Technical overview of wave and tidal stream energy

What is marine energy?

'Marine energy' is a term used to describe all forms of renewable energy derived from the sea.

Tidal energy occurs due to large movements of water in the sea. As tides come in and out (flow and ebb), water near the coast is raised and lowered and the potential energy of this tidal range can be exploited. It is also possible to harness the kinetic energy of the moving water in the tidal stream itself.

Wave energy occurs due to movements of water near the surface of the sea. Waves are formed by winds blowing over the water surface, which make the water particles adopt circular motions. This motion carries kinetic energy, the amount of which is determined by the speed and duration of the wind, the length of sea it blows over, the water depth, sea bed conditions and also interactions with the tides.
Two important things to realise about wave energy and tidal energy are:
Waves occur only in the volume of water closest to the water surface, whereas in tides, the entire water body moves, from the surface to the seabed; and
In tides, the energy is due to a net movement of water, but in waves, the water acts as a carrier for energy, moving it in some direction, but does not undergo a net movement itself.

How can marine energy be harnessed?

A wide variety of concepts have been proposed for the extraction and conversion of marine energy to electricity. Some of these are introduced below:

Tidal power

Several types of device have been designed to capture tidal stream energy:

Tidal stream turbines – These work on a similar principle to wind turbines and indeed may look quite similar. Both horizontal- and vertical-axis machines are being investigated, some with ducting/cowling around the rotor. The turbine may be coupled directly to a standard generator via a gearbox, or use an alternative power train design;

Reciprocating tidal stream devices – These have hydrofoils which move back and forth in a plane normal to the tidal stream, instead of rotating blades. One design uses hydraulic pistons to feed a hydraulic circuit, which turns a hydraulic motor and generator to produce power; and

Venturi effect tidal stream devices – In these, the tidal flow is directed through a duct, which concentrates the flow and produces a pressure difference. This causes a secondary fluid flow through a turbine.

Alongside these options, there is a debate about the relative merits of fixing devices to the seabed for stability and deploying floating devices to allow retrieval for maintenance. Some tidal stream devices are being demonstrated in the UK and the MEC has a work package to look at all the designs mentioned above.

Tidal power can also be extracted from tidal barrage and tidal lagoon systems. These are outside the scope of the MEC but are mentioned here for completeness. The tidal barrage is a long-established, technically-proven concept which essentially involves a structure with gated sluices and low-head hydro turbines. Bridging two sides of an estuary, the principle of operation is to allow water to flow into the area behind the barrage with the flood tide and out during the ebb tide. As water flows out, the collected head of water turns the turbines to generate power. A tidal barrage has been in operation at La Rance on the northern French coast for more than 40 years, and schemes have previously been proposed in the UK, notably at the River Severn. The tidal lagoon operates in a similar way to the barrage, but uses an impoundment structure rather than a barrage.

Wave Power

The problem of wave energy extraction is complex and many designs of device have been proposed. It is helpful to introduce these in terms of their physical arrangements and energy conversion mechanisms.

Physical arrangements

Placement – Devices may convert wave power at the shoreline, near to the shore or offshore. The distinction between near-shore and offshore is often related to design requirements for water depth (this generally increasing with distance from shore), the energy content of waves (this being greater offshore), and access for deployment, retrieval, operation and maintenance.

Fixing – Near-shore and offshore devices may be either bottom-mounted or floating, the former being fixed to the seabed by a static member and the latter moored to hold on station.

Reaction – Wave energy devices need a system of reacting forces in order to extract energy and this is one of the biggest design challenges. To create such a system, two or more bodies need to move relative to each other, while at least one body interacts with the waves. There are numerous approaches towards this, some of which are being considered in the MEC. One approach is to allow one body to move freely with the waves, while another is held static (as in the case of a floating buoy reacting against the seabed). Alternatively, all of the bodies may be dynamic.

End stop – Within the reaction system, a common requirement is to avoid situations where the relative motion is so large that destructively high forces occur between the bodies, (e.g. a hydraulic piston being forced beyond the end of its stroke).

Wave energy devices can be classified by means of their reaction system, but it is often more instructive to discuss how they interact with the wave field. In this context, each moving body may labelled as either a **displacer** or **reactor** .

Displacer – This is the body moved by the waves. It might be a buoyant vessel, or, as in the case of Oscillating Water Column (OWC) devices (see below), a mass of water. If buoyant, the displacer may pierce the surface of the waves or be submerged.

Reactor – This is the body that provides reaction to the displacer. As suggested above, it could be a body fixed to the seabed, or the seabed itself. It could also be another structure or mass that is not fixed, but moves in such a way that reaction forces are created (e.g. by moving by a different amount or at different times). A degree of control over the forces acting on each body and/or acting between the bodies (particularly stiffness and damping characteristics) is often required to optimise the amount of energy captured.

In some designs, the reactor is actually inside the displacer, while in others it is an external body. Internal reactors are not subject to wave forces, but external ones may experience loads that cause them to move in ways similar to a displacer. This can be extended to the view that some devices do not have dedicated reactors at all, but rather a system of displacers whose relative motion creates a reaction system.

The generality of the above might suggest there are many ways in which a wave energy device can be configured and indeed this is the case. Some of the most well-known device concepts are introduced below:

Oscillating Water Column (OWC)– This comprises a partly submerged structure (‘collector’) which is open to the sea below the water surface so that it contains a column of water. Air is trapped above the surface of the water column. As waves enter and exit the collector, the water column moves up and down and acts like a piston on the air, pushing it back and forth. The air is channelled towards a turbine and forces it to turn. The turbine is coupled to a generator to produce electricity.

Overtopping– This consists of a structure over which the waves topple, a reservoir to collect the water and hydro turbines installed at the bottom of the reservoir. The head of collected water turns the turbines as it flows back out to sea and the turbines are coupled to generators to produce electricity.

Point absorber– This is a floating structure that absorbs energy in all directions by virtue of its movements at or near the water surface. It may be designed so as to resonate – that is, move with larger amplitudes than the waves themselves. This feature is useful to maximise the amount of power that is available for capture. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors.

Terminator – This is also a floating structure that moves at or near the water surface, but it absorbs energy in only a single direction. The device extends in the direction normal to the predominant wave direction, so that as waves arrive, the device restrains them. Again, resonance may be employed and the power take-off system may take a variety of forms.

Attenuator – This device is a long floating structure like the terminator, but is orientated parallel to the waves rather than normal to them. It rides the waves like a ship and movements of the device at its bow and along its length can be restrained so as to extract energy. A theoretical advantage of the attenuator over the terminator is that its area normal to the waves is small and therefore the forces it experiences are much lower.

There are many further different design concepts. One other device that was considered in the MEC is the **Wave Rotor**, which is a form of turbine turned directly by the waves. It is coupled to a generator in order to generate electricity.

Other devices use contained volumes of water, or exploit differences in water pressure. Flexible structures have also been suggested, whereby a structure that changes shape/volume is part of the power take-off system.

Common terms in wave energy and tidal stream energy

The energy content of waves is a function of wave height and wave period

Wave height – A measure of the amplitude of oscillation of water particles, in the vertical direction with respect to a fixed point. Since the oscillations exhibit a range of values in real sea conditions, it is helpful to talk about a representative wave height. The significant wave height (Hs) is commonly referred to and is approximately equal to the average height of the highest one-third of the waves. (The actual definition is four times the root mean square of the water levels relative to the mean water level. The mean water level is the level the sea would be at if it was still).

Wave period – The time that elapses between successive peaks or troughs of a wave passing a fixed point. Like wave heights, waves exhibit a range of periods and a representative term is helpful. The zero up-crossing period (Tz) is one such term and is the average time interval between successive crossings of the mean water level in an upward direction.

Sea state – In real sea conditions, many wave heights and periods occur simultaneously and it is necessary to resort to a statistical description. Data for a particular site can be summarised on a scatter diagram, which is a record of the wave motions, showing the number of occurrences of particular combinations of Hs and Tz. Each combination of Hs and Tz is referred to as a sea state.

Tidal stream energy resource
The energy content of tidal streams is a function of current velocity.

Current velocity – The speed of water particles moving in the tidal stream in the mean flow direction.

Marine energy generation devices

Efficiency – This can be defined in several different ways. A simple view is to consider ‘resource-to-wire’ efficiency: the ratio of the energy a device actually captures to the energy that is available to be captured.

Availability – The proportion of time a device is ready to generate, irrespective of whether the resource is suitable for generation.

Capacity factor – The energy produced during a certain period divided by the energy that would have been produced had the device been running continually and at maximum output