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Marine renewables: a new innovation frontier

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The UK has a large marine renewable energy resource and has been developing a range of wave and tidal technologies for exploiting it. However, progress on moving to the commercial scale has been slow, in part, it is argued, as a result of the way this area of innovation has been supported by the government. This paper looks at the technologies and how they are being developed in the UK and elsewhere. It notes that, although the UK is still in the lead in terms of novel device development, unless better support is provided, the UK might lose out to device developers from other countries in the race to capture the very large global market that is opening up for the relevant technologies.

Keywords: marine renewable; wave energy; tidal energy; energy policy; energy innovation

Introduction

The UK has a large marine energy resource. Tidal barrages across estuaries and tidal lagoons in estuaries might, taken together, generate about 20% of UK electricity, while wave energy and freestanding tidal current turbine projects might also supply 20% of UK electricity and possibly much more (Carbon Trust 2006).

There has been interest in large-scale tidal barrages for many years, particularly on the Severn, and a wave energy development programme was launched in the 1970s. In addition interest has also grown in tidal current turbine technology. However it has only been recently that real progress **Q1** has been made, in part because of growing concerns about climate change and energy security.

The UK government is currently reviewing the prospects for tidal barrages and lagoons, but the basic (hydro) technology of this 'tidal range' approach is well established, so the main issues are costs and environmental impacts. By contrast, wave and tidal current turbine technology is at a relatively early stage of development although there are several hundred new wave energy and tidal current turbines devices under test at various scales at present around the world. It is one of the more prolific areas of innovation at present, with many of the new wave and tidal devices being UK-based (Elliott 2007).

Although the UK is still in the lead in both wave and tidal energy, several other countries are moving ahead rapidly, and UK developers are facing major problems as a result of the level and

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type of support being offered by the government. This paper explores how the UK may be risking the loss of a technological lead.

Marine energy technologies

The tides are due to the gravitational pull of the moon, so it is basically lunar energy, although the tidal patterns and heights are modified by the pull of the sun. One way to capture the energy in tides is by building a barrage across a tidal estuary to trap high tides, with the head of water then being let out through hydro turbines. This is how the 240 megawatt (MW) barrage on the Rance estuary in France works and it is the basis of the proposed 8.6 gigawatt (GW) Severn Tidal Barrage. That could have significant environmental impacts, and, rather than blocking off the estuary with a barrage, it is also possible to let the tides create a head of water in bounded reservoirs built in shallow water in estuaries – so called tidal lagoons.

Q1 Alternatively, and the focus of increasing attention in recent years, the energy in the horizontal tidal flows can be harvested using free standing tidal current turbines – in effect, underwater wind mills. As small freestanding structures with relatively slowly rotating blades, they should have much less environmental impact than tidal range systems and they can be installed on a piecemeal, modular basis.

The most advanced system so far developed is Marine Current Turbines' propeller-type tidal turbine, a 300 kilowatt (kW) Sea Flow version of which was tested off the North Devon coast **Q2** (Figure 1). A twin rotor 1.2 MW SeaGen version is now being commissioned in Strangford Lough in Northern Ireland. But there are many other designs under development, including hydrofoil systems and devices with vertical axis turbines. Indeed, as often happen in the early phase of the innovation process, the present phase of development is typified by a large number of often very different designs, with for example, different ideas emerging for ensuring easy access to the device rotors for maintenance. Gradually, however, a dominant design is likely to emerge, with propeller systems mounted on piles driven into the seabed being seen as the most likely winner.

Whereas tidal energy is mostly lunar derived, wave energy is the result of wind moving over water and since the winds are caused by the differential heating effects of the sun on land and sea, it is in ultimately solar derived. Given that the sea swells caused by the wind last for some time after the wind has died down, waves in effect store wind energy, so they are less variable than the winds.

However, since wave movements are complex, it is hard to extract the energy. Some of the more successful devices involve a cavity resonator, with a hollow Oscillating Water Column (OWC) capturing the energy in the up and down motion of the waves by forcing the air blown out or sucked in by the wave motion through a two-way Wells turbine. The pioneers were Wavegen, with their 500 kW Limpet device built into a rocky outcrop on the shore of the Isle of Islay in Scotland. It was the first to be connected to the grid, but there are also many floating buoy devices, which are tethered to the seabed and bob up and down in the waves, with an internal piston driven by the fixed connection to the sea bed. There are other ideas – hinged flaps mimicking the swaying of reeds, with their swinging action use to drive a generator directly, or via pumps on the device feeding pressurised fluid to a generator on the shore. The most direct approach of all is the 'overtopping' system with the waves running up a ramp into a **Q3** reservoir to create a head of water, which can be run out through a turbine. The most advanced system so far, the Pelamis (Figure 2), has a series of segments linked by hydraulic couplings, which are actuated by the snaking motions caused by the waves as they move down the flanks of the device.

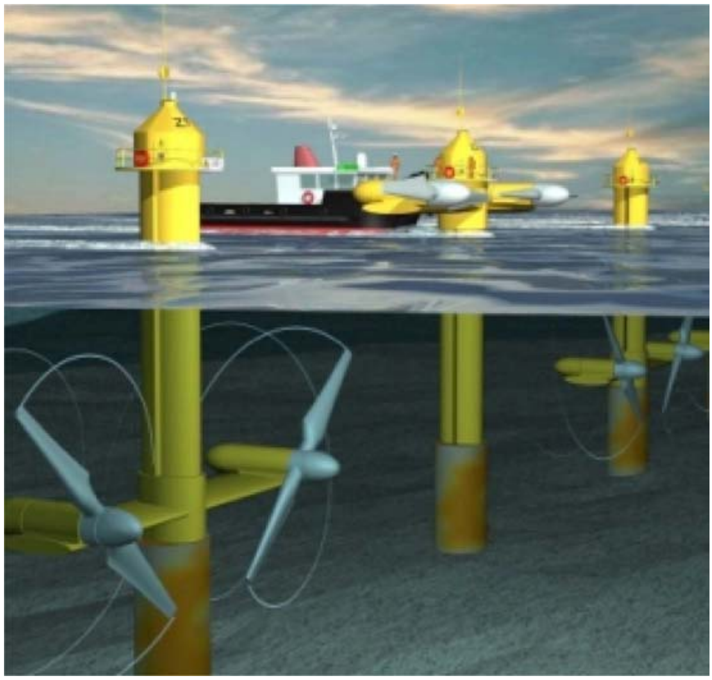

Figure 1. Marine Current Turbine's concept – with one set of blades raised out of the water for maintenance access.

Figure 2.

Locating on shore, as with the Limpet, is the easiest and is least prone to wave damage, but the energy resource is less than out to sea.As with tidal current devices, getting access for maintenance is a key issue: floating devices like the Pelamis can be towed in to harbour, which gives them a major advantage over fixed offshore systems.Working on systems out to sea is risky and expensive. Indeed some studies have suggested that this cost, and the cost of providing power links back to shore, is a key factor in determining the trade offs between complex and simple, easier to maintain systems, and between getting access to more energy out to sea and near shore/on shore operation with less energy available.

The development prospects for wave and tidal current technology look good. For example, learning curve (or progress ratio) studies based on initial trends of cost/kilowatt-hour (kWh) against kW installed, have suggested that tidal energy projects might have learning curve slopes (on log–log scales) of up to 10% while that for wave might be up to 15%, although the latter might start from higher unit price levels, so that tidal projects may get to lower costs more rapidly.

Wave energy is usually seen as a larger resource that tidal current energy, since the latter is geographically defined, whereas in theory wave energy can be captured many miles out to sea. **Q4** However a reassessment of tidal current flows has suggested that earlier assessments of the resource were underestimated, by a factor of perhaps ten or maybe more (MacKay 2008). In addition, tidal current devices operate in a basically linear energy flow regime and, if fully submerged, are in a much calmer working environment than wave energy devices which have to operate in the chaotic interface between sea and air, so tidal flow systems are basically easier to develop than wave systems. It is therefore perhaps not surprising that, while work on wave energy initially dominated, tidal projects now seem to be outnumbering wave energy projects, although there are still many new wave concepts emerging.

At present the UK seems to be the most prolific in the marine renewables innovation field. Indeed, it is getting hard to find a University that does not have a wave or tidal hardware or assessment project underway. There are also many new start-up companies, some of them spun out of university groups. Some ambitious projects have been announced. For example there are plans for an 8 MW tidal farm off the west coast of England, using Lunar Energy's sea-bed mounted 'ducted rotor' system. Some novel ideas have emerged, for example, Tidal Delay's turbine system, which feeds power when available to warm a heat store, which can produce steam to drive a generator continuously. Another group has developed an oscillating hydrofoil 'Pulse Tidal' generation system, which is being tested in the Humber estuary.

However, as with all innovation, it is taking time, and, so far, although several others are doing well, only Pelamis and SeaGen have made the transition to commercial-scale projects. In part this seems to be because of the way the government has set up its support system.

The UK support programme

Q1 The UK government has recently proposed some radical renewable energy targets, in line with a new EU directive, aiming to get 15% of UK energy from renewable sources by 2020, with renewable electricity possibly expanded to 30–35%. However, the project selection and deployment process is still ongoing, and is seen as being ultimately up to the private sector, within the competitive market context created by the Renewables Obligation cross-subsidy system. Wind power, both on and offshore, is likely to be the main option, since it is the cheapest of the major renewables and the UK wind resource is very large (Elliott 2008).

The government has, however, launched a new study of larger-scale (above 1 GW) tidal energy options for the Severn Estuary, looking at tidal barrages across the estuary and tidal lagoons – bounded reservoirs built in shallow coastal water. One of the issues is how such scheme might be funded, with some form of public support being a possibility.

Apart from a 1 GW 'tidal fence' concept, with tidal current turbines mounted in it, tidal current turbine projects are not included in the study: like wind, they are seen as being best developed by private finance within the context of the Renewables Obligation, but with some initial extra support via the governments £42 million Marine Renewables Deployment Fund.

However, so far, no projects have been able to get support from this fund, since none have as yet met its requirement for three-month, full-scale, at-sea tests. Moreover, as a result of the slow progress to commercial deployment, none yet have been eligible for support under the Renewables Obligation, which has recently been adjusted so that marine wave and tidal current project could, **Q1** when ready, receive double the number of Renewable Obligation Certificates (ROCs) for the energy delivered, i.e. 2 ROCs/MWh.

The situation may improve in time. Some R&D funding is available for university groups from the research councils, while the Carbon Trust is providing acceleration support for some developments and more is promised from the new Energy Technology Institute. Some corpo rate investment is also beginning to emerge. By contrast the Scottish Executive is proving to be more effective with its marine support programme having allocated £13 million in direct granted aid to nine wave and tidal current projects. It has also proposed that the Scottish version of the Renewables Obligation be adjusted to provide 3 ROCs/MWh for tidal current projects and 5 ROCs/MWh for wave projects. These commitments reflect its enthusiasm for renewables gener ally – Scotland already gets 20% of its electricity form renewables and has the very ambitious target of getting 50% by 2020.

Even so, with new marine technologies emerging in other EU countries and in the USA, Australia, New Zealand, South Korea and elsewhere (as will be discussed below), there are concerns that the UK's lead in wave and tidal power may be lost (NATTA 2007).

Marine energy choices

The problems facing marine energy in the UK are not just related to the level and types of funding support. There is also the question of direction. For example, there is a debate over which of the various tidal options should be favoured, reflecting different technical, economic and environmental perceptions.

There is much industry support for the large 8.6 GW Severn Barrage, because it uses known (hydro) technology and would generate around 4.6% of UK electricity over a year's operation; it also has strong political support. However, the barrage is strongly opposed by many environmental groups, who see it as a major ecological threat, blocking off an entire estuary.

Some opponents have argued that it would also be overly expensive, with one study, produced for WWF/RSPB et al., claiming that its electricity would cost around two times more than that from most other renewable projects (Frontier Economics 2008).

There are also some key technical issues. A large single barrage on the Severn would only deliver power for a few hours twice in every (roughly) 24 hour tidal cycle, and given that the lunar cycle shifts continually, this power output would not often be matched well to peak power demands. As a result, at least in the absence of major energy storage facilities, the value of the energy it produced would be low. A study by the generally pro-barrage Sustainable Development Commission concluded that, by the time it was built, the Severn Barrage would only displace

By contrast it has been argued that a distributed network of several smaller tidal barrages or lagoons and/or large numbers of tidal current projects, all located around the coast, would be much more efficient and flexible, since the arrival time of the tides is delayed by several hours at each point. Being modular, such a system would also be easier to build and finance on a piecemeal basis and it would have much less environmental impact, particularly in the case of tidal current turbine systems. The counter argument is that tidal lagoons and tidal current turbines are as yet untested ideas and their ecological benefits have yet to be proven. In addition they may cost more.

There are also wider strategic issues. The large Severn Barrage would clearly be a very visible commitment for a government keen to be seen to be supporting renewables, but, if it was chosen, it could absorb funding which might otherwise go to the other, arguably, more efficient and flexible projects. For example there are proposals for smaller barrages, lagoons and tidal fences on other estuaries around the UK, notably the Mersey, as well as for tidal current turbine projects off Scotland, Wales, the Channel Islands and elsewhere.

Challenges from overseas

Although the UK has among the best tidal and wave sites in the world, the potential for tidal and wave projects elsewhere is also large. The global wave energy resource has been put at 2000–4000 terawatt-hours (TWh) and that for tidal currents around 800 TWh. In 2005, Douglas-Westwood consultants put the total global tidal market in the range £155–444 billion and that for wave as £450–1175 billion, and new markets are opening up around the world, most recently in China.

Therefore, although the UK still leads in marine renewables, it is not surprising that there is also a lot of work going on in this area elsewhere. For example, within Europe, there are wave and/or tidal projects in Ireland, Portugal, Spain, Norway, Sweden, Denmark, Finland, Germany, France and the Netherlands. Perhaps the most developed are the propeller type tidal current device – the Lànstrøm turbine – developed by a consortium of Norwegian companies including Statoil and ABB; and the Open Centre Tidal Turbine developed by the Irish company, Open Hydro, which has rotor blades running in an outer ring. There are plans to install both of these in UK waters.

Japan has also been involved with wave energy for many years and has developed a number of causeway-mounted OWC wave units as well as the large floating Mighty Whale wave system. Many other countries, however, are now getting into the field.

In New Zealand, Crest Energy Ltd are planning to build a 200 MW tidal power plant with 200 tidal turbines just north of Auckland and there are plans to have a 1 MW array of floating sub-sea turbines installed in the Cook Strait between the North and South Islands

Australia is also active in the field. Energetech/Oceanlinx has installed a novel 500 MW OWC wave device at Port Kembla near Wollongong, 100 km south of Sydney, anchored 100 metres off a popular surf beach, and its technology is being adopted elsewhere.

In the USA, Verdant Power has installed a series of tidal turbines in New York's East River, and there are proposals for testing tidal current devices in the Golden Gate area in San Francisco. There are also many wave projects underway in the USA, perhaps the most developed involving the OPT wave buoy system. One developer, the Aqua Energy Group,
Q5 which is working on a number of projects including one in Washington State, has suggested that offshore wave power has the potential to satisfy 5–10% of total US power demand within 20 years.

Canada, which has had a long history of involvement with tidal range projects in the Bay of Fundy, is also now pushing ahead with a number of tidal current projects there, as well as on the west coast. The Canadian Company, Blue Energy, has developed a 'tidal fence' concept, in which

H-shaped vertical axis turbines are mounted in a modular framework structure. They see this as being suited to installation in causeways between islands, and have developed ambitious plans for a 4-km long tidal fence between the islands of Samar and Dalupiri in the Philippines, with a total estimated generating capacity of 2200 MW at peak tidal flow (1100 MW average).

However, some of the most impressive work is being carried out in South Korea and it is worth looking at that in some detail, in order to make comparisons with the approach adopted in the UK.

Tidal and wave energy in South Korea

In a paper at the 2008 World Renewable Energy Congress, Chul Hee Jo, from Inha University, Inchon, South Korea, reported that since the west coast of the Korean peninsula has the maximum of 9.72 m of tidal range with high current speed, there are several tidal range (barrage) projects ongoing or planned, while the south coast, with high current speed along the islands, was also very attractive for tidal current power.

He noted that the first tidal current power facility was installed in 2003 in Uldolmog on the south coast. This area has a narrow channel with 5.5 m/s current speed. Following the first 100 kW helical turbine in 2003, there are plans for 1 MW facility with a budget of about US$6 million dollars. In **Q6** addition, in 2007, an intensive site survey was conducted in Daebang straight, with a maximum speed of 2.1 m/s being measured, and a 20 MW tidal current project, with a US$50 million budget, is planned, involving the South-East power company and Kyongnam province, along with Inha University.

An even bigger tidal current project is planned for 2015 at Wando – a 300 MW facility, led by the Korean Midland Power Company and Hyundai Samho Heavy Industries, and Cheonra-namdo and Wando province, with a budget of about US$900 million. The UK's Lunar Energy Company has been contracted to work on this project.

There is also the 254 MW Ocean Current Power Farm Project in Shiwah area, where there is a tidal barrage already nearing completion with ten 25 MW turbines being installed. The tidal current project is expected to start by 2010 and has an estimated budget of about US$600 million, with the involvement of Ocean Power Inc. and Inha University.

Other large tidal range projects include a 430 MW plant at Saemangeum scheduled for com pletion by 2012, with a budget of about US$800 million; and the 812 MW Gangwha tidal range power plant, with a budget of about US$2 billion, involving Korea Midland power company and three construction companies. It is planned to be completed in 2014. Finally, there is the 520 MW Garolim project, involving a consortium lead by Korea West Power Company with POSCO, Daewoo and Lotte construction companies, with a budget of about US$1 billion.

Chul Hee Jo's WREC paper also reported a series of smaller wave energy projects, including a 500 KW over-topping type system, which will be developed and installed by 2010, and a 500 KW Oscillating Water Column (OWC) unit planned to be finished in 2011. A 60 kW OWC had already been developed and tested in 2001, with total budget of about US$8.5 million and a BBDB (Backward Bent Duct Buoy) floating system was tested in 2007.

However, clearly, tidal power dominates. Taken together, if all the various tidal range and tidal current projects are all successfully developed, they would involve around 2.5 GW of installed capacity, putting South Korea well ahead in the field. The UK may have more tidal current and

Comparisons with the UK

In South Korea it seems that private sector investors and companies are willing to risk capital on a range of novel medium scale projects, reflecting a more aggressive and imaginative approach to innovation. In addition, there are good links with university groups and local provincial authorities that can presumably lower the risks.

By contrast, in the UK, government and industry seems to be focussing heavily on one large barrage, while leaving the development of smaller wave and tidal current projects to 'product champions' who tend to be in small university groups or SMEs spun out from them, or even lone inventors and enthusiasts, struggling at the margins with bank loans and double mortgages. As indicated above, there are some support programmes, but so far these have not been very effective.

There has been some sign of corporate interest. For example, Rolls-Royce has invested £1.5 million in the seabed mounted tidal current device being developed by Bristol-based Tidal Generation Ltd (TGL) and taken a 23.5% equity stake. However, in general, investors still seem to be wary. Thomas Royle, Commercial Development Manager, from Gurit commented, 'Despite Cleantech being perceived as the only growing investment sector, feedback from within the industry claims that it appears this is not reflected for Tidal, presumably because of the very large perceived risk and large financial entry requirements' (Tidaltoday.com, 21 August 2008).

Those in the embryonic UK tidal and wave energy industry are hoping that by developing successful projects in the UK, they can attract investment for manufacture here. A vital stage in that process is the deployment of commercial-scale projects in UK waters. So they are particularly dismayed at the slow progress under the various UK support schemes, and by the fact that, for example, the first full scale installation of the Pelamis has been in Portugal not the UK; Spain was also pushing ahead in the field with the funding regimes in existence in those countries being seen as more attractive.

Paul O'Brien, senior executive for renewable energy at Scottish Development International commented, 'If Spain and Portugal get their act together and come out with a tender for 300–400 MW of wave power, they could get the whole industry in the next ten years' (NewEnergyFocus.com, 11 August 2008).

The decision announced in October 2008 by Scottish Power to install 60 MW of tidal current turbine capacity energy in three tidal energy farms off Scotland and Northern Ireland, using the 1 MW Lànstrøm tidal turbine – developed and tested in Norway – suggests that UK device developers may face increasing challenges.

Conclusion

Following the 1973/74 oil crisis, the Labour Government launched a wave energy programme, with some prototype devices being tested in open water. However, after around £15 million had been spent on it, in 1982, on the basis of some heavily contested costing estimates, the Conservative administration cut the programme back and closed it entirely in 1992. Work on tidal energy was also halted. It was not until the late 1990s and rising concern about climate change that the New Labour government began to resuscitate the wave and tidal programmes.

In 2001 the House of Commons Select Committee on Science and Technology, commented bitterly that 'given the UK's abundant natural wave and tidal resource, it is extremely regrettable and surprising that the development of wave and tidal energy technologies has received so little support from the Government' (Select Committee 2001).

Funding levels gradually recovered, however. Although there had been some limited work in between times, mainly supported by the EU, no real technological progress had been made and many of the original research teams had been broken up so it took time to get restarted. Moreover, as indicated above, the support scheme introduced by the government – the Marine Renewables Deployment Fund (MRDF) – has not helped, with no projects having been eligible so far.

Despite this, the government's Renewable Advisory Board in a review in 2007 commented that 'the MRDF is fundamentally a sound scheme. It, in itself, is not a failure, but the R&D process has failed to supply the technologies that the MRDF was established to support' (RAB 2008).

It seems that once again the UK has been unable to exploit its initial lead in a key area of innovation effectively.

However, it is not too late to remedy the situation. For example, there have been proposals for accelerating marine renewables with more direct grant support for new projects, and for a Feed-In Tariff scheme, along the lines used so successfully for supporting renewables elsewhere in the EU, to help projects establish themselves at commercial scale.

There is no doubting that innovation in this area, like any other, can be risky and difficult, and certainly the offshore environment is a challenging one, but it would seem perverse for the UK, with its long history of marine and offshore engineering excellence, and its very large marine energy potential, not the take the challenge seriously.

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