SCOTTISH EXECUTIVE

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Note: This document is only a section of the Final Environmental Report

Scottish Marine Renewables SEA
Environmental Report Section B: Marine Renewables – Resource and Technology

Scottish Executive
March 2007

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B1 Introduction

B1.1 Approach

Areas of wave and tidal energy resource have been identified via four main sources of information:

- The Forum for Renewable Energy Development in Scotland, Marine Energy Group (MEG) Report, 2004 – Harnessing Scotland's Marine Energy Potential
- The Carbon Trust Marine Energy Challenge
- The Department of Trade and Industry (DTI) Atlas of Marine Renewable Energy Resources (ABPMer et al, 2004)
- Consultation with developers

A summary of these sources of information is given below.

B1.1.2 The Forum for Renewable Energy Development in Scotland, Marine Energy Group (MEG) Report, 2004 – Harnessing Scotland's Marine Energy Potential

The executive summary of the MEG report states that by 2020 "we could see 1300 megawatts of marine energy capacity installed in Scottish Waters". The report drew on a number of studies to reach this assessment, including the 2001 "Scotland's Renewable Resource" document produced by Garrad Hassan.

The MEG reports examined both wave and tidal power potential. The wave power assessment considered offshore constraints (without further explicit definition) and generic areas further offshore than the present study's 12 nautical mile extent. The MEG assessment concluded that wave energy generation could make a full or large-part contribution to providing 1300 MW of marine energy by 2020. In addition, a separate tidal power assessment examined geographical areas and capacities based on prototype devices for 2005, through to more developed commercial devices by 2020. This assessment refers to "full installation" and a reduction due to environmental or other constraints does not appear to have been applied. This assessment indicated 104 MW of tidal power capacity at an early stage, rising to a potential 2336 MW of capacity by 2020.

The Garrad Hassan report provided tidal resource estimates for 2010 and 2025, based on constraints predominantly based on navigation issues. Their constrained capacity estimates for 2010 was 1601 MW and for 2025 was 2875 MW. Both the MEG report and the earlier Garrad Hassan report aim to provide an overview of the potential energy resource by type and broad geographic area only.

B1.1.3 The Carbon Trust Marine Energy Challenge

In 2004, as part of the Marine Energy Challenge, the Carbon Trust commissioned an assessment of the UK tidal stream resource (Black and Veatch, 2005). The conclusions of this "Phase I" study are summarised below.

- A "Flux Method" was developed as a method for calculating the amount of energy available for extraction at a site.

- The Flux Method included a Significant Impact Factor (SIF) which represents the fraction of the total energy resource which is available for extraction. The SIF is an estimate of the potential environmental constraint based around the concept that only a certain reduction in flow speed in an area is likely to be acceptable before significant economic or environmental effects occur. It is not intended to be an explicit measure of the actual environmental designations and competing uses in an area, but rather as a surrogate measure of the potential effects of energy removal.
- For the purposes of the Phase I study, the authors assumed a SIF of 20% for all sites assessed, while highlighting the site to site variability of the SIF. This assumption was significantly refined in the Phase II study
- The report concluded that much of the UK resource is concentrated in the Pentland Firth and the Channel Islands, and predominantly at a depth greater than 40 m. Recommendations were also made that the Phase II study should focus on the development of more robust "SIFs" for the most important sites.

A "Phase II" study was then carried out, focusing on the ten most important sites identified during Phase I. Site widths and depths were confirmed, and associated current speeds extracted from the Marine Energy Atlas and published Admiralty data.

Further consideration was given to SIFs in this study and it was determined that the SIF was likely to vary with the type of site considered, e.g. narrow channels, wide channels, sea lochs, open seas. It also considered technology implications in terms of the lower end "cut-in" current speed required for energy generation to start and the maximum rated velocity (at which the device reaches maximum output and assumed to be c.70% mean spring peak velocity). Based on these considerations the technically extractable resource was then re-assessed. This assessment reduced the technically extractable resource identified in the Phase 1 study by 20%.

Table B1.1 below gives a summary of the estimations of installed capacity (in MW) for various sites within the SEA study area that were calculated based on the two studies discussed above for a study considering the variability of UK marine resources (Environmental Change Institute, 2005), also undertaken for the Carbon Trust as part of the Marine Energy Challenge project.

Table B1. 1: Summary of estimates of potential installed capacity based on studies undertaken for the Carbon Trust

Site	Installed Capacity (MW)
Northern Isles	
Shetland Yell Sound East Channel	58
Shetland Yell Sound West Channel	49
Shetland Blue Mull Sound	42
Orkney Westray Fers Nes	19
Orkney Papa Westray	74
Orkney North Ronaldsay Firth	3
Orkney Falls of Warness	54
Orkney Eday Sound	19
Western Scotland	
Kyle Rhea	7
Mull of Galloway	109
Mull of Kintyre	7
Mull of Oa	6
Sanda Sound	8
Pentland Firth	
South Ronaldsay to Swona	294
Inner Sound	40
Duncansby Head	440
Pentland Hoy	194
Pentland Skerries South	1324

Note: No SIF has been included for the smaller sites; these figures to not take into account rated velocities or capacity factors; initial site focus was on locations with depths >30m and mean spring peak velocity of >2.5m/s were found.

B1.1.4 *The Department of Trade and Industry (DTI) Atlas of Marine Renewable Energy Resources*

The Atlas of Marine Renewable Energy Resources (ABPMer et al, 2004) was used to give an initial overview of the areas of interest for wave and tidal stream energy development. This study maps modelled wave and tidal resource around the UK. The wave model cell size is approximately 12 km by 12 km in the SEA study area and the tidal model cell size is approximately 1.8 km by 1.8 km. Therefore, although the Renewables Atlas gives a good overview of the potential resource available, it does not necessarily identify all areas of potential interest for development, particularly for tidal resource (often close to shore).

B1.1.5 *Developer Workshop*

Therefore, a workshop was held (organised jointly with EMEC) with renewables device developers in October 2005 to discuss the exploitation of tidal and wave energy around Scotland. One of the objectives of the workshop was to learn more about the resource requirements and operating characteristics of the devices. At the workshop the developers identified several areas where they felt there may be potential for tidal development that are not identified in the high level studies noted above.

It should be noted that the sources of information above, whilst giving a good indication of potential areas of interest for marine renewable energy development, are not exhaustive or definitive. Additionally, the SEA must also consider the impacts of submarine cables that will transport the power generated to shore. Therefore, this SEA has not focussed solely on those areas identified as being of development interest. Rather, the SEA has covered the entire study area.

The study area and the areas of interest for development (identified from the four sources of information noted above) are illustrated on Figure B1.1 (accompanying the chapter). The resource requirements of wave and tidal devices are outlined on sub-sections B1.2 and B1.3 below.

B1.2 Wave Resource

Most of the waters off north and west Scotland are open to the ocean and are not shielded by islands. Therefore, they are potentially attractive for siting wave devices. However, the attractiveness of the site depends largely on its energy resource, which is largely governed by two key factors: coastal orientation relative to the prevailing wave direction, and seafloor depth characteristics.

- As the prevailing wind direction and the area of greatest fetch are westerly, west facing sites generally have greatest energy resource.
- Seabed friction progressively removes energy from ocean waves when they encounter seafloor depths of less than about 100 m and the resource decreases steadily shoreward with decreasing depth. The most attractive sites are those where deep water can be found close to shore as this means a larger resource and lower development and operating costs.

Wave energy devices require sea states with significant wave heights above approximately 1.5 m. Power output increases with wave height until the device is working at full capacity (typically wave height of 4 – 6 m), above which the additional wave energy cannot be captured but simply increases the loading on the device and any mooring system.

Existing wave technologies can occupy a range of water depths from 5 m to almost 100 m, and technological advances are likely to result in waves in greater water depths being exploited. This means that devices could potentially be a significant distance offshore. However, this SEA focuses on the area between the shoreline and the 12 nautical mile limit.

B1.3 Tidal Resource

Tides are regular and predictable, which is one advantage over wind and wave energy. Tidal energy generation falls into two main categories:– potential energy from the tidal range (i.e. the increase and decrease in water level that drives tidal barrage installations), and kinetic energy from the tidal flow itself.

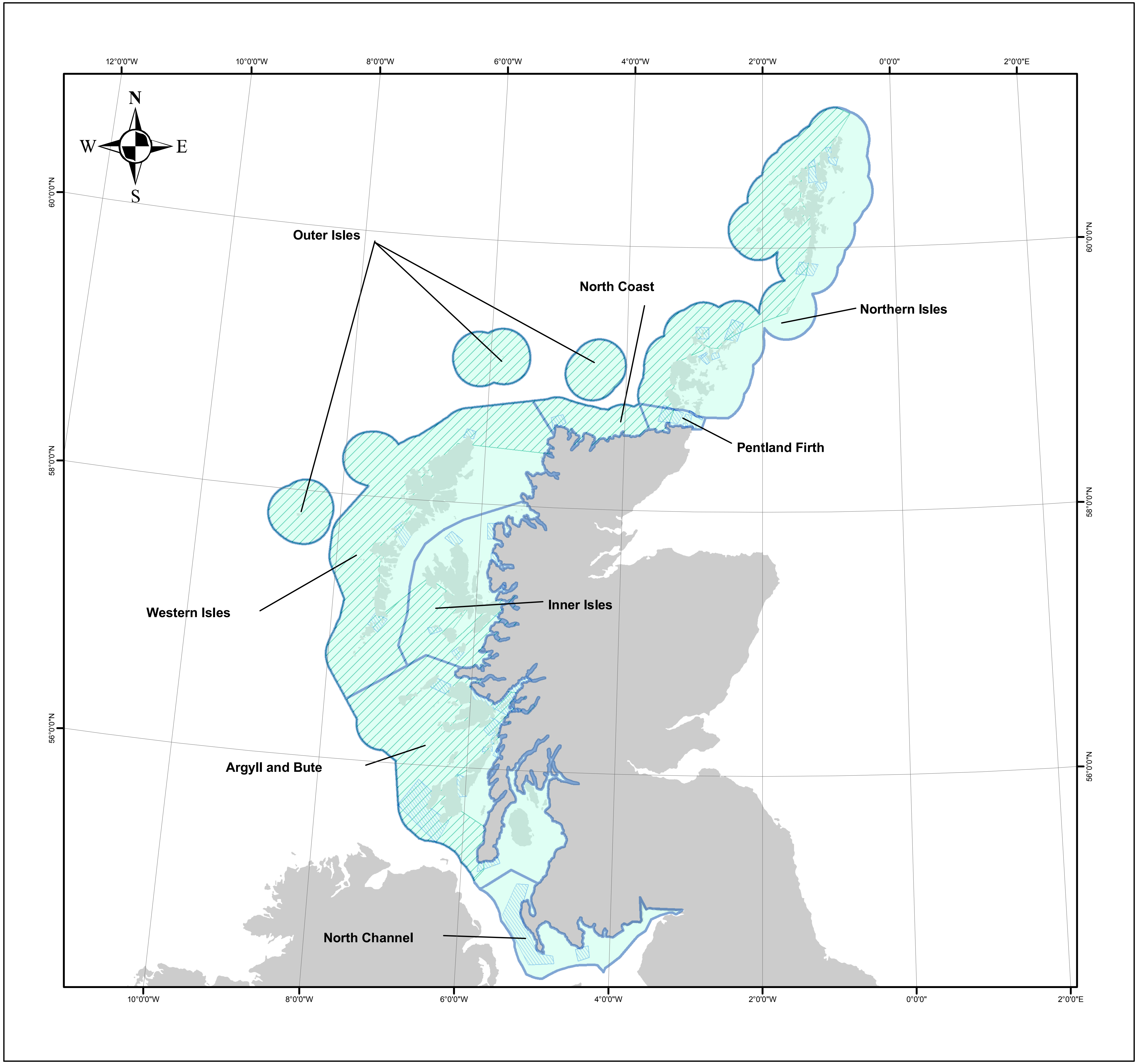
Present tidal energy technology requires current speeds to reach about 2.5 m/s at the peak of a spring tide. Lower peak spring speeds may be un-economical, while substantially higher speeds pose engineering design challenges that may still require further development. At present, there are also limitations on the depth of water in which tidal devices can be installed. However, it is expected that the operating envelope for tidal stream devices, in terms of current speed and depth, will grow over the coming years as the technology develops.

In contrast to wave resource, potential tidal resource sites are fewer and confined to relatively small areas. Largely, potential tidal sites do not overlap with the sites of high potential wave development.

The amount of energy available from tidal device development in Scotland has been estimated in a number of studies as noted in sub-section B1 above.

Scottish Executive Marine Renewables Strategic Environmental Assessment

Figure B1.1: SEA study area



Legend

Study area

Potential development area

Tidal resource

Wave resource

Kilometres
0 30 60 120 180 240

Date	1 January 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SeaZone Solutions Ltd	
File Reference	P736\GIS\Mxd\SEA\Baseline maps	
Checked	RD	GIS Specialist
	FLB	Project Manager

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B2 Device Information

B2.1 Introduction

A developers' workshop was held in October 2005 to discuss the exploitation of tidal and wave energy around Scotland and specifically the SEA study area. One of the objectives of the workshop was to learn more about the operating characteristics of the devices and their potential environmental effects (e.g. anchoring systems, moving parts, area occupied per MW). The workshop was organised jointly with the European Marine Energy Centre (EMEC).

Present indications are that there is interest in developments of all sizes from single installations for community use to major inputs (from device arrays) to the National Grid. As the SEA is driven by the desire to help achieve the Scottish Executive's renewable energy targets, the focus is on larger-scale development with access to the national electricity market, which will be necessary for substantial development.

Clearly the environmental effects associated with a device or device array are dependent on its design; for example, a seabed-mounted device may be compatible with shipping and certain devices may not require the use of anti-foulants. Through consultation with device developers it has been possible to build an understanding of potential impacts. A summary of the information requested at the developers' workshop and through subsequent consultation is provided below.

This exercise sought to ascertain:

- Water depth requirements
- Water column position
- Protrusion above the sea surface
- Methods of mooring/attachment to the seabed and installation techniques
- Moving parts in contact with sea water
- Potential numbers of devices in arrays and device array footprints
- Noise emissions
- Potential pollution sources
- Maintenance requirements
- Decommissioning.

The amount of information available for a specific device is largely dependent on its stage of development. For a very small number of devices, an EIA has been undertaken including detailed assessment of factors such as noise production. This not only helps to understand the effects of that specific device but also for similar devices. In the case of tidal devices in particular, many of the design factors are similar.

B2.2 Device Types

B2.2.1 Wave

Wave energy devices require sea states with significant wave heights above about 1.5 m. Power production increases with wave height until the device is working at full capacity (typically wave amplitude of 4-7 m), above which the additional wave energy cannot be captured but simply increases the environmental loading on the device and any mooring system.

It is envisaged that the operating envelopes for wave devices are likely to remain relatively stable in the medium term.

Offshore wave energy devices use a variety of methods to convert their movement in response to wave action into electrical energy. They fall into six main categories:–

- Oscillating water column;
- Point absorber;
- Attenuator;
- Terminator;
- Over-topping; and
- Wave rotors.

Each is described briefly below.

Oscillating Water Column (OWC)

These devices operate by means of the movement of waves being trapped by a container which in turn moves air through the device. The route by which the air enters and leaves the container leads it through a turbine which has aerofoil blades that respond to air motion in either direction by rotation in one direction. The turbine is connected through a gearbox to a generator.

Such devices can either be mounted on the shoreline (e.g. the Limpet device installed on the shore of Islay) or float offshore. There are a number of potential variations in the floating offshore devices. These include devices with several different chambers tuned to respond to waves of different periods; devices that can pressurise the air and store it at pressure before it is released into a turbo generator; and devices which make use of parabolic reflectors to focus wave action to the entry point of the OWC.

OWC devices typically have no moving parts in contact with the sea.

Point absorber - Point absorbers are effectively driven by buoys or floats which respond to the vertical movement of the wave. The configurations vary widely from moored buoys to articulated units that absorb energy along the line of travel of the wave, some that internally self-react and others which react against an external weight or mooring.

Mechanical or hydraulic means are used as power take-off to connect to the generator. Configurations also vary from floating to fully submerged devices.

Attenuator – These are moored to lie in line with the wave path and extract a percentage of energy from the passing wave fronts.

Terminator – Terminator devices are set across the path of the wave front effectively bringing it to a stop to take energy from the wave. Oscillating water column devices can also act as terminators.

Over-topping - Over-topping devices capture water from waves into a reservoir before it flows back to the sea through a low head turbine. They are generally moored and positioned offshore where the wave action is sufficient to ensure consistent over-topping to maintain energy output.

Wave Rotor - This concept is only offered by one developer (Ecofys) at present. The sub-sea rotor is designed to pick up energy from the rotational movement of water in waves.

A summary of the key wave devices currently in development (as at 2006) is presented in Table B2.1. However, it is important to note that it is not the aim of the SEA to evaluate the environmental effects of specific devices; instead, judgements on the significance of effects will be made at a generic level. Additionally, information available for each device is highly variable depending on the stage of development of the device and the commercial sensitivity of the information.

Table B2. 1: Wave devices

Type	Developer	Device
Oscillating water column	Wavegen	Limpet Shoreline Wave Energy Converter
Oscillating Water Column	Wavegen	Near-shore Wave Energy Converter
Oscillating water column/terminator	Energetech	Energetech
Oscillating Water Column	ORECon	MRC 1000
Oscillating water column/point absorber	Embley Energy	Sperboy
Overtopping/terminator	Wave Dragon	Wave Dragon
Overtopping	WavePlane Production	WavePlane
Overtopping wave capture variant	Wave-Master	WaveMaster
OWC variant	OWEL	Wave energy converter "Grampus"
Attenuator	Ocean Power Delivery	Pelamis
Point absorber	Advanced Wave Energy	Waveroller
Point absorber	AWS Energy	Archimedes Wave Swing
Point absorber	C-wave	C-wave
Point absorber	Ocean Power Technology	PowerBuoy
Point absorber	Aqua Energy	AquaBuOY
Point absorber	Clear Power Technology	Wavebob
Point absorber	Wave Star Energy	Wave power system
Point absorber	UMIST	Manchester Bobber
Point absorber	Lancaster University PS Frog	PS Frog Lancaster
Point absorber	SeaVolt Technologies	Waverider
Point absorber	The Engineering Business	EB Frond
Point absorber	Fred Olsen	Buldra
Wave rotor	Ecofys	Wave Rotor

B2.2.2 Tidal

Present technology for tidal stream energy devices requires current speeds to reach about 2.5 m/s at the peak of a spring tide. Lower peak speeds may be uneconomical, while substantially higher speeds pose engineering design challenges that may still require further development. At present there are also limitations on the depth of water in which tidal devices can be sited (the maximum depth noted by tidal device developers was 70 m, with most requiring water depths of 10 – 40 m). However, the operating envelope of tidal stream devices, in terms of current speed and depth, will grow over the coming years as the technology is improved upon. This was made clear during the SEA developers' workshop in October 2005.

Marine turbines work much like wind turbines but are driven by flowing water rather than air. As water is 800 times denser than air and has a much slower flow-rate, the turbine experiences much larger forces and moments. This leads to turbines with much smaller diameters, than wind turbines, for example.

Tidal resources are regular and predictable, which is one advantage over wind and wave energy. Tidal energy generation falls into two broad categories:

- potential energy from the tidal range, i.e. the increase and decrease in water level, such as a tidal barrage, and
- kinetic energy from the tidal flow itself, for example marine turbines.

The SEA is not evaluating tidal barrages for commercial and environmental reasons which are explained in Section 5.2.2 of the SEA Scoping Report dated February 2006.

There are three main types of kinetic energy tidal devices:–

- horizontal axis turbines,
- vertical axis turbines,
- and venturi devices.

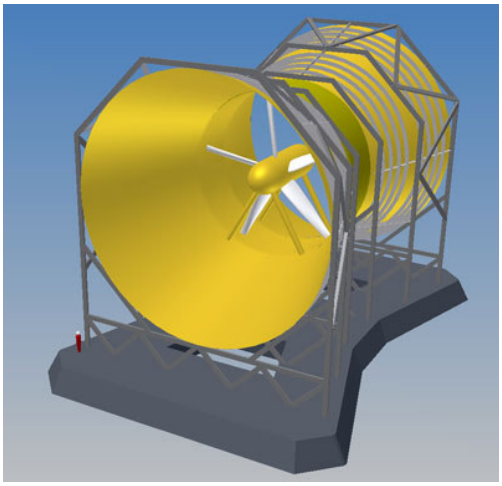
Each is described briefly below.

Horizontal Axis Turbines - These devices are the most commonly employed technology type in tidal stream generation. Turbine blades rotate around a horizontal axis to drive a generator.

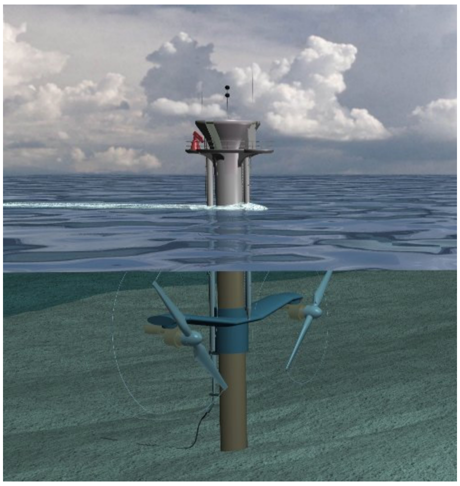
The variants include:

- Shrouding of the turbine to create a venturi effect, increasing tidal flow through the turbine.
- The type of foundation used – some are on gravity bases, some on a mono-pile, some mid-water on a moored buoyant support and one or two devices are designed to hang off a floating barge.
- The method by which reversal of flow (i.e. from the ebb to flood direction and vice versa) is catered for by adjustment of blade angle or physically turning the device over or around its vertical axis.
- The number of blades on the turbine; three is most common, whilst five blades are employed in at least one case.
- Turbine blades can be supported by a doughnut-shaped structure that is open in the centre.

Figure B2. 1: Examples of horizontal axis turbines



Source: Lunar Energy - http://www.lunarenergy.co.uk/corporate-company.htm

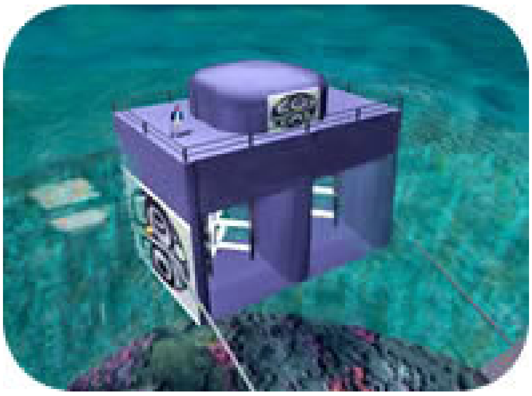


Source: MCT - http://www.marineturbines.com/projects.htm#

Vertical Axis Turbines – There are currently fewer vertical axis turbines in development than the horizontal axis turbines and several are in the very early stages of development. As with the horizontal axis turbines, the number of blades and the configuration of the blades vary between devices. Vertical axis turbines are typically founded on gravity bases. Certain vertical axis turbines also fit well into a “tidal fence”[1] configuration that offers flexibility to allow incorporation in transport links across tidal sounds.

[1] Multiple devices installed next to each other in a row between two islands for example

Figure B2. 2: Example of a vertical axis tidal turbine



Source: Blue Energy - http://www.bluenergy.com/images.html

Venturi - These are typically horn-shaped devices. Water flowing through the device speeds up in the constriction of the venturi throat (a smoothly shaped opening through the device). As the water speeds up, the pressure in the stream drops to a minimum just after it passes the throat. This pressure drop is used to suck air into the flow-stream through a series of pipes connected to each segment of an array of devices. This air is sucked in through a turbine which drives the generator.

Figure B2. 3: Example of a venturi type device

Source: HydroVenturi - http://www.hydroventuri.com/subpage.html

Tidal flows can also be used to create an oscillatory motion of hydroplanes, but it is understood that development of hydroplanes has ceased at present. Therefore, the SEA will, whilst acknowledging the potential for other device types such as hydroplanes, make use of information from those devices currently under development and will focus predominantly on turbines.

A summary of the key tidal stream devices currently in development (as at 2006) is presented in Table B2.2. It is important to note that it is not the aim of the SEA to evaluate the environmental effects of specific devices. Instead, judgements on the significance of effects will be made at a generic level.

Table B2. 2: Tidal devices

Type	Developer	Device
Horizontal axis turbine	Lunar Energy (Rotech Engineering)	Rotech Tidal Turbine (RTT)
Horizontal axis turbine	Marine Current Turbines	SeaGen/SeaFlow
Horizontal axis turbine	THGL	THGL
Horizontal axis turbine	SMD Hydrovision	TidEL
Horizontal axis turbine	Verdant Power	KHPS + others
Horizontal axis turbine	Kinetic Energy Systems	Bowsprit Generator/Tidal Generator/Hydrokinetic Generator
Horizontal axis turbine	RTV/SSE	Neptune
Horizontal axis turbine	Seapower	Exim
Horizontal axis turbine	Open Hydro	Open Centre Turbine
Horizontal axis turbine	Statkraft	-
Horizontal axis turbine	Tidal Generation	TIDE-GEN
Horizontal axis turbine	Hammerfest Strom	-
Horizontal axis turbines	Underwater Electric Kite	-
Venturi	HydroVenturi (Imperial College)	HydroVenturi
Vertical axis turbine	Blue Energy	Davis Hydro Turbine
Vertical axis turbine	GCK Technology	Gorlov Turbine

B2.2.3 Generating Capacity

The generating capacity of a device is the total power that the device can produce when operating in optimal conditions (i.e. peak energy generation). Optimal conditions for wave and tidal devices are not constant due to the influence of weather and the tidal cycle. Therefore the actual power produced is somewhat less than the generating capacity of the device. The ratio of mean electricity generation to peak electricity generation is called the capacity factor.

The capacity factor for both wave and tidal devices ranges from around 20% to 40%, depending upon specific site and device characteristics (Callaghan, J. and Boud, R., 2006).

The predicted generating capacity for wave devices ranges from 200 kW per device for the smallest OWC devices to up to 2.5 MW and 7 MW for point absorber and over-topping devices, respectively.

The predicted generating capacity for tidal devices ranges from 40 kW per device to just over 2 MW per device for large horizontal axis turbines. The output at peak flow (typically between 2.5 and 4 m/s) in a spring tide is commonly used to determine the generating capacity of the device. Available tidal energy is proportional to the cube of the current velocity, and therefore the range obtainable for the same device in different locations is very large.

B2.3 Device Characteristics

As noted above, a range of information has been sought from developers to inform the assessment of environmental effects. However, as there are very few commercial-scale devices deployed and many devices are still in the concept or prototype stages, it has been difficult to obtain consistently detailed information.

An overview of the information obtained regarding the variations in device requirements and characteristics/attributes is given below and summarised by device type in Table B2.3.

B2.3.1 Depth Requirements

Depth requirements vary considerably across device types.

Wave devices – There are a cluster of wave devices that need depths in the 50 to 80 m range (mainly of the point absorber type), a number of devices that operate in the 30 to 50 m depth range (point absorber, over-topping and OWC devices), and a small group of devices that can operate in 10 to 15 m (OWC and wave rotor devices). The shoreline OWC devices can operate in water depths of only 4 m but require sites where water depth increases rapidly with distance from shore.

High energy waves are associated with the deeper water (50 m and beyond) and large wave arrays are likely to be developed in such depths. As water becomes shallower, the wave energy is attenuated by interaction with the seabed and, therefore, inshore arrays will be of devices that can take off power at the lower energy levels.

Tidal devices - Tidal devices vary in depth requirements based on their configuration, so surface-piercing piled devices are typically located in the 25 to 30 m depth range, whereas bottom-founded devices can operate in depths of 40 to 50 m or deeper. Most devices can be scaled to shallower water depths if required.

The extent of the high energy tidal streams will dictate locations and heavily influence the types of device that may be economic to deploy in a given location.

Proximity to shore - The relationship between water depth and proximity to shore is difficult to summarise due to the wide variations around the Scottish coastline. Placement of marine energy generation devices is more related to capturing the highest energy wave or tide-race than it is about proximity to land. The shoreline wave devices or those which operate in very shallow water need to be at the shore. Only one tidal device - the venturi system - requires being relatively close to land as a pipe manifold is needed to connect the devices to the air turbine which drives the generator on land. Although the distance from shore will be largely influenced by resource availability, cabling costs and maintenance costs will also be taken into account when planning developments and it is likely that sites close in-shore will be developed before sites further offshore are considered.

B2.3.2 Position in Water Column

The majority of devices or their moorings/fixings occupy a large proportion of the water column.

Wave devices – Generally wave devices are driven by wave action at the sea surface and as such the major components of the devices are located at or close to the sea surface. However, although the key elements of the device are located at the sea surface, the devices are moored to the seabed resulting in the majority of the water column being occupied. Table B2.3 below summarises the approximate sub-surface depth and widths of a range of wave devices.

Table B2. 3: Example dimensions of wave devices

Device	Device type	Rated Capacity (MW)	Device Width (m)	Estimate of Sub-Surface Depth (m)
Sperboy	OWC/point absorber		4.5	12
Wave Dragon	Over topping/ terminator	4	260	10-13
Wave Dragon	Over topping/ terminator	7	300	10.5 - 14
Wave Dragon	Over topping/ terminator	11	390	11.5 - 15
PowerBuoy	Point absorber	0.15	11	35
Buldra	Point absorber		33	12.5
Pelamis	Attenuator	0.75	3.5	2.5

Source: Adapted from ABPMer (2006) prepared for CCW/CE

Tidal devices – Tidal stream resource is typically more equally distributed through the water column than wave resource. Therefore, tidal devices can be bottom-founded and do not necessarily require structures at the sea surface. However, some devices require surface structures to enable access for maintenance and repair and/or may need to be marked by buoyage or lights if they represent a hazard to navigation. Typically, devices that are bottom-founded can be varied in size according to the water depth.

B2.3.3 *Protrusion Above Sea Surface*

Some devices float on the surface itself or are suspended from floats on the sea surface. Others have structures that protrude above the surface that house machinery and facilitate access to the device for maintenance and repairs.

Wave devices – The majority of wave devices break the sea surface with only a small proportion being fully submerged. Wave devices that do break the sea surface or which float typically have a low profile with between 2 and 14 m freeboard visible.

Tidal devices – The majority of tidal devices have no requirement to break the surface; however, some do have structures at the surface to allow access for maintenance and repair. Even if the device does not have to break the surface for access, they may be required to be marked by buoyage and lighting for navigational safety reasons depending on their position in the water column.

B2.3.4 *Mooring Methods and Installation Techniques*

There are several methods of attaching devices to the sea-bed. In descending order of installation difficulty, the key methods of attachment are as follows:

- Piling
- Gravity structure (including caissons)
- Anchors
- Clump weights.

The complexity of the technique and invasive nature of the form of installation employed has potential to impact the time-scales associated with installation of the devices.

Piling - Installation on piles is limited to one type of wave device (the wave rotor) but several tidal devices are set on mono-piles. Piles used to secure and mount commercial-scale renewables devices tend to be approximately 4 m in diameter and, typically, are driven some 20 m below the seabed.

The location for piling has to be surveyed, and trial coring may take place to inform pile design. The industry usually drills into the soil and rock layers below the sea-bed using a jack-up vessel. It may be necessary to prepare the seabed to level areas where the jack-up feet (spud cans) will sit on the seabed. The jack-up may take 3-7 days to drill, set, and cement a pile into position. Once the pile is set, the topside structure of the device has to be lifted on to the pile and secured. This is very dependent on the exact design of device and may take 1 to 4 days. Removal of the jack-up may involve waiting on suitable weather/tide conditions. In an array, the jack-up may move from site to site drilling and setting piles, then it or another vessel with a suitable crane will follow through lifting and setting topsides. The installation of rotors may be a subsequent operation or they may be lifted and fitted at the same time. This, again, depends on the exact design of the device.

Gravity Base - Gravity bases are used widely by a number of both wave and tidal stream technologies. By their very nature they are bulky and heavy, although some designs may be ballasted down after they have been set on the seabed. In size they may be 20 to 40 m square or oblong with a variable aspect ratio from device to device. Good design of gravity bases involves inclusion of features that will assist removal of the gravity base at the end of its useful life.

Generally, following site survey and sea-bed preparation, the site will be marked with buoys and/or sonar devices and the gravity base (made buoyant by temporary closures of some elements, buoyancy bags or supported between barges) will be towed and positioned on site by tugs. The ballasting down operation will commence and be completed within, usually, a number of hours, so that the whole operation at site is completed within 1-2 days in a favourable weather window.

Additional work may then be required to add on some parts of the device, which in a number of cases can be removed at intervals for maintenance.

These operations tend to be much quicker than mono-pile installation but also tend to be more weather sensitive.

Anchors – A large proportion of wave devices and a small number of tidal technologies are moored with anchors and chains or wires.

Generally, anchors are pre-set by a support vessel in the area at pre-determined positions; this may be done over a period of 2 to 4 days. The device is then towed to the site by a suitable vessel and the anchor handler retrieves the anchor chains/wires and they are fastened to the device. It is highly desirable to complete the attachment of the device within daylight hours, so the duration of this stage of installation is very short.

Clump Weights - Clump weights vary from being steel blocks at the smaller end of the size range to fabricated steel baskets that are loaded up with large link chain to provide weights of several tens of tonnes.

These are pre-installed from a vessel with suitable lifting gear over 2 to 3 days and subsequently the device is towed to site and attached to the chains or wires that are associated with each clump weight. The seabed disturbance is very similar to that for anchoring and is incurred only in the areas upon which the weights are placed.

B2.3.5 Moving Parts in Contact with the Sea Water

The key moving parts associated with devices are turbine blades.

Wave devices - The majority of wave devices do not have moving parts such as turbines in contact with sea water and those that do typically use mesh protection (sometimes referred to as “trash rags”) to prevent fish, mammals etc from being sucked into the turbines. Some wave devices have hinged sections that move with wave action.

The wave rotor type device is the only wave device that has moving turbine blades in contact with sea water which are thought to rotate at approximately 25 revolutions per minute.

Tidal devices – All tidal devices apart from the venturi type have moving turbine blades in contact with sea water. The turbine devices commonly operate at between 20 and 30 revolutions per minute and turbine diameters for commercial horizontal axis turbines are typically some 10 to 16 m but can be varied according to site characteristics. Information available on vertical axis turbines would suggest that turbine diameters also vary (from approximately 3 m to approximately 6 m in diameter and up to 6 m in height), depending upon the device configuration.

B2.3.6 Shrouding

Shrouding is the encasing of a device within a container which is open at both ends. Only one of the devices listed in Table B2.2 above is fully shrouded. The shroud increases the power available from a rotor by a factor that may be as high as fourfold, subject to the exact design.

B2.3.7 Noise

Construction and installation, operation, and decommissioning of marine renewables devices (and, to a lesser extent, the associated cables) give rise to noise emissions. During construction and installation the key sources of noise are geophysical survey, shipping and machinery, pile driving, drilling, rock placement, and trenching. Noise associated with operation is related to the action of valves, motors, fans, gearboxes, turbines and other mechanical features. Noise associated with decommissioning is similar to that associated with installation and construction.

Current understanding and knowledge would suggest that construction noise for marine renewable devices is likely to be far greater than operational noise. The noise levels associated with construction, operation and decommissioning will be detailed in the relevant section of the ‘Level 1’ assessment of the SEA. This will be informed by the available information (from COWRIE and ETSU, for example) on construction and decommissioning noise and a specialist study on the predicted operational noise of marine renewable devices and arrays.

In general, wave and tidal developers have sought to minimise noise from their devices in operation. This is achieved by removing as many mechanical parts as possible to above the waterline, thereby designing out as much noise as possible. This also makes for better efficiency as noise is a means of dissipating energy.

B2.3.8 Coatings and Antifouling

Fouling of marine renewable devices by marine organisms such as algae and molluscs can reduce their efficiency. A small number of both wave and tidal device developers report that they use special antifouling coatings to prevent fouling of their devices by marine organisms. Historically, antifouling paints have contained organo-tin biocides such as tributyl-tin (TBT) which has been found to cause deformations in oysters and sex changes in whelks, or copper which is also toxic to a wide spectrum of marine wildlife. The organo-tins and copper from the antifouling coating leach out killing barnacles and other marine life that have attached to the structure. Use of organo-tin antifouling coatings are now banned but the use of copper is still permitted.

There have been some rapid developments in antifouling materials in recent years with non-toxic, non-stick coatings made of silicon or Teflon being developed which prevent the settling of marine organisms. Scandinavian developers have specifically committed to use benign coatings from an early stage in their conceptual development.

It is expected that the majority of developers will seek to use non-toxic antifouling materials as far as possible.

Some devices also use sacrificial anodes (cathodic protection) (see below) to protect against corrosion.

B2.3.9 Sacrificial Anodes

It is usual to protect steel structures by attachment of “sacrificial anodes” which are attached to steel objects in corrosive environments (such as seawater).

An anode is a piece of readily corrodible metal attached (by either an electrically conductive solid or liquid) to the metal you wish to protect. This piece of metal corrodes first, and generally must dissolve nearly completely before the protected metal will corrode (hence the term "sacrificial").

Based on a typical device installed in 50 m water depth, it is estimated that discharges of aluminium would add an extremely small 1.31 x 10-5 % per year to the ionic material (other than the common salts of sodium, magnesium, potassium and calcium that make up the mean inorganic solids content (US office of Saline Water, 1959)) in seawater.

B2.3.10 Hydraulic Fluids

Devices which use hydraulic systems will normally be designed such that at least two seal or containment failures are required before a leaking fluid reaches the sea. It is not possible to be definitive for every device listed in this document as a number of them are still at concept stage and this aspect is a matter for detailed design. However, the industry’s design guidelines (Carbon Trust, 2005), if followed, would lead a developer to minimise risks of hydraulic fluid leakage. Details of the risk of leakage would need to be included in the project EIA submission necessary to obtain consent to install the device.

Leakage of oil from mechanical equipment or lubricated joints in contact with sea water is difficult to quantify and determine. It should be noted that many of the devices avoid having mechanical components in contact with the sea; however, this is not always possible. Tidal rotors, for example, have to make contact with the sea to operate. Once again, the precise nature of the containment of oils and greases is a matter for detailed design and must be addressed in individual cases in project EIAs.

Furthermore, design leakage rates will be small as part of the approach to creating low-maintenance devices which, in this context, means that device developers aim to design devices that do not require frequent oil replacement or grease injection into bearings. The general approach used by developers would be to select efficient containment systems that minimise leakage.

Where a device design will result in some unavoidable seepage to the sea, biodegradable options are likely to be selected for both hydraulic and lubricating oils and greases.

B2.4 Maintenance Requirements

In general, device developers are seeking to design for minimum maintenance. Those wave developers who have given an indication of times for maintenance give times ranging from a few hours to a few days per year. Tidal device developers who have given an indication of maintenance times give values from a half day to two weeks per year.

Planned interventions are arranged such that a minimum of offshore working is required, sometimes with the device being taken off-site to a safe haven for work to be carried out.

Access to devices for breakdown maintenance is likely to be limited by weather conditions. It is generally unlikely that developers will attempt to do other than inspection or minor work offshore for safety reasons.

Access to devices has safety implications and developers are responsible for ensuring that appropriate facilities are built into the device and proper procedures are developed for access and egress. Wherever possible, developers are planning to carry out most activity without actually accessing a device unless a properly designed platform is provided for that purpose. Developers are aware of the safety issues associated with device maintenance and will seek to comply with all safety requirements.

B2.4.1 Removal of Devices from Site

Ease of removal for repair and maintenance is an important factor in the overall concept of devices and the systems to facilitate removal in whole, or more frequently, in part, are key objectives of the design.

Wave - A minority of wave developers have opted for full removal of the device for repair and maintenance activities, whereas another small group have specified use of divers or remotely-operated vehicles to carry out maintenance, rather than temporary removal. Where removal is planned, design focus has been to minimise the specification of vessel required for the task to control costs as far as possible.

Tidal - Tidal technologies are, typically, fixed via piles or gravity bases and therefore rely on systems to remove or access the essential parts of the device where the turbine, gearbox or generator are located, rather than removing the whole device. These systems are quite specific and often a proprietary part of the technology.

Safety issues are as large an influence on the techniques employed for removal as they are for maintenance of the devices.

B2.4.2 Decommissioning

The necessity for site clearance in the UK arises from the requirements of the OSPAR Convention which, in this case, is enforced by the Crown Estate. Developers are required to make provision for undertaking of site decommissioning and clearance by providing predicted methods and financial planning for decommissioning work as part of their lease agreements. A specific permit is required to leave or dump any item or parts on the seabed and such permits would be examined on a case-by-case basis.

Decommissioning entails a similar scale of works undertaken by similar mechanical means to construction and installation.

Good design of marine renewable energy devices involves inclusion of features for facilitating removal and decommissioning. For example, a gravity base may have internal piping installed that enables connection of an air pump to jet out the mud below the gravity base and allow it to be lifted more easily for removal.

A summary of characteristics of the various device types considered is presented in Table B2.4 below.

Table B2. 4: Summary of device characteristics

Device Category		Water Depth	Position in Water Column			Moving Parts in Contact with Water		Shrouding		Noise Emission Source		Mooring Method						Pollutant			Maintenance Location	
			Structure Pierces Sea Surface	Device (including moorings) Occupies Entire Water Column	Device Occupies only Lower Portion of water Column	Turbine	Other	shrouded	Not Shrouded	Above Water	Below Water	Shoreline Mounted	Gravity Structure	Anchors	Clump Weight	Monopile	Tripod	Antifouling Paint	Sacrificial Anodes	Oils and Hydraulic Fluids in Contact with Water	In Situ	Towed to Shore or Shelter
Oscillating Water Column - Shoreline	Wave	Greater than 4m, getting deeper rapidly	● (3.5m above sea level	●	N/A	X	X	N/A	N/A	●	X	●	X	X	X	X	X	N/D	N/D	X	●	N/A
Oscillating Water Column - Nearshore	Wave	10 – 15m	N/D	●	N/D	X	X	N/A	N/A	●	X	X	●	X	X	X	X	N/D	X	X	N/D	N/D
Oscillating Water Column - Offshore	Wave	30 – 50m	● (Example given of 6m above sea surface)	●	X	X	X	N/A	N/A	●	X	X	○	○	X	X	X	X	X	X	●	N/A
Over Topping/Terminator	Wave	30 – 50m	● (Up to 14m)	●	X	●	X	X	●	N/D	N/D	X	X	○	○	X	X	○	○	○	●	X
Point Absorber – Nearshore	Wave	5 – 40m	N/D	●	X	X		N/A	N/A	N/D	N/D	X	○	X	X	○	X	N/D	N/D	N/D	N/D	N/D
Point Absorber/Attenuator – Offshore	Wave	30-80m	● (Up to 10m)	●	X	X	○	N/A	N/A	○	○	X	X	○	○	○	X	○	○	○	○	○
Wave Rotor	Wave	N/D	N/D	○	○	●	X	N/A	N/A	N/D	N/D	X	X	X	X	●	X	N/D	●	N/D	●	●
Vertical Axis Turbine	Tidal	10 – 40m	○	○	○	●	X	X	●	N/D	N/D	X	○	○	○	X	X	○	X	N/D	●	X
Horizontal Axis Turbine	Tidal	10 – 70m	○ (Up to 10m)	○	○	●	X			N/D	●	X	○	○	○	○	○	○	○	○	○	○
Venturi	Tidal	Variable – tailored to fir	X	X	●	X	X	N/A	N/A	N/D	N/D	X	●	X	X	X	X	X	X	X	●	X

Key: N/A – Not applicable N/D – No data ● - All devices in category ○ - Some devices in category X – No device in category

B3 Development Size Assumptions

For the purposes of this SEA, assumptions have been made on the power generating capacity of an array of marine renewable energy devices and the number of devices in such an array in order to give an indication of the potential scale of environmental effects.

The information in sub-section B2 demonstrates that there is currently a large range of devices in development, and generating capacity of a single device ranges from 40 kW to 7 MW.

The assumptions with regards to the number of devices in an array and footprints of arrays are outlined in sub-sections B3.1 and B3.2 below. For this SEA it has been assumed that commercial device arrays will be approximately 50 MW in generating capacity and will contain approximately, 20 to 50 devices. This assumption is considered to be a best case development scenario, assuming that the technology matures successfully and that financial support mechanisms are made available to aid the development of the industry. It is also influenced by the following:-

- A recent report of the BWEA/npower Juice Fund “Path to Power” project which defines a significant commercial project as being more than 30 MW and predicts that such projects will begin to come to fruition around the year 2012 (Bond Pearce, 2006).
- The requirement for this SEA to take into account the Scottish Executive’s target of generating 40% of electricity from renewable sources by 2020 and the Marine Energy Group work that concluded that by 2020 1,300 MW of marine energy capacity could be installed in Scottish Waters.

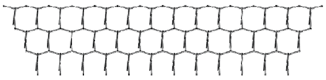
B3.1.1 Numbers of Devices in Commercial Arrays

The numbers of devices that are likely to be incorporated into commercial arrays varies depending upon the device types and the development site characteristics. Due to the current developing state of the industry, the majority of device developers have not fully addressed the design issues associated with large arrays of devices. The following information is therefore indicative only.

Wave - Developers are quoting numbers of devices from between 20 and 600. However, it is very early in the development process for a number of these and it seems most likely that the early commercial arrays will contain between 20 and 50 devices, built in stages over two or three years. The degree of interaction between devices is not yet fully understood in many cases and developers will look to evaluate this further in smaller pre-commercial arrays that may consist of 5 to 10 devices. A typical array size of 20 – 50 devices with an installed capacity of approximately 50 MW is assumed in this SEA.

Examples of arrays of wave devices are outlined in Table B3.1 below.

Table B3. 1: Example wave device arrays

Example Arrays ↓(Direction of Approaching Waves)	**Example Installed Capacity (MW)**	**Typical Separation (m)**
Pelamis  (4 x 0.9 km)	29.25 (39 * 0.75 MW units)	> twice device length (120 m)
Wave Dragon (4 x 0.8 km)	49 (7 * 7 MW units)	> 1 unit width (300 m)
PowerBuoy Arrangement of 25 x 4 units (Maximum footprint 4 x 0.8 km)	15 (100 * 0.15 MW units)	Between 200 m and > 6 unit diameters (33 m)

Source: ABPMer 2006 prepared for CCW/CE

Tidal – Developers are suggesting numbers of devices from about 30 to 100 in an array. Clearly, the lower figure is a likely starting point for commercial arrays and, as with wave devices, developers will wish to gather more data on the extent and nature of wakes created by tidal stream devices. Tidal arrays will always be highly dependent on location, to the extent that it is difficult to envisage a “standard” array at this time. The extent of a tidal array cannot be determined without detailed survey of the pattern of tidal current in a location.

A typical array size of 30 – 50 devices with an installed capacity of approximately 30 - 50 MW is assumed in this SEA.

B3.1.2 Device Array Footprints

The potential footprints of single devices, arrays and the spacing of units within arrays are very device specific. The range of “area take up” and a discussion of unit spacing for wave and tidal devices are given below. As before, this information is indicative only.

Wave – Information from device developers suggests that first-generation commercial wave device arrays are likely to take up areas of approximately 1 km by 4 km in oblong shapes similar to wind farms. The exact size and shape of the array will be influenced by the individual device configurations and environmental factors. Due to the different configurations of devices it is difficult to generalise on the extent to which they take up space (e.g. a point absorber buoy in deep water may have moorings that spread out a significant distance and increase its separation from its neighbours in the array).

Tidal – Little information is available on the potential footprints of tidal device arrays. Based on current information, a 30-unit tidal array could typically be expected to occupy 0.5 km2, arranged in an oblong shape, the short dimension of which would be dependent on the width of the high energy tidal stream. This is a conservative estimate based on the fact that developers are still developing understanding on device spacing and the extent of wake effects. As knowledge and understanding increases it is likely that a greater number of devices and/or megawatts will be associated with the same footprint. It should be noted that areas of tidal resource are typically small in comparison to areas of wave resource due to the specific topographical features required to create the faster flowing tidal streams. Therefore, the size of tidal arrays will be restricted by resource availability to a greater extent than wave device arrays.

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