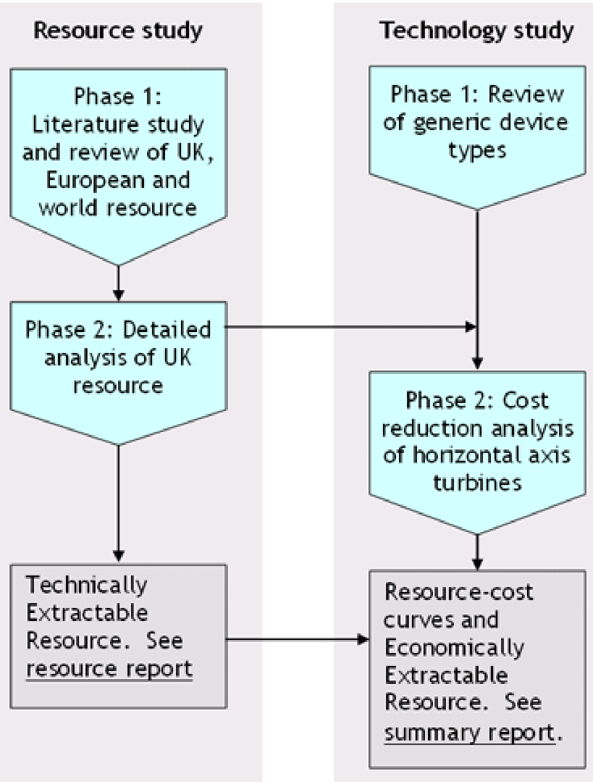
The UK tidal stream resource and tidal stream technology

As a key part of the Marine Energy Challenge, the Carbon Trust asked Black & Veatch (B&V) to study the tidal stream energy resource and options for generation technology. This article summarises the project's conclusions.

Figure 1 shows the scope of the project. Two reports were delivered as the project's culmination, one about the UK tidal stream resource and the other giving a brief summary of the complete project. The resource report describes results of detailed analysis work and updates previous findings about the UK resource, while the summary report comments on an analysis of the cost-of-energy reduction potential of tidal stream generation systems. The two reports can be read in conjunction or readers may prefer just the summary report.

Figure 1: Overview of Marine Energy Challenge tidal stream project



Resource study

Methods of estimating tidal stream resources

B&V found that the 'farm' method of resource estimation that has been used in some previous analyses has limitations for tidal stream situations because it does not necessarily take account of the limit of upstream energy flux. Subsequently, Black & Veatch adopted the 'flux' estimation method, which has also been proposed independently by Robert Gordon University (RGU). The two methods are discussed in Figure 2.

Figure 2: 'Farm' versus 'flux' calculations

Estimates of a tidal stream site's resource have formerly been made by imagining a "farm" of generation devices (like a wind farm), arranged in a grid-like formation. The 'extractable energy' depends on the number of devices deployed, which is taken to be a function of the size of device, the device's efficiency, and the 'packing density' of devices within the plan area, (all assumed to be constant for a particular site). The major problem with this estimation methodology (which is broadly correct for wind farms) is that the energy within a tidal stream site is broadly fixed by the flow entering the upstream cross-sectional area of the site, and therefore has a limit that is not taken into account by this "farm" methodology.

In the "flux" analysis, the total energy of a site is considered to be that which flows into it through the upstream cross-section of the tidal stream, independent of the number of devices, their size, efficiency and packing density. Therefore it is possible to conceive of sites where the "farm" methodology would give rise to more energy being "extracted" from this "farm" layout than actually existed within the site (as defined by the "flux" analysis). Preliminary work by B&V showed that this could well be the case for many of the tidal stream sites now that the characteristics (device size, efficiency and packing density) of the "farm" have been improved significantly since the 1993 and 1996 studies. This showed that the application of the flux approach was extremely important in order to set the limit for the "farm" approach.

Whilst B&V were investigating the "flux' approach it was discovered that Robert Gordon University (RGU) had also recently (independently) started using this methodology in order to be able to quantify environmental and economic impacts. This approach was being used because the energy flux approach also allows the effects of the devices' energy extraction to be reflected in the overall flow velocity, a further weakness of the farm-based method. From a hydraulics viewpoint, introducing the obstruction of a device into the tidal stream must alter the upstream and downstream flow patterns, and consequently affect the energy available for extraction – an economic impact. Furthermore, RGU has argued that there is a limit to the reduction in flow velocity before environmental impacts become significant. So it is important to take this device-resource interaction into account more fully in any resource analysis.

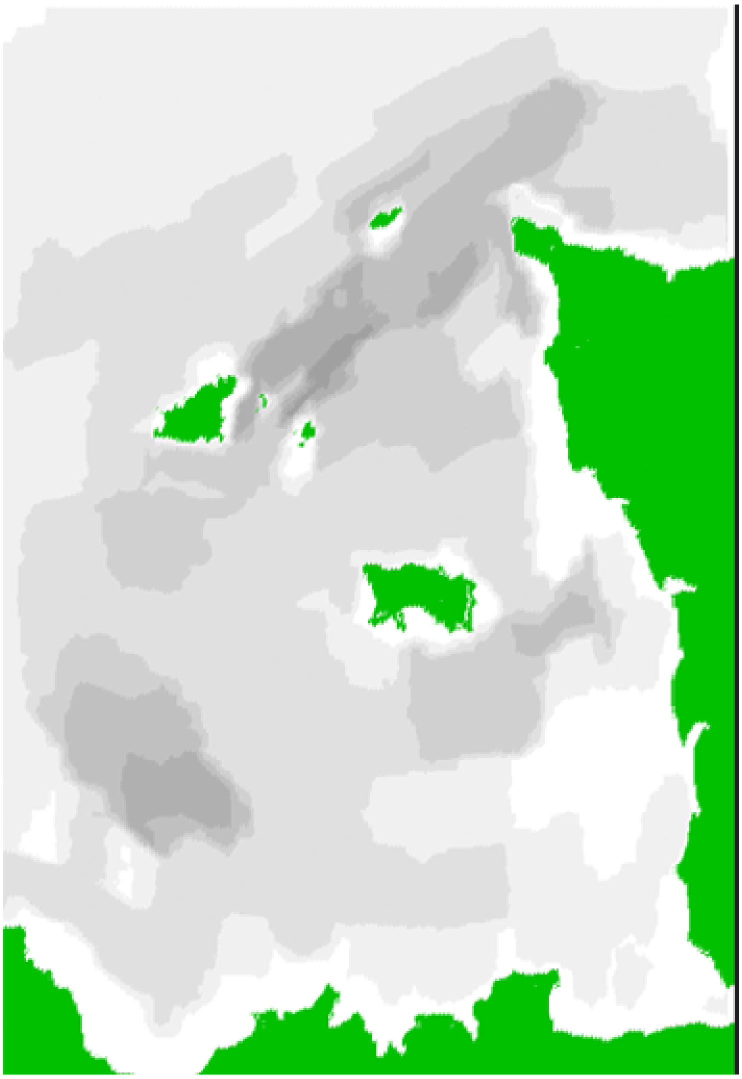
In context of the flux method, B&V identified a key parameter, the Significant Impact Factor (SIF), to describe the amount of energy that is extractable from a site without significant environmental or economic impacts. This should be determined for sites individually, but to allow a preliminary estimate of the total UK technically extractable resource, a SIF of 20% was assumed.

UK tidal stream resources

Drawing on a combination of previous resource studies and new calculations, B&V found that the UK tidal stream resource appears to be about half the entire European resource, and is probably 10 to 15% of the known world resource.

Subsequent work focused on improving certainty about the UK resource, by validating B&V model input data against the DTI Marine Energy Atlas and Admiralty Chart data and developing more detailed SIF estimates for important sites. RGU also assisted by conducting flux modelling of the Channel Islands, developing a new visualisation method they have recently applied to the Pentland Firth in work for the Scottish Executive, as illustrated in Figure 3.

Figure 3: Tidal flows around the Channel Islands. The darker greys show faster tidal streams (- white areas indicate flow less than 0.05 m/s, and black greater than 6 m/s). Image courtesy of Robert Gordons University.



Key results of this work are as follows:

- The UK technically extractable tidal stream resource is ~18 TWh/year ± 30 %, which is roughly 5% of current UK electricity demand. This is the amount of energy that could be extracted without significant environmental or economic impacts. After application of site-specific SIFs.
- Approximately half of this resource lies at deep water (>40m depth) sites with a mean spring peak velocity, Vmsp, greater than 3.5 m/s. About one fifth is at sites of depth 30m to 40m and Vmsp between 2.5 m/s and 4.5 m/s.

- Some uncertainty remains in these resource estimates due to uncertainty in the total energy resource and the estimation and application of SIFs. Detailed site measurements are necessary to clarify the former and further modelling of environmental effects the latter. Nevertheless, the updated results suggest that tidal stream generation has the technical potential to contribute meaningfully to UK electricity demand.

Technology study
B&V studied a number of generation device types in generic form. These included horizontal axis turbines, vertical axis turbines, oscillating hydrofoil machines and venturi-based devices. The study aimed to evaluate the benefits of different approaches and linkages between the resource potential and device development, bearing in mind that in order to evaluate likely costs of energy, it is necessary to consider economies of scale.

B&V considered several fundamental design options including method of fixation (seabed foundations, moorings) and shrouding. Estimates of capital costs, operating costs and energy yield were developed in order to predict the cost-of-energy of technologies at the present stage of development. Initially a standard set of site and resource conditions was assumed but this was later extended to make comparisons across different types of site.
In keeping with cost-of-energy reduction investigations across the Marine Energy Challenge, it was decided to explore the potential for cost-of-energy reductions. Horizontal axis turbines were chosen as the subject of this exploration because most information was available to the study team about this type of machine and read-across is possible from wind turbines. Considering the conclusion noted above that much of the UK resource lies in deep water, it was appropriate to consider designs of horizontal axis turbine that are deployable at such sites. However, designs applicable to shallower water were also studied.

The key outcomes of this exercise are predictions of future costs-of-energy for tidal stream farms, with consideration of optimisation and scaling effects for particular site conditions. These have been linked to the UK resource breakdown to estimate the quantities of generation capacity that could be installed in future and at what cost. This is reflected in the new UK resource-cost curves given in the report. Notably, these curves indicate that the cost of tidal stream generation could become competitive by developing UK sites. A further important conclusion is an estimate of the economically extractable UK resource, which is distinguished from the technically extractable resource by the cost-of-energy. This is 12 TWh/year, approximately 3% of UK electricity demand. Considering the carbon saving this represents together with the potential opportunity of exporting generation technology (recalling that the UK resource is approximately 10% to 15% of the world resource), it appears the UK could obtain both environmental and economic benefits from tidal stream energy