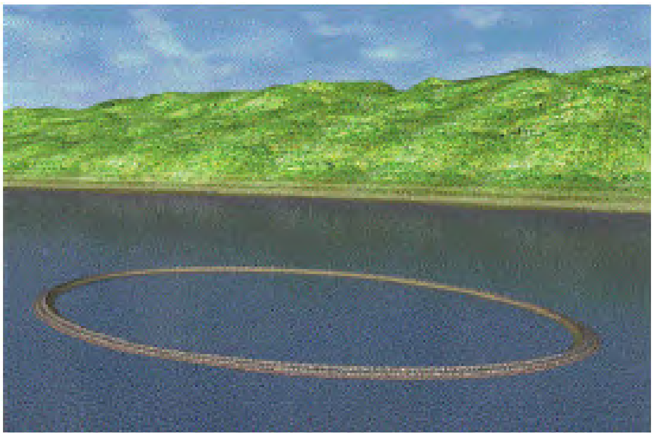


Figure 2.7 Cross-section of the subtidal lagoon suggested for Swansea Bay[4]

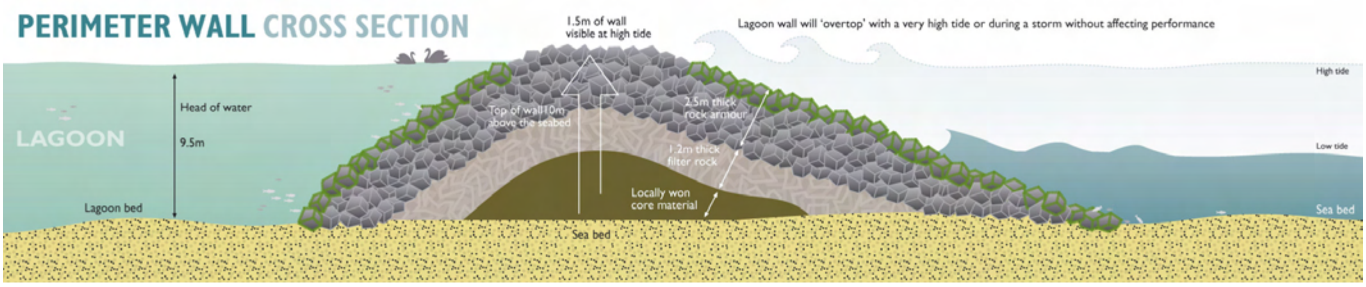
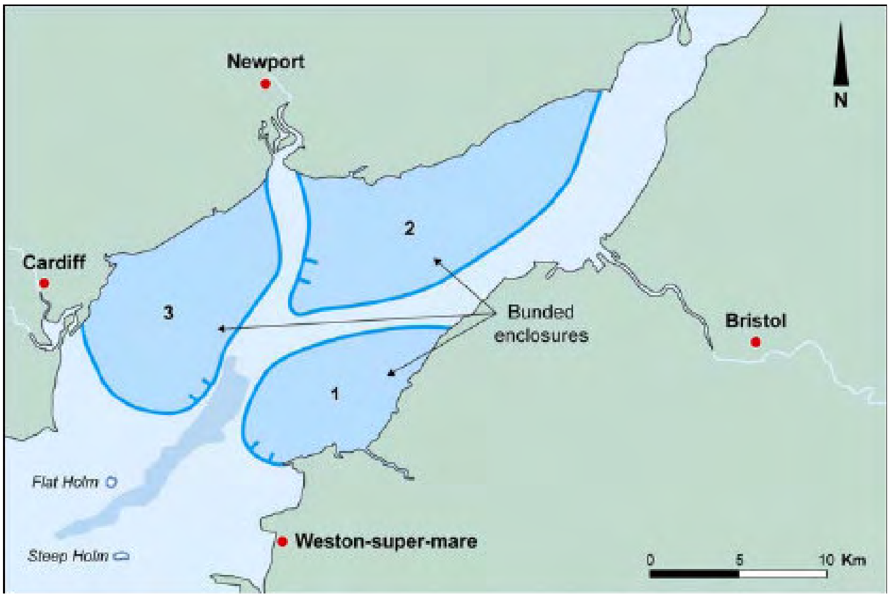


Figure 2.8 Shore-linked Russell Lagoons suggested for the Severn Estuary[5]

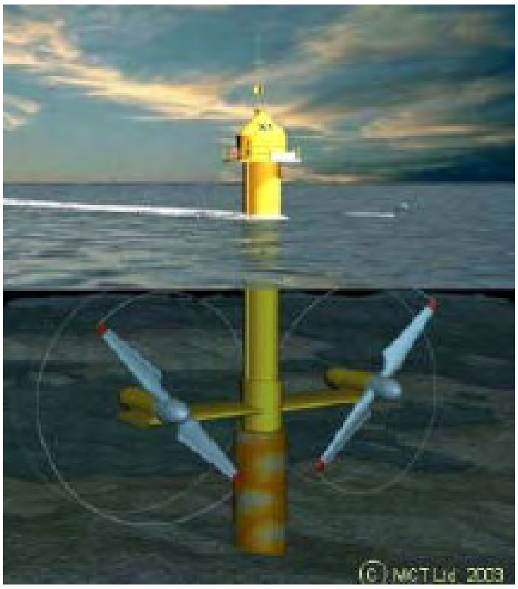


2.3 Tidal stream

Tidal stream devices are smaller than barrages or lagoons and they do not necessarily rely on long solid barriers. Instead, they extract a portion of the energy from the tidal stream flowing past them using some kind of actuator. An obvious approach is to place a rotor into the flow (Figure 2.9), but there are other options too (see below).

These devices do not aim to extract all the energy from the flow, but just a fraction of it. Indeed, there is a theoretical maximum amount of energy that can be extracted at each location. There must always be some water flow, and the flowing water represents some unused energy. Tidal stream devices can be installed individually or in large numbers. This contrasts with tidal barrages or lagoons that cannot begin to function until the whole solid wall is completed. Tidal stream devices are likely to be installed in farms that can be built in stages and extended later. Tidal stream devices are still an emerging technology with a number of different designs under development.

Figure 2.9 Tidal stream turbine[6]



Axial-flow tidal stream device with a fixed mono-pile foundation.

2.4 Comparing tidal technologies

One of the best differentiators between different types of tidal energy systems is the cost of the energy they produce. This cost includes all costs of building, planning, deploying, operating, maintaining and decommissioning the schemes, as well as the energy they produce and the cost of the money used to finance them. The cost of energy allows all energy generating technologies to be broadly compared. This is particularly relevant to comparing tidal energy technologies with each other and with other forms of renewable energy.

Whilst there are several commercial tidal barrages installed around the world, the only tidal stream units are pre-commercial prototypes. Tidal barrages rely on conventional technologies including dams, breakwaters and hydropower, and the real innovation in them is in their design details. The design of each barrage is specific to its location, and thus the details differ greatly between schemes too. By contrast, tidal stream designs are so new and untested that it is difficult to determine with meaningful confidence which one has the most potential at this stage.

In this section of the report we look at some specific tidal-barrage proposals, the Cardiff Weston barrage in the Severn Estuary being by far the largest. A generic approach to barrages would not be informative. Due to the lack of public domain technical information, the barrage information is mostly derived from the Cardiff Weston proposal. The situation is similar for tidal lagoon as it is a novel concept; the tidal lagoon information is mostly derived from the Swansea Bay proposal. However, for tidal stream the approach we take is generic. Distinguishing between different tidal stream devices at their current stage of development is difficult, as so little is proven about their performance, and crucially about the cost of the energy they produce.

However, there are some generic differences between types of tidal stream device that may indicate their longer-term potential when deployed at commercial scale. For example, the configuration of the rotor may make slight differences to the overall cost of energy, but given the uncertainty over the performance of different configurations it is difficult to conclude which rotor makes the most difference. Theoretically there will be only slight differences between different rotor configurations. However, the way that the system can be installed dictates the location in which it can be deployed (for example in terms of water depth). Most of the tidal stream resource is in locations with certain characteristics (for example, deep water). This means that tidal stream devices which can be deployed in deep water areas can be deployed in more locations, and therefore they have the greatest scope for replication. With replication comes mass production, and further economies of scale which will reduce the cost of the energy produced by the device. This means that some tidal stream device designs have a stronger future than others, simply because they have access to a larger market.

Tidal barrages are only ever built as single units. There are no significant economies of scale in building more than one barrage. The economies of scale which do exist are in the size of the barrage itself. A big powerful barrage is more economic than a small one. This also means that if the barrage is not economic when it is first built it is unlikely to ever be (unless there are significant changes in the energy markets).

Because tidal stream devices are still in prototype stages of development, at the moment they seem to be too expensive to be economic. Indeed, right now they are considerably more expensive than other forms of renewable energy, and certainly more expensive that other forms of conventional energy. This is not a fundamental problem with the technology, but rather a reflection of their state of development. Most units are prototypes, which cost perhaps ten times more than the first production machines are likely to cost. These prototypes are often installed as single units rather than the multi-unit farms we would expect in fully commercial projects. Thus there are currently no economies of scale in manufacture, project development or system infrastructure of tidal stream devices. The success of this industry is reliant on the technology developers proving their concepts technically, and then moving into a manufacture and project development phase to steadily increase the number installed and benefit from ‘learning by doing’ and economies of scale.

- **This report treats barrages, and to some extent lagoons, as single schemes and discusses their merits accordingly. Most of the information is obtained from two specific proposals – the Cardiff Weston barrage and the Swansea Bay tidal lagoon.**

- **Tidal stream devices are considered generically but also compared and contrasted on various features to demonstrate which if any has the greatest scope for replication, learning and thus cost reduction.**

2.5 Configuration of tidal stream technology

Tidal stream devices use different methods of securing the device to the seabed. They can use a number of different types of actuators – rotors, reciprocating hydrofoils and potentially other types too – to capture energy from the tidal stream.

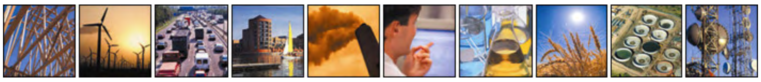
2.5.1 Placement

A tidal stream device must be secured in place so that it captures energy from the tidal stream and remains in a specified location to avoid posing a hazard to other users of the sea. It is possible for a device to be fully submerged or surface piercing, regardless of whether it is fixed to the seabed or floating.

The method of fixing the tidal stream device determines the types of location in which device can be deployed. Much of the resource is in certain types of location (see Section 3.1) and this means that energy extraction technologies which can work in these locations have access to the larger part of the market. There is more tidal stream resource in deeper water areas, meaning that floating tidal stream device designs (which are easier to deploy in deep water) have potential in the longer term. However, as tidal stream technologies are still in the early days of development, it is probably better to deploy devices in areas with less energetic tidal streams while the technology is still improving (see Figure 3.6). This means that in the short term, tidal stream devices which are fixed to the seabed in shallow waters are useful. Technologies that can be developed in lower energy ('easy') areas and then graduate to higher energy ('difficult') areas are those with greatest overall potential.

Fixed

There are two common methods of fixing a structure to the seabed – piling and gravity-based foundation. A mono-pile is a column which is installed into the seabed. Depending on the type of seabed the column is either grouted into a socket that has been bored in the seabed or is percussion-driven into the seabed. Using installation technology that is currently available, mono-piles can be installed in a range of seabed types in water depths up to

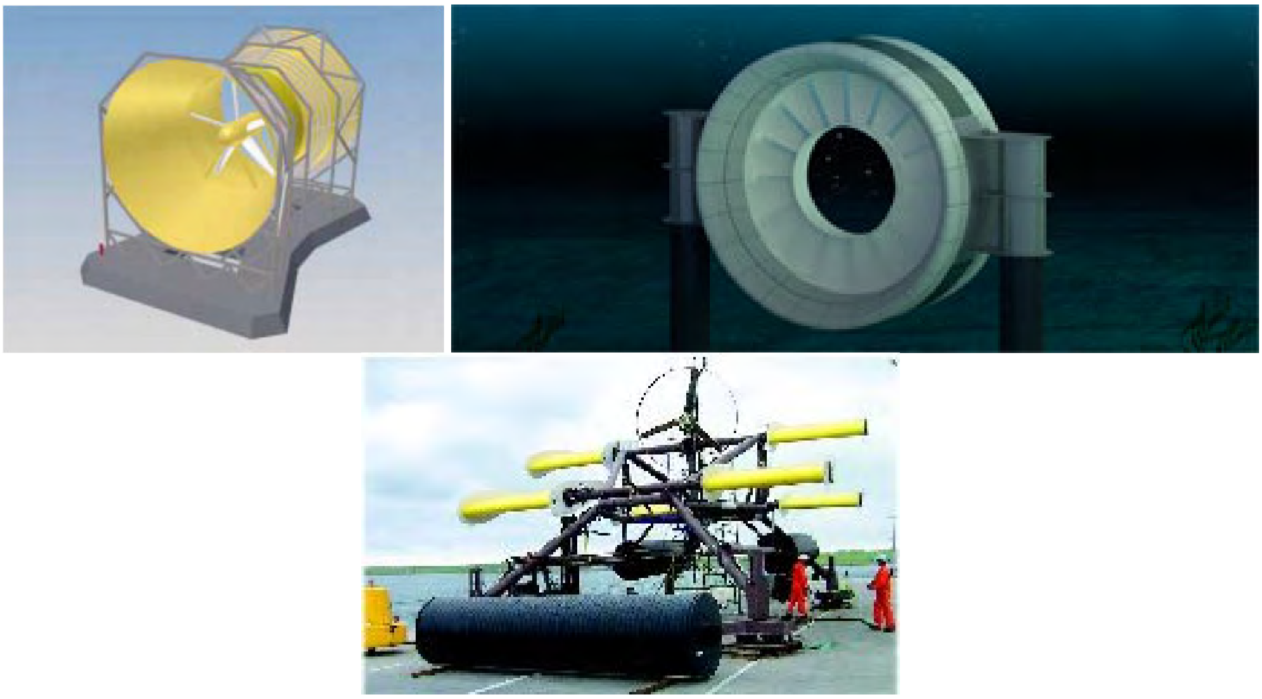


approximately 40m. Mono-pile installation technology is being used extensively for offshore wind farms. Marine Current Turbines Ltd (MCT) uses a mono-pile as the support structure for their Seaflow and SeaGen turbines[6] as shown in Figure 2.9.

A gravity-based foundation does not require drilling into the seabed, although the seabed must be levelled and prepared with a layer of crushed stones. The gravity force of a concrete caisson is used to keep the complete structure in place and in an upright position. The Lunar Rotech Tidal Turbine (RTT) [7] and Open Centre turbine[8] are both fixed to the seabed using a gravity-based foundation, as shown in Figure 2.10.

Traditional fixed foundations can become practically and economically unfeasible in deep water. Installing devices in strong tidal streams is a complicated procedure, and the forces exerted by the tidal stream on the device place constraints on the type and design of its foundations. A proposal, from Robert Gordon University, to ease installation is to use an arrangement of hydrofoils to anchor the device to the seabed[9] (see Figure 2.10).

Figure 2.10 Examples of fixed tidal stream devices



Gravity-based foundations are used to secure the Lunar RTT[7] and Open Centre turbine[8] in place. Both designs use axial-flow turbines. Arrangement of hydrofoils proposed by Robert Gordon University[9].

► **Fixed foundations are currently limited to certain water depths and this limits their access to some of the more energetic deepwater areas.**

Floating

A floating tidal stream device uses moorings and anchors to tether it to the seabed. The device may have its own mooring system, or it may be attached to a floating structure, as shown in Figure 2.11. A buoyant submersible system would consist of a buoyant tidal stream device floating at the required water depth, which is restrained by a mooring system. The TidEl, being developed by SMD Hydrovision Ltd[10], uses this form of mooring. An alternative to this is a surface-mounted system, where a floating structure is attached to the seabed via moorings and anchorages, and the tidal stream device is located under this structure on a frame that provides sufficient submergence. A proposed tidal stream device from Statkraft in Norway has two pairs of turbines attached to a floating raft[11]. The moorings could be deployed using specialised anchor handling vessels which are already used for placing deepwater moorings.

Floating systems have relatively light anchor systems that could be placed relatively quickly. This is an important consideration, as anchors are easiest to deploy during slack tide (the time between ebb and flood tides), and this is usually a short period of time. However, there are some challenges for engineers in keeping the floating unit stable whilst it is in operation.

Theoretically at least, floating devices could be serviced by detaching them from their moorings and floating them away. However, coupling flexible electricity cables to floating devices is more difficult than coupling them to a fixed structure. These cables are needed to carry electricity back to shore.

Floating systems may be needed for deepwater areas, because the practical length of monopiles is limited, and the deployment of gravity foundations with seabed preparation becomes much harder in deep water. In the UK the deeper areas of ocean contain the most of the tidal stream resource.

► **Floating systems are slightly more difficult to engineer than fixed structures, but may be more suitable in deeper water areas. Much that has been learnt from fixed systems can be applied to floating systems.**

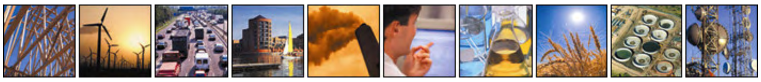
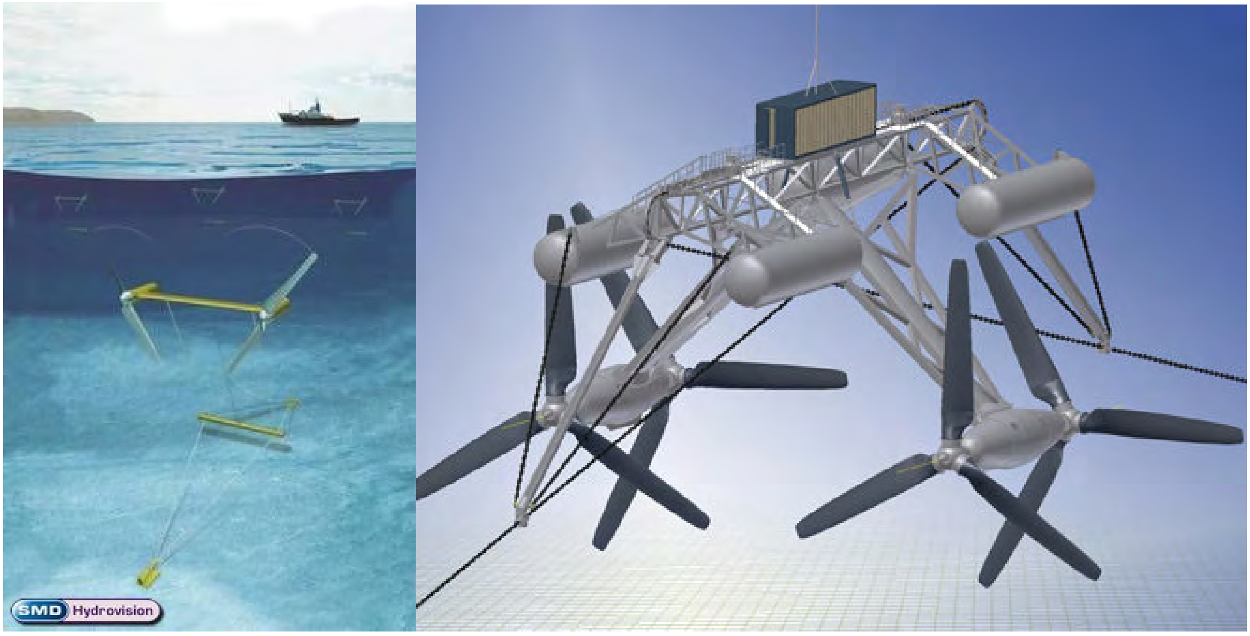


Figure 2.11 Examples of floating tidal stream devices

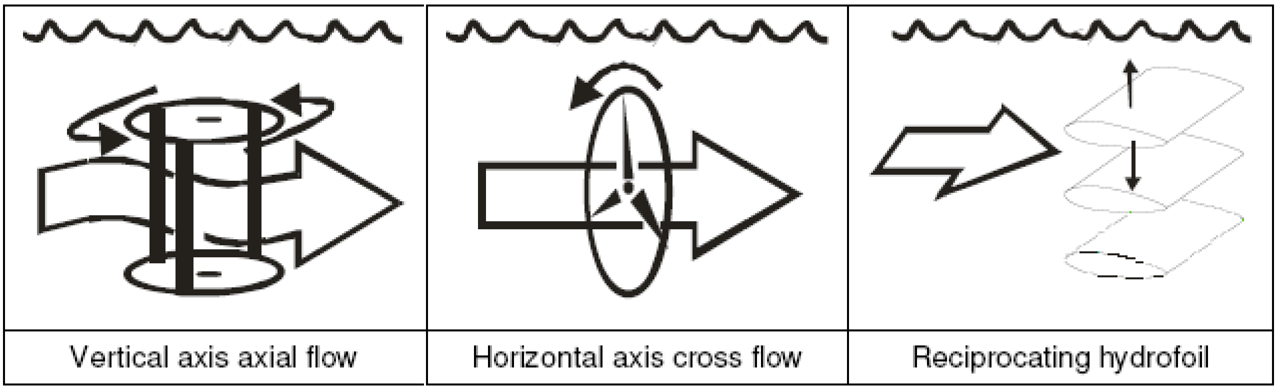


Buoyant submersible system used for the TidEl device[10] and surface-mounted system used by Statkraft[11]. Both designs use axial-flow turbines.

2.5.2 Rotor configuration

There are several different rotor configurations that may be used in tidal streams. There is little fundamental difference between them in terms of energy capture. Each has advantages over the others. The cross-sectional area or ‘swept area’ presented to the flow determines the energy capture of the device. The larger the area, the greater the energy capture. The shape of the swept area has some minor influence on the performance of the system. The rotor types are described below.

Figure 2.12 Schematic of different rotor types



Vertical axis axial flow

Horizontal axis cross flow

Reciprocating hydrofoil

Axial-flow

Axial-flow rotors extract energy from the water flowing along their axis of rotation, see Figure 2.9, Figure 2.10 and Figure 2.11. This is much the same as most modern wind turbines. These systems usually have rotors that prescribe a circle. Examples of axial-flow turbines include those being developed by MCT[6], SMD Hydrovision Ltd[10], Lunar Energy Ltd[7] and OpenHydro Group Ltd[8].

Cross-flow

Cross-flow rotors extract energy from water flows across (perpendicular to) their axis. Their rotors spin round and their blades move back and forth across the flow. These devices tend to produce a square cross section to the flow (though many other shapes are possible too). Cross-flow turbines are being developed by Edinburgh Designs[12] and Blue Energy[13], see Figure 2.13.

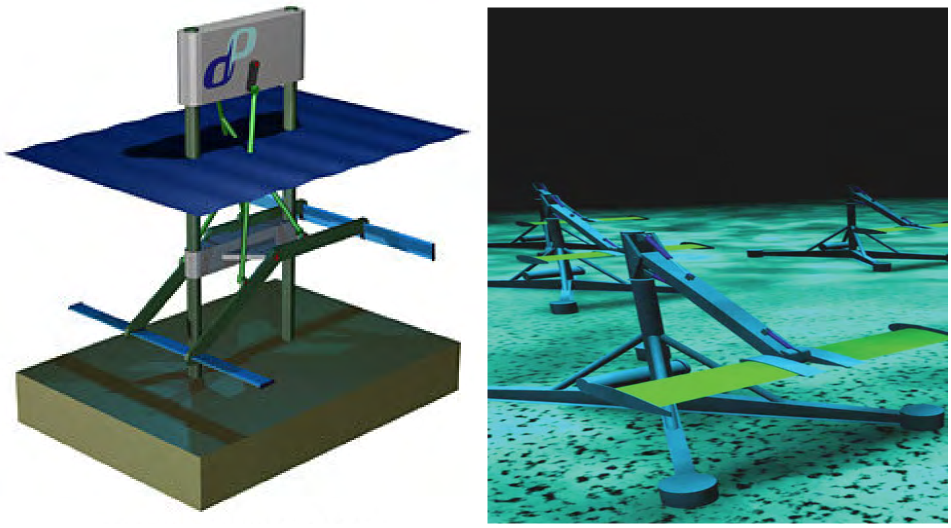
Figure 2.13 Examples of tidal stream cross-flow turbines

Edinburgh Designs[12] and Blue Energy[13] cross-flow turbines.

Reciprocating hydrofoils

Reciprocating hydrofoils do not rotate but are forced to move up and down repeatedly by the tidal stream. To convert this movement into rotation for the generator the hydrofoils are connected to a linkage that is used to drive a rotating shaft, either mechanically or by using hydraulics. Again these present a square cross section to the flow. Pulse Generation Ltd[14] is developing a device that uses reciprocating hydrofoils and the Engineering Business Ltd (EB)[15],[16] has investigated this type of system in the past, see Figure 2.14.

Figure 2.14 Examples of reciprocating hydrofoils



Device designs from Pulse Generation Ltd[14] and EB[15].

- ► **There is little to distinguish the hydrodynamic efficiency of different rotor types. Each has advantages over the others in terms of cost and performance.**

2.5.3 Ducting

For the rotor configurations described above, it is possible for the rotor to be free stream or ducted.

Free stream

A free stream device has the rotor placed directly in the tidal stream. Examples of this are the devices shown in Figure 2.9 and Figure 2.11.

Ducted

A duct is a cowling placed around the turbine to enhance flow through the rotor. The velocity of the tidal stream passing through the turbine may be increased by channelling a large amount of water through a smaller cross-sectional area. This may be beneficial in low-speed sites, or can allow the use of a smaller rotor to produce the same power output. Ducts also provide protection for the blade tips. Ducts can also be used to adjust the direction of flow. The Lunar RTT[7], shown in Figure 2.10, is an example of a ducted device.

The cost of the duct is balanced with the saving on the cost of the rotor. If the duct can be provided at a lower cost than a larger rotor then it may have some advantages. Experience in wind energy suggests that the performance improvement alone from ducting does not justify its cost[e] but the evidence is not yet available to determine whether the ducting of tidal stream devices will justify the additional material cost.

► **Ducted systems can make the working section of the rotor smaller for the same power output, and can straighten flow through the rotor. This can be an advantage if the cost of the ducting is less than the cost of a larger rotor.**

Other systems

One other system has been proposed. This is known as a venturi system, and it is illustrated in Figure 2.15. The system ducts water through a nozzle, which is like a wide tube that becomes narrower. A secondary circuit in a parallel duct is connected between the narrow and wide parts of the nozzle. Water flowing through the nozzle causes a pressure drop across the secondary circuit, and this causes a fluid to flow within the secondary circuit. A turbine is then placed in this secondary fluid flow. There are many similarities between this system and the ducted horizontal-axis system described above, but instead of a rotor placed in the duct, it has a turbine placed in a secondary circuit. There is currently no evidence to suggest that this system will offer significant technical benefits over the other methods described here. Additionally there is no evidence that this system will work in free-stream applications. It could work in a barrage as an alternative to a conventional hydro turbine.

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[e] A New Zealand company developed a ducted wind energy system in the 1990s. Known as the Vortec, this system was described as a Diffuser Augmented Wind Turbine (DAWT). A 7m diameter prototype was installed at Waikaretu south of Auckland. Despite strong funding, this system never achieved the theoretical performance needed to justify its cost.

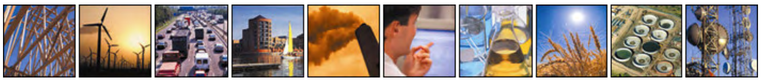
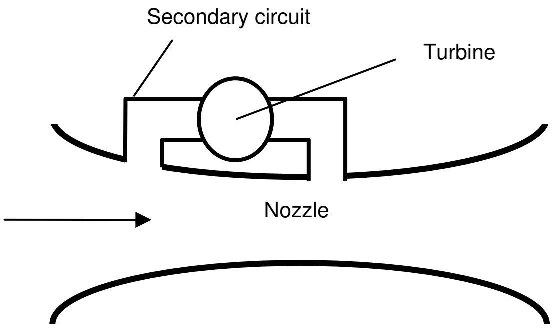


Figure 2.15 Schematic of a venturi system



Flow through the duct is from left to right

2.6 Status and deployment of tidal energy technologies

There are currently no commercial tidal energy schemes operating in the UK. Therefore much of the information contained in the remainder of this report is based on prototype or early-stage schemes. Many aspects of these schemes (e.g. design, costs) are likely to change during further research, development and testing. Experience will be gained through production, construction, installation, operation and maintenance of tidal energy schemes. When tidal energy technologies reach commercial development, they can benefit from economies of scale in production. Cost reductions can occur through the experience gained from producing large numbers of a device. This is often referred to as ‘learning’[17], and the potential for learning varies between the different technologies.

The nature of tidal barrages is that they are one-off schemes in particular locations, and it is unlikely that large numbers of barrages would be constructed in the UK. Barrage technology has little potential to benefit from learning. It is not possible to make cost savings through bulk production, as only one individual scheme would be constructed at any time, and each scheme would be different. The components that would be produced in bulk (e.g. turbines and concrete) are standard components which already benefit from economies of scale. The materials supply chain for very large schemes such as the Cardiff Weston barrage would need to be carefully considered, since this could upset the local market for the materials required and possibly result in increases in price.

There is more potential for learning in tidal lagoons. The tidal lagoon is a novel use of a conventional technology that, to date, has not been constructed. This means that the construction of the first scheme will provide experience that may improve the design, construction and installation of future schemes. However, the design of a tidal lagoon does not allow for savings through bulk production, as it is largely a civil structure which must be designed specifically for the site location. Tidal lagoons do use large quantities of materials which do not attract significant economies of scale, indeed they may suffer from problems with shortage of materials supply in a similar way to barrage schemes.

Tidal stream devices offer the greatest potential for learning. As the devices are still a technology under development, further research and testing may lead to design developments that improve the operation of the devices. The devices are modular, and therefore a tidal stream farm will be constructed from a number of identical devices. As more and more devices are installed, experience will be gained through production, construction, installation and operation and maintenance. This will lead to cost savings, and the devices will benefit from economies of scale. This has been observed for other renewable energy technologies; there have been cost reductions for photovoltaic cells and wind turbines as the scale of manufacturing increases and installed capacities rise[17],[18],[19],[20],[21],[22],[23].

► **There are currently no operating commercial tidal energy schemes in the UK.**

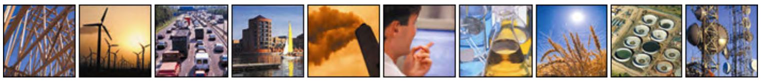
► **Tidal barrages are likely to be large one-off installations which could be installed in a limited number of locations in the UK.**

► **Tidal lagoons would be moderately large installations that could be duplicated in UK waters.**

► **Tidal stream devices are likely to be individually small, but deployed in farms of increasing numbers over time. The scale of deployment is crucial to the commercial success of tidal stream technologies.**

There are a number of tidal stream devices which are currently under development. These devices are at different stages of development, ranging from concept designs to part-scale models that have been tested at sea. The stages of development have been classified as:

- Concept design – initial design of the device;
- Detailed design – detailed design of the device and all of its components, with sufficient detail for construction, usually verified with computer modelling;
- Part-scale model – testing of device components or a part-scale model in a wave tank or at sea;
- Full-scale prototype – testing of a full-scale device at sea, which may or may not be connected to the electricity network;
- First production model – first full-scale device installed at sea and connected to the electricity network, selling the electricity generated although not necessarily at a competitive price;
- Pre-commercial array – first small array of full-scale devices installed at sea and connected to the electricity network, selling the electricity generated although not necessarily at a competitive price;

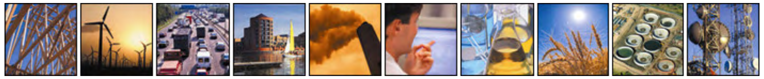


- Commercial farm – installation of multiple devices generating electricity at a price that can compete within the electricity market.

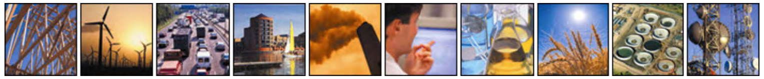
Table 2.1 provides a list of the devices that are known to be under development around the world. There have been no full-scale prototypes to date but there are plans to produce full-scale prototypes of some of the listed devices in the near future.

Table 2.1 Tidal stream devices under development (at February 2007)

Developer	Device	Placement	Rotor configuration	Ducting	Progress	Latest news	Website
Hammerfest Strøm	Blue Concept	Fixed	Axial	Free stream	Part-scale model	Part-scale model is still being tested. It has been in the water for 3 years.	www.e-tidevannsenergi.com
Marine Current Turbines Ltd	Seaflow/SeaGen	Fixed	Axial	Free stream	Part-scale model	Have deployed a 300kW prototype device (not grid connected). They are planning to install full-scale prototype in Strangford Lough during 2007.	www.marineturbines.com/home.htm
OpenHydro Group Ltd	Open Centre Turbine	Fixed	Axial	Free stream	Part-scale model	Installed a 250kW test unit at EMEC January 2007 for testing. It is not yet grid connected.	www.openhydro.com/home.html
The Engineering Business Ltd	Stingray	Fixed	Reciprocating	Free stream	Part-scale model	A 150kW prototype was tested in Shetland. Development discontinued.	www.engb.com/services_09a.php
SMD Hydrovision Ltd	TidEL	Floating	Axial	Free stream	Part-scale model	A scale model was tested at NaREC. Full-scale prototype is planned for installation at EMEC.	www.smdhydrovision.com/products/?id=27
Robert Gordon University & AREG	Seasnail	Fixed	Axial	Free stream	Part-scale model	A 150kW unit to prove the innovative foundation concept has been tested.	www.rgu.ac.uk/cree/general/page.cfm?pge=10769

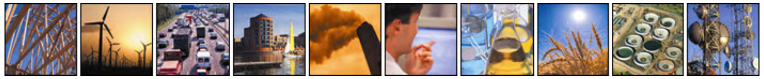


Developer	**Device**	**Placement**	**Rotor configuration**	**Ducting**	**Progress**	**Latest news**	**Website**
Scotrenewables	Scotrenewables Tidal Turbine (SRTT)	Floating	Axial	Free stream	Part-scale model	Planning to install full-scale prototype at EMEC.	http://www.scotrenewables.com/index.html
Blue Energy International	Blue Energy Ocean Turbine	Fixed	Cross-flow	Ducted	Part-scale model	Tank testing during 2006.	www.bluenergy.com/index.html
Ponte di Archimede International S.p.A.	Kobold Turbine	Floating	Cross-flow	Free stream	Part-scale model	A 130kW part-scale model has been tested in Italy. Planning full-scale prototype during 2007.	www.pontediarchimede.com/language_us/index.mvd
Lunar Energy Ltd	Rotech Tidal Turbine	Fixed	Axial	Ducted	Part-scale model	Planning to install prototype at EMEC.	www.lunarenergy.co.uk/index.htm
GCK technology	Gorlov Turbine	Not known	Cross-flow	Free stream	Part-scale model	Not known.	www.gcktechnology.com/GCK/
Hydroventuri Ltd	Rochester Venturi	Fixed	Other	Ducted	Part-scale model	A version of the device has been tested in a river.	www.hydroventuri.com/news.php
Marine Energy Generation Ltd	DeltaStream	Floating	Axial	Free stream	Part-scale model	Planning full-scale model during 2007/08.	www.peterbrotherhood.co.uk/search.aspx?search=tidal
Seapower	Exim	Floating	Not known	Not known	Part-scale model	Not known	www.waterpowermagazine.com/story.asp?sectionCode=46&storyCode=2019602
Swanturbines	Swanturbine	Fixed	Axial	Free stream	Part-scale model	Planning to install a 350kW part-scale model in 2007.	http://www.swanturbines.co.uk/
UEK Systems	Underwater Electric Kite	Floating	Axial	Ducted	Part-scale model	Not known	www.uekus.com/index.html



Developer	Device	Placement	Rotor configuration	Ducting	Progress	Latest news	Website
Verdant Power	IEGT	Fixed	Axial	Free stream	Part-scale model	Not known	www.verdantpower.com/index.html
Edinburgh Designs Ltd	Vertical Axis Tidal Turbine	Floating	Cross-flow	Free stream	Concept design	Not known	no website
Pulse Generation Ltd	Pulse Generator	Fixed	Reciprocating	Free stream	Concept design	Planning part-scale model for 2007.	www.pulsegeneration.co.uk/index.asp
Statkraft	Not known	Floating	Axial	Free stream	Concept design	Not known	www.statkraft.com/pub/innovation/tidal_power/index.asp
Tidal Generation Ltd	Tidal Turbine	Fixed	Axial	Free stream	Concept design	Planning to install part-scale model at EMEC.	http://www.tidalgeneration.co.uk/index.html
Hydrohelix Energies	HXE	Fixed	Axial	Ducted	Not known	Not known	www.cci-entreprises.icomme.fr/public/stand.php?id_stand=418
J.A. Consult	Tidal Stream Turbine	Fixed	Axial	Free stream	Not known	Are working on a deep-water tidal device concept.	www.tidalstream.co.uk
Weir Group and SSE Generation Ltd	Neptune	Not known	Axial	Not known	Not known	Planning to install at EMEC. Thought to be a fixed, axial-flow machine.	www.scottish-southern.co.uk

EMEC is the European Marine Energy Centre in Orkney. NaREC is the New and Renewable Energy Centre in Blyth, Northumberland. Planned developments are proposals from the developers, they are not schemes which have received planning consent, although standard planning consents are not required to test devices at EMEC.

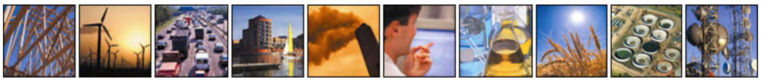


2.6.1 Tidal stream projects

Table 2.1 shows the wide range of devices under development. Table 2.2 summarises the past, present and future tidal stream projects that involve testing devices at sea. The following paragraphs provide a more detailed description of the devices that are at the most advanced stages of development. However, although these devices may currently be industry fore-runners, the industry is still at an early stage of development so it is possible that another device listed in Table 2.1, or another which is yet to be invented, becomes the industry leader.

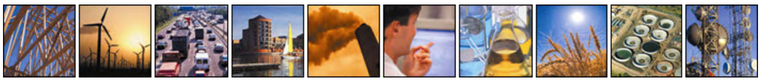
Table 2.2 Tidal stream projects

Developer	Device	Capacity	Date of project	Location of project
Ponte di Archimede International S.p.A.	Enermar	130kW	1999	Part-scale model was installed in the Strait of Messina, Italy.
The Engineering Business Ltd	Stingray	150kW	2002	Part-scale model was installed in Yell Sound, Shetland Islands.
Hammerfest Strøm	Blue Concept	Unknown	2003	Part-scale model was installed in Kvalsundet, Norway and connected to the electricity network.
Marine Current Turbines Ltd	Seaflow	300kW	2003	Part-scale model was installed off Lynmouth, Devon and generated into a dump load.
Robert Gordon University	Seasnail	150kW	2004	Part-scale model was installed in Eynhallow Sound, Orkney.
Marine Current Turbines Ltd	SeaGen	1.2MW	2007	Full-scale prototype is planned for installation in Strangford Lough, Northern Ireland. Project has the necessary planning consents.
OpenHydro Group Ltd	Open Centre Turbine	250kW	2007	Part-scale model has been installed at the EMEC, Orkney.
Ponte di Archimede International S.p.A.	Kobold Turbine	Unknown	2007	Full-scale prototype is planned for installation in China.
Lunar Energy Ltd	Rotech Tidal Turbine	1MW	2007	Full-scale prototype is planned for installation at the EMEC, Orkney.
Pulse Generation Ltd	Pulse Generator	100kW	2007	Part-scale model is planned for installation in The Humber, Lincolnshire.
Swanturbines	Swanturbine	350kW	2007	Part-scale model is planned. Location is unknown, possibly Swansea Bay.
Marine Energy Generation Ltd	DeltaStream	1MW	2007/2008	Full-scale prototype is planned. Location is unknown.
Scotrenewables	SRTT	1.2MW	2008	Full-scale prototype is planned for installation at EMEC, Orkney.
OpenHydro Group Ltd	Open Centre Turbine	Unknown	Unknown	Full-scale prototypes are planned for installation off Alderney.



Developer	**Device**	**Capacity**	**Date of project**	**Location of project**
SMD Hydrovision Ltd	TidEl	1MW	Unknown	Full-scale prototype is planned for installation at the EMEC, Orkney.
Tidal Generation Ltd	Tidal Turbine	500kW	Unknown	Part-scale model is planned for installation at EMEC, Orkney.
Weir Group and SSE Generation Ltd	Neptune	2.4MW	Unknown	Full-scale prototype is planned for installation at the EMEC, Orkney.

EMEC is the European Marine Energy Centre in Orkney. Planned developments are proposals from the developers, they are not schemes which have received planning consent, although standard planning consents are not required to test devices at EMEC.



Hammerfest Strøm

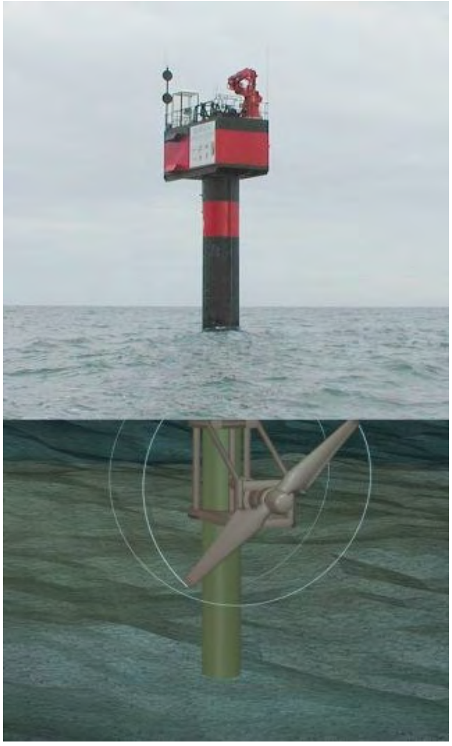
Hammerfest Strøm is developing a fixed axial-flow turbine called the Blue Concept. A part-scale model of the turbine has been constructed, and was installed in Kvalsundet, Norway (Figure 2.16). This device is connected to the electricity network, making it the first grid-connected tidal stream device in the world. The future plans are to install a pilot project of 20 turbines within the Kvalsundet, to gain experience of installation and construction work[24]. Hammerfest Strøm's main aim in deploying the prototype is to prove both its performance and its reliability. They claim that the turbine has been submersed continually for the last three years with only minor inspection and intervention by divers.

Figure 2.16 Hammerfest Strøm prototype turbine being installed at Kvalsundet[24]

Marine Current Turbines Ltd

In 2003 MCT installed a mono-pile mounted, 300kW axial-flow turbine off Lynmouth, Devon (Figure 2.17). This turbine was not connected to the electricity network, but did generated electricity into a dummy or ‘dump’ load. This allowed the device to be tested, and experience of installation and operation and maintenance to be gained. The next stage of the development is to install a 1.2MW device called SeaGen, in Strangford Lough, Northern Ireland. SeaGen will consist of two axial-flow 600kW turbines mounted on a mono-pile.

Figure 2.17 Seaflow turbine installed at Lynmouth[6]



Hybrid image – photo above and artist’s impression below.

The Engineering Business Ltd

The Stingray device developed by the Engineering Business (EB) is a reciprocating hydroplane device. EB has completed a programme to design, build, install offshore, test and decommission a 150kW part-scale model of the device. The device was installed in Yell Sound, Shetland Islands (Figure 2.18). However, EB subsequently discontinued development of the Stingray as it was believed that the funding available was ‘*not on the scale or basis that would allow EB to rapidly or profitably make Stingray a commercial reality*’[15].

Figure 2.18 Stingray commissioning in Shetland[15]

OpenHydro Group Ltd

OpenHydro Group Ltd is developing a fixed axial-flow turbine called the Open Centre Turbine. A 250kW test unit was installed at the European Marine Energy Centre during January 2007 (Figure 2.19). The test turbine has been mounted on a twin mono-pile structure to allow easy access to the turbine and to minimise the cost of testing future turbines. It is planned that a commercial turbine will have a gravity-based foundation. The test turbine is not yet grid-connected, but the plan is to connect it to the local electricity network later in 2007. OpenHydro has recently signed a deal with Alderney Renewable Energy to build several 1MW turbines off the coast of Alderney. The pilot project will be monitored before a tidal energy farm is agreed.

Figure 2.19 OpenHydro's turbine test rig at EMEC[8]

SMD Hydrovision Ltd

SMD Hydrovision Ltd is developing a floating, axial-flow tidal device called TidEl. Two turbines are mounted on a crossbeam, and the device is buoyant so a mooring system is used to hold the device in place. A 1:10 scale model of the TidEl has been tested in a flume at the National Renewable Energy Centre (NaREC), and a full-scale prototype is planned for installation at the European Marine Energy Centre (EMEC).

Figure 2.20 TidEl part-scale model[10]

2.7 Key technical challenges for tidal stream devices

2.7.1 Research and Development priorities

Several studies have been completed to look at the technical R&D priorities for tidal stream technologies. Some of these are compared in Table 2.3. The International Energy Agency (IEA) and World Energy Council (WEC) studies comprise a rational argued ‘wish list’ of technology development areas. The Carbon Trust priorities are derived from an assessment of the effect of each area on the total cost of energy, identifying high priority areas as those that have greatest influence on the cost of energy.

Table 2.3 Research and Development priority areas for tidal stream technologies

International Energy Agency[25]	**Carbon Trust**[26]	**World Energy Council**[27] **(based on priorities for wave energy)**
Technology Information Centre Resource Assessment Operation & Maintenance Biofouling Impacts on Marine Life Sealing Weather and Wave Forecasting Cavitation Interaction with the Marine Environment Turbulence Installation foundations	**High priority** Structural Materials (Floats, device body, piles etc) Gearbox (and alternatives) **Medium priority** Rotors Mooring Tethers, Anchors and Connections Device-mounted electrical plant (AC/DC/AC Converter etc.) Subsea Cabling Offshore Substation	Moorings – long-term fatigue of lines and connections Standard couplings for quick-release and re-attachment of moorings and cables Standard flexible electrical connectors Reduced-cost production of cables, construction and laying offshore Environmentally acceptable fluids for hydraulic systems Direct-drive power generators Cost engineering Streamline of the planning and regulatory processes Development of suitable approaches to grid connection Cost-effective materials, design and construction methods

There is plenty of common ground between the studies. Clearly moorings, offshore operations, generator design and electrical connections are all considered important. However, structural costs comprise a large proportion of capital costs, and are ranked highly in the Carbon Trust study. Whilst there is much to gain in lowering structural costs, it is hard to find innovative solutions in this area, as structural technology is quite mature. In the case of tidal stream technologies, the innovation is making the best use of the structure rather than simply lowering its cost.

Gearboxes represent another significant cost. Not all tidal stream devices use these, but where they are used they are quite unique. They carry very high loads, and have high torque and high speed-increasing ratios. This makes them rather unusual, even compared to wind turbine gearboxes. It took some time for wind energy gearbox technology to mature, and some of the early gearboxes had many problems. It is important to avoid these mistakes in tidal stream devices, especially as replacement of faulty units is far more complex at sea.

Much can be learnt from other industries, and while many of the challenges faced by tidal technologies have sophisticated technological solutions, not all these solutions are available at the low cost needed to make tidal stream a viable method of energy generation.

2.7.2 Current research

As the tidal energy industry has yet to develop into a commercial market, a significant amount of research is currently being undertaken by device developers, universities and consulting engineers. Table 2.4 provides an overview of DTI grants currently held for tidal energy research.

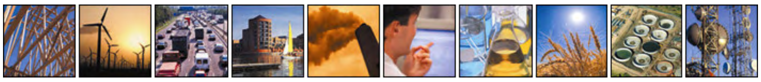


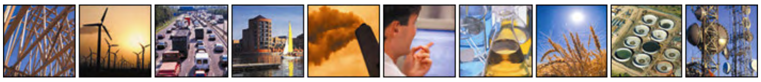
Table 2.4 DTI grants currently held for tidal energy research[28]

Organisation	Device	Research title	Proposed outcome of research	Dates of project	Value of grant
IT Power Ltd (with Pulse Generation Ltd, University of Hull and CIC Omec Ltd)	Pulse Generator	Development, test and demonstration of high efficiency, shallow flow tidal device	Deploy a grid connected 1/5th scale, 100kW device in The Humber.	November 2005 – October 2007	£1,896,847
Garrad Hassan and Partners Ltd (with Lunar Energy Ltd, SMD Hydrovision Ltd and University of Southampton)	Rotech Tidal Turbine TidEl	Performance characteristics and optimisation of marine current energy converter arrays	Develop a design tool for tidal stream turbine arrays through model and full-scale testing as well as numerical modelling.	December 2005 – November 2008	£536,498
Lunar Energy Ltd	Rotech Tidal Turbine	RTT Tidal Stream Technology Development	Deploy RTT tidal device at EMEC for testing.	March 2005 – December 2007	£5,619,019
SMD Hydrovision Ltd	TidEl	Novel Moored Tidal Stream Generating Equipment	Deploy a full-scale 1MW TidEl device at EMEC, conduct an environmental impact assessment and prove economic viability of the TidEl.	May 2005 – February 2008	£4,463,000
The Weir Group Plc (with SSE Generation Ltd and Strachan and Henshaw Ltd)	Neptune	Project Neptune Phase 2 – Experimental Development	Deploy a full-scale 2.4MW prototype at EMEC.	September 2005 – June 2007	£8,233,644

In February the Scottish Executive announced more than £13 million of funding for nine different marine energy projects. The tidal energy projects that received funding are listed in Table 2.5.

Table 2.5 Scottish Executive funding for tidal energy projects

Project	Objective of project	Value of grant
Tidal Generation Ltd Tidal Turbine	Extract a core sample of seabed from its potential berth area	£77,000
OpenHydro Group Ltd	Part-funding for installation of 250kW prototype at EMEC	£1.214 million
Scotrenewables Tidal Turbine	Part-funding for installation of full-scale prototype at EMEC	£1.796 million



3. Technological differentiators

Section 2 provides an introduction to the types of technology which have the potential to generate electricity from tidal energy. This section describes a number of technological differentiators that allow a comparison of these technologies. As many of the technologies are still under research and development, and have yet to reach commercial operation, it is not always possible to provide accurate or definite values. In these cases a range of values may be provided, or a qualitative comparison of the technologies may be given.

3.1 Resource

3.1.1 Tidal range

The global tidal range resource can be calculated by identifying estuaries that have a large tidal range. Suitable sites are not common, but have been identified in the UK, Argentina, Australia, Canada, Chile, China, France, India, Korea, Mexico, Russia and USA. The available energy is approximately proportional to the square of the tidal range and the extraction of energy is only considered practical at sites with a large tidal range and where the geography provides suitable sites for a generation scheme. The total world resource has been estimated to be between 386TWh/y[29] and 560TWh/y[30].

The UK[f] tidal range resource is approximately 19TWh/y[29] and this is mostly found in the Severn Estuary. This could meet approximately 4.7% of the UK electricity demand[31] with the Cardiff Weston barrage alone meeting 4.2%.

3.1.2 Tidal stream

There have been few studies which estimate the world tidal stream resource, and it is difficult to determine the accuracy of the values available. Black and Veatch[32] completed a review of the reports that give a value for the global resource, and summarise the wide range of values quoted. This range of values is partly due to the fact that different tidal stream sites are included in the calculations, and that different calculation methodologies are used. The estimates suggest that the global resource could be 765TWh/y, and that the extractable resource is likely to be around 20% of this value. Black and Veatch conclude that '*it can be stated with certainty that there is a large global tidal stream resource, and that it is very difficult to estimate accurately*'.

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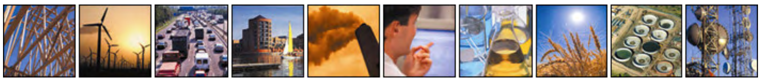
[f] For the purpose of this report, and for ease of reading, UK means the United Kingdom of Great Britain and Northern Ireland and the British Islands (including the Channel Islands and the Isle of Man).



The UK tidal stream resource can be estimated more accurately. Black and Veatch[33] estimates that the technically extractable resource is 18TWh/y, and that this figure is accurate to ±30%[g]. This represents approximately half of the European resource, and could provide approximately 4.5% of the UK electricity demand[31]. Of the technically extractable resource, about 63% is in sites with water depths greater than 40m, 30% at sites with depths between 30 and 40m, and the remainder is a limited resource in shallower sites. This distribution of resource by water depth has implications for the choice of foundation types, see Section 2.5.1.

Table 3.1 Tidal energy resource[29],[30],[32],[33]

Location	Extractable tidal range resource (TWh/y)	Extractable tidal stream resource (TWh/y)
World	386 – 560	150
UK – deep water	-	11.3
UK – shallow water	-	6.7
UK – total	19	18

- ► **There is approximately the same amount of tidal stream and tidal range energy in the UK and each could meet about 4 to 5% of the UK's electricity demand. As the two resources are located in different locations it may be possible to meet up to 10% of the UK's electricity demand from tidal energy.**

3.2 Resource location

As described in Section 2, the tidal energy resource is highest in areas with specific seabed topography. For example, the tidal range is greater in estuaries and basins that benefit from strong coriolis forces, and which have a size and shape that creates resonance. Tidal streams are generally fastest in channels and around headlands. Therefore the tidal energy available around the UK coast is concentrated in a small number of locations.

Figure 3.1 is taken from the Atlas of UK Marine Renewable Energy Resources produced by the DTI[34], and shows the mean spring tidal range. This shows that the tidal range is greatest in the Severn Estuary and along the north-

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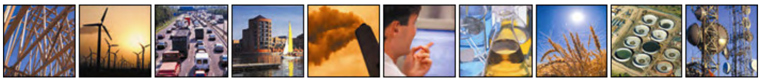
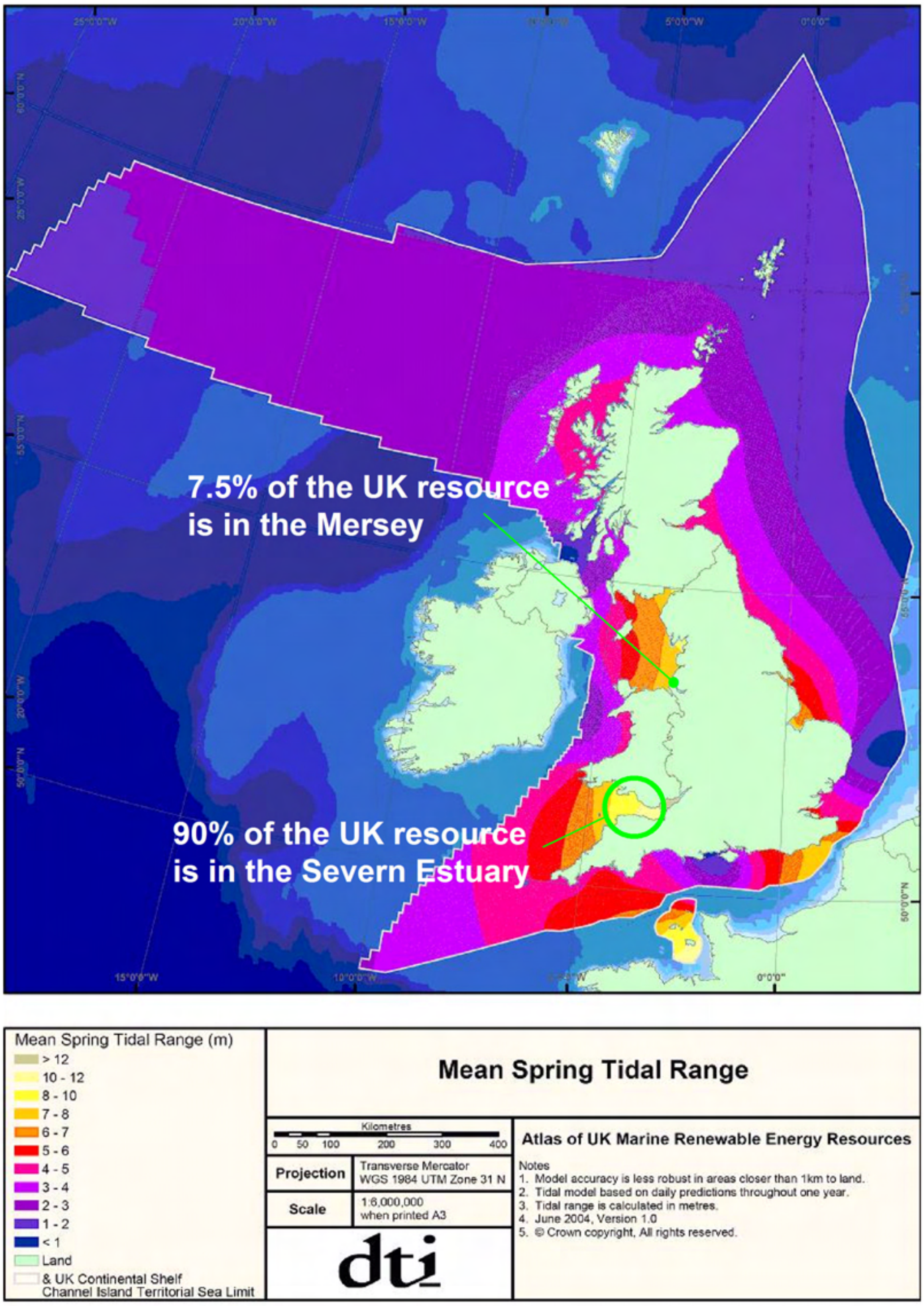
[g] This estimate relies on updates previous work on the UK tidal stream resource but also relies on state-of-the-art resource modelling knowledge from organisations such as Robert Gordon University who have contributed to several studies including the DTI marine energy atlas.



west and south-east coasts of England. The six sites listed in Table 3.2 have mean tidal ranges between 5.2 and 7.0m[29]. However, as shown in Figure 3.1, 90% of the available resource is situated in the Severn. This is the resource which can be exploited by tidal range technologies.

Figure 3.2 shows the annual mean tidal power density, which is the resource which can be exploited by tidal stream technologies. The map shows that the areas with the greatest power density are located around the Scottish islands (Shetland, Orkney and various islands off the west coast), the Severn Estuary, Anglesey, the Isle of Wight and around the Channel Islands. Black and Veatch[35] has identified 57 tidal stream sites around the UK coastline. However the resource is mainly concentrated in the Pentland Firth and the Channel Islands. The ten sites listed in Table 3.2, and shown in Figure 3.2, contain the majority of the resource. Most of the resource in the north of Scotland is in deep water. The shallow water sites tend to be around the coast of Wales, the Bristol Channel and off the south coast of England.

Figure 3.1 UK mean spring tidal range and tidal range sites[34]



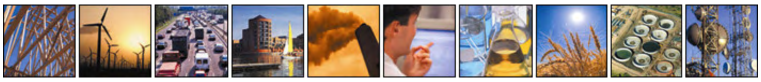
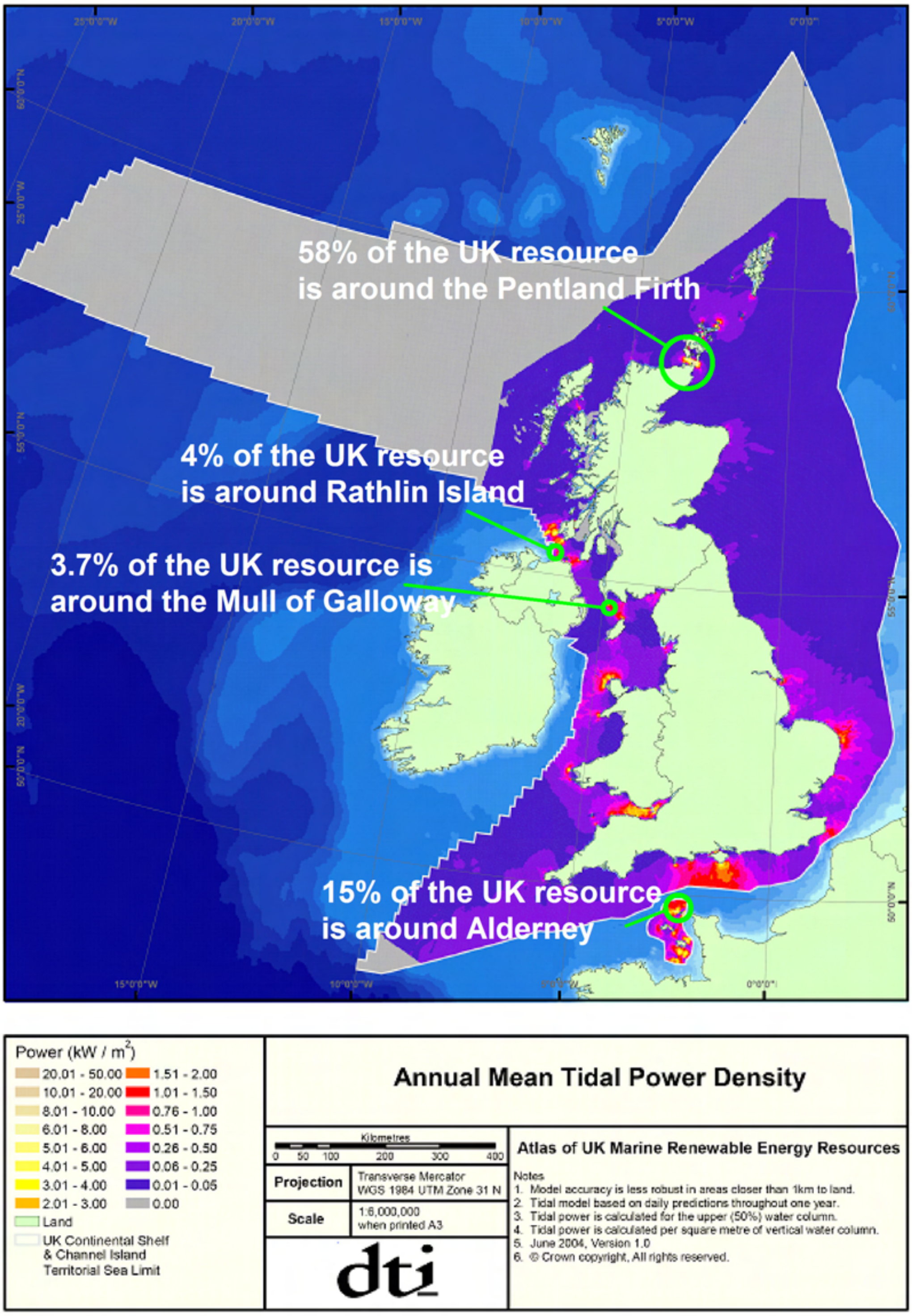


Figure 3.2 UK annual mean tidal power density and tidal stream sites[34]



Annual Mean Tidal Power Density

Atlas of UK Marine Renewable Energy Resources

Notes
1. Model accuracy is less robust in areas closer than 1km to land.
2. Tidal model based on daily predictions throughout one year.
3. Tidal power is calculated for the upper (50%) water column.
4. Tidal power is calculated per square metre of vertical water column.
5. June 2004, Version 1.0
6. © Crown copyright, All rights reserved.

Table 3.2 Breakdown of some key tidal energy sites in the UK

Tidal range sites[29]		Tidal stream sites[35]		
Site name	**Resource (TWh/y)**	**Site name**	**Area**	**Resource (TWh/y)**
Severn	17	Pentland Skerries	Pentland Firth	3.9
Mersey	1.4	Strøma	Pentland Firth	2.8
Duddon	0.212	Duncansby Head	Pentland Firth	2.0
Wyre	0.131	Casquets	Alderney	1.7
Conwy	0.06	South Ronaldsay	Pentland Firth	1.5
		Hoy	Pentland Firth	1.4
		Race of Alderney	Alderney	1.4
		South Ronaldsay, Pentland Skerries	Pentland Firth	1.1
		Rathlin Island	North Channel	0.9
		Mull of Galloway	North Channel	0.8

A full assessment of the UK tidal resource is provided in the Contract 1 report to the Sustainable Development Commission[36]

- **Most of the tidal range resource in the UK is concentrated in the Severn Estuary.**
- **Most of the tidal stream resource is in the Pentland Firth and Channel Islands. Both of these sites are in areas where there is limited electrical grid capacity (see Section 3.3.1).**

3.2.1 Water depth

Tidal range

Since most of the tidal range resources are in specific locations water depth is less relevant to distinguishing between tidal range options. However, water depth is an important factor when considering the potential of tidal range schemes in smaller estuaries. A study[37] of tidal energy from small estuaries found that the water depth was the limiting factor in the viability of many of the estuaries. At low tide many of the estuaries dry out or are very shallow (less than 3m), whereas 8m water depth is generally required to ensure that the standard hydroelectric turbines within the barrage are submerged (5m depth is possible with some dredging). The study identified the sites in Table 3.3 as worthy of further investigation for the suitability of installing a tidal barrage. A further 2600GWh/y of resource could be available if there was no limit on water depth, as this extra resource is situated in water less than 8m deep.

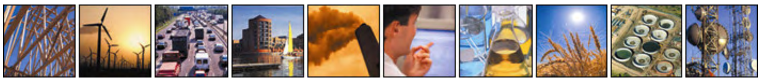


Table 3.3 Tidal range resource in small estuaries with water depth greater than 8m[37]

Site name	Resource (GWh/y)
Langstone	50
The Beacons to Deganwy	57
Fleetwood Outer	110
Menai (Garth)	205
Shelley Bars / Piel Island / Roa Island	275
Whiteford Point / Bury Point	540

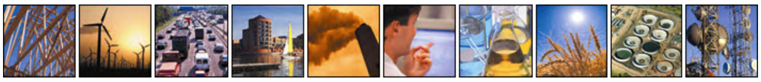
Tidal stream

As shown in Table 3.1, the tidal stream resource can be classified by water depth. The majority of the UK resource is in deep water sites. Of the sites listed in Table 3.2, nine have a water depth greater than 58m; only the Race of Alderney is a classed as a shallow site, with a depth of 33m[35]. The water depth has implications for the support-structure that can be used for tidal stream devices. As described in section 2.5.1, a mono-pile foundation can only currently be installed in water depths of up to 40m. Therefore the number of sites available for development of devices requiring a mono-pile will be limited. Furthermore, the majority of the shallow-water sites have a lower flow than the deep-water sites so the resource in these areas is smaller. Table 3.4 shows that only 12.5% of the resource in shallow sites has a high flow, whereas 80% of the deep-water sites have a high flow.

Gravity-based foundations are also limited by water depth, but it may be possible to install such devices in deeper water than mono-pile foundations. However for sites with a significant water depth (for example Casquets which has a water depth of 115m) floating devices may be required. Therefore the capture of tidal stream energy from the most energetic sites (i.e. those listed in Table 3.2), will require floating devices (or a novel fixed support-structure).

Table 3.4 Characteristics of tidal stream sites[35]

Type of tidal-stream site	Resource (TWh/y)
Low flow (< 3.5m/s) shallow (< 40m)	7
High flow (≥ 3.5m/s) shallow (< 40m)	1
Low flow (< 3.5m/s) deep (≥ 40m)	2
High flow (≥ 3.5m/s) deep (≥ 40m)	8



- **Water depth may be one of the main barriers to the development of tidal range schemes in small estuaries.**
- **The majority of the high energy tidal stream resource is in deep waters. Only a relatively small amount is found in shallow waters.**

3.3 Power production

One of the main differences between tidal range electricity generation and tidal stream generation is the power production from a single scheme. A tidal range scheme has a large potential energy output. The maximum possible energy output from a device is called the installed capacity. For example, the Cardiff Weston tidal barrage suggested for the Severn would have an installed capacity of 8640MW and could generate up to 17TWh per year[1]. This installed capacity would be more than double that of the largest conventional power station currently operating in the UK[31]. A tidal lagoon scheme impounds a smaller area of water than a barrage, and therefore it has a smaller installed capacity. The proposals for a tidal lagoon for Swansea Bay suggest an installed capacity of 60MW, which could generate approximately up to 124GWh per year[38]. This capacity of installation is comparable to the first UK offshore wind farms.

As a barrage or a lagoon is a large civil engineering structure that impounds a volume of water, the structure must be completed before generation can begin. For a barrage similar in size to the proposed Cardiff Weston barrage it is estimated that it may take seven years from construction starting until barrage closure, and a further two years until full power generation can commence[1]. The construction period for a tidal lagoon is estimated to be two years[38]. For both technologies it is estimated that a two or three-year period will be required before construction begins to allow detailed design and planning of the construction[1],[38].

Tidal stream devices are modular, therefore the installed capacity of a tidal stream scheme can range from that of a single device to tens or hundreds of devices. Many of the devices under development are designed so that a full-scale device will have an installed capacity of 1MW. The results from the Marine Energy Challenge[17] suggest that the capacity factor[h] for a tidal stream farm may be of similar magnitude to wind farms, between 20% and 45%, depending on the technology and the site (the capacity factor allows for the fact that the tides do not flow all the time and that the devices only produce their maximum power some of the time). Therefore a 1MW tidal device would produce between 1750 and 3900MWh per year. This is comparable to the rated power of wind turbines that

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[h] The capacity factor is the energy produced during a year of operation as a proportion of the energy that would have been produced had the device been running continually and at maximum output. Maximum output can only occur when the tidal flows is at its maximum. Since this occurs only some of the time the average output is less than the maximum.

$$\text{Capacity Factor}[/] = \frac{\text{Annual Energy Production}[kWh]}{\text{Installed capacity}[kW] \times \text{Hours in Year}[h]} = \frac{AEP}{IC \times 8760}$$

were installed during the 1990s. Tidal stream ‘farms’ will be constructed by installing multiple devices and connecting them together using submarine cables. It is envisaged that the first farms will have a capacity of approximately 5MW and larger schemes will be of comparable size to wind farms, i.e. 30MW or more.

Due to the modular design of tidal stream devices, it is possible for small tidal farms to be constructed initially, and for these to then be extended to include more devices in the future. For a large tidal farm it may be possible for small groups of tidal stream devices to begin generating before the whole farm is completed, depending on the design and construction timetable of the farm.

Table 3.5 Power production from tidal energy schemes

	Tidal range		Tidal stream		
	Barrage*	Lagoon*			
Installed capacity (MW)	8460	60	1 x 1MW	5 x 1MW	30 x 1MW
Annual energy production (MWh/y)	17,000,000	124,000	1750 – 3900	8760 – 19,710	52,560 – 118,260

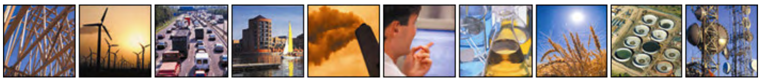
* The barrage scheme is the Cardiff Weston proposal. The lagoon scheme is the Swansea Bay proposal.

► **Barrages could represent single multi-gigawatt schemes, lagoons could represent single multi-megawatt schemes and tidal stream farms could vary in size from individual megawatt-scale units to multi-megawatt farms or larger.**

3.3.1 Electricity network connection

The UK electricity grid comprises several different interconnected networks. The existing power stations are connected together by a large, high voltage grid called the transmission system. Since this grid carries very large amounts of power it operates at a high voltage of 132kV or more. Electricity from the transmission system is carried to particular places by the distribution system that runs at voltages below 132kV and down to 11kV. The final leg of the journey is through the low-voltage system that serves our housing estates and light industrial operations. The electricity we use in our houses is around 240V.

The voltage of the electricity system dictates how much power it can absorb. Conventional coal and gas power stations typically produce power in the range 1000MW-2000MW and connect to the transmission system. Distributed renewable technologies such as wind farms connect to the distribution system at 33kV or more. Only very small systems below say 20kW can connect into the low voltage supply to say a light industrial unit at 415V.



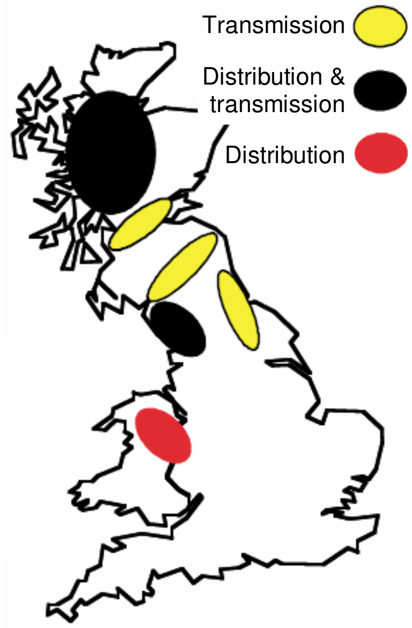
The size of a tidal energy scheme will determine the voltage at which it will connect to the onshore electricity network. A single tidal stream device could be connected to the local electricity distribution network at 11kV; such connections are quite common in small wind farms. As the size of a tidal farm increases it will require connection at either 33 or 132kV[39]. A lagoon is likely to require connection at 132kV or above. A barrage as large as the Cardiff Weston barrage proposed for the Severn Estuary would require connection to the high-voltage transmission network[1]. As with the development of any power generation scheme, the connection of tidal energy to the electricity network will require modification of the existing network. This may involve:

- Construction of new overhead lines or underground cables;
- Reinforcement or modification of existing overhead lines or underground cables;
- Construction of new substations; and
- Expansion of existing substations.

The work required will depend on the size of the proposed tidal energy scheme and the configuration of the existing network at the point of connection.

Some of the smaller more geographically dispersed tidal stream technologies may be accommodated into the current electricity network with minimal upgrades, whereas large tidal stream, barrage and lagoon schemes will probably require significant network upgrades. Network upgrades will also be required in locations where arrays of tidal stream devices may be located, such as the Pentland Firth.

Figure 3.3 Location of key electrical network capacity constraints[40]



There are already constraints within the existing distribution and transmission networks, see Figure 3.3, and these may impact on the development of tidal energy generating schemes. The distribution and transmission networks in the north-west of Scotland are currently constrained, and this is having an impact on the development of onshore wind energy generation in the north and west of Scotland, as there is insufficient capacity on the network to accept new generation. Without reinforcement, this would also impact on the development of tidal stream energy generation in the Pentland Firth, as it would not be possible to transmit the electricity generated here to consumers who are mainly concentrated in the south of England. It is not currently possible to connect any significant new power generation to Orkney, as the local demand is very low and there is very little capacity on the submarine cable connecting Orkney to the mainland. This connection will need to be upgraded if tidal stream devices wish to connect to the Orkney electricity network. The transmission network constraints between Scotland and England are also a major bottleneck in the system. The high-voltage transmission network may need reinforcement as the volume of tidal energy increases. Although there are fewer transmission network constraints in the south of England, network reinforcement would be required to accommodate power produced from the potential Severn barrage (the costs for this reinforcement are included in the Cardiff Weston barrage proposals cited here).

The current electricity network constraints will have serious implications for the development of UK sites with the greatest tidal resource. The majority of the deep tidal stream resource is located in the north of Scotland, and it is not currently possible to connect new power generation in these locations to the electricity network. Many of the shallow tidal stream sites are located around the Welsh coast and the south of England, and it may be possible to accommodate generation from these sites within the existing electricity network. Table 3.6 provides a comparison of the network connections for tidal energy schemes and the current network constraints.

Table 3.6 Electricity network connections for tidal energy schemes

	Tidal range		**Tidal stream**	
	Barrage	**Lagoon**	**Deep**	**Shallow**
Connection voltage (kV)	275 – 400	132	11 – 132	11 – 132
Required network upgrades for connection	Transmission network upgrades	Some local distribution and transmission network upgrades may be required	Local distribution network upgrades will be required and transmission network upgrades as capacity increases	Some local distribution and transmission network upgrades may be required
Constraints caused by existing system	Tidal range resource is close to consumer demand and strong transmission network	Tidal range resource is close to consumer demand and strong transmission network	Current distribution and transmission network constraints mean there is only capacity available for very small schemes	Most of the shallow resource is close to consumer demand and strong distribution and transmission network

- **The spare capacity in the electricity grid is limited. This means that connecting large quantities of power will be difficult without upgrades to the existing grid.**
- **There are some bottlenecks in the electricity system between where a lot of the resources (in the north) are and the centres of electrical demand (more concentrated in the south).**

3.4 Capital cost

The capital cost of a tidal energy scheme is the greatest expenditure required for the project, because the fuel for the scheme (i.e. tidal energy) is free. The annual operation and maintenance (O&M) costs are only a fraction of the initial investment[i].

The capital cost is made up of the cost of the generation device (materials, components and labour in manufacturing and fabrication processes), the cost of installation, the cost of associated foundations or moorings, and the cost of connecting it to the onshore electricity network. The dominant capital cost will vary depending on the type of tidal energy scheme and its location, as will the distribution of the different capital costs for the scheme. The capital cost is not fixed, and will change over time as a result of developments in technology, changes in the costs of raw materials and components, and benefits gained from experience in manufacturing and deployment. The capital costs for the first tidal lagoon and tidal stream schemes will be high as a result of the lack of experience in constructing and installing the scheme and the risk involved for investors (as the technology is unproven). However, confidence and experience will grow as the number of schemes installed increases, and developers will benefit from economies of scale. Therefore future costs will be reduced.

All of the costs stated in the following section are 2006 prices. Any costs that were obtained from sources published in a different year have been modified to 2006 prices. The inflator used was the All New Construction Output Price Index (COPI). The prices were updated using the value for Quarter 2 of 2006.

3.4.1 Tidal barrage

The capital cost of the Cardiff Weston barrage has been estimated to be £12.8 to £17.4 billion over a seven-year construction programme (including large ship locks in the barrage) and £12.5 to £17.0 billion over a five-year programme (including smaller ship locks)[1]. The breakdown of these costs is shown in Table 3.7. The dominant cost for the barrage is the civil works, which make up approximately 60% of the total barrage capital cost. The cost of connecting to the electricity network is approximately 15% of the barrage capital cost, so it also has a significant influence on the total project cost.

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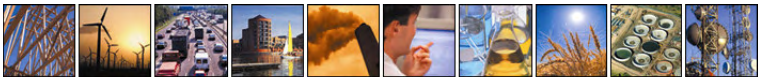
[i] O&M may represent 20-30% of the total life-cycle project cost and of the total cost of energy.



A smaller barrage scheme would have lower capital costs than that of the Cardiff Weston barrage. The economics of smaller schemes have not been investigated to the same extent as the Cardiff Weston barrage. The distribution of costs for a smaller barrage is likely to be similar to that in Table 3.7, although the cost of connecting to the electricity network may have less influence on the total project cost if less network upgrades are required to accommodate a lower capacity of generation.

Table 3.7 Comparison of construction costs[1]

Construction programme duration	**7-year** **£M**	**5-year** **£M**
Pre-consent costs	124	124
Barrage capital costs:		
Civil works	9029	8619
Turbine generators	4198	4384
Transmission & control	671	671
Management & engineering	795	795
Environment	25	25
Drainage, sea defences, port works and compensation	211	211
Total barrage capital cost	**15053**	**14829**
Off-barrage transmission capital cost*	**2291**	**2291**
Annual costs:		
Operation & maintenance	79/year	79/year
Off barrage	60/year	60/year

*Assume 10% of lines underground. The costs stated in the table were updated in the report[1] from 1988 prices to 2001 prices. The accuracy of the updated costs was judged to be ±15%. The updating of costs in this report will have introduced further uncertainty in the values.

3.4.2 Tidal lagoon

The capital cost of the tidal lagoon proposed for Swansea Bay has been calculated to be £81.5 million by Tidal Electric Limited, and £234 million by independent reviewers[38]. Table 3.8 highlights the differences in these cost estimates. Both estimates reveal that the dominant cost is that of the lagoon impoundment, which makes up 50 to 60% of the total capital cost.

Table 3.8 Tidal lagoon cost comparisons[38]

	TEL cost (£M)	Review cost assessment (£M)
Capital cost		
Impoundment	48.5	137
Powerhouse structure	12.7	46
Turbine plant & equipment	14.1	14.1
Additional plant and installation costs	0	3
Connection to grid and other costs not assessed	3.7	3.7
Sub-total	**79**	**203.8**
Contingencies allowance 10%	not included	20.4
Sub-total	**79**	**224.2**
Other costs		
Consented, detailed design, supervision of construction	2.5	10.1
Total cost	**81.5**	**234**

TEL cost is that provided by Tidal Electric Limited, reviewers' cost assessment is that calculated by the cited report authors.

3.4.3 Tidal stream

Due to the infancy of the tidal stream industry, the number of different devices under development, and the reluctance of developers to share potentially commercially-sensitive information, the information available on the economics of tidal stream devices is limited. Furthermore, the cost information currently available is for prototype and first production models, and these costs will reduce when the devices benefit from economies of scale. The results of the Carbon Trust's Marine Energy Challenge[17] indicate that the first prototype tidal stream devices could cost up to £8,000/kW[j], as shown in Figure 3.4, but certain devices have already been built for under £4,800/kW. It

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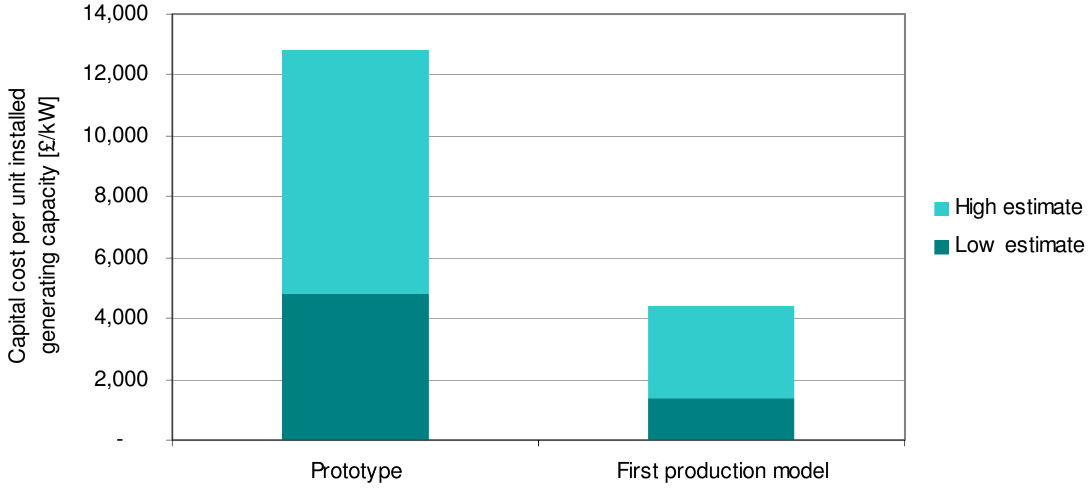
[j] Which compares to £600-800/kW for onshore wind power and £1000-1500/kW for offshore wind power.

is estimated that first production models could have costs between £1,400/kW and £3,000/kW. This would suggest that the first 5MW farm would cost between £7 and £15 million. Ofgem (the gas and electricity regulator)[41] provides a similar estimate of costs, stating that early small projects will have a capital cost of £2,584/kW.

Although there are a number of different tidal stream device designs, research by Black and Veatch[33] concluded that '*there was not a major[sic] difference in the economics of the horizontal or vertical axis turbine configurations, and both have a variety of advantages and disadvantages*'. Therefore the costs currently quoted in public-domain documents for tidal stream devices generally refer to a generic device.

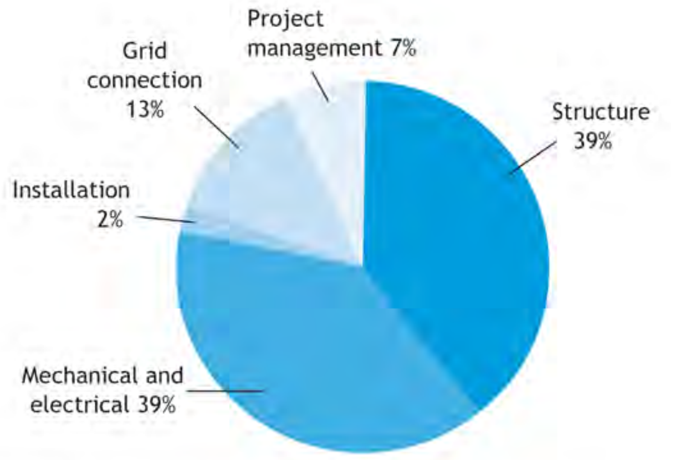
Figure 3.4 Capital costs of first prototype and first production tidal stream devices[17]



The breakdown of costs for a specific tidal stream farm studied in the Marine Energy Challenge[17] is shown in Figure 3.5. This shows that the dominant costs are the device support structure and the mechanical and electrical components (rotor, generator etc.).

Table 3.9 provides the breakdown of costs for a different tidal stream device that uses two axial-flow turbines installed on a mono-pile structure. This shows that for a 1MW single device scheme the capital cost is dominated by the installation cost, which is 55% of the total cost. This reduces to 31% for a 5MW farm and 15% for a 30MW farm. The reduction in installation cost is because all of the schemes involve mobilisation of the equipment (including a jack-up platform) which is used to install the support piles and the submarine cables[17]. The mobilisation cost is likely to be significant, as it involves moving the equipment from its current location to the site and back again. This means that installing a greater number of devices reduces the installation cost per device. Compared to the 1MW single device, additional offshore items (such as cables and substations) are required for the 5MW and 30MW farms. However, the increased cost of these components is outweighed by the decreased installation costs for a farm, so overall the cost per installed MW is smaller for larger farms.

Figure 3.5 Breakdown of capital costs for a tidal stream farm[17]



Based on data gathered during the Marine Energy Challenge. The chart refers to a specific type of tidal stream energy generator, and is not representative / typical of tidal stream technologies as a whole. There are considerable variations between different technologies, project locations and project sizes (number of machines installed). Also, future design improvements, performance/cost optimisations and learning effects could change the relative weighting of some cost components.

Table 3.9 Cost estimate for tidal stream schemes of 1MW, 5MW and 30MW capacity[39]

Capital Cost Item	1MW device cost (£)	5MW farm cost (£)	30MW farm cost (£)
1MW baseline unit	903,386	4,516,932	22,901,472
Additional offshore items	0	330,355	3,238,523
Installation	1,462,974	2,579,231	5,594,810
Onshore items	57,510	223,340	3,004,674
Overhead items	262,037	599,136	1,524,978
TOTAL CAPITAL COST	2,685,907	8,248,994	36,264,457
Unit Total Capital Cost [£/kW]	2,700	1,700	1,200

3.4.4 Operation and Maintenance

There are annual costs associated with operation of a tidal energy scheme, which are normally referred to as operation and maintenance (O&M) costs. These costs cover maintenance (both planned and unplanned), overhauls, licences, insurance and ongoing monitoring of the tidal conditions and performance of devices[17]. O&M costs will vary depending on the size and location of the installation, and are also likely to vary from year to year. It is difficult to estimate O&M costs as a result of the lack of experience of operating commercial tidal energy schemes; however it is possible to use experience and costs from other industries as an indication.

The O&M costs will vary depending on how and where the maintenance is carried out. If maintenance is carried out on-site, specialist vessels may be required to gain access to the site, and it is necessary to wait for a suitable weather window. Waiting on weather can have a significant impact on costs, as vessels and crew will be incurring costs while waiting to access the site.

Planned maintenance will probably be scheduled for summer months when suitable weather is more likely; however unplanned maintenance may be required at times of poor weather conditions. Maintenance off-site will also require suitable weather for retrieving the device or components, but the suitable weather window can be shorter as maintenance will then be carried out in a dock or onshore. A second weather window will be required to reinstall the device or components on-site.

For a tidal range scheme, maintenance will be carried out both on- and off-site. For example, any repairs to the barrage or impoundment must be carried out onsite, however the electrical components (e.g. generators) are generally designed so that they can be removed and transported to shore for maintenance and repair.

Tidal stream devices are generally designed so that the serviceable components (e.g. generator or gearbox) can be retrieved and transported to shore for maintenance and repairs. For a fixed device, any repairs to the support-structure and foundations are likely to be carried out onsite. A floating device may be designed so that the whole device can be detached from its moorings and towed to a dock for maintenance and repairs. Although this will make maintenance simpler, it will mean that the device is out of service (and therefore not generating electricity) for a period of time. Once the maintenance is completed, a suitable weather window will be required to allow the device to be reinstalled on site. For large tidal stream farms it may be cost effective to have replacement devices. This would allow a substitute device to be connected to the farm while the original device is undergoing maintenance. This will reduce the loss of generation, but will introduce additional capital cost to the development.

The estimated O&M costs for a tidal barrage such as the Cardiff Weston barrage are £139 million per year, and this equates to less than 1% of the total capital cost[1]. For a tidal lagoon the O&M costs are estimated to be 0.5% of the capital cost per year, and it is also expected that an allowance of £4 million will be required for a major overhaul of the mechanical and electrical equipment every 20 years[38]. For tidal stream devices there is less information available regarding O&M costs. An Ofgem study[41] estimates that the initial O&M costs for a tidal stream device are £100/kW per year and this is based on the assumption that costs for a 1MW tidal stream device are similar to that of a 3MW offshore wind turbine. For a specific tidal stream device the annual O&M costs were estimated to be £75,193 for a 1MW scheme, £283,616 for 5MW and £1,389,700 for 30MW[39]. This equates to 2.8%, 3.4% and 3.8% of capital costs respectively. O&M costs per tidal stream device will decrease on larger tidal farms as the vessel mobilisation costs can be shared over a number of devices. For the 1MW scheme O&M costs £75.2/kW per year but this falls to £46.3/kW per year for the 30MW scheme.

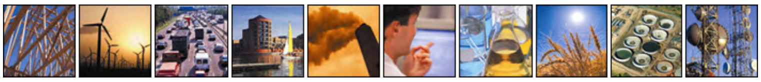


Table 3.10 Capital and O&M costs

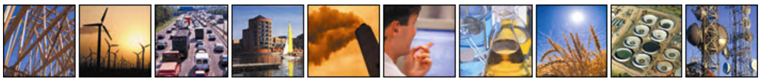
	Tidal range		Tidal stream		
	Barrage	**Lagoon**	**First production model**	**First 5MW farm**	**Commercial 30MW farm**
Capital cost – high (£M)	17,400	234	3	15	-
Capital cost – low (£M)	12,500	81.5	1.4	8.2	36.3
O&M (%) [as a proportion of capital costs]	< 1%	0.5%	2.8%	3.4%	3.8%

3.4.5 Decommissioning

Once a tidal energy scheme has reached the end of its generating life the developer must decommission the scheme (or alternatively the developer may wish to continue using the site and install new tidal stream devices, as some wind farm developers do). It is necessary for the developer to remove the scheme from service and restore the environment to an acceptable state. The scheme lifetime of a tidal barrage is expected to be 120 years. After this time it is expected that the generating components will be removed from the barrage, and that the barrage structure will remain in place. There are differing opinions as to the most appropriate method for decommissioning a tidal lagoon, which is also estimated to have a lifetime of 120 years. Tidal Electric Ltd[42] proposes that the turbine/generator equipment and the concrete power station structure are removed, and that the lagoon structure will remain in place. The embankment would be allowed to become an artificial reef, or an island if the lagoon becomes positively silted up. However, the Crown Estate (which owns virtually the entire seabed out to 12 nautical miles from the coast) may require the complete structure to be removed so that it does not pose a residual hazard to third parties[38]. This would incur a significant cost, estimated to be in excess of £200 million.

For a tidal stream farm, the devices would be removed from site at the end of their 20-year lifetime. For floating devices this is likely to be a relatively simple operation, as it will only require the removal of anchors from the seabed. Devices with a gravity-based foundation will be removed from the seabed. A mono-pile foundation may be left in the seabed after being cut off below the level of the seabed, or it can be removed using a vibration hammer. Submarine cables are usually de-energised and left in-situ, as the removal of cables causes more damage to the seabed than leaving them in place.

► **The costs of tidal barrages are unlikely to decrease, since only a small number would ever be built and each would be different. The costs of tidal lagoons are dominated by their materials costs which also are unlikely to change as more are built. Tidal stream devices, however, are likely to reduce in cost as the technologies improve, more numerous and larger schemes are built and as they benefit from economies of scale.**



3.4.6 Financing

The full cost of energy comprises the total capital cost, operating, maintaining and decommissioning the devices. Additionally there is the cost of financing the schemes. Organisations that invest in schemes and those who lend money to them expect a return on their investment. The return they expect depends on the level of risk in the project.

A low-risk project will have a very certain future whereas a more risky project might not. Tidal energy technologies are fairly risky since they are new. This means that the returns investors expect are quite high compared with that they might expect on more proven technologies such as a gas power plant. In order to compare the different technology options with each other, a technique called the ‘discounted cash flow analysis’ can be used. In this analysis, a risky project would have a high ‘discount rate’ and a less risky project a low ‘discount rate’. The rates reflect the return expected by investors on the money they invest in the project. A project financed with a high discount rate will produce energy at a higher cost, as the cost of financing is high. As confidence in a technology grows, the discount rate it attracts can reduce. In this report we use discount rates of 8-15%. A 15% discount rate would represent a new partly proven energy technology, and 8% would represent a well proven, widely deployed energy technology.

A standard method for the financial evaluation of long-term projects is the Capital Asset Pricing model based on the Net Present Value (NPV) of cash flows. It measures the excess or shortfall of cash flows for the lifetime of the project, in present value[k] terms, once financing charges are met[43]. An excess cash flow indicates that the project will be profitable, whereas a shortfall of cash flow means the project will lose money and should be rejected. This method of evaluation can make renewable energy schemes appear unattractive, because the majority of the cost of a scheme is incurred in the early years of the project (high capital costs) whereas the costs for the remaining years (annual O&M costs) are much lower; however the income from the project is spread relatively evenly over the project lifetime once the scheme starts generating electricity. This has an impact on the NPV, as values in the early years have a greater weighting, and this is when costs are high and income is zero (until the scheme is constructed and operating). In comparison, conventional sources of electricity generation (such as oil or gas) have costs spread more evenly over the lifetime of the project as a result of the annual fuel costs.

The advantage of this discounted cash-flow (NPV) approach is that it allows the costs of all energy-generating technologies to be compared fairly and directly.

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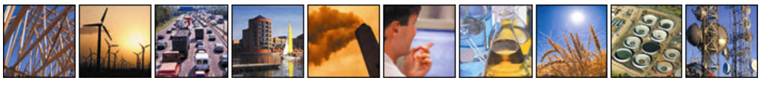
[k] The present value of future cash flows is calculated using Discounted Cash Flow. This is necessary because cash flows in different time periods cannot be directly compared since most people prefer money sooner rather than later. The discount rate used to calculate the present value takes account of the risk associated with uncertain cash flows and will therefore be higher for unproven technologies. Typical discount rates used in economics are 8% (mature technologies) and 15% (higher risk but proven technology investments).



Although tidal range schemes use relatively proven technology, and might therefore attract low discount rates, large schemes such as a tidal barrage may be perceived to be a large investment risk as a result of the long construction period and very high capital costs. As described in Section 2.2.1, a large tidal barrage (such as the suggested Cardiff Weston barrage in the Severn) could take up to 12 years to complete, from initial planning and design to operation. This would be 12 years where the project has significant outgoings (capital costs of up to £17.4 billion) but no income; there will also be the requirement to pay for investigations such as an Environmental Impact Assessment (EIA) prior to construction. The capital is at risk during this time, and over the 12 year period material costs are likely to change, possibly resulting in the requirement for larger investments. Such a large scheme represents a large financial commitment, and it may therefore be difficult to attract investors. For very large schemes it is probable that some public money will need to be used for financing, along with a significant amount of private investment.

Tidal stream devices are considered high risk because the technology is yet to be commercially proven, and as such attract high discount rates. However, although the investment risk may be high, the initial amount of money required for a tidal stream farm is much lower than for large civil constructions such as tidal barrages or lagoons. Tidal stream farms also have the advantage of being modular, which means that the construction period of a farm could be split into sections, with the first few devices generating electricity and producing income before the whole farm is complete. As a result of this, investors in successful tidal stream farms could expect to start receiving a return on their investment much earlier than investors in a large barrage scheme. This may make tidal stream technologies more attractive to investors despite the initial risk of unproven technology. Investor confidence in tidal stream technology is likely to increase as more devices are tested successfully at part- or full-scale.

The financing of any tidal energy scheme should allow for decommissioning costs at the end of the project. However, the contribution of decommissioning costs to the total cost of the scheme is low. Using the discounted clash flow analysis method, costs that occur later in a project are discounted more than those which occur earlier in a project. Since decommissioning occurs at the very end of a project, its cost is discounted the most. As a result, when compared to capital and operating costs, decommissioning costs make only a small contribution to the overall cost of a scheme.

3.5 Current and future energy costs

The cost of energy produced from a tidal energy scheme is dependent on the amount of electricity generated (i.e. the power production described in Section 3.3) and the cost of producing this electricity (i.e. the capital, O&M and decommissioning costs described in Section 3.4). The cost of the scheme must be balanced with the amount of electricity produced to ensure that the scheme is profitable, i.e. an expensive scheme must generate enough electricity to produce sufficient income to cover the costs. This is the logic behind the NPV methodology described in Section 3.4.6. In order to cover the costs of building and operating the tidal energy scheme, and to make a return on the investment, a certain level of income is required from the electricity which is generated. This represents the cost of energy. In order for electricity suppliers to purchase the electricity generated, the cost of energy must be equal or less than the cheapest alternative (another form of renewable or conventional power generation)[17]. This approach therefore calculates the cost not the price of the energy. The price is dictated by the electricity market and may include some additional market support such as the UK's Renewable Obligation Certificates[1].

As suggested in Section 3.4, the capital costs for the first tidal energy schemes will be high. This means that the required income for the electricity produced will also be high, and it will be more expensive than other forms of power generation. The cost of energy from the first tidal stream farms has been predicted to be between 9p/kWh and 18p/kWh, with central estimates in the sub-range 12p/kWh to 15p/kWh[17]. For comparison conventional generation can generate power at somewhere near 2.5p/kWh.

The cost of energy for tidal lagoons is shown in Table 3.11. The developers (TEL) of one of the tidal lagoon schemes have asserted that the costs could be as low as 3.5p/kWh[42] (unknown discount rate). Although this value may be optimistic as an independent review calculated the cost to be 17.2p/kWh at 8% discount rate[38]. The cost of energy generated from tidal lagoons may fall as the capacity of individual lagoons increases after experience is gained from smaller schemes.

As tidal barrages use many standard components and construction techniques the cost of energy is lower than the novel tidal stream and tidal lagoon technologies. The cost of energy from the Cardiff Weston barrage has been estimated to be 7.5p/kWh using a discount rate of 15%, with the cost falling to 6.8p/kWh if only half of the required electricity network upgrades are attributed to the project, though of course the consumer would still need to meet these costs[1]. A more recent investigation of the cost of energy from the Cardiff Weston Barrage has been made by Black & Veatch[44], who estimate that at a 15% discount rate the cost would be in the region of 19 - 22p/KWh. A study[37] of smaller barrage schemes indicated that there appears to be a number of small tidal range sites that have a similar cost of energy to Cardiff Weston barrage. There is less scope for cost reductions for tidal barrages, as they are one-off schemes involving mainly civil construction, and will not therefore benefit from the economies of scale of producing devices in bulk, or from learning from experience.

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[1] The UK's current support mechanism for renewable energy is the Renewables Obligation. This places a requirement on suppliers of electricity to source a proportion of their power from renewable energy sources. That proportion will increase year by year. To prove that they have supplied their share they must present a number of Renewable Obligation Certificates. Each certificate represents 1MWh of renewable electricity. These certificates can be bought and sold. The supplier can generate their own renewable energy and thus generate their own certificates or they can buy the certificates from others. Any spare certificates they have they can then sell. The Government has also set an upper limit on the value of the certificates called the 'buy-out' price. Should they choose to the suppliers can instead pay this price for any certificates they are short of. Money raised from the buy-out is shared amongst the other suppliers based on the number of certificates they have. The value of the ROCs vary depending on how many the generators can produce, and this will depend on effects like how much wind blows and how the ROCs are traded. The net effect of the ROCs is to provide an additional income to renewable energy generators for the electricity they sell over and above the income they can generate by selling directly to the electricity markets. Income from the sale of a unit of renewable energy is thus higher than for the sale of conventional energy by the value of the ROC. The ROC is currently valued around £35/MWh or 3.5p/kWh.

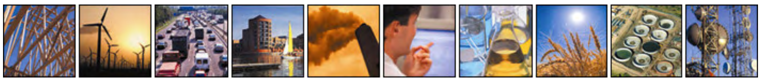


Table 3.11 Cost of energy estimates for tidal lagoons

Discount rate	Unit cost of energy (p/kWh)	
	Ref 38	Ref 39
8%	17.2	-
10%	21.4	4.1 – 6.6
15%	32.5	6.2 – 9.9

As the tidal energy industry develops, it is expected that the cost of energy will fall. The Carbon Trust[17] has estimated the potential reductions in cost of energy from tidal stream devices as the more devices are installed (Figure 3.6). This figure shows that the cost of energy from the first tidal stream devices may cost up to 11p/kWh. However, as the number of devices installed increases, the cost of energy decreases as a result of learning effects. The cost of energy may have fallen to 7p/kWh by the time 1GW of capacity has been installed, and after 1.5GW has been installed, the price could drop below 5p/kWh.

The lowest cost of energy is estimated to be 3p/kWh at sites with the highest tidal stream velocity. The increase in cost of energy at a cumulative installed capacity of 2.8GW is because the most attractive sites have been developed and the remaining sites are less suitable; the cost of developing these sites is greater and / or the amount of electricity generated is less. Cost estimates for specific tidal stream devices are shown in Table 3.12 and Table 3.13.

Figure 3.6 shows that only when installed capacity reaches 2.8GW will the price of tidal electricity be able to compete with conventional energy which, at the time this research was done (2005), had a base electricity price of around 2.5p/kWh. If that base price rises to 5p/kWh (for example as a result of increased oil costs) then all tidal energy units produced after installed capacity reaches 1.6GW will be competitive. If, however, we take into account the UK’s support mechanism for low-carbon technologies (the ROC), which currently pays an additional premium of around 3.5p/kWh for ‘green power’ (electricity produced from renewable resources), then tidal stream might be economic compared with other renewable energy technologies after a capacity of only 1GW is installed. If the base cost of electricity were to double to 5p/kWh, immediately then all but the low-speed resource would be competitive with other forms of renewable energy supported by the ROC.

The growth of the tidal stream industry and the consequent cost reductions is crucial to its competitiveness. Box 1 below compares the growth of the wind industry with the possible growth of the tidal stream industry.

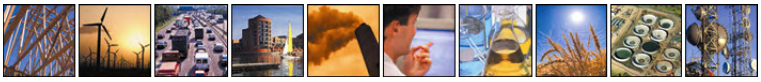
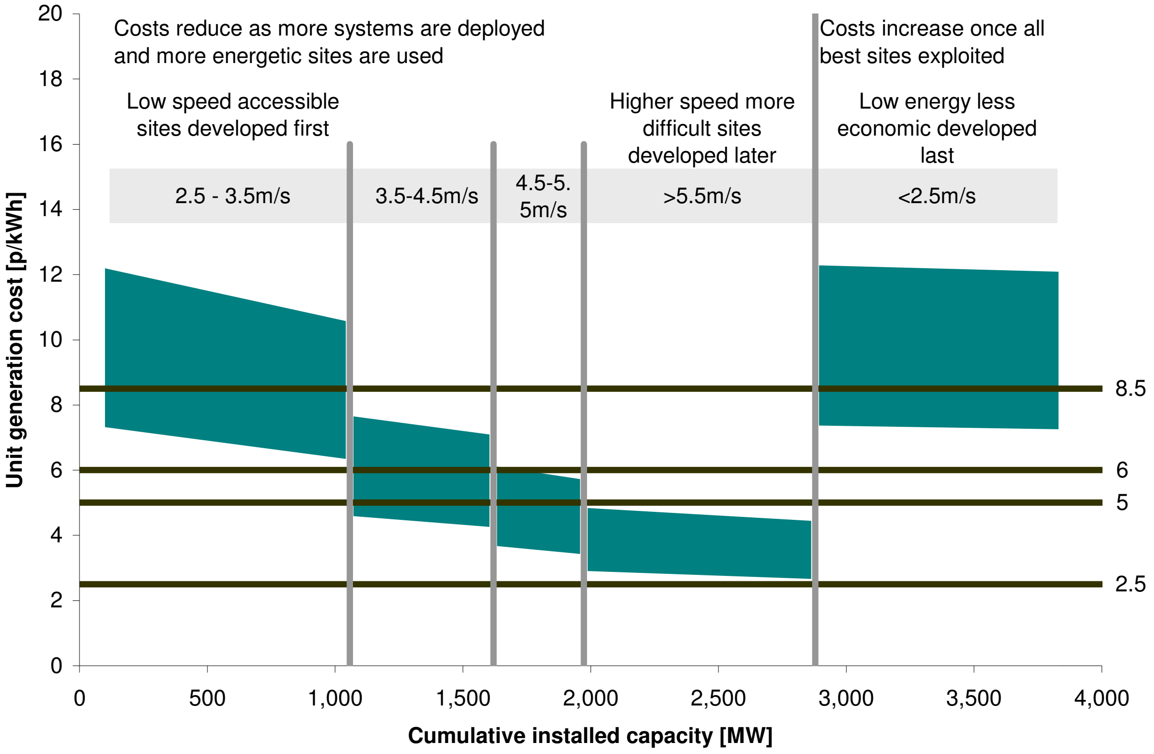


Figure 3.6 UK tidal stream step-wise cost-resource curve[17],[33]



Note: This chart is adapted from the Carbon Trust cost-resource curve for tidal stream. It assumes deployments in a logical sequence depending on mean spring peak velocity of each site (shown here in m/s). Costs are shown as a range (±25%) representing the uncertainty in estimating them. Costs are based on a discount rate of 15%. Also shown on this chart is the base cost of energy relevant to the study. 2.5p/kWh represents the base or 'brown' electricity cost; 5p/kWh represents a notional high electricity cost due to fuel price rises. The 6p/kWh and 8.5p/kW prices represent support from the ROC in additional to the high and low base electricity prices.

Table 3.12 Cost of energy for baseline tidal stream device design and design with production savings[39]

Discount rate	Unit cost of energy (p/kWh) for different scheme sizes		
	1MW	5MW	30MW
Baseline design (10% discount rate)	12.0	7.6	6.4
Production savings (10% discount rate)			5.7
Baseline design (15% discount rate)	15.8	10.0	8.4
Production savings (15% discount rate)			7.5

Production savings accounts for the reduction in capital costs that can be achieved when producing devices in bulk.

Table 3.13 Cost of energy for 500kW tidal stream baseline site[12]

Discount rate	Unit cost of energy (p/kWh)
8%	8.5
10%	9.4
15%	12.1

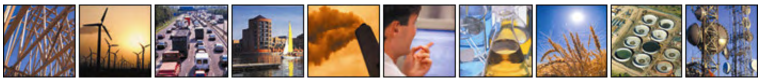
The US Electric Power Research Institute (EPRI) has also made some estimates of the cost of energy from tidal stream systems[45]. Their estimates use an 18m diameter ~1MW MCT Seagen machine at a range of different locations and in a range of different sized projects. Here we summarise their results using a comparable cost of energy method to the other figures presented here.

Table 3.14 EPRI cost of energy estimates for several possible tidal stream schemes in the USA

	Knik Arm	Tac Nars	Golden Gate	West Pass	Head Harbour	Minas Pass
Installed capacity	66	68	40	12	66	250
Capital cost [£m]	57	53	47	12	35	251
Operation and maintenance [£m/y]	2	2	2	1	1	9
Assumed* decommissioning costs [£m]	6	5	5	1	4	25
Discount rate	15%	15%	15%	15%	15%	15%
Project life [y]	20	20	20	20	20	20
Annual energy production [GWh]	128	121	129	40	64	1,140
Capacity factor	22%	20%	37%	38%	11%	52%
Unit capital cost [£/kW]	861	783	1,163	1,034	532	1,005
Cost of energy [p/kWh]	8.8	8.7	7.2	6.3	10.7	4.4

The cost of energy is calculated based on an assumed operational life of 20years, at a discount rate of 15%, with decommissioning costs assumed* to be equivalent to 10% of capital costs. All costs are converted from 2005 to 2006 money using the UK COIP. The currency conversion used is £1=$0.5. This analysis approach relies on an implicit assumption that US manufacturing and operating costs are similar to UK costs.

These represent a lower cost of energy view. The unit capital costs of £530-1200/kW are below those for offshore wind. The lowest costs quote are lower even than onshore wind. These costs clearly represent fully commercial schemes after significant learning has occurred. The costs of energy are predicted to be in the range 4.4-10.7p/kWh,



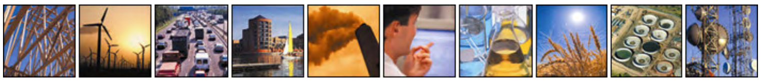
with the lowest costs being achieved by a single 250MW development. The costs calculated by EPRI themselves are in the range 2-6p/kWh (4-12¢/kWh).

Table 3.15 Summary of cost of energy estimates

	Tidal range		Tidal stream		
	Barrage	Lagoon	Low	Medium	High
Cost of energy (p/kWh):					
8% discount rate – high	-	17.2	-	-	-
8% discount rate – low	-	3.5	-	-	-
10% discount rate – high	-	21.4	12.0	7.6	5.7
10% discount rate – low	-	4.1	9.4	-	-
15% discount rate – high	7.5	32.5	15.8	7.0	5.0
15% discount rate – low	6.8	6.2	11.0	-	3.0

Low, medium and high refer to the level of tidal stream device deployment. Low is the initial full-scale devices installed in the water; medium is the first small farm and high is large-scale farms or multiple small farms.

- **There are several views of the cost of energy. It is important to understand the scale of the development, the amount of learning that has occurred, and to ensure that the costs include all relevant costs.**
- **The costs of energy from tidal barrages and lagoons are likely to stay relatively fixed as these do not benefit greatly from being built in large numbers. Tidal stream devices however are likely to be more expensive in the early stages with costs reducing as they are deployed in larger numbers.**



Box 1 The growth of the wind energy industry and a comparison with tidal stream

The growth of wind energy is impressive. Many suggest that tidal energy technologies might follow a similar growth pattern. This may be the case for tidal stream energy systems. Tidal barrages however, have fewer opportunities for learning and mass production so will not develop in a similar way to wind energy. Tidal lagoons with their simple technology and large use of raw materials will also not follow the same development path as wind energy. Whilst there are similarities between wind and tidal stream technologies there are some crucial differences too.

Wind energy has been around for thousands of years, and electricity generating systems for hundreds of years. The real growth in the industry came during the oil crises of the 1970s, when energy costs soared. At that time, the environmental advantages of the technology were not as important as their contribution to securing energy supplies. Tidal stream technologies are entering the market under quite different circumstances. Energy costs are very low and low-carbon technologies are valued much more.

There were two groups of wind energy machines developed in the 1970s. The first group comprised very large turbines of 1 to 5MW, and the second very small kW-scale machines. The UK and Germany particularly developed the ambitious large machines, and relied on aerospace technology and centralised government R&D programmes. The Danes developed the smaller systems, often privately based and using simple components adapted from other uses, such as tractor gearboxes.

The large machines developed in the UK and Germany were often very well engineered and many worked well. However, they did not necessarily deliver energy at a low cost. The Danish approach, however, was to begin by building small turbines and slowly increase the size. This approach has only just delivered a commercial 5MW turbine. Eventually the good science from the early large-scale wind programmes was united with the more practical small-scale approach, and the wind industry took off. Ultimately it was the organic approach that worked.

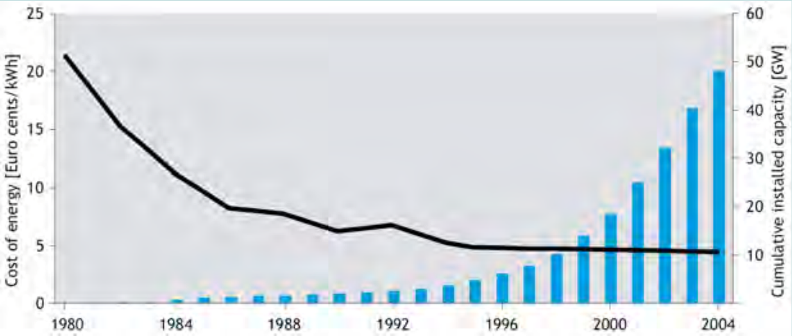
The near-organic growth of the wind industry was possible because systems could be built at any scale. Indeed, turbines are available today in sizes ranging from a few watts to several megawatts. Even now these are mostly installed on land, where they can readily be fixed.

The cost of wind energy has reduced over time as the number of turbines deployed has increased. There have been two complimentary effects that led to these cost reductions. The first is that the turbines became more cost-effective as they were made larger. The energy output is a function of the rotor area, which is proportional to the square of the blade length. Thus small increases in blade length led to much greater power outputs. Larger machines are also taller, and can therefore access the stronger winds found higher up. The second cost reduction was achieved through mass production. The machines were built in large numbers, and this resulted in significant economies in manufacture.

The market growth was also supported by strong home markets in Denmark where much of the technology originated. The United States offered tax incentives in the early stages of the wind energy market, in the late 1980s, which helped encourage the installation of a large number of turbines in the US. However, when the tax incentives stopped so too did the US growth. Many of the early machines installed during this period were not robust, and many failed.

Since that time, markets have grown, particularly in Europe. Germany and now Spain are strongly developing wind energy. The United States is now also keenly pursuing the technology, and China is installing large numbers of machines to meet its growing energy demands.

All of these factors have reduced the cost of energy from wind over time. The learning and installation curves for wind energy are summarised below.



Growth figures from BTM Consult (2005).

Cost of energy data:

1980-1994 for Denmark: Chapman and Gross (2003), 'The technical and economic potential of renewable energy generating technologies: Potentials and cost reductions to 2020';

1995-2005 for Denmark and USA: Milborrow (2006), Windpower Monthly vol 22., No.1.

Chart taken from Future Marine Energy[17].

Tidal stream energy will not be developed in large numbers at small scale. The cost of the deployment and submarine electrical cable alone suggest that they have to be at a reasonable (MW) scale to carry this cost overhead. They are placed in the sea, where it is more difficult to access the machine for maintenance and repair. This means that they need more careful and less experimental design than wind did. Individual machines will cost millions of pounds rather than thousands, and this means that there are far fewer people who can afford to develop a new tidal stream technology. Any early system problems could stretch the developers' pockets.

However there are some similarities to wind energy. When the tidal stream systems are deployed, they can benefit from similar economies of scale to wind. They can be made larger (although this is limited by working water depths), and they can be mass manufactured. They could follow a similar overall cost reduction path to wind energy, but they have a higher hurdle to jump for the early schemes.

3.6 Size

The size of a tidal generating scheme has an important effect on economies of scale. It also differentiates clearly between the different technology types. It is also very useful in distinguishing between different environmental effects.

The proposed Cardiff Weston barrage would be sited between Lavernock Point, near Cardiff and Brean Down, near Weston-super-Mare, which is a distance of 15.9km[1]. The widest part of the barrage is 74m, where it contains turbines. It will be narrower at other sections. This means that the barrage is likely to have a 'structural footprint' between 795,000 and 1,176,600m^2, i.e. this area of seabed will be used for the construction of the barrage. This equates to a footprint of between 92 and 136m^2 per MW installed capacity. However the barrage will have an impact on a much larger area of sea. It would provide shelter to over 220km of coastline of the basin above the barrage[1]. The area of this basin is 480km^2.

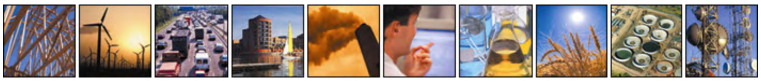
The proposed Swansea Bay 60MW tidal lagoon uses an embankment 9km long to impound approximately 5km^2 of sea. The width of the embankment depends on the sea state at the proposed site. For the lagoon in Swansea Bay this has been calculated to be between 65m and 100m[38]. This means that the embankment of the lagoon will have a 'structural footprint' of 585,000m^2 or 900,000m^2; 9750 or 15,000m^2 per MW. The area of the total scheme is 5km^2.

A gravity-based tidal stream device uses concrete caissons to provide sufficient weight to hold the device in place on the seabed. The size of the caisson required for a 1.5MW device may be approximately 21m by 27m[7]. This would give a 'structural footprint' of 500 to 600m^2; 333 to 400m^2 per MW.

For a 1MW device installed on a mono-pile the diameter of the pile is likely to be between 3m[6] and 4.2m[39]. The diameter of the pile must be designed to withstand the forces acting upon it, so this may vary depending on the device design (e.g. the height of the device to be placed on the pile) and the sea conditions at the installation site. The pile is grouted into a pre-drilled socket on the seabed. The length of the pile socket is estimated as four times the pile diameter, but this may vary due to the site and foundation conditions[39]. A single device will therefore have a 'structural footprint' of between 7 and 14m^2.

A floating device is likely to have the smallest 'structural footprint' as it only requires anchors on the seabed to secure the device in place. These anchors will probably be pins that screw into the seabed and the mooring chains or cables will be attached to them. The anchors will have a smaller diameter than a pile and only two should be required for the mooring of a device[10],[11].

A tidal stream farm will have multiple devices so the 'structural footprint' will simply be the footprint of one device multiplied by the number devices in the farm. Additional offshore infrastructure (e.g. cables and substations) will be required but these will only use a small area of the seabed. The total area of impact of a tidal farm will be larger than the footprint because the devices will be placed in a line or an array. The area will vary depending on the configuration of the layout, i.e. the spacing required between devices. The spacing required will depend on the



energy capture area of the device, as it will be important to ensure that neighbouring devices do not interfere with one another, and that the tidal resource is captured in the cost-effective way.

Table 3.16 Structural footprint of tidal energy schemes

	Tidal range		Tidal stream		
	Barrage	**Lagoon**	**Fixed (piled)**	**Fixed (gravity based)**	**Floating**
Structural footprint (m^2 per MW)	92 – 136	9750 – 15,000	7 – 14	333 – 400	Negligible

The barrage scheme is the Cardiff Weston proposal. The lagoon scheme is the Swansea Bay proposal.

Table 3.16 provides a comparison of the ‘structural footprints’ of the different tidal energy schemes. This reveals that even though a barrage is a very large structure, it produces a significant amount of power so the footprint per installed MW is less than the footprint of a gravity-based foundation. The scheme that requires the greatest area of seabed per installed MW is a tidal lagoon while a floating tidal stream device requires the least area.

3.7 Material volume

The structure of all tidal energy technologies can generally be divided into three categories:

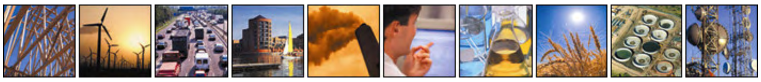
- Support-structure;
- Turbine (method of energy extraction) and generator;
- Other electrical equipment.

The amount of material required per technology for each of these categories can be compared per MW of installed capacity. The support-structure has the greatest variation in quantity of materials across the different technologies. The main materials used are concrete, aggregates and steel, and the ratio of these materials varies between the different technologies.

The materials required for turbines, generators and other electrical equipments per MW of installed capacity will be comparable between the different technologies, as many of the components used are standard components. The main materials used are steel for the turbines and generators and copper in the electrical cables.

3.7.1 Tidal barrage

The structure of a tidal barrage is shown in Figure 2.5. The barrage has various sections – turbines, sluices, shipping locks and embankments. The turbines and sluices are housed in ballasted concrete caissons; concrete is the most abundant material in the structure. Studies on potential barrage schemes indicate that the volume of



concrete required for construction of the barrage can range from 936 to 6884m^3 per MW of installed capacity[m][46]. The sluices, which have a total area of 35,000 square metres[1], are made from steel. The design of the sluice gate is not specified, so it is not possible to calculate the volume of steel required; however it is evident that the quantity of steel required is only a fraction of the volume of concrete required. Aggregates are likely to be required for construction of the embankment and also for providing ballast to the concrete caissons.

3.7.2 Tidal lagoon

There are two main structures that make up the tidal lagoon – the embankment and the power house. Studies carried out for the Swansea Bay tidal lagoon proposal identified rubble-mound construction as the most suitable and cost effective option for the embankment[47]. The aggregates used are likely to be sand and rock armour; over 6 million cubic metres will be required to construct a 9km long embankment[38]. The power house will be constructed from concrete caissons. It is estimated that 61,000m^3 of concrete will be required for its construction[38]. This equates to 100,000m^3 of aggregates per MW of installed capacity and approximately 1000m^3 of concrete per MW. As the tidal lagoon is still a novel concept, other construction methods and materials may be identified as more suitable in the future.

3.7.3 Tidal stream

The support-structures used for tidal stream devices are either mono-pile, gravity-based or a mooring system. Mono-pile structures are predominantly steel whereas gravity-based are concrete and aggregates. A mooring system will require very little material as it will consist of anchors and chains or cables.

A mono-pile supporting a 1MW turbine is likely to require 16.8m^3 of steel[48]. It is assumed that a gravity-based foundation would be ballasted with aggregates so that the ratio of concrete to aggregates would be 50:50. Therefore a gravity-based foundation would require approximately 1500m^3 of both concrete and aggregates per MW of installed capacity[49].

If a tidal stream device is designed to have a duct this will also add to the materials required for construction of the device. For example, the duct may be 27m long with an inlet diameter of 21m for a 1.5MW turbine. This is likely to be constructed from steel but could also be made from concrete.

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[m] These figures are calculated from data in a report by AEA (2007) to the Sustainable Development Commission, which estimates that a Mersey barrage with an installed capacity of 700MW would require 1,030,000m^3 concrete, a Loughor barrage with an installed capacity of 5 MW would require 34,420m^3 concrete, and a Duddon barrage with an installed capacity of 100MW would require 93,667m^3 concrete.

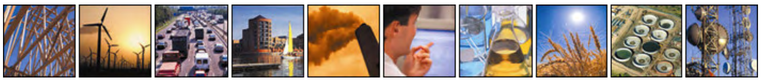


Table 3.17 Comparison of material volumes required for the support-structures of tidal energy schemes

	Tidal range		Tidal stream		
	Barrage	**Lagoon**	**Fixed (piled)**	**Fixed (gravity based)**	**Floating**
Volume of steel (per MW)	< $10m^3$	-	16.8 m^3	-	Low
Volume of concrete (per MW)	936 – 6884 m^3	1000 m^3	-	1500 m^3	-
Volume of aggregates (per MW)	unknown	100,000 m^3	-	1500 m^3	-

The values shown in the table are estimates and will vary between specific scheme designs

Table 3.17 provides a summary of the material volumes required for the different tidal energy schemes. Although these values are only estimates, as the actual values will vary depending on specific scheme designs, they show the dominant materials required for construction of each type of scheme. The tidal lagoon requires the greatest quantity of materials, with $100,000m^3$ of aggregates required per installed MW for the construction of the lagoon impoundment. Although the tidal barrage is a large structure, the volume of concrete required per MW may be comparable to that required for a gravity-based foundation of a tidal stream device. A floating tidal stream device clearly requires the smallest quantity of materials for its support structure. Adding ducting to a tidal stream device will also increase the volume of materials required.

- **The materials required vary between the different tidal energy technologies.**
- **Barrages and lagoons may require significant quantities of materials due to the large civil structures whereas floating tidal stream devices may use far less material.**

3.8 Lifecycle carbon emissions

Tidal energy, as with other renewable energy technologies, reduces emissions of carbon dioxide from electricity generation by replacing the use of fossil fuels such as coal, gas or oil. The reduction in CO_2 emissions will vary depending on the type of generation that is being replaced. The standard value for carbon emissions from the current UK generation mix is 0.43kg of carbon dioxide per kWh of electricity delivered to the consumer[50]. Table 3.18 provides an overview of the possible reductions in CO_2 that could be achieved by different tidal-energy schemes.

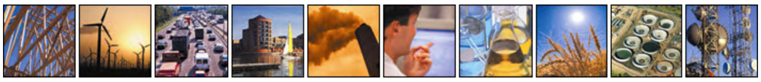
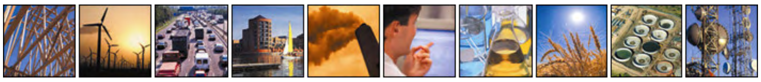


Table 3.18 Carbon dioxide reductions by tidal energy schemes

Tidal energy scheme	Capacity (MW)	Lifetime (years)	Reduction of CO_2 per year (tonnes)	CO_2 reduction over lifetime (tonnes)
Tidal barrage	8460	120	7,310,000	877,200,000
Tidal lagoon	60	120	53,320	6,398,400
Tidal stream farm	30	20	22,600 – 50,850*	452,000 – 1,017,000*

The reduction values provided only account for the CO_2 reduction achieved by replacing the burning of fossil fuels.

*This range results from the different output expected from sites with different energy levels (and thus different capacity factors).



Although no CO_2 is emitted during the operation of tidal-energy schemes, the manufacture, construction, installation, maintenance and decommissioning will all lead to some indirect emissions. It has been found that the greatest amount of emissions is produced during the manufacture of structural materials[51]. This is due to the large amount of energy required to produce steel or concrete combined with the high carbon intensity of the energy mix, along with the emissions associated with concrete manufacture itself. In the case of aggregates, emissions are mostly the result of the transportation of materials.

Therefore the type and quantity of materials required to construct the schemes will determine the amount of carbon dioxide produced. If the amount of emissions produced during manufacture and the emissions reductions through tidal energy generation are known, it is possible to calculate the 'CO_2 emissions payback period'. The payback period is the length of time it takes for the tidal-energy scheme to offset the quantity of carbon dioxide that was produced during the manufacture of the scheme. Studies have shown that this period is five to 36 months for tidal barrages and two to 12 months for tidal lagoons[46]. There have been no studies into the payback period for specific tidal-stream devices but is estimated to also be short[17].

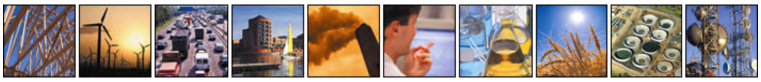
► **Overall carbon benefit of tidal energy technologies is positive. Some studies have estimated that tidal range schemes could recoup the carbon emitted in making them within three years of beginning operation.**

3.9 Summary

There is sufficient tidal energy in the seas surrounding the UK to meet 8 – 10% of the UK's electricity demands. Half of this energy could be obtained from tidal range and half from tidal stream. Most of the tidal range resource is concentrated in the Severn Estuary. Most of the tidal stream resource is in the Pentland Firth and the Channel Islands; the majority of this resource is in deep waters while only a relatively small amount is found in shallow waters. Devices with fixed foundations may have limited access to some of the more energetic deepwater areas. Floating devices may be more suitable in these locations but face a greater engineering challenge.

Tidal barrages could represent single multi-gigawatt schemes, lagoons could represent single multi-megawatt schemes and tidal stream farm sizes could vary in size from individual megawatt-scale units to multi-megawatt farms or even larger. As tidal barrages are likely to comprise large one-off installations the UK might install only one. Several tidal stream devices are likely to be installed due to the modular nature of the technology.

Much of the tidal range resource is located close to the electricity transmission network whereas the tidal stream resource is in areas where there is limited electrical grid capacity. The lack of grid capacity means that connecting large quantities of power will be difficult without upgrades to the existing grid. Furthermore there are bottlenecks in the electricity system between the main area of tidal stream resource (in the north) and the centres of electrical demand (more concentrated in the south).



The costs of tidal barrages are fixed, since only a small number would ever be built and each would be different. The costs of tidal lagoons are dominated by their materials costs which also are unlikely to change as more are built. Tidal stream devices however are likely to reduce in cost as the technologies improve and numerous and larger schemes are built and as they benefit from economies of scale. Therefore the cost of energy from tidal barrages and lagoons is likely to stay relatively fixed. However the cost of energy from tidal stream devices is likely to be high in the early stages but then reduce as the devices are deployed in larger numbers.

The volume of material does not vary greatly between technologies, though fixed tidal stream devices may swap concrete for steel in some instances and floating tidal stream may use far less materials. The very large projects, such as developing the Cardiff Weston barrage, might cause shortages of supply of certain materials, and care in planning for this would be needed.

The overall carbon benefit of tidal energy technologies is positive. They are all expected to recoup the carbon emitted in making them within one to three years of beginning operation.

This section has described the technological differentiators that allow a comparison to be made between the different technologies that can be used to generate electricity from tidal energy. The comparisons made are as definite as possible given the immature status of the tidal energy industry. Particularly for tidal stream it is often necessary to refer to a generic device as the industry has yet to converge on the most suitable device(s). As the industry develops and experience is gained from operating tidal energy schemes the values and assumptions stated in this report will become more accurate and well-defined.

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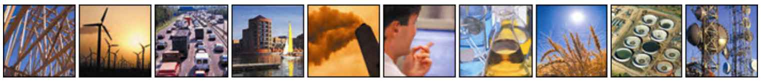


4. Environmental differentiators

4.1 Outline

4.1.1 Available information

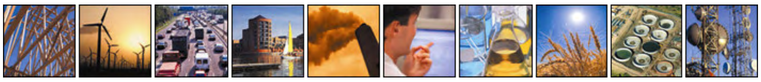
The generation of tidal power, whether using tidal range or tidal stream technologies, requires the placement of artificial structures within the ocean. By their nature these structures are designed to remove energy from the water, and by their presence they will have additional influences on the physical, chemical and ecological features of the environment in which they are placed.

This chapter aims to outline the main environmental effects which may arise as a result of tidal energy in the UK, and to differentiate between the potential environmental effects of different tidal technologies. However, this assessment is limited by the lack of available observational data, as there are currently no functioning full-scale tidal energy projects in the UK.

The only large scale functioning tidal barrage in the world is at La Rance in France, although there are smaller barrages elsewhere in the world. Some environmental data are available for this scheme, although monitoring of the project has been limited. The Severn Estuary was extensively studied as part of an Environmental Impact Assessment (EIA) which was undertaken during planning for the construction of a potential barrage, although much of this work is now dated. There are no functioning coastal lagoon projects in the world to date, although some initial investigations have been made into the suitability of Swansea Bay for the construction of a lagoon.

Some tidal stream devices have been deployed in prototype stages, and a limited amount of environmental data is available from these deployments. However, these devices are not full scale, nor are they deployed in areas which are likely to be used for commercial generation of tidal power. In addition, the environmental impacts of prototype devices (which are still under development) cannot necessarily be taken to represent the potential impacts of generating tidal power from the final device on a commercial scale. There are additional issues in multiplying up the impacts of one prototype device in order to assess the cumulative effects of the deployment of a number of tidal devices together as a farm.

Despite the lack of direct observational data relating to tidal energy, a considerable amount of information exists regarding the environmental effects of constructions in the marine environment. Barrage and lagoon technologies essentially require the construction of a ‘wall’ structure to impound water, and it is therefore possible to predict some of the potential environmental effects of these structures based on observations of other solid constructions in coastal environments, such as harbour walls, jetty extensions, bridges and breakwaters. Tidal lagoons and barrages have also been built in some UK estuaries for reasons other than power generation, and this also provides useful information about the potential environmental effects of tidal range constructions. A considerable amount of information exists regarding the environmental impacts of dredging activities as a result of the marine aggregates



industry, and the offshore wind and oil and gas industries provide information about environmental impacts of drilling and piling in offshore environments. There is also a significant amount of information available regarding the effects of subsea cabling activities.

It is therefore possible to predict potential effects of tidal energy on marine and coastal environments based on our current understanding of environmental mechanisms. However, until site- and device-specific environmental assessments and modelling are carried out, or observations of functioning tidal energy programmes can be made, there remains a gap in our understanding of the environmental effects of tidal energy.

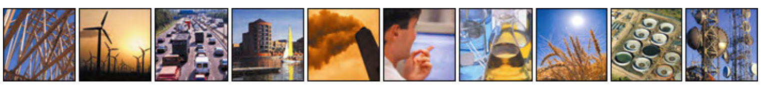
► **Many forms of tidal energy have not been built at full scale. This means that little is known about the environmental effects of tidal energy. However it is possible to predict the potential environmental effects of tidal energy based on information gained from other marine constructions such as oil platforms and harbours.**

Location

A generic analysis of environmental effects of tidal energy is made more difficult by the fact that the effects of a particular technology are likely to vary in extent and magnitude depending on the location in which it is placed. Different locations have different physical, chemical and biological characteristics, and will therefore be affected in different ways.

Tidal range technologies (barrages and lagoons) must be constructed in areas with large tidal ranges. The majority of the tidal range resource in the UK is found in the Mersey and Severn Estuaries, with the Severn Estuary alone accounting for 90% of the UK tidal range resource[34]. As the number of sites available for the construction of tidal range technologies is limited, it is easier to characterise the potential environmental effects of this type of tidal energy. Tidal range technologies are likely to be deployed in areas which are close to shore, with tidal barrages spanning estuaries and tidal lagoons in estuaries or shallow bays[52]. These areas are better studied than many parts of the marine environment. They tend to have large amounts of seabed sediments which support a variety of different ecological communities, both on the seabed and in intertidal (shoreline) areas. As a result of tides, currents and wave action, these sediments are usually very mobile within the estuaries or bay. The vertical movement of the tides, and the corresponding patterns of coastal exposure and inundation have a large influence on the physical, chemical and biological characteristics of these environments. In estuaries, the interface between freshwater from rivers and saline water from the sea is also an important environmental characteristic for physical, chemical and biological processes. With respect to the ‘human’ aspects of the environment, bays and estuaries are often sites with considerable levels of shipping and fishing (both commercial and recreational) and industrial, residential and recreational activities on the coastline.

The location of the tidal stream resource is more variable, and is likely to change over time as the technology develops. The general characteristic of the tidal stream resource is that of high current velocities. This resource



tends to be located in specific areas around the UK, with the two key areas being the Pentland Firth (containing 58% of the UK resource) and Alderney (containing 15% of the UK resource)[34]. The speeds and depths of the tidal stream resource in the UK are summarised in Table 4.1 below.

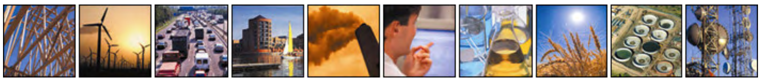
Table 4.1 Environmental characteristics of tidal stream resource locations (adapted from [35])

	Low flow (< 3.5 m/s)	**High flow (≥ 3.5 m/s)**
Shallow water (< 40 m)	7 TWh/y 38.9 %	1 TWh/y 5.6 %
Deep water (≥ 40 m)	2 TWh/y 11.1 %	8 TWh/y 44.4 %

These data indicate that the majority of the high energy resource is located in deep water environments. However, it is likely that the early deployments of tidal stream devices (either singly or in small farms) will occur in the most accessible sites (those in shallower water with lower velocities), with progression to the more energetic sites as technology develops. As the available resource is utilised, the final stages of development are likely to return to the lower energy sites (this progression is outlined in more detail in Section 3.5). This means that the environmental effects of the early tidal energy schemes may be rather different to those of the later schemes, both as a result of changes to the technology and deployment in environments with different characteristics.

Compared to shallow water sites, relatively little is known about high energy deep water environments as a result of the practical difficulties involved in surveying these sites. As a result of reduced human disturbance (for example as a result of the difficulties with trawling in high energy areas), some of these sites may represent a significant 'pristine' ecological resource[58]. However, ecological communities in these deepwater locations are poorly understood, and many are already impacted by trawling and underwater noise. Communities are believed to be influenced by factors such as sediment, temperature and water movements. Human activity has the potential to affect these areas[53], but as a result of the lack of understanding of these ecosystems, it is difficult to predict the nature of the effects.

► **The environmental effects of tidal energy will be different in different environments. The tidal range resource is in shallow water, and most of the tidal stream resource is in deeper water. Different types of tidal energy technology will therefore be placed in different environments.**



4.1.2 Environmental effects at different stages of development

The environmental effects of tidal energy are not limited solely to the operational effects of the technology. Any tidal generation facility, be it tidal range or tidal stream, will require construction, maintenance and decommissioning. These stages of the project bring with them the potential for secondary environmental effects arising from such activities as increased boat traffic, land-based activity and construction, dredging, piling, and cable-laying. The relative magnitude of these effects will differ between tidal technologies.

Construction

This is the stage during which the tidal technology is deployed. For large constructions such as tidal lagoons or barrages, construction activities can cause large environmental effects. The requirement for drilling and piling significantly increases the level of air-borne and underwater noise, during construction, and increased boat traffic and use of heavy equipment may pose significant problems for navigation of other vessels in the area. Direct effects on the seabed are greatest at this stage of development, including the loss of seabed habitats and the mobilisation of sediments in addition to dredging for sediments required for construction. There are significant practical difficulties associated with the construction of large structures in high energy areas. The construction of a barrage which crosses an estuary completely is a huge undertaking and is likely to take years to complete, resulting in longer-term effects at construction stage. It has been estimated that the construction of the Cardiff-Weston barrage in the Severn Estuary would take around 9 years, although it is likely that tidal lagoons will take less time to complete (in the region of 2 years).

The environmental impacts of deploying tidal stream devices are less than those of tidal range technologies, because less construction is required. In many cases it is likely that the device can be constructed onshore and transported to the site for deployment, which minimises the effects of construction and the length of time taken for deployment. Fixed devices may require dredging, drilling and piling in order to secure monopiles or to construct gravity bases. This will cause direct damage to the seabed and mobilisation of sediments, as well as requiring increases in boat traffic, and causing temporary effects on noise and air and water quality. Installation of floating devices may result in fewer effects, as the moorings required are less invasive.

Installation of both tidal range and tidal stream technologies requires the laying of cables to carry electricity back to shore. For tidal barrages and tidal lagoons which connect to the shore, some of the cables can be incorporated within the structure, and this minimises the impact of placing cables on the seabed. Tidal lagoons which do not connect to the shore and tidal stream devices must be connected to land by a seabed cable, which will require a level of dredging, digging, jetting or ploughing prior to placement, and thus increase the effect on the environment.

Operation

This is the stage when the technology has been placed in the ocean and is generating electricity. The act of removing energy from the water will result in environmental effects, and the presence of structures in the water column and on the seabed will affect currents and the movement of sediments. There may also be effects on the ecological features of the environment. The magnitude of these effects is dependent on the technology device deployed. The operation of a barrage or large coastal lagoon is likely to have more effect on the environment than the operation of tidal stream devices, although the cumulative effects of an array of tidal stream devices need to be assessed rather than the operation of a single device.

Maintenance

Maintenance operations will be required throughout the active life of any tidal power facility. This requires the use of boats and heavy equipment, and will have similar effects on the environment as construction, although the effects will be of shorter duration.

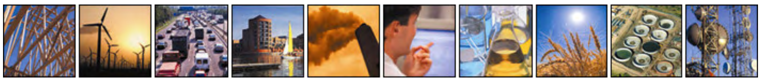
It is essential to maintain the impounding ability of tidal range technologies, and maintenance will be ongoing throughout the life of the construction. The continual assault on the impounding structure by waves, strong tidal currents and the weight of impounded water results in the requirement for regular inspection and repair work. In addition it will be necessary to dredge out sediments which have been deposited behind the impounding wall in order to allow continued generation of electricity.

Maintenance of tidal stream devices may require periodic raising of the device for cleaning and repairs, and repair of fixed bases or moorings. Cables may also need to be raised for maintenance purposes. Tidal stream devices are likely to require less frequent and invasive maintenance than tidal range technologies.

Decommissioning

Once tidal technologies have reached the end of their useful life, they can be removed from the sea. The developer has a responsibility to plan for decommissioning, and there are regulations which constrain the types of materials which can be left on the seabed. Decommissioning may occur when the technology is too old to generate useful amounts of electricity, if it is damaged, or if it can be replaced by a more efficient technology. The lifespan of tidal range technologies is in the region of 100 years. Tidal stream devices are not likely to last so long; their lifespan is likely to be in the region of 20 years.

The process of decommissioning varies between tidal technologies. Decommissioning of large sub-surface structures such as barrages and lagoons requires the use of heavy equipment and explosives. Significant amounts of sediment may have accumulated behind these structures, and its release during decommissioning could result in far-reaching environmental effects, particularly if the sediment has been contaminated with toxic substances. It is likely that a large amount of debris will remain on the seabed following decommissioning. This will remain in the environment permanently, and may be moved around by tidal currents, effectively increasing the seabed area affected by the tidal range technology. The decommissioning process is also likely to cause temporary increases in levels of terrestrial and underwater noise, temporary decreases in air and water quality, and a temporary impact on the landscape and visual quality.



Decommissioning of tidal stream devices is likely to result in less disturbance than decommissioning of other tidal devices. Whilst there will be the requirement for increased boat traffic, and temporary effects on noise level and air and water quality, the structures are much smaller in size and there is less solid construction to destroy. Floating devices which are simply moored or anchored to the seabed can be removed with relatively little effort, and it may be possible to leave the mooring bases on the seabed. Removal of fixed devices will result in greater disturbance, particularly in the case of monopiles. It may be possible to leave gravity bases on the seabed, however, should they be removed this would result in significant seabed disturbance and sediment mobilisation. The removal of landward cables from tidal stream farms will result in a level of seabed and shoreline disturbance; usually these will be left in place in order to prevent excess damage to the environment.

Secondary effects

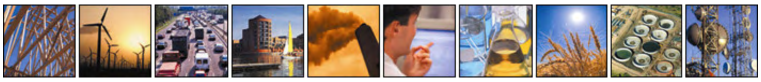
In addition to the direct environmental effects of tidal energy schemes on the marine environment, it is possible that there will be secondary environmental effects. These may include the effects of terrestrial power cabling and the requirement for accessory infrastructure such as roads, railways and ports. It is difficult to predict the environmental effects arising from these secondary issues, as they are likely to vary greatly between locations. Secondary environmental effects are not discussed further in this report.

► **Construction, operation, maintenance and decommissioning of a tidal energy scheme will have different effects on the environment. In many cases construction and decommissioning activities cause as much disturbance to the environment as the operation of the tidal energy scheme. It is important to consider the potential effects of tidal energy schemes at different stages of development.**

4.1.3 Structure of this chapter

This chapter aims to highlight all the potential effects on the environment which may result from tidal energy schemes. It should be stressed that the tidal energy will not necessarily result in all of these effects, as many of them are specific to certain types of environment or to certain types of technology. However, within each section the potential effects are described, and then discussed in relation to different tidal technologies in order to present a means of differentiating between technologies. An effort has also been made to highlight the differences between effects occurring at construction, operation, maintenance and decommissioning stages of tidal technologies.

The headings within this chapter are designed to address the main issues which must be considered by any developer during the Environmental Impact Assessment (EIA) process. EIA is a statutory requirement for all



developments which are listed on Annex I of the EU ‘EIA Directive’[n], and may be required for developments listed on Annex II of the directive. An EIA will be required prior to the construction of any tidal power generating facility which exceeds 1MW installed capacity.

Each section concludes with a summary table highlighting the key differences between different forms of tidal technology in terms of their effects on the environment. Suggestions for the type of investigations required prior to the construction of a tidal energy scheme in a particular location are also included, although these lists are by no means exhaustive. In many cases, environmental effects are highly site-specific, and this generic advice would need to be adapted to meet the requirements of specific tidal energy schemes in specific locations. Some considerations for reducing the potential environmental impacts described are also included.

4.2 Seabed, sediments and hydrodynamics

Tidal developments, regardless of the type of technology used, require structures to be placed on the seabed. In terms of barrage and lagoon technologies, these structures are equivalent to large walls, and may include rock armouring and concrete caissons. For tidal stream technologies, structures on the sea bed vary depending on the type of device. Fixed devices may require a mono-pile or a gravity base made by flattening the seabed and limiting it with crushed rock. Floating devices will require moorings or anchors on the seabed.

It is also necessary for landward cables to be installed in order to transport the generated electricity to shore. In the case of barrages and lagoons, these cables may be incorporated into the structure built on the seabed, or carried above the sea; for tidal stream devices these cables will lie on the seabed or be buried beneath it. A farm of tidal stream devices will need a structure of connecting cables and junctions on the seabed in addition to the main cable carrying electricity back to shore.

The placement of structures or cables on the seabed will have a variety of effects on the physical environment. These can include scouring of sediments, deposition of sediments and the necessity for pile-driving, digging or dredging. The type and magnitude of impact will vary between construction, operation and decommissioning stages of a tidal development project. Different tidal technologies will have different effects on the seabed environment. Maintenance requirements during the operation of tidal technologies, such as sediment dredging or anchor lifting, may also affect the seabed.

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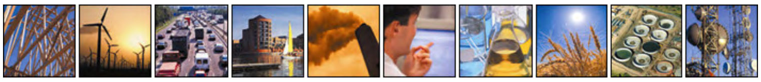
[n] *Council directive on the assessment of the effects of certain public and private projects on the Environment 1985* (85/337/EEC) (as amended in 1997 by Council Directive 97/11/EC). This directive was transposed into UK Law by the *Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 Act* (Statutory instrument number 293) and the *Environmental Impact Assessment (Scotland) Regulations 1999* (Circular 15-1999).



4.2.1 Direct seabed effects

Footprint of tidal power scheme

The construction of a structure on the seabed will cause direct damage to the area upon which it is placed. The amount of damage caused depends on the size of the "footprint" of the tidal technology. Barrage and lagoon structures are large, and cover a significant area of the seabed. Fixed tidal stream devices have a much smaller footprint (although the combined footprint of a farm of such devices would be larger than that of a single device). Floating tidal stream devices have the smallest footprints, as they are attached to the seabed by moorings or anchors which take up relatively little space. As discussed below, the effect on the seabed is not limited to the area taken up by the tidal structure or device. The requirement for cabling and the effects on sediment transport processes can increase the area of seabed affected by the development.

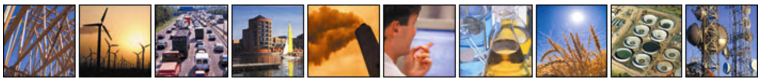
Placing a structure on the seabed has an immediate effect on the environment by removing an area of seabed habitat[54]. Organisms living in the sediments may be killed, while more mobile organisms such as fish and crabs may be able to move away[55]. Obviously the larger the footprint of the tidal power scheme, the more habitat will be destroyed; tidal barrages and lagoons will result in more damage than tidal stream devices[55]. Some areas of seabed have a rich and diverse community of organisms, while others have very few organisms. There are some important habitats and organisms on the seabed which are protected by national and international law. In order to prevent serious effects on these habitats and species, it may be necessary to control where tidal power schemes are placed.

Construction activities on the seabed can also affect surrounding areas of seabed by the mobilisation of sediments and their deposition on habitats nearby. More invasive construction methods involving dredging, rock armouring and infilling (such as those used for constructing tidal barrages and lagoons) are likely to have the greatest effect. The construction of mono-pile or gravity bases for fixed tidal stream devices will have a greater effect than constructing moorings or anchorages for floating tidal stream devices.

While the structure is in the water, it is likely to create a new type of habitat for marine organisms. During the lifetime of the tidal power scheme a new seabed community may develop around it. On decommissioning, this community will then be disturbed, and the area will have to be re-colonised all over again. This means that seabed damage by the placement of tidal power schemes will occur both during construction and decommissioning.

Although tidal barrages and lagoons have a larger seabed footprint than a tidal stream device, the deployment of devices as a farm, with the associated cables and junctions, can increase their footprint. In general, the footprint of fixed tidal stream devices, which require a monopile or a concrete/gravel base, will be greater than that of floating tidal stream devices, which only require moorings or anchors.

For the construction of barrages and tidal lagoons, a large amount of aggregates and sediment in-fill will be required. This is likely to be acquired by dredging, either near the construction site or elsewhere. Dredging also



causes damage to the seabed, and this increases the effective footprint size of barrages and lagoons. Dredging for aggregates is not required for tidal stream devices.

► **Placing tidal range structures or tidal stream devices on the seabed disturbs the seabed habitat. Tidal range schemes generally have larger footprints than tidal stream schemes, and are likely to have a larger effect on the seabed.**

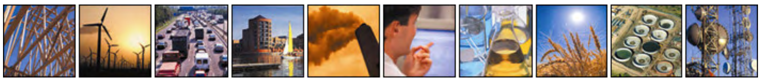
Cable laying

Electricity generated by exploiting the tidal power resource must be carried to land in cables. In the case of large barrages and tidal lagoons, which are built in shallow water reasonably close to shore, at least some of the cables may be incorporated into the structural design or carried on top of the structures. Tidal stream devices require cables to be laid on the sea bed; tidal stream farms in offshore deep water will require much longer cables than those in shallower inshore waters.

The laying of cables is an additional effect on the seabed, as cables are usually laid in shallow trenches on the seabed or buried beneath it, although there are some less invasive techniques available[55]. The digging, dredging, ploughing or water jetting associated with cable laying during the construction of tidal power schemes will have an effect on the seabed habitat in the area of the cable route. The cabling arrangement for a farm of tidal stream devices is likely to be complex, with the requirement for numerous sub-cables from individual devices and cable junctions in addition to the main landward cable. The disturbance caused to the seabed by this cable laying increases the effective footprint size of a tidal stream device farm. However, it is likely that the disturbed area will be recolonised relatively rapidly by organisms from the surrounding areas [55]. If cables are removed during decommissioning of a tidal scheme, this can result in further seabed disturbance. For this reason, cables are likely to be left in place after decommissioning.

For both tidal range and tidal stream technologies there will also be an effect on intertidal (shoreline) habitats where the cable comes ashore. This may involve significant excavations in order to bury the cable and prevent excessive erosion of sediment around the cable in the high wave environment close to shore, resulting in disturbance to intertidal habitats and communities[58]. Many of these habitats are protected under national or international legislation.

► **Cable laying and the removal of cables disturbs the seabed. This increases the area of seabed affected by a tidal energy scheme. Tidal stream devices, particularly those deployed as a farm and/or in offshore waters, will need the most cables.**



4.2.2 Scour and deposition

The effect of a tidal power scheme on the seabed is not limited only to the area where the scheme and its cables are placed. The placement of a solid structure on the seabed in an area where there are strong currents will have an effect on the erosion, transportation and deposition of sediments in the area. By their nature, tidal stream devices will be placed in areas where the current is strong. Tidal range structures do not require fast currents, but the impoundment of water and its release through sluices creates flows of water which can affect sediments.

The presence of a tidal power structure in the water is likely to increase local current velocities by forcing water to take a different current path or direction. In areas where the seabed is covered by soft sediments, increased current speeds can mobilise greater quantities of sediment and/or larger sediment particles (e.g. sand particles as well as silt particles). This can cause increased erosion and ‘scouring’ effect at the base of the structure[55]. The amount of scour will vary with the type and size of the base structure used, and the sediment which is present on the seabed. In many areas of high current velocity there is little sediment on the seabed, and for tidal stream devices in these areas scour will be less of an issue. Inshore waters, and particularly estuaries, have large amounts of sediment. Tidal range constructions and tidal stream devices placed in these areas are likely to incur more scour effects.

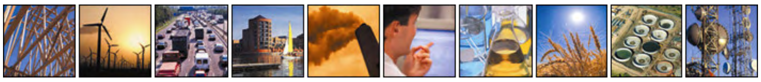
Scour effects around the base may have important consequences for the physical stability of tidal power structures. This is more likely to be an issue with fixed tidal stream devices rather that floating tidal stream devices (which have smaller bases on the seabed) or tidal range devices (which have large firm foundations). The design of tidal structure foundations in soft sediment areas will need to be assessed carefully for long term viability.

Scour can also occur around seabed cables, particularly if they are not buried very deeply. This can result in ‘free spans’ where the cable does not touch the sediment beneath it.

The mobilisation of sediments by increased current velocities results in the sediment being transported in the water column and deposited elsewhere where the currents are too weak to carry them in suspension. The suspension and movement of large quantities of sediment within the water column can be called a ‘sediment plume’. The speed and distance travelled by a sediment plume will depend upon the local current velocities. Sediment plumes can have significant environmental impacts within the water column and after deposition. This deposition may occur on another part of the seabed, or (if the tidal power structure is located in inshore waters) on the shoreline. The deposition of sediments may change the characteristics of seabed or coastal environments, and smother organisms living there[55].

By the nature of their design, tidal stream devices remove energy from the currents flowing past them. This can reduce the flow velocity immediately downstream of the turbine quite significantly, with the effects discernable for some distance[55],[56]. The removal of tidal energy by tidal stream devices may also result in localised deposition of finer sediments which were carried in the water passing through the devices[57].

The effects of scour and deposition will occur during the operation stage of a tidal power scheme, although the effects may last beyond decommissioning if significant structures are left on the seabed. The level of effect on the sediment transport processes resulting from the operation of a tidal power scheme depend on the size of the



structure placed in the water. Tidal barrages and tidal lagoons are likely to have a greater impact than tidal stream device farms, particularly as they would be placed in shallower coastal waters. The smallest effect would be seen with a floating tidal stream device which has a minimal seabed footprint.

► **Tidal structures affect sediment transport by changing the speed and direction of currents. This means that a tidal energy scheme can have an effect on areas at a distance from the scheme. The effect is greatest with tidal range structures, as they are larger and result in more erosion and deposition of sediments.**

4.2.3 Effect on the coast

The generation of tidal power in inshore waters has the potential to affect the coastline. These effects are likely to be greatest with tidal range structures, which have significant effects on the tidal range and flow of currents in an area[58]. Tidal stream devices do not affect tidal range, although they extract energy from tidal currents and may have surface-piercing structures which create a surface 'wake' effect [57].

A tidal barrage or lagoon obstructs the flow of currents in an area, and can force currents to flow in different directions. In addition to effects on the seabed, significant changes in current direction or increases or decreases in current velocity have the potential to affect coastal environments. Some sections of coast may be exposed to increased current flows, resulting in erosion. Others may be exposed to slower currents, resulting in deposition. These localised changes in current direction and velocity may, over time, lead to net changes in the balance of erosion and deposition within an area. Changes in the rates of erosion and deposition, combined with the effect of impounding or 'containing' sediments upstream of a barrage, may have associated effects on the amount of suspended sediment within the channel downstream. This effect may have particular significance for estuarine areas, which rely on a constant supply of sediments to maintain their natural sedimentation balance. Through the impoundment process, downstream locations may become starved of sediment as a result of impoundment, or subject to large influxes of sediment on the release of water which are beyond the capacity of the system.

Change in the frequency and magnitude of sediment supply may have important consequences for coastal and estuarine areas and the ecology which they support. In addition to this, changes in the patterns of erosion and deposition within an area may reduce the ability of the coast to respond to the sea level rises which are predicted as a result of climate change. This in turn will lead to wider erosive issues and associated complications for coastal and estuarine management within the region.

Depending on the location, a farm of tidal stream devices placed in coastal waters may have similar effects on coastal environments. However, as farms are likely to be placed in areas experiencing high current velocities, the effect of removing energy from the currents is likely to be less. Tidal range technologies are likely to be placed in lower energy environments such as bays and estuaries, and changes in current regime within these environments are likely to result in more significant environmental impacts.

- **Tidal energy in inshore waters can change the patterns of sediment erosion and deposition along the coast. This has implications for flood risk and sea defences, as well as for the structure of estuaries. The effects of tidal range schemes on the coast is likely to be greater than the effect of tidal stream schemes.**

Tidal barrages can also change the patterns of coastline inundation, as they hold back water at high tide and disrupt the natural tidal cycle. This may result in increased deposition of sediments on shoreline habitats in sheltered areas, or increased erosion in exposed areas as waves can attack the shore at the high tide mark for longer periods of time. Many intertidal species are adapted to a natural cycle of exposure and inundation by the tides, and there may be changes in intertidal communities as a result of disturbance of the natural tidal cycle.

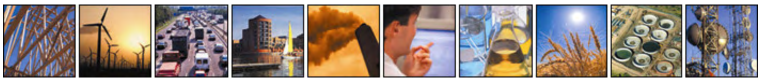
- **Shoreline habitats and species may also be affected by longer periods of inundation at high tide as a result of the impoundment of water behind a barrage.**

Flood risk

There are possible flood risk issues associated with the construction of tidal power schemes. These are associated with tidal range structures rather than tidal stream devices, as tidal range structures by their design have large scale effects on the movement of water within coastal areas. The effects of a barrage which completely crosses an estuary are likely to be much greater than the effects of a tidal lagoon which encloses an area away from the coastline.

Flood risk issues associated with tidal barrages can be both positive and negative. As a result of the fact that the barrage cuts across an estuary, it can act as a flood protection device (in a similar way to the Thames Barrier, which protects London from tidal surges in the North Sea). The height of a barrage and its ability to reflect wave energy away from vulnerable areas of coastline may reduce the risk of existing upstream flood defences being breached, although it would still be necessary to maintain flood defences upstream of the barrage. This protection will become increasingly significant in the face of climate change and sea level rises. However, whilst a barrage may protect the upstream coastline upstream by reflecting wave energy and preventing tidal surges, this protection is not afforded to downstream coastline. In fact, the reflection and refraction of wave energy away from the barrage towards surrounding coastal areas may increase the wave impact and coastal erosion downstream of the barrage, increasing flood risk in these areas.

Tidal barrages act by impounding water at the upper end of the estuary at high tide, and then releasing it at low tide. This means that water levels in the upper estuary will remain high for longer periods of time, and the ebb and flow current regimes will change. If a significant amount of water is impounded, there is the potential for waves to form behind the barrage as a result of wind action, and these waves will be reflected back from the barrage. Wind driven waves generated within barrage impoundments may exacerbate flood risk issues both locally and further afield.



The waves generated across the deeper body of water may be higher and more energetic than those previously experienced in the area. These waves may further increase erosion at the foreshore, reducing bank stability and eventually undermining flood defences. The high water levels, change in tidal current regime and wave action may result in the flooding of low-lying coastal areas behind the barrage. The significance of flooding impacts will depend upon the location of the barrage and the characteristics of the shoreline.

In the light of climate change, rising sea levels and increased storminess, its clear that any barrage scheme requires careful consideration and evaluation of associated long-term flood risks.

► **Tidal barrages can have positive and negative effects on the risk of coastal flooding. Coastal lagoons and tidal stream devices are not likely to affect the level of flood risk.**

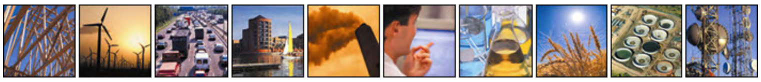
Effects on rivers and groundwater

The maintenance of high tide levels for longer periods of time behind an impounding structure also has the potential to contaminate groundwater with saltwater. Groundwater is freshwater which is held in a layer of porous rock below ground level. The rock holding the water is called an aquifer. Where the aquifer meets the coastline, there is the potential for saline water to enter the aquifer. The extent of natural saline intrusion into aquifers is dependent on the geological and hydrological characteristics of the aquifer, and the extent of freshwater abstraction from the aquifer on land. This will differ greatly between estuaries. However, if high levels of saline water are maintained for extended periods of time behind a barrage, this increases the risk of saline intrusions into the aquifer. The impoundment of water behind a barrage also reduces the flushing of contaminants from the estuary, and it is possible that these could also penetrate the aquifer and lead to additional water quality issues.

Where a river enters the sea there is intrusion of sea water up the river as a result of the rise and fall of the tide. The saline water from the sea mixes with the freshwater from the river to create an area of ‘brackish’ water. Further up the river the effect of saline water becomes less and less until the river is entirely freshwater. The ‘tidal limit’ of a river is the distance upstream that the saline water can travel. Changing the tidal range within an estuary, and artificially maintaining high tide levels upstream of a barrage has the potential to affect the penetration of saltwater into rivers which enter the estuary. This has implications for the use of water within the river, as abstractions for irrigation or public water supply may become contaminated with saline water.

These effects on river and groundwater are only likely to occur with the construction of tidal barrages which cross an estuary completely. Tidal lagoons only impound discrete areas of water away from the shore, and tidal stream devices do not impound water at all.

► **Tidal barrages hold back water at high tide, and this saline water can affect freshwater resources at the top of the estuary. Tidal lagoons and tidal stream devices do not do this.**



4.2.4 Effect of impoundment

Unlike tidal stream devices, tidal range structures generate power by impounding water at high tide and releasing it at low tide. Once the structure has been constructed, the impoundment of water has the effect of reducing current velocities within the water held back behind the structure. As the velocity decreases, sediments ‘settle out’ of the water column and are deposited on the seabed[59]. Over time, these sediments can build up to a level where it is necessary to dredge them out, as the disturbance of natural currents prevents the natural removal of sediments.

As impounded water is released through sluices and turbines, the localised increases in current speed have the potential to cause significant scour of the seabed which are equivalent to the ‘plunge pool’ effect below a waterfall. This can mobilise large quantities of sediment into the water downstream of the impoundment structure. In addition, the sudden localised increases in current velocity could be a risk for vessels navigating in the area.

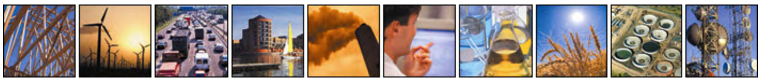
These effects of impoundment only apply to tidal range technologies, as tidal stream devices do not impound water or significantly interrupt the flow of water. The impoundment effects associated with a tidal lagoon are on a smaller scale to those associated with a tidal barrage, as the amount of water impounded is smaller. The effect of impoundment will be cumulative throughout the lifetime of the tidal range structure, becoming more of an issue the longer the structure is in the water. The collection of sediments behind impounding structures will require ongoing maintenance activities such as dredging, which cause additional environmental effects. On decommissioning, care will need to be taken when the impounding structure is dismantled, as the sudden release of sediments from behind the structure and the return of natural currents to the area have the potential to significantly affect both the hydrodynamic and sedimentary regime of the area.

► **Tidal range devices impound water, and cause deposition of sediments and the formation of ‘plunge pools’ below turbines. Tidal stream devices do not cause these effects.**

4.2.5 Effect on the water column

All tidal power schemes are designed for the extraction of energy from water, and have moving parts (turbines, rotors, reciprocating hydrofoils, gears etc.). Friction effects of moving parts on the water column may produce heat, which is transferred through water. The effects of this generation of heat on the environment are not well understood, but it is unlikely that the amount of heat generated by tidal power devices will result in significant environmental effects, particularly as the heat will be quickly dissipated by the currents around the tidal energy scheme[55].

The potential for contamination of the water column through the generation of tidal power is discussed in Section 4.6 below.



- **Friction associated with tidal energy may generate heat in the sea, but the effects of this on the environment are likely to be small.**

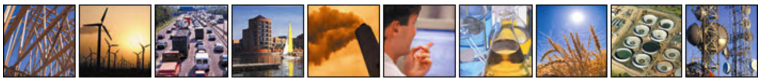
4.2.6 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on the seabed, sediments and hydrodynamics, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of fixed and floating devices, as this is the key technological differentiator which affects the environmental impact. This table is intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

Table 4.2 Summary of effects of tidal energy on seabed, sediments and hydrodynamics

	Tidal Range		**Tidal stream fixed**			**Tidal stream floating**			**Sites affected**	**Ability to mitigate**
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**Few All**	**low high**
Direct seabed effects	high	high	low	med	high	v. low	Low	low / med	🟦🟦🟦	🟩
Cable laying	v. low	low	low	med	high	low	Med	high	🟦🟦🟦	🟩
Scour and deposition	high	high	v. low	low	med	negl.	v. low	low	🟦🟦	🟩
Effect on the coastline	v. high	med	negl.	v. low	low	negl.	negl.	v. low	🟦	🟩🟩
Flood risk	high	low	n/a	n/a	n/a	n/a	n/a	n/a	🟦	🟩🟩
Rivers and groundwater	med	low	n/a	n/a	n/a	n/a	n/a	n/a	🟦	🟩🟩
Impoundment	high	low/med	n/a	n/a	n/a	n/a	n/a	n/a	🟦🟦🟦	🟩
Water column	negl.	negl.	negl.	negl.	negl.	negl.	negl.	negl.	🟦🟦🟦	🟩

‘negl.’ indicates a negligible effect on the environment



Information required

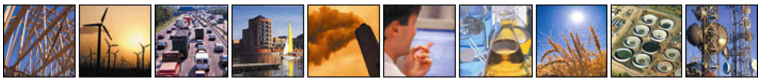
If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on the seabed, sediments and hydrodynamics is:

- Characterisation of benthic ecology in the area chosen for the tidal power scheme, including the presence of any protected habitats or species;
- Understanding of the seabed sediment processes in the area (erosion, transportation and deposition);
- Understanding of coastal sediment transport processes, and identification of vulnerable shoreline habitats in order to optimise choice of location;
- Modelling of the effect on sediments of placing of structures in the area, taking into account the type of base required and the amount of cabling;
- Modelling of the energy capture by a tidal stream device, and any surface wake effects or sub-surface vortex effects;
- Characterisation of tidal range and tidal current characteristics of the area, and modelling to predict the impact of a tidal energy scheme on these characteristics;
- (In the case of a barrage) full flood risk assessment of low-lying areas, taking into account the most up-to-date sea level rise predictions, and modelling to predict the impact of tidal energy on local flood risk.

Mitigation of effects

The potential effects of a tidal energy scheme on the seabed, sediments and hydrodynamics could be reduced by:

- Sensitive design of base structures to protect against excessive erosion and to reduce the amount of damage to benthic habitats;
- Choice of location to reduce impacts to sensitive habitats and species on the seabed;
- Coastal defence construction in order to reduce flood risk and/or to protect vulnerable shoreline habitats;
- Choice of offshore locations for tidal energy in order to reduce risk to coastal areas;
- Continual maintenance of impounding structures to prevent excessive sediment build-up;
- Monitoring of vulnerable groundwater resources to assess levels of saline intrusion;
- Construction sluices in rivers in order to create artificial tidal limits and protect freshwater abstractions.



4.3 Noise

Tidal developments have the potential to affect the amount of noise both above and below the water. This will occur during the generation of power, but mostly as a result of construction, maintenance and decommissioning activities associated with the project.

4.3.1 Underwater noise

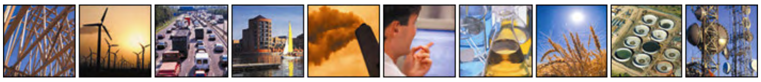
Noise and vibrations travel particularly well through water, and may travel great distances from their source. The installation, operation and decommissioning of tidal stream devices, barrages or lagoons are likely to cause increases in the amount of underwater noise. Whilst the sea is not a quiet place, particularly in coastal regions, increases above ambient (background) noise levels have the potential to harm fish and marine mammals, or to disturb their behaviour. This is discussed further in Section 4.9.

During construction and decommissioning stages, underwater noise levels will rise as a result of activities such as pile-driving, dredging, drilling, construction of walls or solid bases, cable laying, operation of equipment such as jack-up barges, and increases in boat traffic[55]. Noise may also be generated during geophysical surveys of an area prior to construction[60], as some survey techniques use sound to ‘see’ what is beneath the seabed.

When assessing the effect of noise in the underwater environment it is necessary to take into account the level of noise and the duration of noise. In general, large developments will result in noise being generated for longer periods of time. The duration of noise generation during the construction of a barrage, which is a huge structure taking years to complete, would be much longer than the duration of noise generated during the construction of smaller tidal lagoons. The construction of bases for tidal stream devices is relatively simple compared with construction of tidal range structure, and would result in much shorter periods of underwater noise. The shortest periods of noise would be generated during construction of moorings for floating tidal stream devices. The construction of tidal stream devices themselves is likely to occur on land rather than at sea, which further minimises underwater noise effects compared to tidal range structures. Although the duration of noise during construction of tidal stream devices may be short, activities such as percussive pile driving (associated with the installation of monopiles) produce very high levels of noise.

Noise produced during the operation of different tidal technologies is likely to be at a much lower level than the noise produced during construction or decommissioning, although the duration of noise generation will be longer. The movements of rotors, turbines and hydrofoils, and the movement of other mechanical parts of the structures may result in levels of noise above ambient levels, although it would probably not exceed the level of noise produced by a boat propeller[55] It will be important to measure the frequency of this operational noise in order fully to understand the effects of this noise on marine organisms. More research is required into the underwater noise and vibration produced in the generation of tidal energy, and the potential for impacts on marine environments [57].

During maintenance operations, underwater noise levels are likely to rise. For tidal stream devices, it is likely that maintenance will occur onshore, with offshore activities limited to retrieval of the device or its components, and



repairs to the base structure. This is likely to result in low levels of underwater noise, particularly for floating devices which are likely to be designed so that they can be detached from their moorings and towed away for maintenance and repair. For tidal range structures, although some parts can be serviced onshore it will be necessary to carry out structural maintenance on site. This will result in higher levels of boat activity and use of equipment at sea, and consequently higher levels of underwater noise. Larger structures are likely to result in the requirement for more maintenance, which will generate more underwater noise.

► **Noise is generated underwater by the construction, maintenance and decommissioning stages of a tidal power scheme. Some construction activities (such as pile driving) generate significant amounts of noise. Noise during operation may be less significant, but will be location and device dependent.**

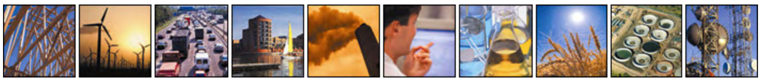
4.3.2 Airborne noise

Airborne noise levels can also be affected by tidal power schemes. Piling activities, movements of equipment and materials, increases in road traffic and boat traffic will all have an effect on airborne noise. This can be a concern for local residents, and may also have effects on birds in the area.

The placement of a tidal generating scheme in an area where there is already a significant amount of coastal activity (such as an estuary containing a commercial port) is likely to have a less noticeable impact on airborne noise, as noise levels are already high. The placement of tidal schemes in less developed areas may result in more perceived disturbance. Tidal range structures are likely to be built in coastal or estuarine areas where there is already a reasonable amount of airborne noise, while the best tidal current resource areas are offshore in deep water, or in areas where there is less commercial activity.

Effects on airborne noise are likely to be most apparent during construction and decommissioning stages, although maintenance activities may also result in increases in airborne noise. In the case of large constructions such as barrages and lagoons, there may be longer term effects on airborne noise levels as construction is likely to take a long time, and will occur close to the coast. For tidal stream devices there is less construction work required at sea, although there will be land-based activities. These are likely to be shorter in duration.

► **Construction, maintenance and decommissioning activities will have an effect on noise levels in the area. The effects are likely to be greatest with tidal range schemes, but may be more noticeable for tidal stream developments in less commercially-developed areas.**



4.3.3 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on airborne and underwater noise, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of fixed and floating devices, as this is the key technological differentiator which affects the environmental impact. This table is intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

Table 4.3 Summary of effects of tidal energy on noise

	Tidal Range		Tidal stream monopile			Tidal stream gravity base/floating			Sites affected	Ability to mitigate
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**few all**	**low high**
Magnitude of underwater noise (construction)	low for approx 7 years	low for approx 2 years	med	high	high	low	low	low / med	🟦🟦🟦	🟩🟩
Duration of underwater noise (construction)	v. long	med / long	short	short / med	med	short	short/ med	med	🟦🟦🟦	🟩🟩
Underwater noise (operation)	low	low	low	low / med	med	low	low-med	med	🟦🟦🟦	🟩
Airborne noise (construction)	high (up to 7 yrs)	high (long)	v. low	low	med	v. low	low	med	🟦🟦🟦	🟩🟩
Airborne noise (operation)	low	low	v. low	v. low	v. low	v. low	v. low	v. low	🟦🟦🟦	🟩🟩

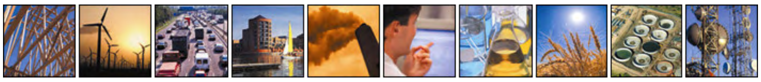
Information required

If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on noise is:

- Assessment of ambient airborne and underwater noise levels prior to construction;
- Assessment of the potential for noise production as a result of the scheme;
- Identification of marine species which may be affected by underwater noise, and local populations who may be affected by airborne noise.

Mitigation

The potential effects of a tidal energy scheme on noise could be reduced by:



- Use of construction, maintenance and decommissioning methods which are least likely to generate noise;
- Design of tidal technologies to minimise noise during operation;
- Timing of noise-generating activities to minimise disruption to noise-sensitive species.

4.4 Seascape and visual effects

The construction of a tidal power development has the potential to affect the landscape and seascape of the installation area. The visual impact of a structure can be evaluated from the coastline, but it may also be necessary to assess the impact of a structure from offshore locations such as ferry routes or recreational boating areas[58]. Significant impacts on seascape may affect the amenity value of coastal areas. The coastline of the UK contains a large number of important and highly-valued landscapes, including Areas of Outstanding Natural Beauty (AONB), National Parks and sections of Heritage Coast. With respect to planning decisions, a number of landscape designations need to be considered. These include World Heritage Sites, National Scenic Areas and Areas of Great Landscape Value. The historic characteristics of the coastline may also need to be considered.

The visual effects of tidal energy schemes will vary with the landscape qualities of their location; in addition to the presence of settlements and infrastructure around the coast, the exposure and remoteness of the area may influence the visual impact of a tidal energy scheme. ‘Large scale’ open landscapes may be less affected than ‘small scale’ closed landscapes, and there may be an interplay between the coastal topography and the structure of a tidal energy scheme which could enhance or mitigate the visual effects of the scheme. In addition to the direct effects of a tidal energy scheme on the landscape or seascape, it is important to assess the ‘experiential impact’ – that is, the ability of the public to continue to enjoy the biodiversity and wider natural environment of the area.

Visual impacts of tidal generation schemes will be greatest for those with structures which pierce the sea surface. For all types of technology there will be the requirement for land-based structures such as substations and landward transmission lines, and the possibility of infrastructure developments such as ports, housing and road networks which will impact the coastal landscape value. The level of the effect will depend on the characteristics of the seascape; placement of tidal generation schemes in ‘pristine’ seascapes is likely to have more of an effect than their placement in an area which already has a significant level of visual impact[55]. Similarly, areas of coastline with high amenity value (for example, exceptional coastal views) may be more affected by the placement of a tidal generation scheme than other areas.

The visual impact of offshore tidal devices themselves will depend on their distance from shore, the height of any surface piercing element of the device, the presence of lights, and the predominant weather and conditions of the area (atmospheric interference, high surface swells or persistent rain or fog can affect the extent to which a surface piercing structure is visible). It has been suggested that 15 km from the coast is the maximum limit for visual disturbance[61], and for any tidal schemes within 15 km of the shore will need to consider visual impacts as part of any EIA. The presence of navigational lights will increase the distance from which the surface piercing structure is visible[52].

Visual impacts are likely to be greatest with large civil structures such as tidal barrages and tidal lagoons, particularly as these are likely to be located in near-shore waters. The visual effect of these structures will be particularly significant at low tide when more of the structure is visible.

Tidal stream devices are likely to have less visual impact, as any surface piercing structures are much smaller (for example, see below), although the cumulative impact of a farm of surface piercing tidal stream devices will be greater than the impact of single devices. Fixed devices attached to mono-piles have a significant surface-piercing component, while gravity based fixed devices or floating devices have much smaller surface piercing components. Even completely submerged devices will require surface markers for navigational safety purposes, although the visual impact of these markers is likely to be small. The placement of tidal stream devices in deeper waters offshore will result in very little visual impact.

Figure 4.1 A photograph of Marine Current Turbine's Seaflow installation at Lynmouth, demonstrating the low visual impact of a single surface-piercing tidal stream device [62]

Visual impacts are not just associated with the device itself during operational stages of development. Construction, maintenance and decommissioning stages of tidal developments will also have associated temporary visual impacts as a result of the use of specialist ships/barges and heavy machinery.

Terrestrial constructions associated with the tidal energy scheme (for example, cabling on the shoreline, substations and pylons) may also affect the landscape value of the coastal area[55], particularly along 'wild coasts' which have previously experienced little human impact[58].

► **Effects of tidal energy schemes on the landscape/seascape features will vary from area to area depending on the characteristics of the coastline. The greatest visual effect on seascape is likely to occur with tidal range structures, as these have the largest surface piercing structures, and will be located close to the shore. The visual impacts of tidal stream devices are likely to be lower, particularly those which are deployed in deep water further offshore.**

4.4.1 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on the seascape and visual environment, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of submerged and surface-piercing devices, as this is the key technological differentiator which affects the environmental impact. This table is intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

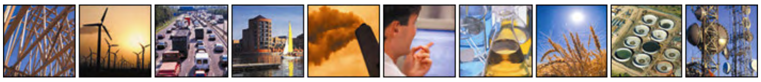
Table 4.4 Summary of effects of tidal energy on the seascape and visual environment

	Tidal Range		Tidal stream submerged			Tidal stream surface piercing			Sites affected	Ability to mitigate
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**few all**	**low high**
Seascape and visual effects	high, close to shore	high, close to shore	negl.	v. low	v. low	v. low	med	med / high	🟦	🟩

Information required

If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on the seascape and visual environment is:

- A character assessment of the landscape/seascape value of the region, which can form a baseline for evaluating change;
- An assessment of the amenity value of the area;
- Compilation of photomontages of the area with superimposed artist's impressions of the surface piercing structures of the tidal scheme – these should be compiled for key viewpoints and areas of high use which may be affected by the scheme;



- Assessment of the attitude of local populations to tidal energy and the possibility of associated visual impacts;
- Consideration of the location-specific plans and documents which may contain landscape objectives or policies for the area.

Mitigation

The potential effects of a tidal energy scheme on the seascape and visual environment could be reduced by:

- Sensitive design of surface piercing elements of tidal generation schemes;
- Choice of location to reduce visual impact (e.g. consideration of coastal areas with low amenity value);
- Minimise temporary visual disturbance during construction, maintenance and decommissioning by using sensitive methods.

4.5 Effects on other users of the sea

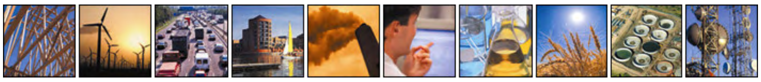
The placement of a tidal development in coastal areas will have effects on people who use coastal waters. These groups include commercial boat operators, commercial and recreational fishermen, and users of recreational craft including yachts, sailing dinghies, jet skis and windsurfers. Other recreational activities such as diving and waterskiing may also be affected. Depending on the location of the tidal energy scheme, offshore activities such as aquaculture, oil and gas extraction, mining and dredging may also be affected[55]. However, these activities are very specific to individual locations, and are not considered further in this report.

4.5.1 Navigation of commercial and recreational craft

Restriction of passage

Estuaries and coastal waters are often areas of significant commercial shipping and port activities, and many such areas also have fleets of recreational craft. Certain areas of coastal water around the UK are also important for military purposes. During its operation, the size and type of a tidal energy scheme will have implications for the movements of these vessels in the sea around it.

The presence of barrage structures across the mouth of an estuary could have significant effects on this activity by restricting the passage of craft up the estuary. Barrage designs incorporate lock structures in order to permit the passage of craft, but compared to the free movement of larger craft along shipping channels this is likely to create bottlenecks, particularly as recreational vessels and small scale fishing vessels would also be restricted to passing



the barrage at these points and there would be a limit to the number of vessels which could pass through the barrage at any one time. The structure of the barrage may restrict the type and size of vessels which are able to navigate the estuary, which could have commercial impacts. The Cardiff-Weston barrage for the Severn is designed to have two shipping locks for large vessels and two locks for pleasure craft. The locks for the large vessels have been designed to accommodate the size of vessels currently using the channel (possibly up to 250,000dwt[o]) in an attempt to avoid adverse impacts on local ports and navigation.

Tidal lagoon structures impound a smaller area of water than a barrage, and they are not constructed across a whole channel. Tidal lagoons therefore create less of an obstruction to navigation. However, the complete lagoon structure will be off-limits to vessels, excluding an area of around 5km^2 of sea from navigation. It is also likely that a buffer zone will be created around the lagoon to prevent vessels passing too close to the structure. Such limitations to navigation may have implications to the choice of location for tidal lagoons, with preferred sites being some distance from major shipping routes.

Tidal stream devices are less likely to have significant effects on navigation, provided that farms are not placed within important shipping channels. A farm of surface-piercing tidal stream devices, whether fixed to the seabed or floating, must be avoided by vessels. The area to be avoided will increase depending on the number of devices within a tidal stream farm, and it is likely that an additional safety zone will be placed around the farm for the safety of vessels and to avoid damage to the devices themselves. It may be possible for small vessels to pass above fully-submerged tidal stream devices[55],[58], especially if they are deployed in deep water. However, this will be dependent not only on the design of the device and the water depth, but on the vessel draft. It is likely that in shallower water that safety zones will need to be established around submerged tidal stream devices, clearly marked with surface markers and navigational buoys. Even in deeper waters safety zones may need to be applied for fishing vessels (see Section 4.5.2).

The restriction of passage by tidal energy schemes, and the requirement for vessels to navigate around or through structures is likely to have an additional environmental effect in terms of carbon emissions. Extra fuel will be used by vessels which are not able to take the most direct route to their destination, or by vessels which are required to wait for lock opening times.

- ► **Tidal power schemes restrict navigation by requiring vessels to avoid certain areas of sea. In the case of barrages, vessels can only cross through locks in the structure. Barrages are likely to have a greater effect on navigation than tidal lagoons or farms of tidal stream devices.**

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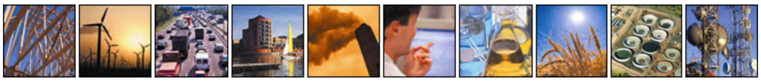
[o] Deadweight tonnes.



Navigational safety

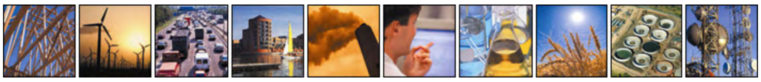
Care must be taken in the choice of the location of tidal generation schemes. If they are located too close to commercial shipping channels then the presence of safety zones around the scheme may result in recreational craft entering the shipping channel to avoid the tidal power scheme and posing a risk to commercial shipping. It is also possible that currents and waves created by the passage of large vessels in the vicinity of tidal stream devices could interfere with their operation.

For both barrages and lagoons it would be necessary to create a safety zone around the turbines, as intermittent high or turbulent flows during power generation could pose a threat to vessels in the immediate vicinity[**38**]. It is also possible that wake effects caused by surface-piercing structures of tidal stream devices, or below-surface turbulence caused by the movements of rotors or hydrofoils could pose a risk to vessels[57].

Restrictions on the placement of offshore renewable energy installations exist in order to prevent significant navigational safety issues[63]. In particular, consideration must be given to the ability of safety vessels to operate in the area in the event of an offshore incident. Increases in boat traffic and the use of heavy equipment and barges during construction, maintenance and decommissioning stages may increase the navigational safety risk in the vicinity of a tidal power scheme[57], and the requirement for vessels to avoid tidal energy schemes may result in increased congestion elsewhere and a consequent increase in collision risk[58]. It is likely that low-lying surface-piercing structures will pose more of a hazard to shipping, as a result of a decreased ability to detect the structure. This may require the increased use of navigational lights and foghorns, with associated visual and auditory disturbance[58].

Cabling also poses a hazard to shipping in that the presence of cables may result in entanglement of anchors or moorings[58]. This may require the creation of safety zones around cables, resulting in further restrictions to navigation. It has also been found that magnetic fields from cables in the Baltic Sea can be detected up to 6m away strongly enough to affect a ship's compass[64]. There is the potential that tidal power developments in shallow water could affect the ability of a vessel to navigate using its instrumentation, creating an additional risk. It is believed that medium voltage AC three-phase cables (which are commonly used for offshore renewable installations) are not likely to cause navigational problems for vessels. However, unburied high voltage DC cables in shallow water may have effects on vessel navigation systems[65].

► **Tidal power schemes can increase navigational safety risks by altering the movement of vessels and restricting the area available for navigation. During construction, maintenance and decommissioning activities there will be increases in boat traffic. Some shallow electricity cables may interfere with navigational systems. The risks associated with different types of tidal power scheme are broadly similar.**



Recreational effects

The impoundment of water behind a tidal barrage may be of benefit to recreational users of the sea by creating larger areas of calm water in which they can operate safely[58]. This would benefit small sailing vessels and motorboats, windsurfers, water-skiers, jet-skiers and divers. This effect will not occur with tidal stream farms, or with tidal lagoons (which are likely to be off-limits to recreational craft).

There may be an opportunity to develop tourism around offshore tidal energy developments, thus increasing the recreational potential of the area. This has happened with some offshore windfarms[52].

However, the presence of safety zones around any type of tidal power generating scheme may restrict access to areas previously used for recreation (for example, diving sites), particularly as the choice of tidal energy locations which avoid commercial shipping areas may result in tidal energy developments in areas used primarily for recreation[58].

Recreational use of beaches may also be affected by tidal energy schemes. Changes in sedimentation patterns resulting from the extraction of energy from the water may alter the nature of recreational beaches. Noise and disturbance caused by the scheme may have the effect of scaring away wildlife, and the potential exists for tidal schemes to affect the water quality of bathing water areas[65].

► **The impoundment of water behind a tidal barrage may benefit recreational users of the sea by creating an area of calm water, but safety zones associated with tidal energy schemes could restrict recreational access. Changes to the characteristics of coastal areas and effects on water quality resulting from a tidal energy scheme could have a negative impact on recreational use of the coast.**

4.5.2 Fishing activities

The impacts of tidal developments on the navigation of craft have already been discussed, and these issues apply equally to fishing vessels. This section considers the effects of different tidal technologies on the ability of fishermen to harvest fish (both finfish and shellfish) using nets, pots, traps and trawls.

Fishing gear can be divided into two main categories. These are:

- **Towed gear**, which includes otter and beam trawls, dredges and seines; and
- **Static gear**, which includes gill nets, lines, pots and traps.

These are illustrated in Figure 4.2below.

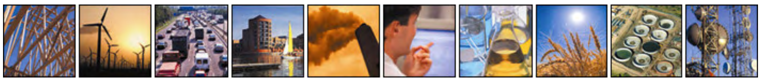


Figure 4.2 Fishing activities

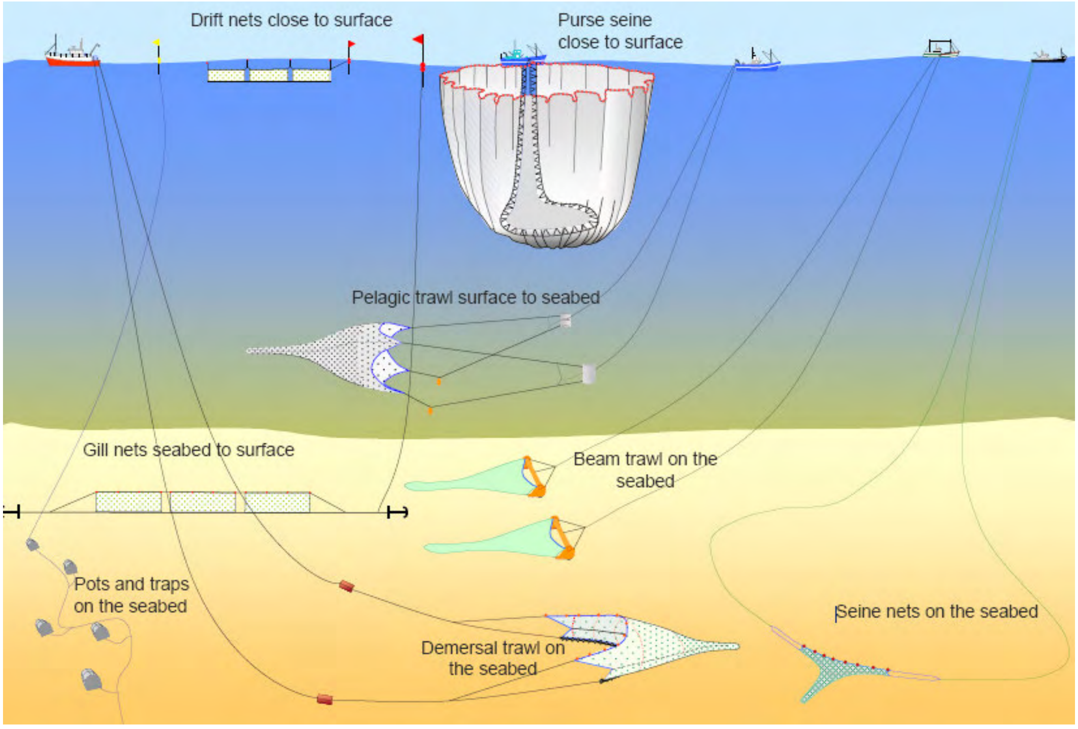


Figure taken from http://www.cefas.co.uk/renewables/4-Activities-in-and-around.pdf

The locations of trawls and the placement of static gear are dictated by the distribution of fish. The effects of different tidal technologies on the location and movement of fish are discussed in Section 4.9.4 below.

The strong tidal currents which allow power generation by tidal stream devices tend to limit commercial fishing opportunities, but the presence of tidal power technologies in the water may restrict fishing activities further. The deployment of towed gear, whether benthic (gear which drags along the seabed) or pelagic (gear which is dragged through the water column), requires considerable skill from the skipper of the vessel. Trawls and nets create drag on the vessel and hinder its manoeuvrability, and gear may extend for hundreds of metres behind the vessel at a variety of depths. The presence of tidal devices within the water, whether surface-piercing or completely submerged, will therefore hinder the ability of fishermen to fish the area with towed gear. Safety zones around tidal stream farms may need to be larger for fishing vessels than for other vessels in order to prevent entanglement of fishing gear with tidal stream devices.

Even at some distance from the tidal devices problems can arise with the use of benthic towed gear (towed gear which drags along the seabed), specifically the snagging of underwater cables which carry electricity from the tidal site to the grid connection on land. These cables often lie on the surface of the sediment or in shallow trenches, rather than being completely buried[55]. Even where cables are buried, scour of sediment around the cables from natural tidal action can result in ‘free spans’ where parts of the cable do not touch the sea floor. As trawls are dragged along the seabed they can catch on these cables. Fishermen are unaware of the problem until the gear is winched in, at which point it is difficult to disentangle the cable and damage to both the cable and the fishing vessel can occur, in addition to the potential loss of catch. It may be necessary to establish safety zones around cable routes in order to prevent these problems; this would restrict fishing over a greater area[55], particularly for farms of tidal stream devices which would have large amounts of underwater cabling. This effect could be mitigated by burying the cable (with the associated seabed disturbance described in Section 4.2.1).

Static gear is often used in estuaries and shallower coastal waters which are likely to be sites where tidal devices are deployed. The presence of tidal devices in the water would restrict fishing activities with static gear by reducing the area of water which could be fished; in addition to tidal devices occupying some of the seabed area, there is a requirement for vessels to navigate around the devices in order to deploy and collect pots, traps and nets. The operation of trawling within shallow coastal waters would also be restricted by safety zones around tidal power generating schemes.

Tidal range structures are likely to occupy a larger area of seabed and result in larger areas of water being off-limits for fishing vessels. In addition to the safety zones around tidal range structures, the requirement to navigate locks in a tidal barrage would further restrict fishing with towed gear in an estuary, as the gear would have to be winched in well before the fishing vessel entered the lock, and could not be re-deployed until the fishing vessel was a significant distance the other side of the barrage.

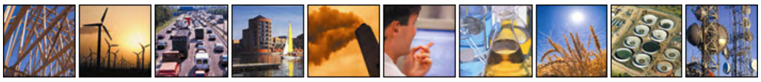
In terms of fish stocks, the presence of safety zones around tidal range structures and farms of tidal stream devices reduce fishing pressure and could be beneficial to fish populations[52], although this has not been shown conclusively. The safety zones may form refuges for mature and juvenile fish, preventing over-fishing and providing safe spawning and nursery areas to bolster fish populations.

Effects of seabed structures on fishing could continue after decommissioning of a tidal development if materials are left on the seabed. This could create additional hazards for fishermen as they may be unaware of seabed or sub-surface structures if surface marker buoys have been removed.

- **Tidal power schemes restrict the area available for fishing, and may make it more difficult for fishing boats to manoeuvre with towed gear. This may have a negative impact on the fishing industry. However, safety zones around tidal power schemes may provide a refuge for fish and have a positive effect on fish populations.**

4.5.3 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on other users of the sea, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location



of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of submerged and surface-piercing devices, as this is the key technological differentiator which affects the environmental impact. This table is intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

Table 4.5 Summary of effects of tidal energy on other users of the sea

	Tidal Range		Tidal stream submerged			Tidal stream surface piercing			Sites affected	Ability to mitigate
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**few all**	**low high**
Restriction of passage	v. high	high	v. low	low / med	high	low	low / med	high	🟦🟦🟦	🟩
Navigational safety	low	low	low	low / med	high	low	low / med	high	🟦🟦🟦	🟩🟩
Access for recreation	potential high (+)	med / high (-)	low (-)	low / med (-)	high (-)	low (-)	low / med (-)	high (-)	🟦	🟩
Access for fishing activities*	high (-)	med / high (-)	low (-)	med (-)	high (-)	low (-)	med (-)	high (-)	🟦🟦	🟩

* Fish stocks may rise as a result of the restriction of fishing effort; this could have a positive effect on fishing

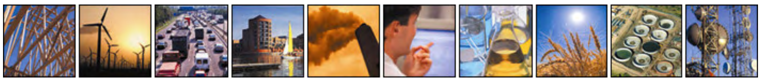
Information required

If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on other users of the sea is:

- Location of shipping channels in relation to the proposed tidal power development, and types of vessels navigating the area;
- Navigational risk assessment modelling for the area, taking into account effects of safety zones, visibility of surface markers etc.;
- Characterisation of the local fishing industry in terms of gear used, target fish species and fishing effort;
- Identification of key fishing areas and analysis of the potential impact of the proposed tidal power scheme.

Mitigation

The potential effects of a tidal energy scheme on other users of the sea could be reduced by:



- Consultation with local fishermen, recreational craft users, harbourmasters and emergency service providers with respect to scheme location;

- Timing of construction, maintenance and decommissioning activity in order to minimise navigational risks and restriction of passage;

- Use of clear marker buoys for submerged tidal devices, and clear navigational buoys to demark safety zones.

4.6 Water quality

There will be potential for pollution and leaching of contaminants from a number of aspects associated with the deployment of tidal devices including hydraulics, moving parts, the installation process and the decommissioning process and these aspects will all need to be considered in detail.

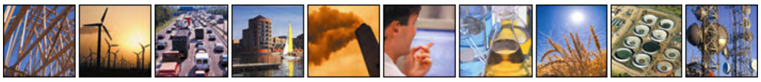
4.6.1 Pollution

The potential exists for chemicals to leach into the water column from concrete and other materials used in the construction of barrages, lagoons or the bases for tidal stream devices[55],[66]. The amount of leaching will depend on the size of the structure in the water; barrages and tidal lagoons are constructed from greater amounts of solid material, and would therefore be expected to have more impact on water quality. It is likely that the decommissioning of solid structures will also release chemicals into the water. Chemicals leaching from solid structures in the water may have toxic effects on marine organisms.

In addition to leaching from solid structures, direct pollution of the water column could result from leakage of lubricants or hydraulic fluids from tidal stream devices. The use of antifoulant paints on underwater structures (paints which prevent marine organisms growing on the structure), or anti-corrosion compounds could also result in toxic pollution of the water column[58],[66]. Sacrificial anodes made of aluminium or zinc are sometimes used to prevent excessive corrosion of metal structures by seawater; metal ions from these anodes may have an effect on water quality. Antifoulants and anti-corrosion measures are likely to be used more extensively on tidal stream devices than tidal range structures, as the encrustation of tidal stream devices with marine organisms, or serious salt-water corrosion will reduce their efficiency.

During construction, maintenance and decommissioning activities, increased boat traffic will increase the chance of fuel and oil leakage from vessels into the water in the vicinity of the tidal development. The construction and maintenance of tidal range structures is likely to result in more boat traffic than construction and maintenance of tidal stream device farms.

The presence of terrestrial developments associated with any tidal development will result in increased run-off and sewage discharges to the coastal waters.



► **Pollution of the water can occur by leaching from solid structures in the sea, leakage of substances from tidal stream devices or spillage from vessels involved in construction, maintenance or decommissioning activities. Impacts are likely to be broadly similar for different tidal energy schemes.**

4.6.2 Resuspension of sediment

Increased resuspension of sediments resulting from seabed scour or dredging associated with construction, cable laying or the flow of water around solid structures in the sea may increase the turbidity of the water. This may restrict light availability for algae within the water and on the seabed. As discussed in Section 4.2, effects on sediment mobilisation processes are likely to be greatest downstream of tidal range structures or around tidal stream devices with mono-piles or gravity bases. The smallest effects will occur with floating tidal stream devices.

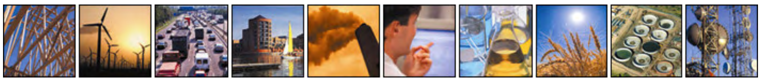
In addition to turbidity effects, sediments which are resuspended may be contaminated with heavy metals, organotins or toxic organic compounds. Sediment particles tend to attract contaminants as a result of their electrostatic charges, and if contaminants are present in the water column then it is likely that they will adsorb to sediment particles. The presence of contaminated sediments in the water column, or their deposition on seabed communities, could cause an impact on local ecology[55]. The dumping of contaminated dredged sediment (for example, sediment dredged during cable laying) could result in water and seabed impacts at a distance from the tidal development. The level of sediment contamination will vary between different tidal resource sites, but they are most likely to be found in shallower coastal waters with high levels of human impact, such as estuaries. Mobilisation of contaminated sediments is therefore more likely with tidal power schemes in these areas.

Estuary sediments contain high levels of organic matter. The resuspension of these sediments may increase the ‘biochemical oxygen demand’ of the water[54] – that is, bacteria in the water column which break down the organic matter may use more dissolved oxygen from the water as a result of the presence of more organic matter in the water. This means that dissolved oxygen levels in the water may decrease, affecting the organisms in the area which need oxygen.

► **Mobilisation of sediment can affect water quality in terms of turbidity, release of toxic chemicals and reduction in dissolved oxygen. Tidal range schemes are likely to have the greatest effect, as they mobilise the most sediments.**

4.6.3 Impoundment of water

The impoundment of water behind tidal barrages or within coastal lagoons increases the potential for impacts to water quality. Impoundment of water does not occur with tidal stream devices.



Impounded water has slower currents, and is not well mixed. This means that any pollutants present in the water do not get diluted so quickly. They stay in the water in higher concentrations for longer periods of time, and this increases the chance of toxic impacts on marine organisms. This becomes an issue particularly with tidal barrages, which significantly alter the flow of water up and down an estuary. Effluents carried into the estuary in rivers (for example agricultural run off and treated sewage effluents) are likely to spend more time in the upper parts of the estuary as a result of impoundment behind the barrage. This increases the chances of nutrient enrichment, algal blooms and eutrophication.

The reduction in flow within impounded water also results in deposition of sediments and loss of turbidity (this is the opposite of the downstream side of the tidal range structure, where turbidity is likely to be greater as a result of faster flows and scour). When turbidity falls, light can penetrate further into the water, and can also encourage the formation of algal blooms (which need the light for photosynthesis). This can have serious implications for the ecology of the area, as discussed in Section 4.9.

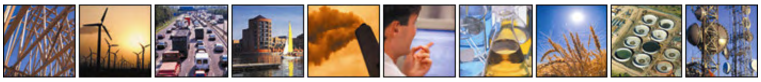
The potential for the build-up of sediments behind a barrage or within a tidal lagoon is high. These sediments may become contaminated as a result of leaching from the tidal range structure or spillage from maintenance vessels. Following decommissioning or maintenance dredging, these sediments will be released into the water, and may spread this contamination over a wide area. Even if there is no contamination of sediments, the release of large quantities of sediment into the water column following decommissioning is likely to have significant environmental effects.

Significant impoundment of water behind a tidal barrage can also change the salinity regime within an estuary. Estuaries contain a mixture of saline and fresh water, and generally have a gradient from pure freshwater in the river to fully saline water in the sea. The placement of a barrage, and the resulting increase in residence time of freshwater in the upper parts of the estuary, has the potential to change the salinity gradient down the estuary[58]. This could have a significant effect on the ecology of the estuary.

► **The impoundment of water by tidal range structures can affect turbidity, cause sedimentation, increase the occurrence of algal blooms and result in less dilution of pollutants. Barrages may also have effects on the salinity structure within an estuary. These effects do not occur with tidal stream devices.**

4.6.4 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on water quality, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of fixed and floating devices, as this is the key technological differentiator which affects the environmental impact. This table is



intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

Table 4.6 Summary of effects of tidal energy on water quality

	Tidal Range		Tidal stream fixed			Tidal stream floating			Sites affected	Ability to mitigate
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**few … all**	**low … high**
Pollution	high	med	low	med	med / high	low	med	med / high	🟦🟦🟦	🟩🟩⬜
Resuspension of sediment	high	high	low	med	high	v. low	low	med	🟦🟦⬜	🟩⬜⬜
Impoundment of water	high	med	n/a	n/a	n/a	n/a	n/a	n/a	🟦🟦🟦	🟩⬜⬜

Information required

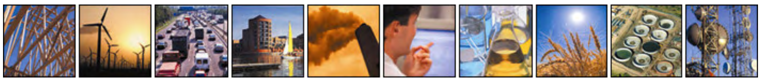
If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on water quality is:

- Assessment of the potential toxicity of materials used in construction or operation of tidal schemes;
- Assessment of the potential for sediment contamination in the area;
- Identification of effluents in local rivers which may cause problems if impounded behind a barrage or tidal lagoon;
- Modelling of the changes in current and/or tidal range resulting from the tidal power scheme, and the potential for contaminants to spread within the area;
- Identification of species and habitats within the area which may be affected by changes in water quality.

Mitigation

The potential effects of a tidal energy scheme on water quality could be reduced by:

- Use of non-leaching materials in the construction of tidal energy schemes, and design of tidal devices to minimise the possibility of leakage;
- Use of responsible antifoulant compounds, or other antifoulant methods such as smooth surfaces or regular removal and cleaning of devices;



- Design of structures to minimise scour and sediment mobilisation;
- Development of hazard management plans (equivalent to oil spill management plans) in order to reduce environmental impact in the event of a significant leakage or spillage.

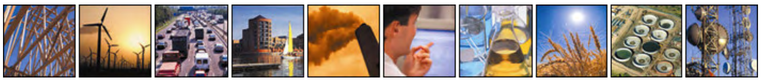
4.7 Air quality

Although the generation of power from the tidal resource does not have direct effects on local air quality, activities associated with construction, maintenance and decommissioning of tidal power schemes may have impacts on air quality. These activities include increased boat traffic during construction, maintenance and decommissioning stages, increased road traffic to and from waterside developments, increased road/rail traffic arising from roads/railways built into a barrage structure, and dust released during construction or decommissioning work. The effect of these emissions to air on the environment (including local populations and sensitive habitats and species) will depend not only on the level of emissions, but on the prevailing wind direction and the distance from the emission source to the point of effect.

All types of tidal technology will have elements which effect the local environment in terms of air quality. All schemes will result in increased waterside activity, increased boat traffic and the requirement for transportation of workers and materials to the coast. However, construction of large tidal range structures, which may take years to complete, is likely to result in more boat and road traffic than the construction of tidal stream device farms which is relatively faster and involves less on-site construction. Maintenance activities are also likely to be more intensive with tidal range structures than with tidal stream devices. It is also the case that barrages and lagoons will be constructed in water close to the shore, and therefore close to the terrestrial areas which may be affected by air pollution.

Barrages may also be used as transport links by incorporating roads or railways into their structure, and this will result in increased emissions to air throughout the duration of the barrage's useful life. The incorporation of transport links into the structure of a tidal barrage will also reduce the likelihood of the barrage being decommissioned at the end of its life.

► **Although the operation of tidal power generating schemes does not directly cause pollution of the air, air quality can be affected by construction, maintenance and decommissioning activities. The larger the construction, the more opportunities there are for air quality to be affected.**



4.7.1 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on air quality, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of fixed and floating devices, as this is the key technological differentiator which affects the environmental impact. This table is intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

Table 4.7 Summary of effects of tidal energy on air quality

	Tidal Range		**Tidal stream fixed**			**Tidal stream floating**			**Sites affected**	**Ability to mitigate**
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**few all**	**low high**
Air quality (construction)	high, approx 7 years	high, approx 2 years	low	med	med / high	v. low	low / med	med / high	🟦🟦⬜	🟩⬜⬜
Air quality (operation)	med / high*	low	negl.	negl.	low	negl.	negl.	v. low	🟦🟦⬜	🟩⬜⬜

* increases if road and/or rail incorporated into barrage structure

Information required

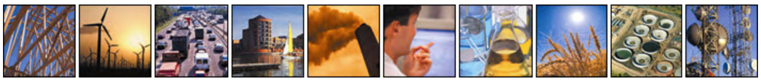
If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on air quality is:

- Characterisation of ambient air quality in the area, and identification of potentially sensitive habitats, species or human populations which may be affected by emissions to air;
- Characterisation of prevailing meteorological conditions in the area;
- Identifications of the type and amount of emissions which may be associated with the tidal energy scheme.

Mitigation

The potential effects of a tidal energy scheme on air quality could be reduced by:

- Timing of activities to limit air quality effects (for example, avoiding times when there is a strong onshore wind, or when there is little movement of air to disperse emissions);



- Adaptation of construction methods to minimise emissions.

4.8 Archaeology and cultural heritage

Many coastal waters contain underwater features of archaeological or cultural heritage importance. These include peat deposits, prehistoric artefacts and wrecks. There are also a number of important sites on coastlines. It is important that developers take account of sites of archaeological or cultural heritage interest at an early stage in planning for tidal energy schemes, particularly as many features of archaeological interest are protected by UK law[p]. In addition to the fact that a significant amount of information exists regarding archaeology and cultural heritage in UK waters, geophysical surveys and core sampling techniques can assist in identification of underwater archaeological features in a development site.

In general, the effects of tidal power schemes on marine archaeology (in common with the effects of other developments in the marine environment on marine archaeology) are likely to be negative and permanent. Direct impacts may arise from the placement of structures on the seabed and the laying of cables, and indirect effects may arise from changes in currents and sedimentation. Access to some archaeological features may also be restricted. Intertidal areas (where there are likely to be more features of archaeological interest) are particularly vulnerable[67].

The placement of tidal developments has the potential to impact features of archaeological or cultural heritage by direct damage to the seabed during construction, and changes in sediment erosion and deposition on the seabed or the coastline. These effects are highly specific to the location of the tidal power generating scheme, as not all areas will have significant features of archaeological or cultural heritage importance. It may be possible to mitigate the effects on archaeological features by careful choice of the location of a tidal energy scheme. High energy sites in deeper water tend to contain fewer features of archaeological importance[55].

Given that archaeological features exist in an area suitable for tidal energy, the level of impact will be related to the seabed footprint of the tidal power scheme, and the extent to which tidal currents and tidal range are affected by the scheme. These effects have been discussed in Section 4.2. Large structures such as tidal barrages, which have a large seabed footprint and a significant effect on the local hydrodynamic and sediment transport processes, will have most effect on archaeological features. Farms of tidal stream devices, with smaller footprints and smaller impacts on hydrodynamic processes, will have the least effect on archaeological features.

Features such as wrecks may be of recreational importance to divers. Restriction of navigational access as a result of safety zones around tidal schemes could result in dive sites becoming inaccessible.

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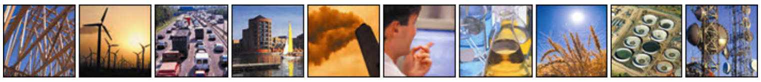
[p] This legislation includes the Protection of Wrecks Act 1973, the Ancient Monuments and Archaeological Areas Act 1979, the Protection of Military Remains Act 1986, the Merchant Shipping Act 1995, the Treasure Act 1996, and the National Heritage Act 2002.



► **Effects on archaeology and cultural heritage are highly site-specific. In general, tidal range structures will have more effect than tidal stream device farms because they have a larger seabed footprint and more effect on the movement of water and sediments.**

4.8.1 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on archaeology and cultural heritage, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of fixed and floating devices, as this is the key technological differentiator which affects the environmental impact. This table is intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

Table 4.8 Summary of effects of tidal energy on seabed, sediments and hydrodynamics

	Tidal Range		**Tidal stream fixed**			**Tidal stream floating**			**Sites affected**		**Ability to mitigate***	
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**few**	**all**	**low**	**high**
Archaeology & cultural heritage	high	med	low	med	high	v. low	low / med	med / high	🟦		🟩	

* Judicious choice of location for construction may allow complete mitigation

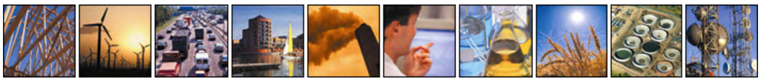
Information required

If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on archaeology and cultural heritage is:

- Identification of archaeological features in the area likely to be affected by the tidal power scheme (this would include a study or relevant literature and possibly geophysical surveys and core assessments);
- Assessment of the importance and vulnerability of features identified.

Mitigation

The potential effects of a tidal energy scheme on archaeology and cultural heritage could be reduced by:



- Choice of location for tidal power scheme in order to minimise impacts on features of archaeological or cultural heritage importance;
- Protection of key sites during construction and decommissioning work.

4.9 Ecological effects

Regardless of the technology used to generate tidal power, effects on the ecology of the area are inevitable. These effects may be seen at the site of power generation, or may occur further afield (for example as a result of changes in tide height, or changes in the movement of sediments). The generation of tidal power can affect habitats on the seabed, in the water column or on the shore. Organisms which may be affected by the generation of tidal power include plankton, invertebrates living in sediments on the seabed or in coastal habitats, fish and marine mammals. These habitats and species can be called 'ecological receptors'.

Many of the species and habitats are protected by national and international legislation (for example, The Wildlife & Countryside Act 1981 (as amended by the Countryside & Rights of Way [CRoW] 2000 Act), the EU Habitats Directive[q] and the EU Birds Directive[r]). Some marine species and habitats are included in the UK BAP (the UK Biodiversity Action Plan). As a result of this legislation there are a large number of statutorily designated sites[s] around coastal and inshore areas, including Sites of Special Scientific Interest (SSSIs), Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and Ramsar sites (Wetlands of International Importance). A number of habitats and species which could be affected by tidal energy are therefore afforded a level of legal protection, and the impacts on these ecological receptors will need to be considered when planning the installation of a tidal energy scheme.

Many of the ways in which the generation of tidal power can affect organisms are connected to changes in the physical or chemical environment. Organisms can be directly affected by changes in their environment (for example by the toxic effects of a pollutant), or they can be indirectly affected (for example by losing a source of food). Changing the characteristics of habitats (for example by removing sediment) can cause significant changes in the types of organisms present.

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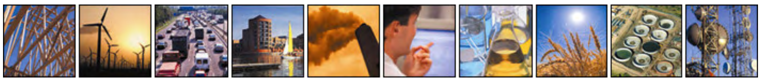
[q] Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora

[r] Council Directive 79/409/EEC on the conservation of wild birds

[s] These are areas which are protected by national or international law as a result of their nature conservation importance. This nature conservation importance may be a result of the area containing rare or endangered species or habitats, or excellent examples of particular habitat types. Many estuaries are designated on the basis that they support large numbers of overwintering or breeding birds. The activities which can be carried out in these designated areas are restricted, and activities outside these areas which may have an effect on their nature conservation importance are monitored.



The ways in which different tidal technologies affect the physical and chemical environment have been described in the previous sections of this chapter. They include changes in water quality, damage to the seabed, changes in the patterns of erosion and deposition of sediments, placement of underwater cables and construction on the shore. Different types of tidal energy have different effects on the physical and chemical environment. It therefore follows that different tidal technologies will have different impacts on ecology.

It is important to remember that different coastal areas may contain different types of species and habitats. Some organisms and habitats are very sensitive to environmental changes, while others are more tolerant. This means that the ecological effects of tidal energy will not necessarily be the same in different areas, regardless of the technology used.

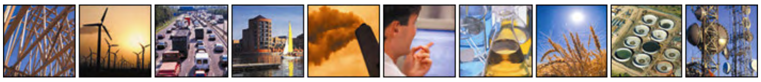
The following sections describe some ways in which different tidal technologies could potentially affect the main ecological receptors.

- **Marine species and habitats are likely to be affected by tidal energy schemes as a result of changes to physical and chemical environments or changes to interactions between organisms.**
- **Different tidal technologies will have different ecological effects, and different locations have different ecological resources.**
- **Many habitats and species are protected by national and international law.**

4.9.1 Plankton

Plankton are plants and animals which live in the water and are moved around by currents in the sea. They are usually microscopic. Phytoplankton are photosynthetic plankton. Zooplankton do not photosynthesise, but eat the phytoplankton or each other. Some zooplankton are larvae of larger organisms, but some spend all their lives as plankton. Plankton are an important food source for many other organisms in the sea.

Changes in water quality can have impacts on plankton. Phytoplankton need light and nutrients to photosynthesise. Changes in the amount of sediment suspended in the water can reduce the amount of light available for phytoplankton, and reduce their rate of photosynthesis and growth. This in turn affects other organisms which rely on phytoplankton for food. The generation of tidal power often results in increases in scour of the seabed, and higher levels of suspended sediment in the water. Conversely, in high energy estuaries where there are naturally high levels of sediment suspended in the water, impoundment of water by a barrage or lagoon structure can result in the settling out of sediment. The associated increase in light penetration of the clearer water can increase rates of phytoplankton growth.



If the nutrient levels in the water increase, for example as a result of mixing of sediments up into the water column, then phytoplankton can reproduce very fast. Sometimes this results in an “algal bloom”. Some phytoplankton (particularly dinoflagellates) produce toxins which are taken in by shellfish as they eat the phytoplankton. This can cause poisoning in humans eating the shellfish, and algal blooms often result in the closure of shellfish fisheries until the bloom disappears. The impoundment of water behind barrages or within coastal lagoons may create conditions in which algal blooms could form. Even non-toxic blooms can have ecological consequences, as the death and decomposition of a large amount of phytoplankton can result in a reduction in the amount of oxygen dissolved in the water.

The mixing of water by tidal currents creates conditions which are favourable for phytoplankton growth. This is an important process in coastal waters and estuaries. The alteration of the direction, or strength of tidal currents by the construction of tidal energy schemes may have effects on the productivity of plankton, and as phytoplankton are at the bottom of the food chain, this may have implications for other marine organisms such as fish and birds.

► **Phytoplankton are important as they form the base of many marine food chains. Plankton growth can be affected by changes in the amount of suspended sediment and changes in tidal mixing. Some blooms of phytoplankton are toxic. Tidal range structures are likely to have the largest effects on plankton growth.**

4.9.2 Benthic communities

Benthic communities are the organisms which live on or in the soft sediments on the seabed. They include worms, shrimps, starfish, sea anemones, molluscs and crabs. Some tubeworms, molluscs and algae can build significant ‘reef’ structures on the seabed. Rich benthic communities occur in areas which have soft sediment on the seabed, as this tends to contain more food for organisms, and helps to protect them. There tend to be different types of benthic communities in areas with high tidal currents[55], which often have less sediment or coarser sediment as a result of erosion. Some of these communities have a high diversity of organisms.

The placement of tidal structures and cables on the seabed will result in localised loss of sedentary organisms, and the displacement of those which can move away. The level of impact is related to the size of the area disturbed, and the intensity and duration of disturbance. Tidal barrages and tidal lagoons are likely to have more impact than tidal stream devices; fixed tidal stream devices will have more impact than floating ones. Some benthic communities are more resilient than others. Although the disturbed area will be recolonised over time, the species composition is likely to change. The presence of different sediments and changes to local current patterns which may result from the tidal development create different habitats. The structure of the tidal development will add another dimension to the environment, resulting in the recruitment of more and different organisms to the area[55]. A three-dimensional structure provides food and refuges for juveniles, and increases the growth and survival of benthic communities; however, this may not be an advantage from a conservation point of view, as in many cases the species are alien to the habitat and the native community structure is affected. The removal of the tidal energy structure during decommissioning may be an additional impact on the benthic community, which may take a considerable amount of time to recover[54].

Changes in the patterns of sediment erosion and deposition resulting from tidal developments will also have an impact on benthic communities. Some soft sediment habitats may be removed by scour effects, and others smothered by deposited sediments. The mobilisation of sediments which may be contaminated with toxic substances may also have an impact on benthic organisms. In addition to these toxic effects, resuspension of sediments which are high in organic matter may result in localised decreases in the availability of dissolved oxygen.

Some types of benthic community are adapted to certain current strengths. These communities may be sensitive to changes in the strength of tidal currents which may result from the extraction of energy by a tidal energy scheme[56].

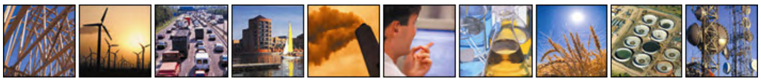
► **Organisms which live on the seabed can be directly affected by construction on the seabed, and indirectly affected by changes in sediment transport processes. Structures in the sea may create new habitats and change the structure of seabed communities.**

4.9.3 Shellfish

Estuaries and shallow coastal waters are important areas for many shellfish species. A number of these species, such as oysters, clams and cockles, are important commercially. Some shellfish species are important from a conservation point of view, and are protected under national or international law.

Many shellfish are filter feeders. This means that they feed by taking in water and extracting small particles of food from it. Shellfish are therefore especially vulnerable to changes in water quality or increased suspended sediments which could result from the installation of tidal power generating technologies. As a result of filter feeding in contaminated waters, shellfish can accumulate large quantities of toxic substances in their flesh. This can cause poisoning in humans eating the shellfish. An example of this is Paralytic Shellfish Poisoning which occurs in humans eating shellfish which have been exposed to toxic dinoflagellates (*Gonyaulax spp.*) in the water. Dinoflagellate blooms can occur as a result of impoundment of water and associated changes in water quality, such as those which could result from construction of barrages or tidal lagoons.

The impoundment of water behind barrages and within lagoons can also cause significant decreases in the amount of oxygen dissolved in the water. Shellfish need dissolved oxygen, and if there is too little oxygen in the water then they will die. For mobile species (such as scallops) this is less of a problem, because they can move away from areas which are low in oxygen. However, some shellfish species (such as mussels) are attached to the seabed and cannot move.



The presence of tidal barrage or lagoon walls, or tidal stream devices, can be an advantage for shellfish. These solid structures in the water can be colonised by juvenile shellfish. This colonisation by shellfish (and other invertebrate species) can be a problem for the operation of tidal stream devices.

► **Tidal structures in the sea can be habitats for shellfish. However, tidal range schemes may result in water quality impacts (such as toxic algal blooms) which could have significant negative effects on shellfish.**

4.9.4 Finfish

'Finfish' is a term which is used to describe all fish which are not shellfish. This group includes many commercially important species such as salmon, dogfish, mackerel, herring, cod, plaice and haddock.

Noise and vibration

Fish are sensitive to vibrations and noise in the water, which they detect with otoliths ('ears') or swim-bladders (gas-filled organs which some fish use to control buoyancy). Some fish species are more sensitive to noise than others. Some fish species use noise to communicate between themselves, or to find food[54]. The construction, operation and decommissioning of different tidal technologies can all result in increased levels of underwater noise, although effects are likely to be greatest during construction and decommissioning stages.

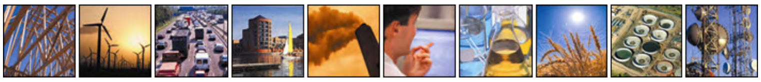
Very loud noise (such as those produced during seismic surveying or percussive pile driving) can scare fish away from the noise source, which could significantly disrupt fish feeding and breeding (as well as commercial fish catches) if the noise was produced for a prolonged period of time[68].

Piling, drilling and cable laying activities produce enough noise to damage the acoustic systems and internal organs of species within 100m of the source[54], and are likely to result in significant displacement of fish. The ability of different species to habituate to underwater noise (i.e. to become used to the source of noise and no longer be disturbed by it) is variable.

► **Changes in underwater noise can have effects on fish by scaring them away from an area. This may disrupt spawning. Loud noise can also cause injury to fish.**

Attraction to structures in the sea

Fish often congregate around structures in the sea, such as boulders or floating debris. Many species congregate in higher current flow as a result of increased food availability. The placement of tidal stream devices in fast slowing water, or the construction of walls for tidal barrages and lagoons is likely to attract fish by forming an 'artificial



reef' structure, in a similar way to that observed around offshore windfarms and oil and gas platforms[55]. This may have an effect on local fisheries, as the ability to fish around tidal energy structures is likely to be restricted by safety zones. The reduction in fishing effort combined with the congregation of fish may result in these areas acting as refuges to enhance local fish stocks, and increase catches elsewhere[58],[69].

The colonisation of the solid surfaces of tidal structures by invertebrates is likely to increase the amount of food available for fish. This may also result in increased fish populations around tidal developments.

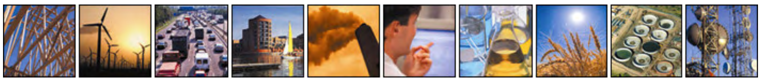
Whilst fish gain shelter, protection and food from tidal power structures, they may also be vulnerable to injury or death resulting from collisions with moving parts. Some reports consider that rotors in tidal stream devices move too slowly to cause damage to fish [55],[57], but the tip speed of some tidal stream devices may reach 12m/s which may result in injury to fish colliding with them[70]. With ducted tidal stream devices (where a cowl is used to increase the flow of water through the rotor) there may be an increased risk of fish being sucked into the rotor blades[55]. The risk may be greater with turbines in tidal range structures, as the currents created during power generation are much faster, and fish are more at risk of being entrained in the flow, suffering abrasions or pinching, or being pinned to screens over the turbines, or of sustaining injuries caused as a result of pressure differentials across the turbines or shear stresses and turbulence[55].

► **Structures in the sea attract fish. Tidal structures may provide new habitats for fish and protect them from fishermen. However, the attraction of fish to tidal stream devices or their entrainment in flows through turbines could result in injury or death.**

Spawning and migration

Fish spawn in a variety of different habitats, usually laying eggs which develop into planktonic larvae before maturing to adulthood. The construction and decommissioning of tidal power structures could disrupt fish spawning habitats directly by building on the habitat or by dumping dredged material on the habitat. Noise generated during construction could also have the effect of displacing adult fish from spawning grounds. During the operation stage, changes in erosion and deposition of sediment resulting from the tidal power structure could excavate or bury spawning grounds[55]. These changes in habitat could cause mortality of eggs and juvenile fish, or a reduction in fish population size as a result of the reduced availability of suitable spawning habitat. Changes in current strength and pattern as a result of tidal developments could also affect the distribution of juvenile fish into suitable habitat areas, and thus reduce survival rates. These issues are of particular concern in fish species which are slow to mature or which already have small populations and low levels of recruitment.

During their lifecycle, many fish species migrate from rivers to the sea and back again. These migratory species include salmon, trout, lamprey and eels. Migratory fish species need to be able to pass through estuary areas, and the presence of a tidal barrage across an estuary is a significant impediment to fish migration[58],[71]. Tidal lagoons and tidal stream devices create much less of a barrier to fish migration.



► **Changes in sediment transport may result in the loss of fish spawning habitat. Fish species which migrate through estuaries to spawn may be prevented from migration by the presence of a tidal barrage.**

Underwater cables

Finfish can be divided into two groups. These are:

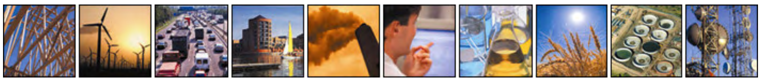
- **elasmobranchs** (the “cartilaginous” fish which include sharks, dogfish, skates and rays. These fish have 5 gill slits); and
- **teleosts** (the “bony” fish which include salmon, mackerel, cod, plaice and herring. These fish have a hard covering over their gills).

Elasmobranch fish navigate and find their food using the weak electric fields which are produced by themselves and the movements of living organisms around them. They can also detect weak electric signals which are generated by geological processes and the Earth’s magnetic field[72]. Underwater cables which carry electricity from tidal devices to grid connection on land have magnetic and electric fields around them as a result of the flow of electricity within them, although the penetration of these fields is likely to be only a matter of a few metres into the water column[55]. This can have an effect on elasmobranch fish, which are able to detect the electric fields. Low frequency electric fields from cables can attract elasmobranch fish, as they may resemble electrical outputs from prey species[53]. High frequency electric fields can repel elasmobranch fish. This can have an effect on the ability of elasmobranch fish to navigate and feed, and may disrupt their breeding if the cable passes through important breeding sites. The ability of elasmobranch fish to habituate to electromagnetic fields is likely to differ between species.

Fish which use magnetic fields for navigation (which include some teleost fish as well as some elasmobranch fish) may suffer brief navigational confusion in the vicinity of cables, or they may be attracted to cables or may avoid them[54].

The structure of tidal barrages allows the incorporation of landward cabling. Tidal stream devices and tidal lagoons must have landward cables which lie on the seabed or are buried beneath it. There is therefore more potential for the cables from tidal devices to disturb elasmobranch fish. An array of cables associated with a farm of tidal stream devices may have more of an effect than a single cable.

► **Cables associated with tidal energy have electromagnetic fields. These electromagnetic fields can have effects on the behaviour of elasmobranch fish. Tidal stream farms will have more cables than tidal range structures.**



4.9.5 Marine mammals

A number of marine mammal species are regularly found in UK coastal waters. These include cetaceans (whales, porpoises and dolphins) and pinnipeds (seals). Many of these species are protected by national and international law.

Structures in the sea

The presence of significant impediments to movement within an estuary, such as a barrage or a collection of tidal lagoons, could have a serious impact on marine mammals. They may be prevented from using their usual routes or blocked from important breeding or feeding grounds[54]. The presence of tidal stream devices is less likely to have a serious impact, although it is possible that marine mammals may need to take significant detours around large farms. The presence of a tidal development may result in displacement of marine mammals from the area, although a level of habituation to the structure may occur.

Marine mammals are at risk of collision with tidal development structures, particularly when feeding, as large numbers of fish may congregate in these areas. Mammals may risk death or injury from collisions with tidal structures. Some reports suggest that the rotors of tidal stream devices turn too slowly to cause significant damage to marine mammals or fish, although the tips of rotors may reach speeds of 12m/s which could cause injury on collision[70].Some reports assume that mammals would be pushed over or through tidal stream device actuators as a result of water flow, provided that the mammal was not larger than the rotor itself[55]. However, this is an area where more research is required. The risk may be greater with turbines in tidal range structures, as the currents created during power generation are much faster, and mammals are more at risk of being entrained in the flow, suffering abrasions or pinching, or being pinned to screens over the turbines, or of sustaining injuries caused as a result of pressure differentials across the turbines or shear stresses and turbulence[55].

Marine mammals may be able to detect and avoid tidal energy schemes, as they are able to perceive the underwater environment well, and are very agile[55]. This may not be the case for older or diseased animals which are less agile and have a lower ability to understand and react to changes in the environment. Juvenile mammals may have a high level of curiosity coupled with less experience, and may also be more vulnerable as a result. The placement of tidal stream devices in fast flowing water may also reduce the ability of marine mammals to avoid them. In addition to this, if tidal energy schemes act as refuges for fish and other prey items, marine mammals may be attracted to them. Noise produced during scheme operation may assist marine mammals in detection and avoidance, or it may result in avoidance of the area and the consequent displacement of sensitive species.

► **The movement of marine mammals may be restricted by tidal energy schemes. There is also the risk that marine mammals could suffer injury as a result of collisions with tidal energy structures.**

Underwater noise

Many marine mammals use sound for communication, location of prey species, and avoidance of predators. Some cetaceans (for example, dolphins) also use sound as a means of navigation (this is called echolocation)[54],[73]. The presence of increased levels of underwater noise in coastal waters as a result of tidal power developments therefore has the potential to affect marine mammals. These effects are likely to be most significant during the construction and operation stages of tidal developments, as activities like pile-driving, drilling and cable-laying produce significant amounts of noise. Noise from boat engines during construction, maintenance and decommissioning activities may also affect marine mammals[55]. During operation of tidal developments, noise levels are likely to be lower, although there may be frequency-specific effects, for example on communication ability.

Being highly mobile species, marine mammals may avoid areas where significant amounts of noise are being generated. This behavioural response could result in disruption of breeding or migration patterns, particularly if tidal developments are located near well-used routes. Changes in the distribution of fish populations as a result of underwater noise could also affect the distribution of marine mammals which rely on fish as a source of food.

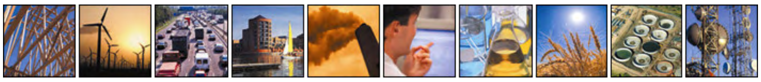
Short term loud underwater noise effects, such as those generated by construction, decommissioning and maintenance operations, may result in temporary effects on marine mammals. This noise may be audible to marine mammals from many tens of kilometres [57]. In the case of large constructions such as barrages or lagoons, this noise effect could be of long duration. The extremely loud noise produced by pile-driving may cause damage to the acoustic systems of marine mammals.

With respect to the consistent low-level underwater noise produced during the operation of tidal energy schemes, it is possible that a level of habituation may occur. This habituation occurs in some cases to noise produced by other human activities in the marine environment[55], although the cumulative impact of anthropogenic noise on the marine environment is not well understood.

► **The presence of increased levels of underwater noise can affect the behaviour of marine mammals and their ability to communicate with each other and find food. Loud noise (such as that produced by pile driving) can injure marine mammals.**

Underwater cables

In a similar way to some fish species, some marine mammals are believed to navigate using the Earth's magnetic fields. The presence of electromagnetic fields generated by the flow of electricity in cables running from a tidal development could result in marine mammals experiencing navigational confusion in the vicinity of cables. Mammals may be attracted to cables or may exhibit avoidance behaviour[54]. There is little evidence that cetaceans and seals are affected by the electric fields around cables, but some cetaceans have been shown to respond to the magnetic fields associated with cables[65].



The nature of tidal barrages is such that landward cabling can be incorporated into their physical structure. Tidal stream devices and tidal lagoons must have landward cables which lie on the seabed or are buried within it. There is therefore more potential for the cables from tidal devices to disturb marine mammals. An array of cables associated with a farm of tidal stream devices may have more of an effect than a single cable.

The potential also exists for marine mammals to become entangled in underwater cables (or other moorings associated with a tidal energy scheme)[55].

► **The electromagnetic fields generated by underwater cabling may have an effect on the navigational ability of some marine mammals. Tidal stream farms will have the most cabling.**

4.9.6 Birds

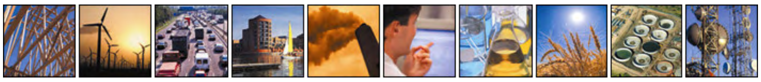
A significant number of birds feed and breed in UK estuaries and coastal waters. Some species are winter visitors, some pass through on migration, and others are present year-round. Many estuaries within the UK are protected under international law as a result of the bird species which they support[74].

Airborne and underwater noise

Large amounts of noise and disturbance occurring in coastal waters is likely to scare birds away from the area. This would be a particular problem during the construction and decommissioning stages of tidal developments, although increases in coastal and vessel activity during maintenance of tidal developments may also have an impact. As a result of the noise or visual disturbance associated with tidal energy schemes, it is possible that birds will avoid tidal energy installations or alter flight paths to avoid them.

Depending on the time of year at which noise levels increase, the breeding or feeding of birds in the area of the tidal development could be seriously affected by the increase in noise and disturbance. Increases in underwater noise have also been shown to reduce the feeding behaviour of diving birds[54]. In this way, underwater noise levels arising from the construction and decommissioning of tidal developments may have a significant effect on seabirds.

► **Noise can scare birds away from an area and disrupt their feeding and breeding. Many coastal areas are important breeding sites for birds and are protected under international law.**



Aerial and subsurface collisions

The aerial collision of birds with offshore wind farms has been a cause of some concern over recent years. Whilst the surface piercing structures of tidal developments are not as large as wind turbines, and they do not have rotating blades, the possibility of bird collisions cannot be ignored. It is possible that birds will be attracted to tidal stream devices as a result of the presence of fish around the devices. This may increase the potential for collisions. The presence of lights on surface piercing structures may result in confusion of birds and increase the chances of collisions. Completely submerged tidal stream structures will present the least opportunity for aerial collisions.

It is possible that diving bid species could be at risk of colliding with submerged structures associated with tidal stream devices, as they may mistake the underwater shape for a school of fish [57]. It is likely that most submerged devices will be placed below the diving depth of most species, but at low tide some deep diving species such as gannets may be affected. The opportunity for collisions is increased with the number of tidal devices deployed in an array.

► **Birds may collide with surface-piercing structures of tidal power schemes, and diving birds may collide with submerged tidal stream devices.**

Habitat change

Birds which use coastal habitats such as soft sediment shores and saltmarsh for foraging and breeding may also be affected by tidal developments. The possibility exists that these habitats could be altered as a result of changes in tidal inundation or sediment transport, and this may have serious implications for food availability for birds. This is discussed further in Section 4.9.7 below.

Birds are known to use the above-surface structures of offshore windfarms as roosting (and potentially breeding) sites[52]. It is possible that surface-piercing structures of tidal energy schemes may provide similar habitat.

► **Changes in coastal environments as a result of changes in sediment transport processes may affect the feeding and breeding habitats of birds.**

4.9.7 Intertidal habitats and communities

Tidal developments have the potential to affect habitats on the coastline by changing the wave and current pattern of the area and the tidal range experienced. These effects can change the sediment dynamics of coastal habitats, resulting in erosion of some areas, increased deposition (particularly of fine sediments) in other areas, and changes in the amount of saltwater inundation in others[58]. Tidal barrages, which hold back large amounts of water at high tide, are likely to have the most effect on intertidal communities. Intertidal habitats may also be disturbed by cabling activities. The placement of cables in shallow water and intertidal areas requires extensive excavations in order to bury the cables and prevent excessive sediment scour. The potential effects on some intertidal habitats are discussed below.

Saltmarsh communities

Saltmarsh habitats are particularly susceptible to changes in tidal range and erosion of sediments, with the main factors determining the rate of erosion being shore gradient, sediment supply and the effect of wave action[74]. Although saltmarsh plants hold sediments together and encourage deposition of more sediment by reducing water velocities, changes in hydrodynamic and sediment regime can result in erosion of these communities[75]. Saltmarsh areas have a variety of unique plants, and provide an important feeding and breeding areas for a variety of wetland bird species. In addition they help to shelter the juveniles of many marine fish and invertebrate species.

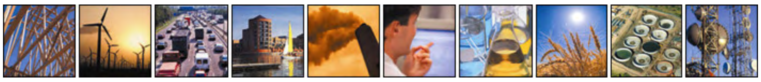
Depending on the shape and exposure of the estuary, changes in tidal range and inundation as the result of the construction of a tidal barrage may result in an increase in saltmarsh extent in some areas, as a result of the high intertidal mudflats being inundated less frequently. However, this may be accompanied by a change in the nature of the upper saltmarsh towards freshwater marsh, as a result of less saline water inundation. Other areas of saltmarsh within the estuary may be reduced as a result of increased wave erosion at high tide. Changes to saltmarsh habitats may have significant effects on bird populations which breed in these areas[74].

Soft sediment communities

Soft sediment habitats in intertidal areas contain a wide variety of invertebrates which live in the sediment, or which shelter in the sediment at low tide and come out to feed at high tide. The nature of these communities is affected by the type of sediment, the amount of organic matter in the sediment, the exposure of the area to wave action and the salinity of water within the sediment (sediment salinity is affected by tidal inundations and exposures, and freshwater inputs from rivers, groundwater or precipitation). Soft sediment communities are important feeding grounds for wading birds[74].

If a tidal power scheme has significant effects on coastal processes as a result of changing current regimes, then changes in the patterns of deposition and erosion could result in significant impacts on the sediment characteristics of these habitats. Changes in the amount or quality of sediment in these areas will in turn affect the organisms present, and this will have implications for bird species which feed in these areas.

Changes in tidal range caused upstream of tidal barrages will change the patterns of exposure and inundation of soft sediment communities[71]. This is likely to affect the sedimentation and salinity characteristics and change the community composition. Changes in water levels which may occur upstream of tidal barrages could cause a reduction in the area of mud exposed at low tide, which would reduce the available feeding area for wading bird species[74]. However, depending on the characteristics of the environment, increased deposition of fine sediments on the remaining intertidal areas may result in an increased invertebrate abundance[76], and it may be able to protect



certain key feeding areas by strategic placement of wave defences in order to prevent significant impacts on bird feeding opportunities[74].

Rocky shore communities

Rocky shore communities vary significantly in species composition depending on the level of tidal inundation and the degree of shelter they have from wave action. Organisms are found at different levels on the shore depending on the degree of exposure which they can tolerate. Changes in tidal range or in the strength of coastal currents as a result of a tidal development could therefore have effects on the distribution of organisms within the habitat, an the composition of the communities. Smothering of exposed rock in the coastal zone with sediment transported from elsewhere in the area would also have a significant effect on rocky shore habitats.

Sand dunes

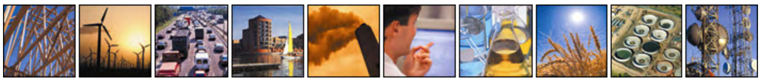
Sand dunes are vulnerable to coastal erosion, as the fore-dunes (those closest to the sea) are made of loose sediments. Further away from the shore, the establishment of vegetation on the dunes makes them more stable. Dunes can help to protect coastal areas from flooding. If the patterns of coastal erosion and deposition change as a result of tidal energy schemes, the supply of sediment to dune systems may be disrupted and erosion could occur. Increased periods of tidal inundation could also increase dune erosion by increasing the time at high water when waves can attack the fore-dunes[56].

► **The characteristics of intertidal habitats depend on coastal sediment processes, hydrodynamic processes and the level of tidal inundation. Changes to tidal range or current strength can have impacts on the diversity and abundance of organisms within these habitats.**

Terrestrial habitats

The landward transmission of electricity from tidal energy schemes may also have an impact on habitats inland of intertidal areas. It is possible that the connection of tidal energy schemes to the national grid may require upgrades of the existing transmission network or construction of new transmission infrastructure such as substations and pylons. This is also likely to have an effect on ecology, with loss of habitat, removal of trees, changes in land use and disturbance of terrestrial communities.

► **Habitats further inland may also be affected by tidal energy schemes if there is a requirement to construct or upgrade grid infrastructure.**



4.9.8 Community interactions

While the previous sections have considered the potential impacts on groups of organisms, it should be stressed that direct impacts on a species or group of organisms can have knock-on effects in other groups of organisms, as the organisms co-exist within the environment and interact with each other. The “ecosystem” is composed of a number of different organisms interacting with each other and with their physical environment.

Different organisms depend on each other as sources of food energy, and the coastal marine ecosystem is built on the energy harvested from the sun by photosynthetic algae and plants. In this way, organisms are linked together in “food webs”, and an effect on one group of organisms can therefore have implications for other organisms which eat them, or which are eaten by them. Community structure is also determined by competitive interactions between organisms (for example, competition for a food source or for space).

Tidal developments have the potential to affect ecology. Displacement or removal of organisms, algal blooms or increases in fish populations have effects on levels of food availability, predation and competition within the ecosystem, and could destabilise the balance of the ecosystem. Disturbance and changes in the availability of food can also have implications for the reproductive success of marine organisms[54]. In these ways, tidal developments have the potential to cause a variety of indirect ecological impacts which are not necessarily predictable.

► **Organisms and their environment are linked in many ways, and organisms are linked together in food webs. An effect on one part of an ecosystem can have predictable and unpredictable effects on other parts of the ecosystem and the species it supports, such as birds, fish, and marine mammals.**

4.9.9 Summary

The summary table below compares tidal energy schemes in terms of their *relative* effects on ecology, rather than the magnitude of their effects, as in many cases the magnitude of an effect will depend on the location of the tidal energy scheme. An indication is given of the site specificity of the effect, and the ability to mitigate the impact of the effect on the environment. Tidal stream devices have been compared in terms of fixed and floating devices, as this is the key technological differentiator which affects the environmental impact. This table is intended to give a broad overview; a comparison of different tidal energy schemes in a specific location may give a slightly different comparison between technologies.

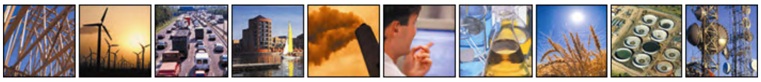


Table 4.9 Summary of effects of tidal energy on ecology

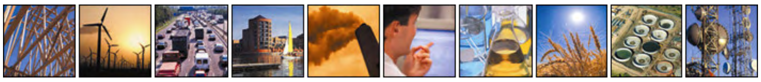
	Tidal Range		Tidal stream fixed			Tidal stream floating			Sites affected	Ability to mitigate
Effect	**Barrage**	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**	**few all**	**low high**
Plankton	high	med/high	v. low	low	low	v. low	v. low	v. low	🟦🟦🟦	🟩
Benthic communities	v. high	high	v. low	low	med	v. low	v. low	low	🟦🟦	🟩
Shellfish	v. high (+ & -)	high (+ & -)	low (+)	low (+)	low (+)	low (+)	low (+)	low (+)	🟦	🟩🟩
Finfish (noise)	high	med	v. low	low	med	v. low	low	med	🟦🟦🟦	🟩
Finfish (attraction)	high (+)	med (+)	low (+ & -)	low (+ & -)	med (+ & -)	low (+ & -)	low (+ & -)	med (+ & -)	🟦🟦🟦	🟩
Finfish (cables)	low	low	low	med	high	low	med	high	🟦🟦	🟩🟩
Finfish (spawning / migration)	v. high	med/low	v. low	low	med	v. low	low	med	🟦🟦	🟩
Mammals (structures)	high	med/low	v. low	low	med	v. low	low	med	🟦	🟩
Mammals (noise)	high	med	v. low	low	med	v. low	low	med	🟦	🟩
Mammals (cables)	low	low	low	med	high	low	med	high	🟦	🟩🟩
Birds (noise)	high	med	v. low	low	med	v. low	low	med	🟦🟦	🟩🟩
Birds (collisions)*	med	med	v. low	low	med	v. low	low	med	🟦🟦	🟩
Birds (habitat change)	high	low	v. low	v. low	v. low	v. low	v. low	v. low	🟦	🟩
Intertidal habitats	high	med	v. low	low	low	v. low	low	low	🟦🟦	🟩

* Assumes tidal stream devices are surface-piercing. Aerial collision risk greatly reduced for submerged devices.

Information required

If a tidal energy scheme is proposed for a specific location, some of the information needed in order to make an assessment of the potential effects on marine and coastal ecology is:

- Detailed knowledge of the ecological receptors in the area – this is likely to including survey work which may take several years to carry out, depending on the state of current knowledge of the location);



- An understanding of how the tidal energy scheme will change the physical environment from the current conditions (for example in terms of current speed or direction, tidal range and inundation, erosion, deposition, salinity, temperature, noise, water quality) – this may require computer modelling in order to predict changes;
- An understanding of the tolerance and vulnerability of ecological receptors identified in the area;
- Location of any statutorily designated sites which may be affected by the tidal energy development, an understanding of the extent to which species from other designated sites may use the area, and the potential impact to legally protected species.

For many deep water sites, this data will be difficult and expensive to collect. Shallow water sites are better characterised and easier to survey.

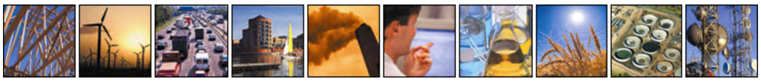
Mitigation

The potential effects of a tidal energy scheme on marine and coastal ecology could be reduced by:

- Timing of construction and decommissioning activities to minimise disturbance to key ecological receptors;
- Use of methods and materials least likely to cause ecological impacts;
- Design of underwater structures to minimise the potential for damage to species and to maximise the potential for creation of new habitats;
- Consideration of nationally and internationally protected sites and species in decisions about the location of tidal energy schemes;
- Consideration of the scale of tidal developments.

4.10 Conclusions

Tidal energy has the potential to affect many aspects of the natural environment through physical, chemical and ecological processes. The ‘human environment’ may also be affected in terms of visual impacts and effects on archaeology and cultural heritage. The potential exists for disturbance of sites and species which are protected by national and international legislation, and as such there will be environmental constraints on the tidal energy industry with respect to the requirement for permitting and consents. The current extent of offshore marine protection in the UK is limited, but this looks set to increase in the future, placing further constraints on the development of the tidal energy industry.



Tidal energy can also be a highly emotive issue in terms of environmental impact, particularly with large scale projects such as the various barrage projects suggested for the Severn Estuary. The public perception of the impacts of tidal energy may place pressures on government and the industry, and have an impact on the development of tidal energy in the UK.

The key to mitigating the potential effects of tidal energy on the environment is an understanding of the effects. Dissemination of this information will assist in addressing public perception of tidal energy. However, this process is currently restrained by the lack of available information directly addressing the effects of tidal energy on the environment. Whilst a wealth of information is available on the effects of constructions in the marine environment, there are currently no commercial scale tidal energy projects in the UK. Most of the tidal stream devices available are at prototype stage, and little environmental information is available regarding their operation. The cumulative impacts of the deployment of tidal stream farms are largely unquantifiable at this stage.

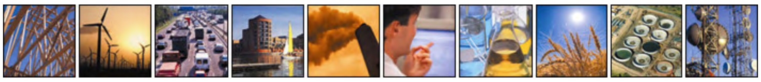
4.10.1 Scale of development

The magnitude of environmental effects will depend not only on the type of tidal energy, but on the scale at which it is constructed.

Tidal barrages are large constructions, but they can only be constructed in a small number of locations. The most feasible location in terms of tidal range resource is the Severn Estuary, and the resource value of other sites is much lower. It may be possible to construct tidal lagoons in a larger number of locations. This means that although the potential environmental impacts of tidal range technologies are large, these effects would be restricted to a smaller number of locations around the UK. Once a barrage has been constructed, another barrage would not be constructed in the same area.

Tidal stream devices are different. They can be deployed in a range of sites and at a range of scales, from a single device to a farm of 30 or more devices or a number of such farms within an area. It is likely that the future will see a number of farms of tidal stream devices deployed within a relatively small area in order to maximise the use of the available tidal resource. This means that the level of environmental effects resulting from tidal stream energy is likely to increase gradually over time, and the cumulative effects of a number of farms operating in one area may become significant. In addition to this, the types of environment affected will change over time, as technological improvements and economic requirements result in the movement of tidal stream farms from shallower water to deeper water and back again (see Section 3.5). Currently, although much can be predicted, little is actually known about the environmental effects of tidal stream devices. It is therefore difficult to predict the magnitude of the cumulative environmental effects resulting from the deployment of tidal stream devices and farms throughout the available tidal stream resource areas. Although the effects of one device may be small, the continued and widespread deployment of devices and farms may result in a gradual build up to a large level of environmental impact.

Tidal barrages and lagoons are large one-off events, which could cause high levels of environmental effect within a relatively short space of time in one or two locations around the UK.



Tidal stream devices are small and modular, resulting in initially low levels of environmental effect which may gradually build up to high levels of effect, spread throughout a wide range of locations. Careful planning will be required in order to prevent low-level piecemeal environmental effects combining to result in widespread and significant environmental effects. This planning would be more effective at an early stage in the development of the UK's tidal stream industry. Such an approach is endorsed by the current DTI guidance on wave and tidal deployment, which suggests an iterative learning-based approach.

4.10.2 Environmental research and development priorities

This chapter has highlighted the known and predicted effects of tidal energy on different aspects of the UK's marine and coastal environments. However, it has also highlighted a number of areas where knowledge is lacking, and where 'environmental research and development' is required.

While there is a general understanding of issues such as sediment dynamics, hydrodynamics, ecology and other aspects of the marine environment, there remain large gaps in our understanding. In particular there is a lack of specific information relating to the potential impacts of tidal energy. Whilst there are operating barrage schemes in the world, no coastal lagoons have been built and tidal stream devices are still at prototype stage. Environmental considerations may appear less important to developers than the technological and economic aspects of device operation, and in many cases reports of prototype operation do not include explicit references to the environmental aspects of the project. Significant environmental monitoring of prototype deployments has not taken place. Research programmes into the environmental effects of offshore wind energy have been initiated (for example the COWRIE programme of research[t]). Information from this programme and equivalents for the tidal industry will be instrumental in clarifying the environmental issues surrounding tidal energy.

In addition to the lack of technology-specific information, more information is required relating to the baseline environmental characteristics of deployment sites. This is relevant to all sites, although the challenges with deep-water sites are greater as the ecology of these areas is less well known and is a matter of ongoing academic study.

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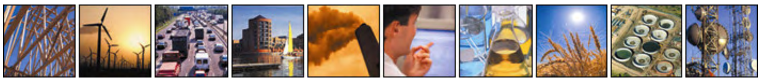
[t] COWRIE (Collaborative Offshore Windfarm Research Into the Environment) is an independent company set up to raise awareness and understanding of the potential environmental impacts of the UK offshore windfarm programme. COWRIE Ltd is governed by a Board of Directors drawn from The Crown Estate, the Department of Trade and Industry (DTI), and the British Wind Energy Association (BWEA).



In terms of investigations of potential development sites, Strategic Environmental Assessment (SEA)[u] of the marine environment is important. SEA is a process of appraisal through which environmental assessments are made in order to factor the sustainable development of the environment into national and local planning decisions. It aims to help inform planning decisions based on the potential environmental impacts of a proposed development. In the UK, the DTI commenced a proactive SEA process in 1999 to assist in regulation of the UK's offshore oil and gas industry. Similar studies have been carried out for the offshore wind industry[52],[58], and the Scottish Executive have recently published a consultation draft of an SEA for marine renewables in Scottish waters [65]. The environmental results of this SEA process and other similar investigations (for example the MESH project (Mapping European Seabed Habitats)) will assist in promoting environmental issues in planning the development of the UK's tidal energy industry.

Impacts on the environment could be further mitigated by the development of a clear planning policy for the UK's coastline and offshore waters which makes provision for tidal energy schemes and is informed by a coherent Marine Spatial Plan (MSP) combined with an Integrated Coastal Zone Management (ICZM) programme. It is important to take into account the interactions of all marine activities on the marine environment. The placement of tidal energy schemes will not be solely determined by the tidal resource; in addition to environmental constraints there are likely be constraints based on existing undersea cables or pipelines, ammunitions dump areas, MoD firing ranges or undersea test or training areas, areas allocated to mineral extraction by dredging, prime fisheries areas and shipping corridors and areas where navigation is difficult[58]. Balancing the requirements and demands of such a wide range of stakeholders, whilst promoting the development of the tidal energy industry, will require extensive consultation, the support of a broad and robust dataset, and a carefully-considered planning strategy.

However, 'strategic' understanding of the environment can only go so far. It is likely that the most important advances in our understanding of the environmental implications of tidal energy will come from project-specific environmental assessments. In the same way that technology develops through 'learning' based on the observation of deployments, so the state of understanding of the environmental effects of tidal-technology will increase through 'environmental learning'. However, this will require careful planning so that environmental monitoring programmes are incorporated into prototype deployment plans, as the amount of environmental monitoring relating to such developments is very limited[54]. This could partially be achieved by making environmental monitoring a requirement for industry funding, and by encouraging the sharing and dissemination of information between developers, academic institutions and statutory bodies.

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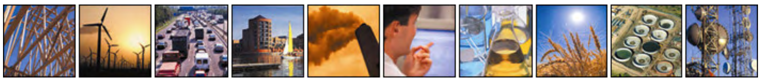
[u] The EU Strategic Environmental Assessment Directive (Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment) has been transposed into UK law by the Environmental Assessment of Plans and Programmes Regulations 2004 (Statutory Instrument 2004 No.1633), the Environmental Assessment of Plans and Programmes Regulations (Northern Ireland) 2004 (Statutory Rule 2004 No. 280), the Environmental Assessment of Plans and Programmes (Scotland) Regulations 2004 (Scottish Statutory Instrument 2004 No. 258), and the Environmental Assessment of Plans and Programmes (Wales) Regulations 2004 (Welsh Statutory Instrument 2004 No. 1656 (W.170))



5. Socio-economic differentiators

5.1 Introduction

It is clear from the preceding chapters that there are a large number of uncertainties surrounding the generation of tidal energy, ranging from the cost of construction and cost of energy to the resource feasibility and the environmental effects of different technologies. As the industry develops, and the issues surrounding technology and environment start to be resolved, the social and economic effects of tidal energy are likely to represent some of the more tangible effects on local and wider communities.

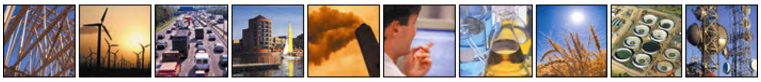
This section provides an overview of the economic and social effects of tidal devices drawn from available information. Currently there are few examples of tidal energy generation within the UK and Ireland, and no commercial-scale schemes at all. This means that there is limited information regarding the economic and social effects available in ‘before and after’ assessments or case studies (excluding work to estimate the costs and feasibility of different technologies). Where information is available it rarely considers the dynamic response of the surrounding area to, for example, an increase in demand for construction employment (so called equilibrium models). Therefore, where appropriate, information on the economic and social effects of similar technologies (such as offshore wind energy developments) has been drawn on in this section.

Economic and social effects are described in two separate sub-sections. However, as they are often strongly interrelated, some economic effects will necessarily be discussed in the social effects section and vice versa. For example, the ‘regeneration effects’ of tidal devices have been included within the economic section, although it could be easily argued that these should be covered in the social and community section. The social section also provides a summary of some of the responses from public and stakeholder consultation that relate to social and community effects.

This section describes a number of social and economic differentiators that allow a comparison of these technologies. As many of the technologies are still under research and development, and have yet to reach commercial operation, it is not always possible to provide accurate or definite values. In these cases a range of values may be provided, or a qualitative comparison of the technologies may be given.

Section 3 illustrates some of the technological differentiators between the types of device and develops recommendations for future research as well as a discussion of the future viability of tidal technology considering the future price of energy. Barriers to the development and growth of tidal energy are described in Section 5.4 together with a review of recommendations made in a number of public sources to advance the development of tidal technologies in the UK.

The chapter concludes with a matrix which summarises the main social and economic effects and compares the magnitude of effects between different tidal technologies.



- **Social, economic as well as environmental effects of tidal technologies are strongly interrelated through complicated ‘cause and effect’ linkages. The type and magnitude of effects are likely to differ between different technologies and locations.**

5.2 Economic effects

This section provides a review of a conceptual framework that describes the significant potential economic effects through the lifecycle of tidal technology devices.

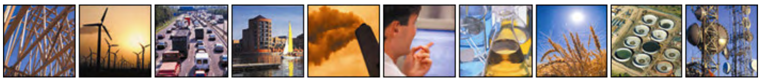
Conceptual framework of economic effects

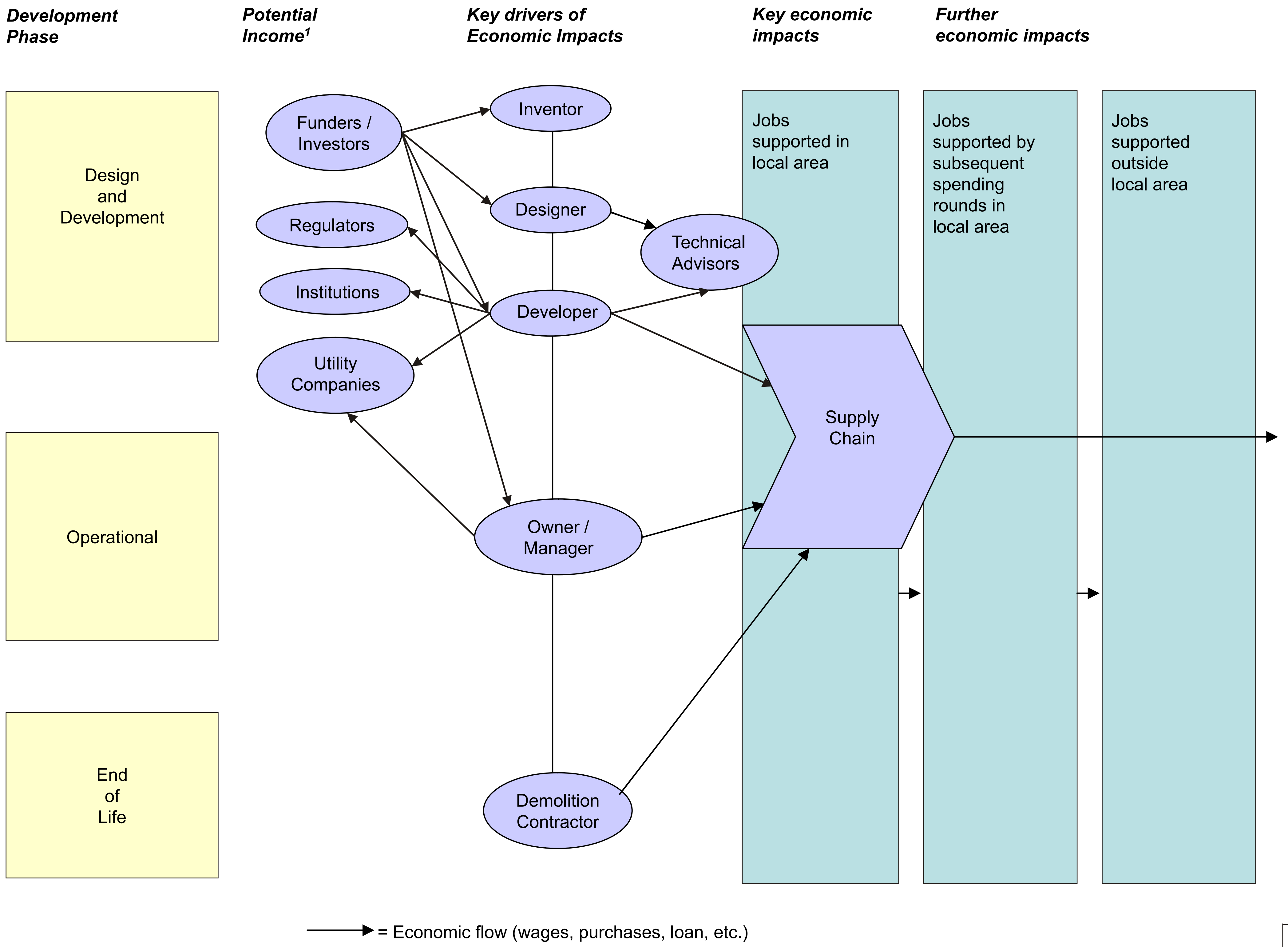
A conceptual framework of the economic effects of tidal technologies is shown in Figure 5.1 to help visualise various terms and concepts described in this section. The framework provides a broad generic overview of the economic effects and is relevant to each of the different types of tidal technology as well as a number of similar renewable energy technologies such as offshore wind power. This sets out the key stages of the development of tidal technology from invention through to decommissioning. These stages are then related to the various economic ‘agents’ (people or organisations involved or affected) who drive the process: from investors - who provide the injection of money into the economy at various stages, through to developers and their supply chain.

Figure 5.1 Conceptual framework of potential economic effects – see following page

Figure 5.1 indicates, schematically, a distinction between direct economic activity which is related to the project as well as knock–on effects (so called ‘indirect’ and ‘induced’ effects through subsequent spending in the local area and beyond). This diagram may also be helpful in illustrating that the overall economic effects of the development are the product of ‘inputs’ (e.g. potential income from investors) and ‘outputs’ (e.g. new infrastructure or number of jobs created in the local area) over the total timescale of the project.

It is important to note the way in which this section describes the economic effects of the development of tidal technology at a site, and to distinguish this approach from the attempts to estimate the relative industry-wide cost or feasibility of a particular technology as described in Section 3. Industry feasibility studies, whilst more relevant in an industry scale assessment, may limit the information available to decision makers. Large scale studies may not consider the more localised economic costs and benefits of a development (for example the effects on the local community). These localised effects may be considered as part of an Environmental Impact Assessment for a particular tidal energy scheme; there are a considerable and varied number of potential economic effects that can be included in the assessment, as well as environmental and social effects. In an attempt to identify and focus on the most significant of these effects, the following sections review the employment and income effects of tidal technologies and examine how these may vary between the different technologies.





[1] Regulators, Utility Companies and Institutions may be significant funders / investors inthe project and are separated out for illustrative purposes

Sustainable Development Commission
Tidal Technologies Overview

Figure 5.1
Conceptual Framework of Potential Economic Effects

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► **There are a large number of interrelated economic effects related to tidal energy schemes that includes both direct and indirect or induced effects. This section considers these effects at a local economy level rather than as an industry wide assessment. It focuses on employment and income as the most significant effects.**

5.2.1 Employment and income

This reviews the potential employment and income effects through the lifecycle of a tidal energy scheme. The effect a particular technology may have on an area depends on the ability of the supply chain and associated labour force to take advantage of the opportunities its development may create. Therefore, this section also provides a review of information available regarding the UK tidal technology supply chain.

Construction

The most significant employment effect occurs during the construction of a tidal energy scheme. The number of construction jobs is broadly a function of the scale and nature of construction activities and capital costs. Estimates of the direct and indirect effects of the construction phases of the Cardiff-Weston barrage scheme for the Severn Estuary have been provided in the case studies [44] which describe between 50,000 to 200,000 person-years of employment during the 7 year construction period (a person-year is one year of work by one construction worker). Total capital costs (taken as a proxy for construction costs) for this barrage scheme have been estimated to be in the order of £15 billion (adjusted 2006 cost) to create the 16 kilometre barrage. This example may be at the higher end of the anticipated range of employment effects of tidal technologies, but serves to illustrate the very significant employment effect construction activities may have over a relatively short period of time. Typical services required for the design and construction of marine energy include[77]:

- Engineering (civil engineering, dry dock facilities, corrosion specialists, electrical system design, hydrodynamic modelling, mechanical engineering, resource assessment, site investigation, testing);
- Planning (financial, legal, planning advice, environmental); and
- Operation and installation (off-shore operational contractors – barges, tugs, jack-ups, dredging, etc., sub-sea inspection, off-shore consultants, onshore construction facilities / compounds).

Construction is normally led by a prime contractor who procures materials, components and labour through the manufacturing and fabrication process. Some activities may be subcontracted including installation of the technology or creation of foundations / moorings, or connecting it to the onshore electricity network. Such activities employ a range of occupations and skills and will vary depending on the type of tidal energy scheme and its location. Capital costs of different technologies have been reviewed in Section 3.4 of this study. The following points provide a summary of some construction information from this section to help illustrate how employment generation may vary:

- Taking the costs to develop the Cardiff-Weston Severn Barrage as an example of **tidal barrages,** these costs have been estimated to be between £10.3 to £14.0 billion (at 2001 prices) over a seven-year construction programme (including large ship locks in the barrage) and £10.1 to £13.7 billion over a five-year programme (including smaller ship locks) [1]. The dominant cost for the barrage is the civil works to construct the barrages (concrete caissons and embankments with a variety of surface protection) and locks, which make up approximately 60% of the total barrage capital cost. The cost of connecting to the electricity network is approximately 15% of the barrage capital cost. The scale of construction activities would likely have significant local and regional employment effects and would attract additional workers into the area during the construction phase [44].

- The capital cost of a **tidal lagoon** has been calculated to be £81.5 million by Tidal Electric Limited, and £234 million by independent reviewers [38]. Both estimates reveal that the dominant cost is that to construct the lagoon impoundment, which makes up 50 to 60% of the total capital cost. The employment effects would be expected to be of a similar nature to tidal barrages but at a smaller scale.

- The information available on the costs of **tidal stream** devices is limited to prototype and first production models (which are likely to be more expensive than later commercial devices). The results of the Carbon Trust's Marine Energy Challenge [17] indicate that the first prototype tidal stream devices could cost up to £8,000/kW [v], but certain devices have already been built for under £4,800/kW. It is estimated that first production models could have costs between £1,400/kW and £3,000/kW. This would suggest that the first 5MW farm would cost between £7 and £15 million. Ofgem [41] provides a similar estimate of costs, stating that early small projects will have a capital cost of £2,584/kW. These total costs are significantly less than the tidal barrage and lagoon technologies and reflect differences in construction techniques. Tidal stream developments do not require the same scale of engineering and are constructed using specialist mobile equipment (such as jack-up platforms) which is used to install the support piles and submarine cables, etc. [35]. The scope of 'centralised manufacture' – where devices are manufactured remotely and then shipped to the local area - can have a considerable effect (i.e. a reduction) on the amount of local employment during construction activities[5].

► **The construction process of tidal energy schemes is likely to offer the greatest employment opportunities. The scale of construction employment is expected to be greater for tidal barrage and tidal lagoon developments.**

Operation and maintenance

The scale of employment related to operation and maintenance reflects the scale of the tidal development and the expenditure required. In the case of the Cardiff-Weston barrage scheme, this is estimated [44] to be around 0.77% of the capital costs (operation, maintenance and off-site costs of £116M per year), excluding replacement costs of plant at £2,400M over 30 years. Operation and maintenance activities will vary depending on the size and location

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[v] Which compares to £600-800/kW for onshore wind power and £1000-1500/kW for off-shore wind power.

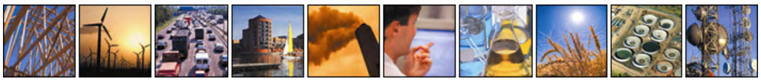
of an installation, and are also likely to vary from year to year. It is difficult to estimate the amount of employment arising from operation and maintenance as a result of the lack of experience of operating commercial tidal energy schemes; however it is possible to use experience and costs from other industries as an indication. Section 3.4.4 provided a review of the variety of operation and maintenance activities undertaken for the different types of technology:

- If maintenance is carried out on-site, specialist vessels and crews may be required to gain access to the site;
- Maintenance off-site may include retrieving the device or components and carrying out maintenance in a dock or onshore, before returning to site;
- For a **tidal range** scheme, maintenance will be carried out both on- and off-site. For example, any repairs to the barrage or impoundment must be carried out on-site, however the electrical components (e.g. generators) are generally designed so that they can be removed and transported to shore for maintenance and repair;
- **Tidal stream** devices are generally designed so that the serviceable components (e.g. generator or gearbox) can be retrieved and transported to shore for maintenance and repairs. For large tidal stream farms it may be cost effective to have replacement devices. This would allow a substitute device to be connected to the farm while the original device is undergoing maintenance;
- For a fixed device, any repairs to the support-structure and foundations are likely to be carried out on-site; and
- A floating device may be designed so that the whole device can be detached from its moorings and towed to a dock for maintenance and repairs.

► **The employment related to operation and maintenance activities will vary between tidal energy schemes depending on the size and scale of the scheme. Not all the work will be carried out on-site. The number of jobs supported by operation and maintenance activities is generally less than those supported by construction and decommissioning activities.**

Decommissioning

Decommissioning activities are generally considered to be similar in scale to the original construction activities[5] and provides a guide for the extent of employment effects. These activities generally involve removing the site from service and restoring the environment to an acceptable state. Section 3.4.5 provided a review of decommissioning activities for the different types of technology:



- The scheme lifetime of a **tidal barrage** is expected to be 120 years. After this time it is expected that the generating components will be removed from the barrage, and that the barrage structure will remain in place.

- Tidal Electric Ltd [78] propose that for **tidal lagoons** the turbine/generator equipment and the concrete power station structure are removed, and that the lagoon structure will remain in place. The embankment would be allowed to become an artificial reef, or an island if the lagoon becomes silted up. In this latter case there may be jobs created as a result of the need to monitor and manage the resulting lagoon structure;

- **Tidal stream** farm devices would be removed from site at the end of their 20-year lifetime. This will involve a range of mobile contractors with barges, etc.; and

- **Floating** devices are likely to be relatively simple to decommission, as it will only require the removal of anchors from the seabed. Devices with a **gravity-based foundation** will be removed from the seabed. A mono-pile foundation may be left in the seabed after being cut off below the level of the seabed, or it can be removed using a vibration hammer. Submarine cables are usually de-energised and left in-situ, as the removal of cables causes more damage to the seabed than leaving them in place.

► **The scale of decommissioning activity can be estimated from the construction process. The amount of employment relates to the type and scale of the tidal energy scheme.**

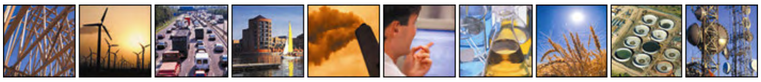
Estimating direct employment effects

There are few attempts in the literature to estimate the amount of direct employment created by tidal devices either as a result of construction or operational activities of similar technologies [77]. These have generally been based on an estimate of the total amount of installed capacity in the UK and employment within a particular market sector, and have been used to provide a high-level estimate of employment effects to help guide policy or planning (a so called top down estimate).

- One estimate of the number of construction jobs generated by the development of tidal stream and wave technological devices is 4 to 4.5 full time jobs per megawatt of installed capacity, and is extrapolated from an off-shore wind proxy[79]. This was considered appropriate given the range of common activities associated with their development. It was postulated, however, that earlier generation tidal development would be more labour intensive and that an employment factor of around 10 jobs per megawatt installed capacity may be more appropriate;

- These studies also presented an estimate of the number of operation and maintenance jobs created by tidal energy: between 0.03 to 0.1 full time jobs per installed megawatt, based on a factor for off-shore wind of 0.06 jobs per installed megawatt; and

- The DTI study of renewable energy supply chain provides a detailed description of another ‘top down’ methodology to estimate the number of jobs in different renewable energy sectors[80].



- **Little information exists regarding the actual number of jobs created as a result of tidal energy schemes. Based on experience in the offshore wind industry, construction of tidal stream devices may create up to 10 jobs per installed MW, and operation and maintenance of these schemes may create between 0.03 – 0.1 full time jobs per installed MW.**

Estimating indirect and induced employment effects

The development of a renewable industry results in the creation of additional income and demand in the economy. This can result in the generation of new jobs, which are described as indirect and induced employment.

Until tidal energy schemes devices are deployed commercially in the UK, estimates of indirect employment may have to rely on estimates from such 'top down' methodologies, or be generated in a 'bottom up' approach with specific information on the actual supply chain and labour to be employed in a particular development. Another method that might be used requires an understanding of the total expenditure attributable to different sectors across the phases of development and operation, using information about the average revenue per employee within a relevant sector. The knock-on employment effects of a development can be defined using employment multipliers. These are used to derive indirect and induced employment, and should be estimated on a location specific basis, preferably using information from input-output tables for appropriate industries. Various levels of multipliers can be used (local, regional or national) and the more localised the multiplier the smaller it will be, as a larger share of expenditure will fall outside the area. Understanding the pattern of expenditure is important in impact assessment and is described further below (see 'Positive or negative effect?'). Table 5.1 provides a summary of the relative employment effects of the different technologies and provides details of available estimates.

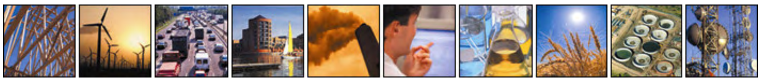


Table 5.1 Summary of relative employment effects

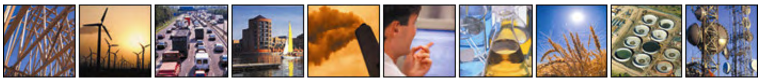
	Tidal range		**Tidal stream - fixed**			**Tidal stream - floating**		
	Barrage [85]	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**
Direct construction employment	High *1,400 to 4,800 (FTE)*	High *2,000 per lagoon (Russell lagoons)*	Medium	Medium	High	Medium	Medium	High
Indirect construction employment	High *700 to 2,300 (FTE)*	High *660 to 1,000 per lagoon (Russell lagoons)*	Low	Medium	High	Low	Medium	High
Direct operational employment	High *340 to 2,300 (FTE)*	Medium	Low	Medium	High	Low	Medium	High
Indirect operational employment	High *100 to 740 (FTE)*	Medium	Low	Low	Medium	Low	Low	Medium
Direct decommissioning employment	High	High	Low	Medium	Medium	Low	Low	Medium
Indirect decommissioning employment	High	High	Low	Low	Medium	Low	Low	Medium

Low, medium and high refer to the level of tidal stream device deployment. Low is the initial full-scale devices installed in the water; medium is the first small farm and high is large-scale farms or multiple small farms. Where used person-years have been converted to Full Time Equivalents assuming 1 FTE = 10 person-years.

Positive or negative employment effects?

It is typically the case that the employment effects of a development have a positive effect on the economy. However, the extent to which the local economy can benefit from the opportunities created depends on the level of:

- leakage - expenditure that is spent outside of the local area, therefore the benefits of that additional expenditure would be felt elsewhere;
- deadweight - expenditure that would have occurred anyway and cannot be attributed to the development;



- displacement - expenditure that occurs at the expense of other expenditure. For example increased spending in one area as a result of the development may result in decreased spending in another area; and

- economic multiplier effects - further economic activity generated as a result of the additional income and local supplier purchases. For example more income in the local area will increase the demand for goods and services thereby benefiting local shops and suppliers.

These effects can be summarised as (net) additionality and are particularly dependant on the maturity of a supply chain and character of the labour market in the area of interest. The following sections consider the supply chain and labour market both in the UK and in the areas local to the potential development sites.

► **Indirect employment resulting from tidal energy schemes is difficult to quantify, as there are no tidal power schemes in the UK to study. In general, it is likely that tidal range schemes will result in more indirect employment than tidal stream schemes. However, the economic benefit that a particular area receives from these jobs can vary depending on the social and economic characteristics of the area.**

UK supply chain for renewables

A study by the DTI[80] investigated the UK supply chain for renewable energy technologies in light of the commitments made in the Energy White Paper (goal of 20% renewable energy by 2020). This considered the structure of the renewable energy industry (it estimated that there were currently 8,000 sustained by the industry, 5,500 adjusted for imports), and made projections of the likely installed capacity (taking into account resource availability and sites. as well as two models of potential energy mix to test the technology dependency, costs through the supply chain, employment sustained, and balance of import activity). Figure 5.2 illustrates the projected capacity for each technology under a 'wind led technology mix' example (Example 1) and a 'broader mix of technologies' example (Example 2):

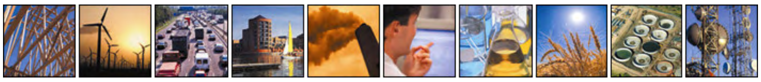
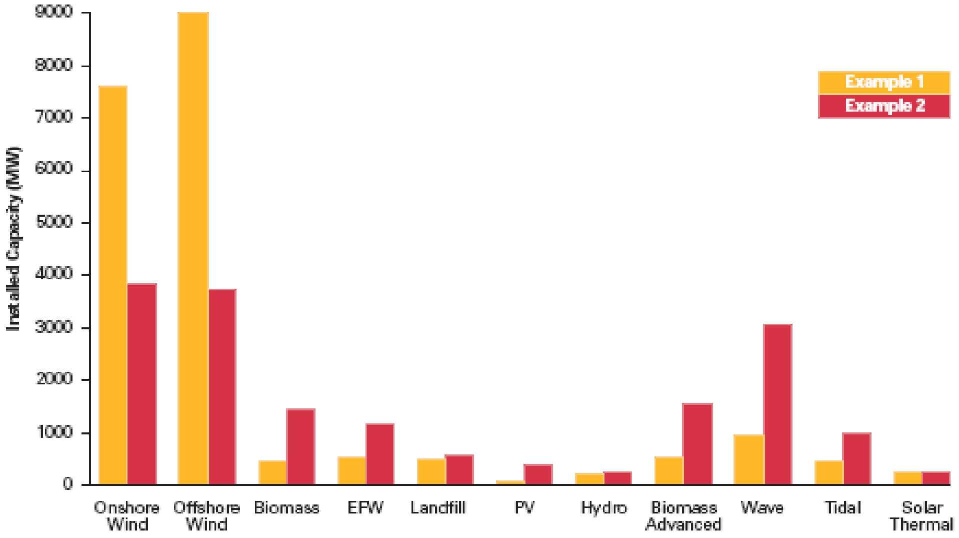


Figure 5.2 Installed capacity in 2020 by technology



Note: Example 1 and Example 2 are both based on the level of predicted demand in the Energy White Paper. They both assume industry average load factors for the technologies and they represent installed capacity in MW electrical (MW thermal equivalent for solar thermal).

Source: DTI (2004)

This figure illustrates that, between the two examples, the installed capacity of tidal technologies may reach almost 1,000MW by 2020. The study went on to examine the implications for the supply chain, and created an estimate of the amount of employment that would be required to supply the industry. Figure 5.3 describes the 'average employment', each year, required to sustain the required growth in the various technologies. The study estimated that in total 17,000 to 35,000 jobs could be sustained by the renewable energy industry. This employment consists of the direct and indirect employment opportunities created by the development of the new technology, the estimated employment associated with exports related to the renewable industry (based on estimations of the capture of the world market in the period 2010 – 2020), and induced employment (using a 0.25 multiplier based on HM Treasury guidance). The study estimates that for an installed capacity of 1,000 there may be up to 2,000 people employed directly and indirectly in the tidal industry.

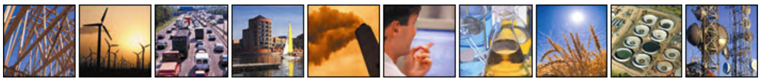
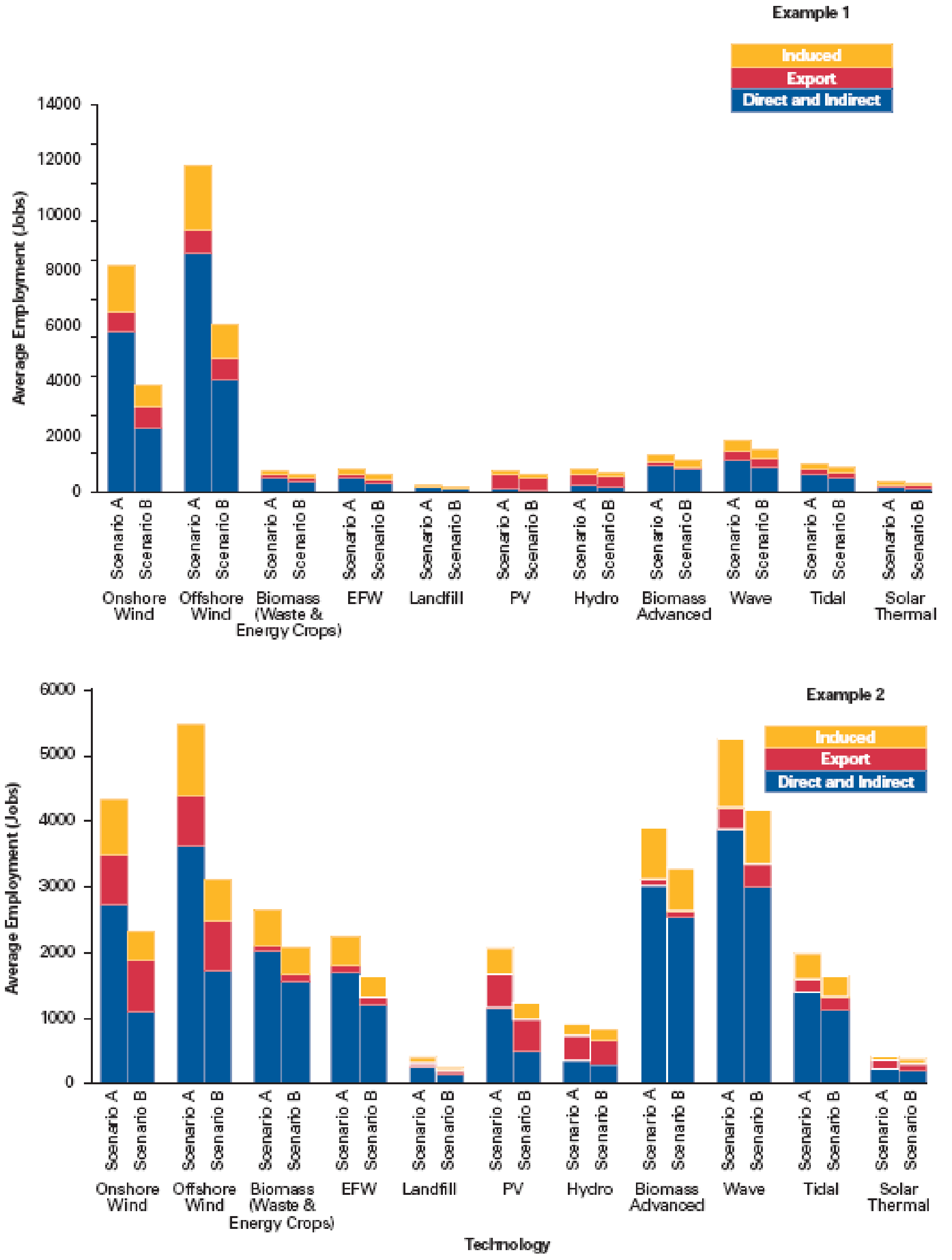
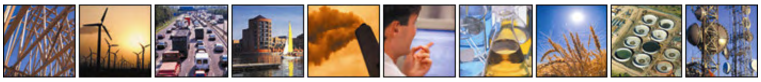


Figure 5.3 ‘Average employment’



Note: Employment levels are likely to fluctuate through the period to 2020 because the MW added per year for each technology will vary from year to year – peaks may be significantly higher.

Source: DTI (2004)



► **By 2020, the DTI have estimated that under certain conditions there could be almost 1000MW installed capacity of tidal power, with up to 2000 people employed directly and indirectly in the tidal industry.**

UK and local supply chain for tidal energy

The DTI report[80] also provided a summary of the main gaps, strengths and opportunities for wave and tidal technologies of importance [w] to the supply chain:

- They are still developing technologies and are expected to have a significant contribution to the future energy mix;
- There is a focus on the development of the industry and a number of demonstration-sites have already been established together with 'embryonic' supply chains – although none are completely established;
- Similar skills are required for off-shore wind turbines for installation and maintenance;
- A 'winning design' and supply base may be developed in the UK represents a significant exported opportunity;
- There are a number of threats to the development including cheaper labour and development costs abroad; and
- As a result of a high level of research and development, the UK is a world leader in tidal and wave technologies.

Whilst the DTI report describes a generally optimistic outlook for tidal energy technologies in the UK the maturity of a supply chain and character of the labour market in the areas surrounding development sites will determine the nature of economic effects.

► **The UK supply chain for the tidal energy industry is not yet fully developed. Local labour markets may be important in strengthening the supply chain.**

Local labour market

The impact on local employment or the ability of the local people to take advantage of the opportunities created by tidal developments in their area depends on a variety of local labour market characteristics. The analysis

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[w] It is not clear if this report considered employment from both tidal stream as well as tidal range technologies, although the recommendations hold, generally, for both.

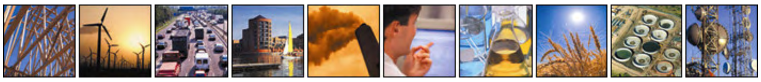
undertaken here focuses on relative sector strengths in local economies as well as local skills levels. Given the wide range of possible areas to be affected, only a high level review of the characteristics of local labour markets is possible at this stage.

In an attempt to analyse the various labour markets under review, a matrix has been created for those areas which may potentially be affected by tidal range developments and those which may potentially be affected by tidal stream developments. The matrices provide a semi-quantitative comparison of some of the labour and skills features of the local area (i.e. the supply) with those likely to be required by the development (i.e. the demand). They consider a range of likely areas that are suitable for either tidal range or tidal stream developments in England, Wales, Scotland and the Channel Islands. These areas have been selected on the basis of the location of the resources for tidal stream and range developments shown in Section 3.2. Information was collected at a local authority area level for those areas adjacent to the possible developments. The list of areas included in the analysis is shown in the table below:

Table 5.2 List of areas included in labour market analysis

Tidal range			Tidal stream	
Cumbria	Carmarthenshire	Gloucestershire	Cumbria	Norfolk
Lancashire	Swansea	Devon	Lancashire	Suffolk
Blackpool	Neath Port Talbot	North Somerset	Isle of Anglesey	Lincolnshire
Sefton	Bridgend	Somerset	Pembrokeshire	Argyll & Bute
Knowsley	The Vale of Glamorgan	Bath & North East Somerset	The Vale of Glamorgan	Dumfries and Galloway
Liverpool	Rhondda, Cynon, Taff	Cornwall	Cardiff	North Ayrshire
Wirral	Caerphilly	East Sussex	Newport	Shetland Islands
Flintshire	Cardiff	Kent	Bristol	Orkney Islands
Denbighshire	Newport	Norfolk	North Somerset	Guernsey
Pembrokeshire	Monmouthshire	Lincolnshire	Isle of Wight	Jersey
Dumfries & Galloway	Guernsey	Jersey		

The strengths and weaknesses of the supply of labour and skills in the area are determined by a comparison with the national situation. Strengths are identified where the value under consideration for the local areas (%) is greater or equal to the national average (%) and weaknesses are identified where the local area (%) is below the national average (%).



Key for tables:

▨	Job area required
	Job area not required
+	Strength of local area
-	Weakness of local area

*The local supply chain analysis refers to data from England and Wales only.

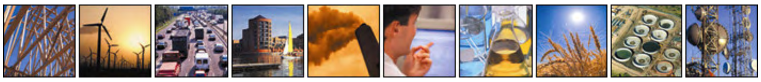


Table 5.3 Tidal range areas: labour market characteristics

Characteristics of 'DEMAND' arising from development ↓	Characteristics of local 'SUPPLY' to service the development ➔	Local Supply chain*														Current Employment by Sector															Current Employment by SOC									Working Age Qualifications				
		Agriculture	Production	Construction	Motor Trades	Wholesale	Retail	Hotels & Catering	Transport	Post & Telecommunications	Finance	Property & Business Services	Education	Health	Public Admin & Other Services	Agriculture; hunting; forestry	Fishing	Mining & Quarrying	Manufactoring	Electricity; gas; water supply	Construction	Wholesale & retail trade; repair of r	Hotel and Catering	Transport storage and communicat	Financial intermediation	Real estate; renting and businesss	Public administration and defence	Education	Health and social work	Other	Managers and Senior Officials	Professional occupations	Associate professional and technic	Administrative and secretarial occu	Skilled trades	Personal service	Sales and customer service	Process; plant and machine operat	Elementary occupations	No Qualifications	Level 1 Qualifications	Level 2 Qualifications	Level 3 Qualifications	Level 4 / 5 Qualifications
Planning	Environmental assessment	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Financial planning	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Legal advice	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Planning advice	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Civil engineering design	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
Engineering and Construction	Dry-dock facilities, cranes, docks,	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Corrosion specialists	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Electrical system design	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Fundamental research into marin	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Hydrodynamic modelling	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Mechanical engineering design	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Resource assessment, wave mor	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Site investigation and surveying	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Wave tank testing	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
Installation	Offshore operations, barges, tugs	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Sub-sea inspection, divers	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
Operation and installation	Offshore consultancy	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Offshore operations, barges, tugs	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Sub-sea inspection, divers	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-
	Monitoring and Security	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	-	-

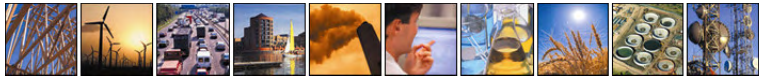
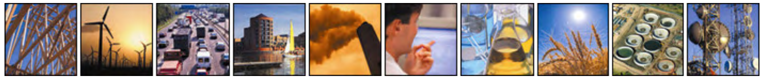


Table 5.4 Tidal stream areas: labour market characteristics

		Local Supply chain*														Current Employment by Sector															Current Employment by SOC									Working Age Qualifications				
Characteristics of 'DEMAND' arising from development ↓	Characteristics of local 'SUPPLY' to service the development ➔	Agriculture	Production	Construction	Motor Trades	Wholesale	Retail	Hotels & Catering	Transport	Post & Telecommunications	Finance	Property & Business Services	Education	Health	Public Admin & Other Services	Agriculture; hunting; forestry	Fishing	Mining & Quarrying	Manufactoring	Electricity; gas; water supply	Construction	Wholesale & retail trade; repair of motor vehicles	Hotel and Catering	Transport storage and communication	Financial intermediation	Real estate; renting and businesss activities	Public administration and defence	Education	Health and social work	Other	Managers and Senior Officials	Professional occupations	Associate professional and technical occupations	Administrative and secretarial occupations	Skilled trades	Personal service	Sales and customer service	Process; plant and machine operatives	Elementary occupations	No Qualifications	Level 1 Qualifications	Level 2 Qualifications	Level 3 Qualifications	Level 4 / 5 Qualifications
Planning	Environmental assessment	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Financial planning	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Legal advice	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Planning advice	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Civil engineering design	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
Engineering	Dry-dock facilities, cranes, docks,	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Corrosion specialists	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Electrical system design	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Fundamental research into marin	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Hydrodynamic modelling	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Mechanical engineering design	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Resource assessment, wave mor	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Site investigation and surveying	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Wave tank testing	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
Installation	Offshore operations, barges, tugs	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Sub-sea inspection, divers	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
Operation and installation	Offshore consultancy	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Offshore operations, barges, tugs	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Sub-sea inspection, divers	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-
	Monitoring and Security	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	+	-	+	+	-	-	+	-	-	+	+	-	-	-	+	+	-	+	+	-



This analysis should be treated with caution in so far as the depth of analysis is concerned. A wide number of local areas have been included which include very rural coastal areas and small towns as well as larger and more industrial towns. Therefore there is likely to be some variation in the various local areas and their characteristics. The aggregated data presented here may therefore mask some unique local characteristics and this analysis should be treated as a broad overview of the local areas. More detailed assessments of the impact of tidal devices (undertaken for instance as part of a planning application) would require a case-by-case assessment of the local area. In the analysis undertaken, no adjustment has been made for factors such as population size or type of area (rural/urban).

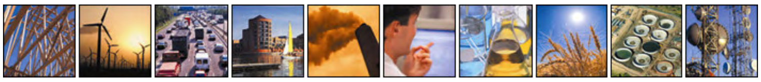
The assessment of supply and demand indicates that:

- Some potential key sector supply chain and employment strengths exist within the local areas. The areas under review for both types of possible development show a relative strength in the construction industry, both in terms of the number of construction businesses located there and the amount of employment they generate. The local areas also indicate strength in skilled trades. These factors suggest the possibility that the local construction industry provide local employment and distribution networks to the development and its construction and maintenance requirements.

- The local areas under review for both tidal stream and tidal range developments have strengths in retail and hotels and catering. This strength is both in terms of the relative number of establishments and the amount of employment it generates. This is in line with expectations since the local areas will be coastal towns, likely to attract many tourists and outside visitors. This could prove to be a local benefit as there is the possibility that contractors may have a lot of in-house professionals that may come in to the local area to do site work. It would be more convenient for them to stay in local hotels than travel into the area each day thereby generating or sustaining employment in those local industries.

This analysis does suggest that in certain key sectors, namely the construction and hotel industries, there is sufficient local employment to meet some of the needs of the construction and operation requirements of the tidal development. This suggests that the opportunities created by the tidal development could be matched by the local labour markets, generating local employment in these sectors. However this will need to be followed up by a case-by-case review to fully establish the extent of the local effects.

► **An analysis of local labour markets has been undertaken in the areas likely to be affected by tidal developments. This has found a relative strength in the construction and hotel industries in the local areas, suggesting that significant employment can be generated in these sectors.**



5.2.2 Wider economic effects

Whilst employment occurring as a result of construction or operational activities is a significant economic effect of tidal technologies, there are a number of other potential economic effects that are likely to occur. These are briefly discussed below.

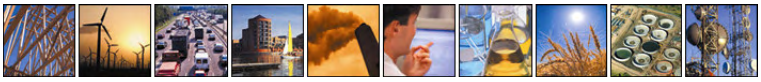
Local Industries

A number of different types of businesses may be affected, for example as a result of changes to their operational activities. An example of this might be the loss of a prime fishing ground as a result of habitat change resulting from the tidal energy scheme. This may require that fishing boats have to travel further to obtain the same amount or quality of fish. This example of disruption to local fishing businesses arises as a result of *environmental effects* of the tidal installations (described in Section 4.5). Tidal barrages may have an effect on local navigation routes (or 'marine access') as a result of their *physical presence* (see Section 3.7). There are a number of types of industries that may be affected with financial implications for their operations, employment and the wider economy. These effects may vary in their scale of impact depending on the size of the industry in question. Smaller industries may be more susceptible to changes and less able to adjust to effects such as the loss of a local fishing ground or change to a local tourist attraction.

- **Ports** – an increase in construction and maintenance activities may create a demand for ports and port related businesses, this demand will vary depending on the scale of activities and the extent that the ports in question can supply sufficient facilities for the development of the device. For example, the Cardiff-Weston tidal barrage proposal [44] effectively encloses the major ports of Cardiff, Newport, Bristol and Sharpness / Gloucester. Ports across the UK have undergone a considerable transition and it is possible that any demand created by tidal technology will help sustain the livelihood of a number of related businesses. Ports may also benefit from improvements made to marine infrastructure as a result of the development of tidal technology, such as dredging of channels or improvements to dry dock facilities;

- **Commercial and recreational shipping** - The effects on navigation are also potentially variable and have been described in Section 3.7 and Section 4.6.1 of this report. In summary, tidal energy schemes restrict navigation by requiring vessels to avoid certain areas of sea. In the case of barrages, vessels can only cross through locks in the structure. Barrages are likely to have a greater effect on navigation than tidal lagoons or farms of tidal stream devices. Whilst this is less likely to a have significant effects on commercial shipping firms (most ship movements are carefully planned to take account of different tidal conditions and availability of locks, etc.) there may be a number of small leisure or recreational marine businesses that may be effected as a result of a development at a particular location;

- **Commercial fishing** – the effect on fishing stock have been discussed in section 4.6.2 and essentially: (i) tidal power schemes restrict the area available for fishing, and may make it more difficult for fishing boats to manoeuvre with towed gear; and (ii) safety zones around tidal power schemes may be beneficial for fish stocks by providing refuge areas. It is unlikely that the majority of areas where tidal technologies are developed are important commercial fishing grounds; disruptions are more likely to affect smaller scale firms and potentially shellfisheries;



- **Aggregates** – some areas of resource may be lost or reduced as a result of tidal installations, potentially affecting some aggregate firm's factor costs. Alternatively, the significant construction associated with the development of tidal barrages or lagoons may create a significant demand for aggregates.

Tourism

The effect on tourism is likely to be complex and dependant on the type and size of tidal development created, the location in which it is constructed and the current tourism uses associated with the surrounding area. For example, the impoundment of water behind a tidal barrage may benefit some recreational users of the sea, but safety zones may block recreational access to coastal water and thereby limit or prevent other associated leisure and tourist activities.

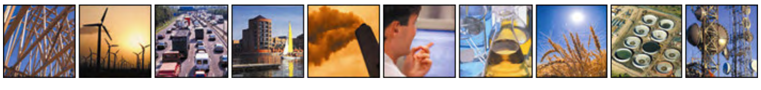
The creation of the tidal structure may also interfere with the natural environment (such as wetlands and other natural habitats, undeveloped coastal areas, or key species such as coastal birds or marine mammals), and the wider seascape and visual effects of tidal technologies may affect the amenity value of the area and affect its attractiveness to visitors. This has the potential to affect tourism dependant businesses.

Unsightly structures may detract visitors from an area of natural beauty. Section 4.5 highlighted that the greatest visual effect on seascape may occur with tidal range structures, as these have the largest surface piercing structures, and will be located close to the shore. The visual impacts of tidal stream devices are much smaller, particular those which are deployed in deep water further off-shore.

However tidal devices may generate new tourism opportunities for the local area; a structure like a tidal barrage may attract visitors who are interested in the scale and nature of engineering, who want to learn about the construction process, or want to view the area from a unique position. This has occurred at many large hydroelectric dam sites around the world. Research based on case studies of other forms of renewable energy sites suggest that visits to renewable energy sites are generally 'ad hoc' (for example, wind turbines, which may have a strong visual impact, may experience a higher number of casual visits[81]. If there is sufficient investment in education or in the provision of information, tourists may be proactively attracted to the site. Given the early stage of development of tidal technologies, tidal energy schemes could serve as opportunities to provide a learning experience or example of best practice, and attract technical visitors such as foreign engineers. It should be noted that tourism of this nature is likely to be a one off experience, and in most cases, people would be unlikely to make repeat visits.

Creating new markets

New transport infrastructure may be developed to serve the construction or operation of the tidal technology or may be incorporated into the structure of the device, for example a tidal barrage, acting as a bridge, could improve the accessibility of particular locations. This may be beneficial to local economies, especially those that may be isolated or rural. New transport infrastructure may open up local economies to wider regional trade benefits, initiate



new developments, or even provide access to better job opportunities. Bridges may also have the effect of reducing a transportation costs for goods.

Wider Regeneration

The overall affect of the various economic and social effects of tidal devices may contribute to the wider regeneration of a local area. The development of tidal devices may help provide key infrastructure or investment in a particular business which initiates a wider set of economic effects. The potential catalytic effect of tidal energy schemes should not be underestimated, and needs to be carefully considered as part of any proposed new development. Local communities, which may be rural and/or deprived with few opportunities for economic expansion, may experience a unique opportunity to further capitalise on some of the potential economic benefits available.

Land value

It is not clear if tidal technologies will have a significant effect on land and property values, although it is reasonable to assume that wider seascape and visual effects of tidal devices may affect the desirability of a particular location.

- **The activities of a number of different types of businesses may be affected by tidal energy schemes. These include ports, fishing, commercial shipping, aggregates, tourism and leisure industries.**
- **Tidal energy schemes may be able to contribute to the regeneration of areas, and assist local economies by encouraging the development of transport infrastructure.**

5.3 Social and community effects

This section presents a review of the potential social and community effects of tidal technologies. The potential effects are considered for people likely to be affected by a tidal power scheme; these are mainly the members of the local population of the area adjacent to the scheme, where the main environmental and economic effects are likely to occur. The potential effects on local populations will be dependant on their social, cultural and demographic characteristics. Social, cultural, economic and environmental impacts on a population are inherently and inextricably linked, and any effects in one area will have associated and residual affects on other aspects. Figure 5.4 provides a simple illustration of the linkages between economic, social, cultural and environmental effects.

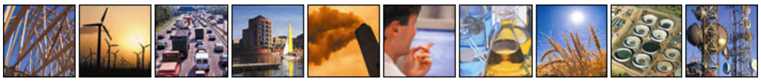


Figure 5.4 Illustration of relationships between social, community and wider effects – see following page

Figure 5.4 serves to illustrate the potentially complex range of effects that may shape the range of social and community effects at a particular location. Some anticipated effects noted in available studies [5][44][78] are described below. However, it should be noted that the undertaking of a full social impact assessment requires detailed understanding and insight into the local cultural context and various socio-economic characteristics of the local population. Such an assessment is therefore highly location-specific, and general conclusions are difficult to draw at a high level of analysis; consequently there are limitations in the estimation of social effects in this report, as a large number of different areas have the potential to be affected by tidal energy schemes. An overview of the range of potential effects on local communities is outlined below:

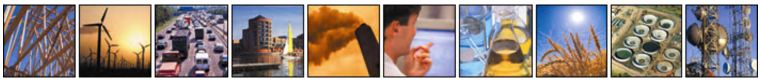
- **Leisure and recreational benefits** - Recreational users of coastal waters such as fishermen, divers, and users of recreational craft including yachts, sailing dinghies, jet skis and windsurfers may be affected, as barrages may increase the amount of recreational space available while lagoons and tidal stream devices may decrease the amount of recreational space available. Social and community implications may also include disruptions to regattas or other community activities, as well as changes in opportunities for exercise and improving health. Any limitations or opportunities with regards to leisure and recreational benefits will also affect tourism (this has already been discussed under wider economic effects).

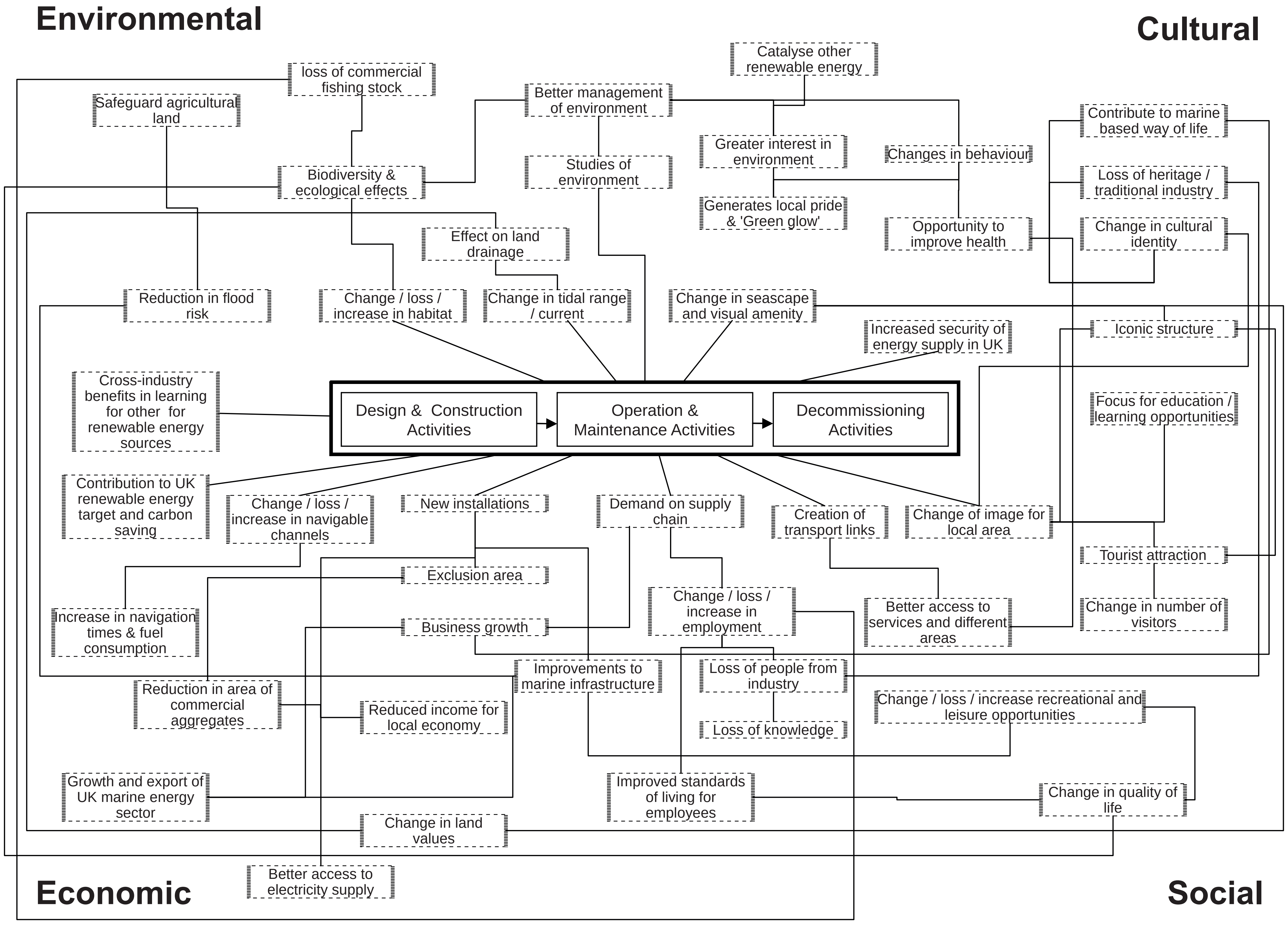
- **Seascape and visual effects** – The potential exists for considerable effects on seascape from tidal energy schemes, as the coastal environment is particularly sensitive to visual impact. It is likely that the visual impact of tidal stream technologies will be less than that of tidal range technologies. Impacts may occur during construction (from the storage of materials and presence of vessels and vehicles) and during operation and maintenance. The overall effect on landscape and seascape will depend upon local conditions.

- **Historical or cultural heritage** - A new development with a strong visual impact may also have an adverse effect on the historical or cultural heritage of a particular area. These visual impacts may come from the tidal development itself, or from new buildings or structures necessary to sustain the development or to support linked industries. Such new buildings or structures might have a significant effect on the character and quality of the historical/built environment of the surrounding local area. The full extent of the effect of new constructions on the character of the area is very much site specific.

- **Education** - The development may increase informal education opportunities locally for schools, local people and visitors, for example an installation may become a location where local school children or engineers can learn about renewable energy.

- **Transport and other infrastructure** - Tidal barrages may improve transport accessibility, potentially creating links between areas. There may be possible negative consequences, such as increased transport infrastructure possibly leading to increased congestion and air pollution. This may prove particularly negative for smaller, rural areas where any increases in pollution (noise, air and visual) might be more noticeable than in larger more urbanised centres.





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Tidal Technologies Overview

Figure 5.4
Illustration of Relationships Between Social Community and Wider Effects

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Where developments are proposed, efforts should be made to maximise the regeneration effects of tidal technologies. For example, where the technology may provide recreational opportunities there may be scope to develop a tourist office, or to regenerate port areas as a result of increased business and employment opportunities.

► **There are a wide range of social and community effects which are interlinked with economic and environmental effects. These include effects on leisure, landscape, historical environment, education and transport. These effects are implicitly site specific, and a more detailed estimation of the exact nature and scale of these effects cannot be made at this stage of assessment.**

5.3.1 Public attitudes and reactions

Under the EU Directive on Public Participation (2003/35/EC), Member States that are drawing up plans and programmes that relate to the environment, need to take steps to undertake adequate public participation (i.e. stakeholder engagement). The Directive allows that the public can express their opinions and comments before decisions about plans and programmes are made, and that the public's comments should be taken into account during the decision-making process. In addition to these legal requirements, effective stakeholder engagement can bring value to the process by identifying potential issues that are of concern to stakeholders in a timely manner. This can allow a proactive approach to be developed in solving these issues, and this can help to build consensus between stakeholders. This approach may require an element of audience development to create a shared level of knowledge or understanding, thereby enabling stakeholders to make well informed decisions.

In considering how a proposed tidal energy development may impact the surrounding community, it is useful to understand current perceptions and attitudes regarding tidal technologies. The results of the stakeholder consultations undertaken as a part of this process were not available in time for this report, therefore experience and research into attitudes and perceptions of renewable energy in general (and wind energy in particular) are presented in this section. A study undertaken in 2003 examined the attitudes and level of knowledge about renewable energy amongst the general public[82] and provides some useful insights that may be applicable to tidal developments:

- Twenty six percent of a nationally representative sample claimed to know a little or a lot about renewable technologies. However, this increased to 43% amongst a sample consisting of people who lived within 5 kilometres of a renewable energy site (either operational or proposed) and were aware that they lived near such a site. This suggests low levels of awareness of renewable technologies in general, and also that public consultation awareness-building exercises may be very relevant to the development process for tidal energy schemes.

- Opinions of renewable energy were generally favourable, with 82% of the general public agreeing that it is much better or a little better to use renewable energy over traditional sources (fossil fuels).

- The survey found a positive correlation between knowledge and opinion – the higher the level of knowledge about a technology, the more positive the opinion of it. Interestingly, the study found that opinions of marine technology and offshore wind farms were higher than predicted (given the relatively low knowledge levels). This is possibly because they are offshore, and are therefore expected to have a smaller impact on personal environment. This finding suggests that public awareness and consultation may play a crucial role in gaining public acceptance of a development.

- Almost two-thirds of the general public stated that they “would be happy to have a clean renewable energy development built in their area.” Resistance was stronger amongst older respondents.

- The survey undertaken also picked up sentiments of ‘nimbyism’[x]. This ‘anywhere but here’ attitude was evidenced in the public reaction to onshore wind farms. Of those who were resistant to onshore wind farms being built in their area, 10% had an ‘anywhere but here’ attitude. Five percent of the respondents answered that their resistance was dependent on the amount or proximity of the wind turbines. This may be particularly felt among residents resistant to tidal developments who may not oppose the concept of tidal technology but rather the way in which it impacts their lifestyle, be it leisure or employment.

- The greatest negative reaction to wind farm developments however came from negative perceptions of their visual impact rather than a nimby attitude. Depending on the type of tidal technology and the extent to which there are surface piercing structures, this is likely to be a significant negative perception for tidal developments as well. (Certain tidal stream technologies may have minimal surface piercing components and therefore present fewer concerns to local residents who are worried about visual effects).

- Experience with windfarms suggests that local concerns or hostility towards the proposed development tend to dissipate once they become operational.

Many of the attitudes and perceptions picked up by the study are useful in gaining a more thorough understanding of how proposed tidal technology developments may be received by local populations, particularly the concerns over visual impacts and the nimby attitude that was evidenced in the findings. This also provides insight into how possible resistance may be overcome. Encouragingly the results suggest that much resistance is often due to limited knowledge and understanding of new technologies and that this can often be countered through increased awareness of the technology.

► **Opinions of renewable energy are generally favourable among the public and over two thirds would be happy to have a site built in their local area. Research indicates that there**

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[x] NIMBY is an acronym for Not In My Back Yard, an attitude where residents oppose a development in their area but do not oppose such development in another’s.

is a positive correlation between knowledge and opinion of renewable energy technologies, but that opinions of marine and off-shore wind technology are higher than predicted, given relatively low knowledge levels. The nimbyism which is in evidence with onshore wind developments may also be an important consideration with tidal energy schemes.

5.3.2 Wider social and community effects

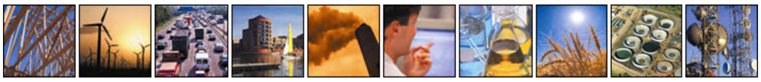
A development of this nature in a local area has the potential to stimulate a wider range of effects which are less specific in nature and difficult to quantify. These include psychological, ethical and spiritual issues related to the environment, society and the impacts of tidal energy schemes on these. These considerations may include:

- An increased awareness of and appreciation for ‘green’ technology and lifestyles amongst local peoples. The development in their local area may improve local awareness and understanding of global issues and the ways in which these issues relate to their daily lives. It may stimulate people to investigate other ‘green’ measures to adopt in their general lifestyle;
- Promotion of self-respect as a result of employment and association with ‘green’ technology; and
- Creation of interest in other sustainable and community based solutions to waste disposal and energy generation. The interest of the public in ‘greener’ lifestyles may be encouraged to the point where they are motivated to investigate and/or initiate other community projects; in turn, these projects may have further reaching positive social and community effects.

► **There are a number of non-quantifiable positive social effects which may be generated by the construction of a tidal energy scheme in a local area. These include changes in lifestyles and attitudes as a result of ‘green’ energy generation in the area.**

5.4 Barriers to growth and recommendations

The tidal energy industry is at an early stage of development and it is considered[80][83] that tidal technology will become commercially viable in the short to medium term (2010 to 2015). Section 3.5 of this report provides a review of the relative cost of the different technologies, and identifies a potential point in the future when the relative price of tidal electricity may be sufficiently reduced to be commercially viable. These price reductions are likely to arise mainly as a result of ‘learning’ from development of installations, and the creation of economies of scale with consequent reductions in the cost of tidal stream technologies. However, a number of barriers to the growth of the tidal energy industry have been identified, and these are outlined below.



Key barriers

‘Future Marine Energy’[17], a report by the Carbon Trust (2006), described the findings of a review of the cost-competitiveness of wave and tidal stream energy. Importantly, this presented the Carbon Trust’s view on the marine renewables sector, identifying barriers and making recommendations for future support. The main conclusions from this study indicated that marine renewable energy could become competitive with other forms of technology in the future and that the growth of tidal stream energy would be affected by:

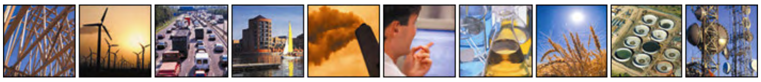
- Strategic and security of supply considerations;
- Availability of finance;
- Technological risks relating to the readiness of technologies to be exploited and how these risks are managed in development;
- Grid access and capacity;
- Variability of power generation; and
- Planning and permitting factors.

The report highlighted a number of reasons to encourage the development of wave and tidal stream developments (namely that these sources of energy had the potential to make a material contribution towards efforts to combat climate change and increase security of supplies, as well as potentially significant returns to the UK from the sales of technology and revenue from generation). The report also made a number of recommendations:

- A need for significant public support and private investment to help accelerate the pace of development activities with an emphasis on cost reduction to help ensure commercial viability;
- Public support to assist the cost-competitiveness of tidal energy where it is above the cost of conventional energy and other renewables as well as providing better clarity of the ‘route to market’ to attract private equity;
- Accelerate and augment ongoing R&D, especially where it can advance detailed design of technologies and focus on ways to reduce costs; and
- Encourage early development of wave and tidal stream arrays to accelerate learning effects from these schemes.

It was suggested that public sector should consider funding in order to:

- Give increased support to R&D, and address cross cutting technology issues (such as grid capacity) to help deliver cost reductions;
- Provide support for the development of tidal technologies until they prove technically viable and provide evidence of reducing costs; and



- Develop a clear long term policy framework of support to the sector giving investment certainty.

'The Path to Power' report[84] by the British Wind Energy Association (2006) presented potential hurdles to the development of wave and tidal energy, revealed in research with industry stakeholders. The hurdles identified, in order of importance, were:

- Funding assistance – i.e. a need for clarity on the existence and form of a support mechanism that will enable the deployment of large scale arrays and significant projects, effectively bridging the gap between support to demonstration-scale technologies and more mature technologies. The report cited available support from the DTI's Marine Renewables Development Fund, the Renewables Obligation and Climate Change Levy;

- Grid capacity and access, especially as most of the better resources are located in areas with limited capacity (particularly off north and west Scotland); and

- Planning and permitting – i.e. stakeholders described a need to put a 'longer term planning and permitting framework' to reduce delays, particularly with regards to SEA and EIA requirements.

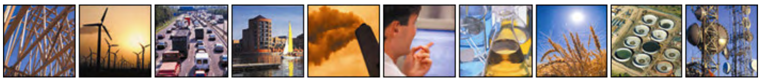
In response to these hurdles a number of recommendations were developed:

- Production of a strategy for the wave and tidal industry by the UK government, led by the DTI setting out the potential and the actions to achieve it;

- Financial support from the DTI to bridge the funding gap with the Renewables Obligation. A revenue rather than capital and to be set at a level to create a sufficient 'market pull' without potential risks. A single UK wide mechanism was preferred;

- Participation, by industry, in existing processes to resolve grid issues. These issues were shared by both on- and off shore wind industries and much effort was underway; and

- The DTI and other relevant departments to begin preparations for SEA in order to complete the process by 2008.



Other barriers

Research

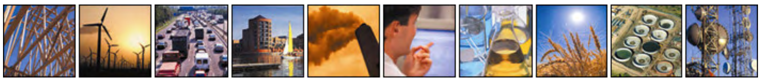
‘The Path to Power’ and ‘Future Marine Energy’ produced a series of recommendations based on experience gleaned from a programme of development support as well as information from the industry’s perspective. The DTI review[80] of the renewables supply chain examined issues from an academic perspective, as well as issues relating to skills and recruitment faced by employers in the sector. Due to the stage of technology development, all aspects of marine energy devices from the design through to connection and O&M are aspects of R&D. The UK is active in all of these R&D areas, and currently has a number of companies and research bodies that are at the prototype stage of development. Common themes emerging from discussions with academics included the following:

- Organising funding around research projects leads to high employment instability for researchers and is frequently a reason for losing staff, and accumulated knowledge;
- The need to win funding to reduce instability was identified by some as a reason for research proposals becoming less innovative. It is often easier to demonstrate success in low risk work and this is a means of developing a track record necessary to secure further funds. This perceived lack of innovation is now seen as a problem in some areas. Similarly, there is a preference towards desk-based work rather than physical modelling;
- A shortage of suitable demonstration facilities emerged as an issue as it affects both current work and the training of young researchers in physical modelling; a lack of full scale demonstration facilities was cited as a critical constraint;
- Availability of funding was identified as the greatest constraint to development of pre-commercial technologies – this included near commercial technologies less eligible for academic grants yet unable to compete in the market; and
- Securing patents was variable but recent developments suggest that consortia and industry collaboration may be growing in response to the capital grants and associated funding arrangements.

Skills and Recruitment

The renewables industry requires a wide range of skills including:

- professional project development skills associated with the exploitation of business opportunities (e.g. financial management, business planning, project management legal skills, marketing and sales & services);
- technical skills associated with the manufacture, construction and installation of renewable energy projects (e.g. electrical, mechanical, civil, combustion, process, electronics, software and environmental engineering);



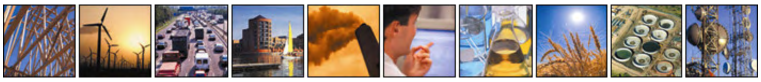
- specialist technical skills in engineering, environmental and planning at a professional level associated with consultancy services, project development and R&D activities;
- specialist knowledge of complex form manufacturing, such as gear profile manipulations, modelling and design;
- heavy engineering and specialist skills in marine off-shore technology associated with the design, development and installation of off-shore wind, wave and tidal projects; and
- power system design and engineering which includes specialist software and hardware control skills to allow for monitoring more complex networks that result from increased renewable projects.

Interestingly, companies interviewed for this study did not consider skill shortages as a critical constraint to their development. Their comments fell into three broad areas:

- Level and quality of general technical skills: the general availability of graduate engineers and trained craft workers has led to an inadequate number of suitable candidates. The low appeal of the engineering profession is a potential cause which is difficult to address directly. Continuity of training and work as opposed to fragmented contracting arrangements could be another contributor. Sponsorship is necessary to attract more undergraduates.
- Level and quality of specialist resource - similar recruitment problems were identified with particular emphasis on electronics and control instrumentation, design and manufacture of composites, specialist fabrication, and project installation and commissioning.
- General Management and Project Management - this was a surprisingly common shortage but may reflect the current abundance of projects under development and the relative immaturity of the industry, however given the transferability of these skills it suggests there is scope for raising the profile of the requirement, possibly amongst those with thermal power sector experience.

The DTI report[80] noted that companies were addressing potential recruitment problems through either in-house training or recruitment from overseas. In-house training has cost implications in terms of time and the inability to fully utilise the resource during the training period. Firms were also considering starting technical apprenticeship schemes to increase individual competence and to obtain professional progression to degree and chartered status. There are also a range of skills that can be transferred from other more mature and developed technologies such as marine off-shore technologies developed for the North Sea oil and gas industry.

► **The potential for growth of the tidal energy industry is widely recognised, although a significant number of barriers have been identified. These include a funding gap, issues with infrastructure and planning, and a lack of clear strategic direction. Skills and recruitment were not primary concerns for firms in the sector.**



- **A number of recommendations have been made to address these barriers, which include making the industry cost competitive, accelerating the development of commercial sites, developing a UK strategy for marine energy, collaboration across sectors to address infrastructure needs, and consideration of planning and regulatory issues.**

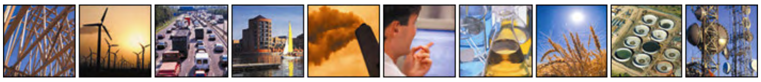
5.5 Summary

The following matrix summarises the information from this chapter (see Table 5.5). The magnitude of different social and economic effects is described in qualitative terms, indicating either: high, medium or low effect relative to the other devices. It has been possible to provide some quantitative information, such as an estimate of direct employment from construction activities, although in the main quantitative information is not available. In many cases (particularly the social and community effects which will depend on a number of site specific factors) the effects are simply uncertain.

Table 5.5 Comparative summary of social and economic effects

	Tidal range		Tidal stream - fixed			Tidal stream - floating		
	Barrage	**Lagoon**	**1 device**	**1 Farm**	**Many farms**	**1 device**	**1 Farm**	**Many farms**
ECONOMIC EFFECTS								
Direct construction employment	High	High	Medium	Medium	High	Medium	Medium	High
Indirect construction employment	High	High	Low	Medium	High	Low	Medium	High
Direct operational employment	High	Medium	Low	Medium	High	Low	Medium	High
Indirect operational employment	High	Medium	Low	Low	Medium	Low	Low	Medium
Direct decommissioning employment	High	High	Low	Medium	Medium	Low	Low	Medium
Indirect decommissioning employment	High	High	Low	Low	Medium	Low	Low	Medium
Commercial fishing	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Commercial shipping	High	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Ports and related activities	High	High	Low	Medium	High	Low	Medium	High
Commercial aggregate dredging	High	High	Medium	Medium	Medium	Medium	Medium	Medium
Tourism and Leisure	High	High	Low	Low	Low	Low	Low	Low
Land and property value	High	High	Low	Low	Medium	Low	Low	Medium
SOCIAL AND COMMUNITY EFFECTS								
Tourism	High	Medium	Low	Low	Medium	Low	Low	Medium
Leisure and recreational activities	High	High	Medium	Medium	Medium	Medium	Medium	Medium
Infrastructure effects	High	Medium	Low	Low	Medium	Low	Low	Medium
Regeneration effects	High	High	Low	Medium	Medium	Low	Low	Medium
Wider social and community effects	High to Medium	High to Medium	Medium to Low	Medium to Low	Medium to Low	Medium to Low	Medium to Low	Medium to Low

Source: Entec



Appendix A
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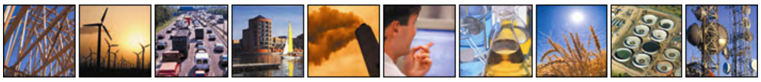

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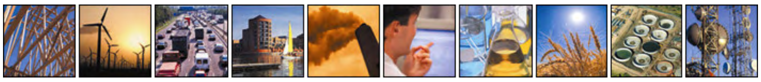

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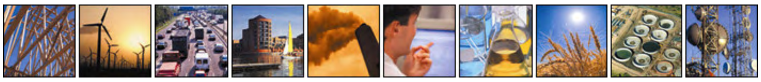

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