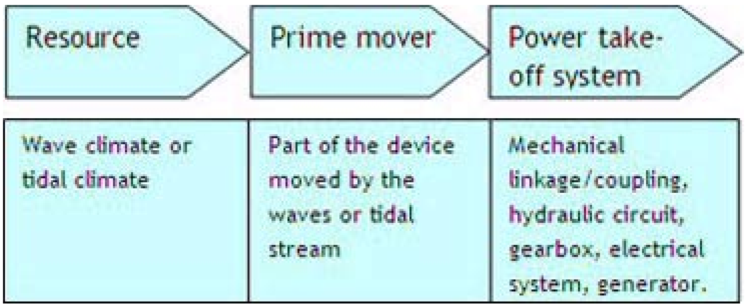
Energy capture performance

Cost of energy is a critical factor to the success of marine renewables, in order for marine renewables to compete with other forms of renewable and fossil-fuelled power generation.

Cost of energy is influenced by performance, capital costs, operating and maintenance costs and risks. The previous article introduced design changes that could be made to marine renewables devices that affect both performance and costs. This article goes on to look in more detail at performance and some of the key factors that affect it.

What influences a device's performance?
Essentially, the energy converted into electricity by a marine renewables device is a function of the resource the device is placed in (local wave conditions or tidal conditions), the device's prime mover (mechanical component(s) that absorbs energy from the resource – e.g. the rotor of a tidal stream turbine), and the device's power take-off system (everything between the prime mover and the electrical terminals for connection to the grid). This is a dynamic system and changes to one aspect can have a significant affect on another.

Figure 1: Key factors influencing the performance of marine renewables devices



Because of the many ways that marine renewables devices can be configured, their performance characteristics vary widely. To understand performance characteristics in detail, it is necessary to look closely at specific device designs. However, it is possible to make general observations about the performance characteristics of wave energy and tidal stream devices and identify requirements for high performance that are common to many design variants.
Some of these requirements also apply to other types of generation plant, and therefore may already be familiar. They include:

- **Efficiency.**
  A simple 'resource-to-wire' definition of efficiency may be useful to describe the absolute performance of a marine energy device but assessments of efficiency open up a large number of questions. These include the theoretical maximum energy that the device could be expected to capture, the intermediate efficiencies of its prime mover and individual power take-off system components, and the certainty to which the resource's energy content itself can be described. Furthermore, overall efficiency may be influenced by certain control and operating regimes that relate to other aspects of the design, including survivability.

- **Availability.**
  The proportion of time that the device is ready to generate, whether or not the wave conditions or tidal conditions are suitable for generation, directly influences the quantity of energy generated over time. Availability is often used to indicate requirements for maintenance and/or levels of reliability, since downtime is usually related to one or both of these things. Especially for offshore devices, device availability is closely related to the developer's overall design maintenance philosophy because access is more difficult than onshore plant. Balancing availability with costs of components and maintenance costs is a key economic argument. It is important to distinguish device availability from resource availability; both are controllable and influence a device's cost-of-energy, but the latter is more a matter of appropriate site/resource selection than a reflection of device performance.

  Variation of power with resource conditions
  During operation, conditions of the resource (either wave energy or tidal stream energy) vary continuously over time. For wave energy devices, three parameters are relevant: wave height, wave period and wave direction, while for tidal stream we are most interested in two: current speed and direction. With some devices direction is unimportant (e.g. point absorber wave energy devices and vertical axis tidal stream devices), but even for devices that do have a directional dependency the other parameters are generally most important. We can reduce the description of wave power capture to a three-dimensional problem (power, wave height, wave period), and descriptions of tidal stream power capture to two dimensions (power, current speed). Figures 2 and 3 illustrate how the parameters are related. The diagrams are an example tidal stream device power curve and wave energy device power surface, respectively. (Note that the diagrams are for imaginary devices and solely for illustration. The graphs for real devices may differ.)

Figure 2: Example tidal stream energy device power curve highlighting conditions where no power is generated

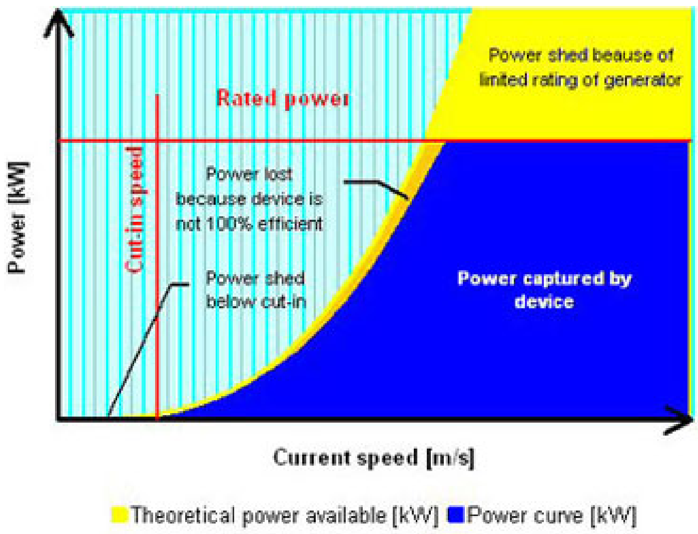
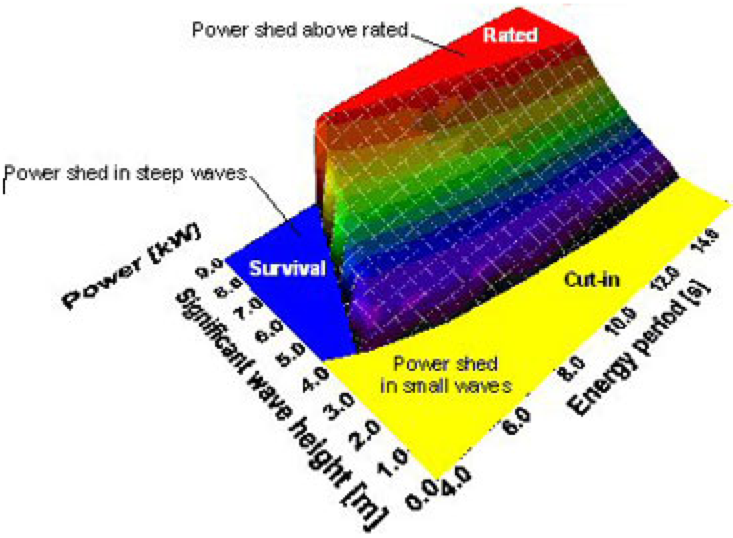


Figure 3: Example wave energy device power surface highlighting conditions where no power is generated



An ideal wave energy device would capture all the power in the waves that it interacts with, and an ideal tidal stream device would capture all the power in the tidal stream cross-section that it intersects. But this is not possible in practice; there are certain conditions in which devices cannot operate and consequently no power is generated. These conditions are illustrated in Figures 2 and 3. Considering Figure 2 first, we can see that at all speeds the power captured is always less than the maximum. This is because the prime mover can never be 100% efficient; (there are a number of well-established theories that indicate the maximum energy that can be extracted from a flowing stream and tidal stream situations are the subject of present research). Furthermore, losses will occur within the power take-off system components. These can be reduced, but in practice there is likely to be an economic minimum beyond which increased costs deliver only modest performance improvements. It can also be seen that the device does not operate over the entire range of speeds and that generation begins only after the speed has reached a certain level. This is known as the 'cut-in' speed, and reflects the lowest speed at which it is economic to begin capturing power. The device designer might also choose to limit the output at high speeds, as indicated by the 'cut-out' speed. Effectively the device sheds some of the available power in this range, and the choice of cut-out power is related to the generator rating. The designer must weigh up the extra cost of installing a higher-rated generator against the relative advantage of capturing more power. (Note that the cut-out region is not to avoid over-speed situations, since the maximum tidal stream speed is within the range it would be possible to absorb power over and is highly predictable. This is unlike wind energy, where extreme wind speeds occur randomly and are often faster than it is economic to capture energy from.)

Figure 3 indicates that there are similar considerations for wave power devices. Again, there is a cut-in region below certain levels of wave height and wave period, and also a plateau where the power is above rated capacity and some of the available power is shed. A similar economic argument applies to the cost of the generator and the performance advantage of increasing its capacity. Unlike the tidal stream characteristic, however, there is also another region where power is shed. This where the waves are large and have short periods. Such waves can be problematic because they tend to be steep and break over the device, causing large structural loads. It may be most economic to avoid generating power in this region and instead concentrate on survivability, (analogous to the high wind speed cut-out region of wind turbines). In practice, wave energy devices may have other survivability strategies that will be reflected in their power surfaces. Also, they may not have such an even response over the range of sea states and/or may be tuned to certain sea conditions.

Assessment of long-term energy capture

Having considered some of the factors that affect instantaneous power and captured this information in either a power curve (tidal stream device) or power surface (wave energy device), it is possible to estimate the energy capture over time. Unlike e.g. wind power and hydro power, performance measurement and long-term prediction techniques for marine energy are still at an early stage of development. Device-specific methods are necessary at present, but it is possible to observe common features of these methods.

Essentially what is needed in addition to the power curve or power surface is historic information on the resource conditions, specifically the frequency of occurrence of tidal stream current speeds or frequency of occurrence of wave heights and wave periods. Figure 4 shows two histograms of current speeds for an imaginary tidal stream site, one simply as a proportion of the time of measurements and the other weighted by energy content. In Figure 5, the energy-weighted histogram is shown in combination with the example tidal stream device power curve from Figure 2. It can be seen that the power curve is a good match to the histogram over most of the range of current speeds. This behaviour is key to the overall device design in enabling the device to generate the maximum energy over time. Also shown is the rated speed, which coincides with the rated power. The designer has chosen this to give the most economic energy capture over time. Finally, the device's energy capture as a proportion of the annual energy available is shown. It can be seen from this that the largest contribution is from currents at – and close to - the rated speed.

Figure 4: Example distribution of tidal stream current speeds as proportions of total time and total annual energy

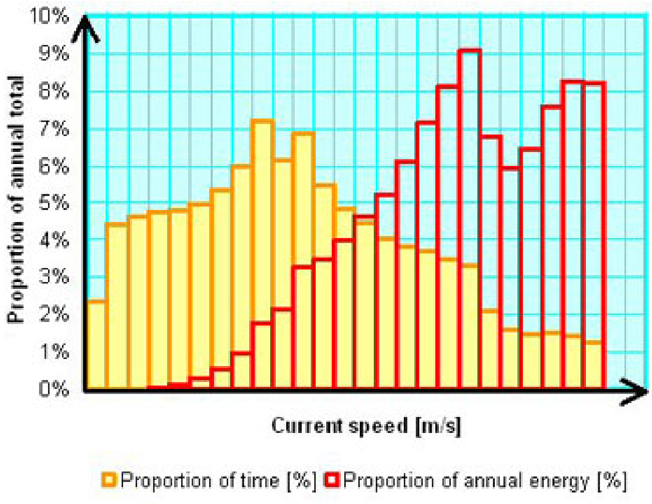
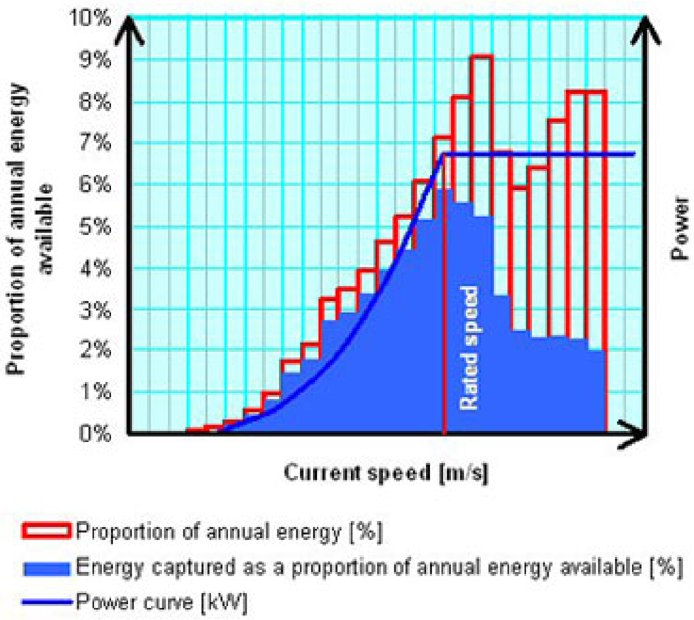


Figure 5: Example distribution of tidal stream current speeds as proportions of total annual energy, with example tidal stream device power curve (Figure 2) overlaid



Figures 6 and 7 are equivalent illustrations for wave energy, with the data in Figure 3 being for an imaginary wave energy site. Comparing Figure 6 with Figure 3, we can see that the overall shape of the wave energy device power surface (Figure 6 - a smooth hill) is quite different to the distribution of wave energy (Figure 3 – several peaks). Figure 7 puts the two diagrams together, using the same colours as Figure 3 to illustrate the annual energy content. With this combination of device and resource characteristics, we can see that the survival region is avoided altogether – a good feature. Also, the device is able to respond to periods in the range 8–10 seconds – another good feature. But on the other hand, much of the resource is below the cut-in curve, and little energy is shed above the rated power – bad features. So perhaps the device is not optimally matched to the resource; the designer might conclude that the device needs to capture waves at lower wave heights and that a smaller generator may be more economic. Furthermore, given the concentration of energy in the period range 8-10s, it might be better to tune the device more specifically to this range, perhaps by narrowing its bandwidth (see the article 'ocean waves and wave energy device design').

Figure 6: Example distribution of wave energy with wave height and wave period. (N.b. This is a scatter diagram in 3D form)

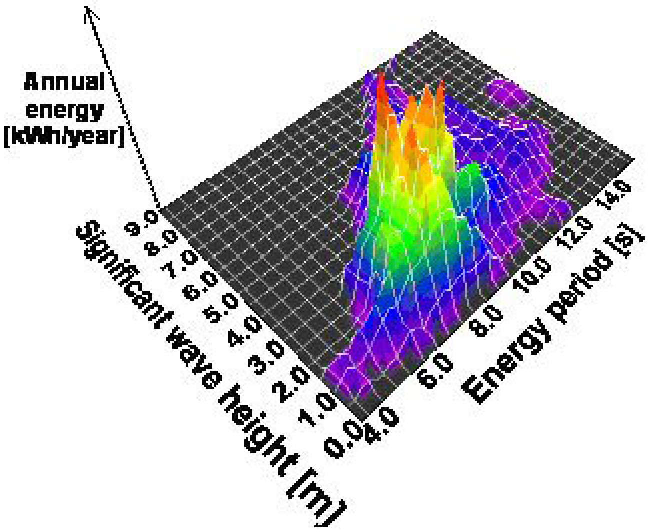
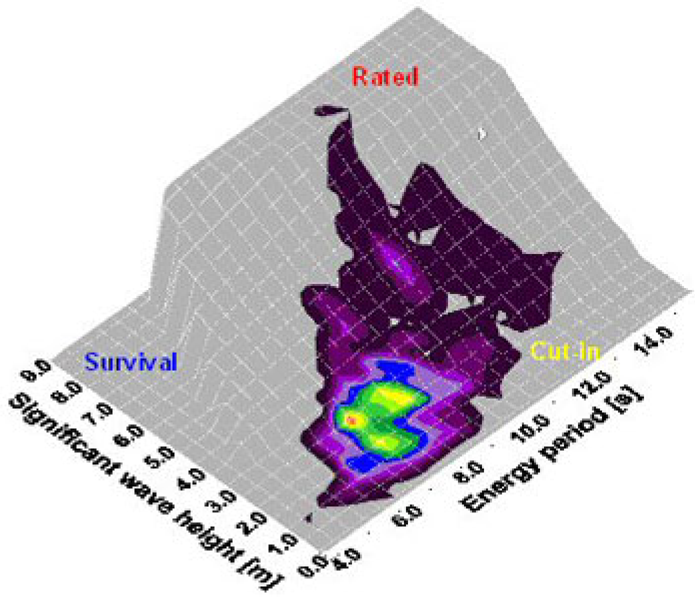


Figure 7: Example wave energy device power surface with distribution of wave energy with wave height and wave period superimposed.



Summary

- Along with capital costs, operating and maintenance costs and risks, the performance of a marine energy device is key to its cost of energy.
- Performance is determined by the wave energy or tidal stream energy resource, the device's prime mover and power take-off system .
- Efficiency, availability, matching to resource conditions and sizing are important factors (in common with other types of energy generation plant).
- The performance of a tidal stream device can be described by a power curve on two axes: power and current speed. For wave energy devices, one need consider a power surface on three axes: power, wave height and wave period.
- Cut-in, cut-out and rated conditions may apply to either wave devices or tidal stream devices. They are based on the designer's judgments about the ranges of resource conditions it is economic to generate in.
- Assessments of long-term energy capture require historic resource information in addition to either the power curve or power surface. By combining the two, one can further understand and optimise device performance.